



**NIST**  
National Institute of  
Standards and Technology

**FY 2010  
Small Business Innovation Research  
Program  
SOLICITATION**

**U.S. DEPARTMENT OF COMMERCE**

**National Institute of Standards and Technology**

**Opening Date: October 30, 2009**

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**NIST – 10 – SBIR**

**PROGRAM SOLICITATION AVAILABLE IN ELECTRONIC FORM ONLY**

**GO TO: <http://www.nist.gov/sbir>**

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**US DEPARTMENT OF COMMERCE NATIONAL INSTITUTE OF STANDARDS  
AND TECHNOLOGY**

**SMALL BUSINESS INNOVATION RESEARCH (SBIR) PROGRAM  
SOLICITATION**

**1.0 PROGRAM DESCRIPTION**

**1.01 Introduction**

The National Institute of Standards and Technology (NIST) invites small businesses to submit research proposals under this solicitation. Firms with strong research capabilities in any of the areas listed in Section 9 of this solicitation are encouraged to participate. **Unsolicited proposals are not accepted under the SBIR program.**

The SBIR program was originally established in 1982 by the Small Business Innovation Development Act (P.L. 97-219). It was then expanded by the Small Business R&D Enhancement Act of 1992, extending the program to the year 2000 and then to 2008. Subsequent legislation has extended the program to January 31, 2010. Note: The evaluation of proposals, source selection, and award of contracts under the solicitation is contingent upon the continued existence of the SBIR program. It is anticipated that future legislation will extend the program on a month-to-month basis until it is reauthorized. Eleven federal agencies set aside a portion of their extramural research and development budget each year to fund research proposals from small science and technology-based firms.

The objectives of the SBIR program are aligned with the legislated purposes of the program which include stimulating technological innovation in the private sector and strengthening the role of small business in meeting Federal research and development (R&D) needs. It also seeks to increase the commercial application of innovations derived from Federal research and improve the return on investment from federally funded research for the economic benefit of the Nation. The NIST SBIR Program identifies and solicits proposals in subtopics that fall within NIST's mission and allow collaboration between NIST scientists and the SBIR awardee whenever possible.

**Subtopics listed in Section 9 of this Solicitation each are annotated with either an "R" or a "TT."**

### **1.01.01 NIST SBIR “R” Subtopics**

Subtopics with the “R” designation address the objective of stimulating small business innovation in areas that meet NIST’s programmatic goals while holding the potential for commercial application beyond NIST for the successful awardee.

### **1.01.02 NIST SBIR”TT” Subtopics**

Subtopics with the “TT” designation address the objective of increasing the commercial application of innovations derived from Federal R&D. While NIST Laboratory scientists conduct breakthrough research that leads to innovations, the range of NIST’s effort does not extend to product development in any of its intramural research areas. The remaining work needed to fully exploit NIST technologies for commercial viability necessarily requires innovation on behalf of the private sector. As with all SBIR awards, these “TT” subtopics are intended to cultivate private sector innovation. Specifically, each “TT” subtopic identifies a commercially promising NIST technology and the technological gaps that must be filled in order to transition it to the marketplace.

Technologies identified with “TT” subtopics are either dedicated to the public domain or are patent protected. If there is no patent or patent application cited, the technology is freely available for use without the need for any license. If a “TT” subtopic cites a patent or patent application, the use of that background invention during the course of the SBIR project requires a patent license. All offerors submitting proposals addressing a subtopic that cites background patented technology must submit a non-exclusive, royalty-free license application which is available at NIST SBIR website: <http://www.nist.gov/sbir> or by clicking [here](#). Only those non-exclusive, royalty-free research license applications accompanying proposals that result in an SBIR award under this solicitation will be granted.

SBIR awards resulting from “TT” subtopics will include, as necessary, the grant of a non-exclusive research license to use the NIST-owned patented background inventions specifically identified within the “TT” subtopic being awarded. SBIR offerors are hereby notified that no exclusive or non-exclusive commercialization license to make, use or sell products or services incorporating the NIST background invention will be granted until an SBIR awardee applies for, negotiates and receives such a license. Awardees with contracts for subtopics that identify specific NIST-owned patented background inventions will be given the opportunity to negotiate a non-exclusive commercialization license to such background inventions. If available, Awardees may be given the opportunity to negotiate an exclusive commercialization license to such background inventions. License applications will be treated in accordance with Federal patent licensing regulations as provided in 37 CFR Part 404.

Once awarded a contract and, where necessary, granted a license to use NIST technology and access to NIST personnel knowledgeable about the invention, it is the goal of this program that the SBIR awardee will be positioned to create and add its own innovation and potentially develop a commercially viable product based on the NIST patent.

## **1.02 Three-Phase Program**

The "Small Business Research and Development Enhancement Act of 1992", as amended, requires the Department of Commerce to establish a three-phase SBIR program by reserving a percentage of its extramural R&D budget to be awarded to small business concerns for innovation research.

This solicitation document requests Phase 1 proposals only.

NIST has the unilateral right to select SBIR research topics and awardees in both Phase 1 and Phase 2. As funding is limited, NIST reserves the right to select and fund only those proposals deemed to be superior in overall technical quality and highly relevant to the NIST mission. As a result, NIST may fund more than one proposal in a specific topic area. Similarly, NIST may decide not to fund any proposals in a given topic area.

### **1.02.01 Phase 1 - Feasibility Research**

The purpose of Phase 1 is for NIST to determine the technical feasibility of the research the awardee proposes and the quality of the awardee's performance. Therefore, the proposal should concentrate on describing research that will significantly contribute to proving the feasibility of the proposed research. Feasibility is a prerequisite to further support in Phase 2.

### **1.02.02 Phase 2 - Research and Development**

Only firms that receive Phase 1 awards will be given the opportunity of submitting a Phase 2 proposal following completion of Phase 1. Instructions for Phase 2 proposal preparation and submission will be provided to Phase 1 awardees typically during the fourth month of the Phase 1 period of performance.

Phase 2 is the R&D or prototype development phase. It will require a comprehensive proposal outlining the research in detail. Further information regarding Phase 2 proposal requirements will be provided to all firms receiving Phase 1 awards.



### 1.02.03 Phase 3 - Commercialization

In Phase 3, it is intended that non-SBIR capital be used by the small business to pursue commercial applications of Phase 2.

### 1.03 Manufacturing-related Priority

**Executive Order (EO) 13329** “Encouraging Innovation in Manufacturing” requires SBIR agencies, to the extent permitted by law and in a manner consistent with the mission of that department or agency, to give high priority within the SBIR programs to manufacturing-related research and development (R&D). “Manufacturing-related” is defined as “relating to manufacturing processes, equipment and systems; or manufacturing workforce skills and protection.” More information on the national manufacturing initiative may be found through links located on the NIST SBIR website: <http://www.nist.gov/sbir>.

The NIST SBIR Program solicits manufacturing-related projects through many of the subtopics described in this Solicitation. Further, NIST encourages innovation in manufacturing by giving high priority, where feasible, to projects that can help the manufacturing sector through technological innovation in a manner consistent with NIST’s mission. This prioritization will not interfere with the core project selection criteria: scientific and technical merit, and the potential for commercial success.

### 1.04 Energy Efficiency and Renewable Energy Priority

The Energy Independence and Security Act of 2007 (P.L. 110-140) directs SBIR Programs to give high priority to small business concerns that participate in or conduct energy efficiency or renewable energy system R&D projects.

The NIST SBIR Program solicits energy efficiency or renewable energy system R&D projects through many of the subtopics described in this Solicitation. Further, NIST encourages innovation in energy efficiency or renewable energy system R&D by giving high priority, where feasible, to projects that conduct energy efficiency or renewable energy system R&D through technological innovation in a manner consistent with NIST’s mission. This prioritization will not interfere with the core project selection criteria: scientific and technical merit, and the potential for commercial success.

### 1.05 Eligibility

Each organization submitting a proposal for both Phase 1 and Phase 2 **must** qualify as a small business concern (**Section 2.12**) for research or R&D purposes (**Section 2.9**) at the time of award for each phase. In addition, the primary employment of the principal investigator must be with the small business at the time of the award and

during the conduct of the proposed research. More than one-half of the principal investigator's time must be spent with the small business for the period covered by the award. **Primary employment with a small business precludes full-time employment with another organization.**

Also, for both Phase 1 and Phase 2, the work must be performed in the United States. "United States" means the fifty states, the territories and possessions of the United States, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands, the Trust Territory of the Pacific Islands, and the District of Columbia. However, based on a rare and unique circumstance, for example, a supply or material or other item or project requirement that is not available in the United States, agencies may allow that particular portion of the R/R&D work to be performed or obtained in a country outside of the United States. Approval by the funding agreement officer after consultation with the agency SBIR Program Manager/Coordinator for each such specific condition must be in writing.

Joint ventures and limited partnerships are eligible, provided the entity created qualifies as a small business as defined in this solicitation. **The small business awardee may enter into subcontracts with universities or other non-profit organizations, with the awardee serving as the prime contractor.**

For Phase 1, a minimum of two-thirds of the research and/or analytical effort must be performed by the awardee. For Phase 2, a minimum of one-half of the research and/or analytical effort must be performed by the awardee.

**Unsolicited proposals or proposals not responding to subtopics listed herein are not eligible for SBIR awards. Only proposals that are directly responsive to the subtopics as described in section 9 will be considered.**

### **1.06 Contact with NIST**

In the interest of competitive fairness, all oral or written communication with NIST concerning a specific technical topic or subtopic during the open solicitation period is strictly prohibited - with the exception of the public discussion group located at <http://www.nist.gov/sbir>. Discussion group questions will be routed to the appropriate person for a response. All questions and responses will be publicly, though anonymously, posted on the discussion group web site.

Potential awardees may not participate in the selection of any topic or subtopic nor in the review of proposals. All offerors, including Guest Researchers, contractors, Cooperative research and Development Agreement (CRADA) partners and others working with NIST may only submit a proposal if they:

Had no role in suggesting, developing, or reviewing the subtopic; and

Have not been the recipient of any information on the subtopic not available in

the solicitation or other public means; and

Have not received any assistance from DOC in preparing the proposal (including any 'informal' reviews) prior to submission.

An Agency may not enter into, or continue an existing CRADA with an awardee on the subtopic of the award.

**Requests for general information on the NIST SBIR program may be addressed to:**

SBIR Program  
100 Bureau Drive, Stop 2200  
Gaithersburg, MD 20899-2200

Telephone: (301) 975-3085, Fax: (301) 975-3482

email: [sbir@nist.gov](mailto:sbir@nist.gov)

**For information on contractual issues contact:**

Maria Gray  
Acquisitions and Logistics Division

Telephone: (301) 975- 5577. Fax: (301) 975-8884

email: [maria.gray@nist.gov](mailto:maria.gray@nist.gov)

or

Mario Checchia  
Acquisition Management Division

Telephone: (301) 975 – 8407. Fax: (301) 975-8884

email: [mario.checchia@nist.gov](mailto:mario.checchia@nist.gov)

## **2.0 DEFINITIONS**

### **2.01 Commercialization**

The process of developing marketable products or services and producing and delivering products or services for sale (whether by the originating party or by others) to the Government or commercial markets.

## 2.02 Essentially Equivalent Work

This occurs when (1) substantially the same research is proposed for funding in more than one contract proposal or grant application submitted to the same Federal agency;

(2) substantially the same research is submitted to two or more different Federal agencies for review and funding consideration; or (3) a specific research objective and the research design for accomplishing an objective are the same or closely related in two or more proposals or awards, regardless of the funding source.

## 2.03 Feasibility

The practical extent to which a project can be performed successfully.

## 2.04 Funding Agreement

Any contract, grant, or cooperative agreement entered into between any Federal agency and any small business concern (SBC) for the performance of experimental, developmental, or research work, including products or services, funded in whole or in part by the Federal Government. **For purposes of this Solicitation, NIST intends to award purchase orders and/or contracts in accordance with the Federal Acquisition Regulation.**

## 2.05 Historically Underutilized Business Zone (HUBZone) Small Business Concern

Status as a qualified HUBZone Small Business Concern is determined by the Small Business Administration in accordance with 13 CFR Part 126.

## 2.06 Joint Venture

An association of persons or concerns with interests in any degree or proportion by way of contract, express or implied, consorting to engage in and carry out a single specific business venture for joint profit, for which purpose they combine their efforts, property, money, skill, or knowledge, but not on a continuing or permanent basis for conducting business generally. A joint venture is viewed as a business entity in determining power to control its management and is eligible under the SBIR and STTR Programs provided that the entity created qualifies as a "small business concern" as defined in herein.

## 2.07 NIST-Owned Patented Background Inventions

There is a background NIST technology, for each "TT" subtopic contained in this Solicitation, some of which are patent protected. NIST-Owned Patented Background Inventions are those patented technologies that NIST owns and has retained patent

rights.

## **2.08 Primary Employment**

Primary employment means that more than one half of the principal investigator's time is spent in the employ of the small business concern. This requirement extends also to "leased" employees serving as the principal investigator. Primary employment with a small business concern precludes full time employment at another organization.

## **2.09 Research or Research and Development**

Any activity that is (a) a systematic, intensive study directed toward greater knowledge or understanding of the subject studied; (b) a systematic study directed specifically toward applying new knowledge to meet a recognized need; or (c) a systematic application of knowledge toward the production of useful materials, devices, services, or methods, and includes design, development, and improvement of prototypes and new processes to meet specific requirements.

In general, the NIST SBIR program will fund Phase 1 and 2 proposals with objectives that can be defined by (b) and (c) above.

## **2.10 SBIR Technical Data**

All data generated during the performance of an SBIR award.

## **2.11 SBIR Technical Data Rights**

The rights an SBC obtains in data generated during the performance of any SBIR Phase 1, Phase 2, or Phase 3 award that an awardee delivers to the Government during or upon completion of a Federally-funded project, and to which the Government receives a license.

## **2.12 Small Business Concern (SBC)**

A concern that, on the date of award for both Phase 1 and Phase 2 funding agreements:

(1) is organized for profit, with a place of business located in the United States, which operates primarily within the United States or which makes a significant contribution to the United States economy through payment of taxes or use of American products, materials or labor;

(2) is in the legal form of an individual proprietorship, partnership, limited liability company, corporation, joint venture, association, trust or cooperative,

except that where the form is a joint venture, there can be no more than 49 percent participation by business entities in the joint venture;

(3) is (i) at least 51 percent owned and controlled by one or more individuals who are citizens of the United States or permanent resident aliens in the United States, (ii) at least 51% owned and controlled by another business concern that is itself at least 51% owned and controlled by individuals who are citizens of, or permanent resident aliens in the United States; or (iii) a joint venture in which each entity to the venture must meet the requirements of either (i) or (ii) of this section.

(4) has, including its affiliates, not more than 500 employees.

Control can be exercised through common ownership, common management, and contractual relationships. The term "affiliates" is defined in greater detail in 13 CFR 121.103. The term "number of employees" is defined in 13 CFR 121.106.

A business concern may be in the form of an individual proprietorship, partnership, limited liability company, corporation, joint venture, association, trust, or cooperative. Further information may be obtained at <http://www.sba.gov/size>, or by contacting the Small Business Administration's Government Contracting Area Office or Office of Size Standards.

### **2.13 Socially and Economically Disadvantaged Small Business Concern**

A socially and economically disadvantaged small business concern is one that is at least 51% owned and controlled by one or more socially and economically disadvantaged individuals, or an Indian tribe, including Alaska Native Corporations (ANCs), a Native Hawaiian Organization (NHO), or a Community Development Corporation (CDC). Control includes both the strategic planning (as that exercised by boards of directors) and the day-to-day management and administration of business operations. See 13 CFR 124.109, 124.110, and 124.111 for special rules pertaining to concerns owned by Indian tribes (including ANCs), NHOs or CDCs, respectively.

### **2.14 Subcontract**

This is any agreement, other than one involving an employer-employee relationship, entered by the awardee of a Federal Government funding agreement, calling for supplies or services required solely for the performance of the original funding agreement.

### **2.15 Women-Owned Small Business**

A small business concern that is at least 51% owned and controlled by a woman or women in accordance with 13 CFR 127.200, 127.201, and 127.202.

## 3.0 PROPOSAL PREPARATION GUIDELINES

### 3.01 Proposal Requirements

NIST reserves the right to not submit to technical review any proposal which it determines has have insufficient scientific and technical information, or one which fails to comply with the administrative procedures as outlined on the Checklist of Requirements in [Section 8.04](#). Proposals that do not successfully pass the screening criteria given in [Section 4.02](#) will be returned to the offeror without further consideration.

The offeror must provide sufficient information to demonstrate that the proposed work represents a sound approach to the investigation of an important scientific or engineering innovation worthy of support. **The proposal must meet all the requirements of the subtopic in [Section 9](#) it addresses.**

A proposal must be self-contained and written with all the care and thoroughness of a scientific paper submitted for publication. It should indicate a thorough knowledge of the current status of research in the subtopic area addressed by the proposal. Each proposal should be checked carefully by the offeror to ensure inclusion of all essential material needed for a complete evaluation. The proposal will be peer reviewed as a scientific paper. All units of measurement should be in the metric system.

The proposal must not only be responsive to the specific NIST program interests described in Section 9 of the solicitation, but also serve as the basis for technological innovation leading to new commercial products, processes, or services that benefit the public. An offeror may submit proposals on multiple subtopics or multiple proposals on one subtopic under this solicitation. When the proposed innovation applies to more than one subtopic, the offeror must submit its proposal under the subtopic that is most relevant to the offeror's technical concept.

**Proposals principally for the commercialization of proven concepts or for market research must not be submitted. Such efforts are considered the responsibility of the private sector.**

The proposal should be direct, concise, and informative. Promotional and other material not related to the project shall be omitted. The complete proposal application must contain four copies of the following:

- (a) Cover Sheet (required form, see [Section 8.0](#))
- (b) Project Summary (required form, see [Section 8.0](#))

(c) Technical Content

(d) Proposed Budget (required form, see [Section 8.0](#))

**One original proposal – this includes original signatures in each of the three required forms along with the technical section - plus three copies of the proposal are required.**

### 3.02 Phase 1 Proposal Limitations

Page length must be **no more than 25 pages**. Each page is to be consecutively numbered, including the cover sheet (2 pages count as one – for the cover sheet only), project summary, main text, references, resumes, any other enclosures or attachments, and the proposal summary budget. The only exception to the page count limitation are those pages necessary to comply with the itemization of prior SBIR phase 2 awards, per [Section 3.03.03.02](#).

Paper size used for the submission must be 21.6 cm X 27.9 cm (8 ½" X 11"). Print size used for the submission must be easy to read with a fixed pitch font of 12 or fewer characters per inch or proportionally spaced font of point size 10 or larger with no more than 6 lines per inch.

Supplementary material, revisions, substitutions, audio or video tapes, or computer floppy disks will **not** be accepted. If submitted these items will not be reviewed by evaluators.

The original and all copies of each proposal must be mailed in one package. **The bottom right corner of the outside of the package must be clearly marked “SBIR – Subtopic (fill in the subtopic # \_\_\_\_\_)”**.

### 3.03 Instructions for Phase 1 Proposal Submission Forms and Technical Content

This section includes instructions for completing each of the three required forms as well as the format required for the Technical Content section. A complete proposal application must include four copies of each of the following: [Cover Sheet](#), [Project Summary](#), Technical Content (up to 22 pages), and [Proposed Budget](#). Any applications received missing any of these required items will be returned without review.

#### 3.03.01 [Cover Sheet](#)

Complete all items in the “Cover Sheet” required form and use as page 1 of the proposal. **NO OTHER COVER WILL BE ACCEPTED.**



Before NIST can award a contract to a successful offeror under this solicitation, the offeror must be registered in the DoD Central Contractor Registration (CCR) database. The CCR allows Federal Government contractors or firms interested in conducting business with the federal government to provide basic information on business capabilities and financial information. To register, visit <http://www.ccr.gov> or call 1-888-227-2423.

The DUNS number is a nine-digit number assigned by Dun and Bradstreet Information Services. If the offeror does not have a DUNS number, it should contact Dun and Bradstreet directly to obtain one. A DUNS number will be provided immediately by telephone at no charge to the offeror. For information on obtaining a DUNS number, the offeror, if located within the United States, should call Dun and Bradstreet at 1-800-333-0505, or access their website at <http://sbs.dnb.com>.

No award shall be made under this solicitation to a small business concern without registration in CCR or a DUNS number.

Offerors are cautioned to identify proposal page numbers that contain their confidential information in the Proprietary Notice section at the end of the Cover Sheet.

### **3.03.02 Project Summary**

Complete all sections of the "Project Summary" form as page 2 of your proposal. The technical abstract should include a brief description of the problem or opportunity, the innovation, project objectives, and technical approach. Keywords should be chosen to describe the proposed work both generally and specifically. In summarizing anticipated results, include technical implications of the approach and the potential commercial applications of the research. **Each awardee's Project Summary will be published by NIST and, therefore, must not contain proprietary information.**

### **3.03.03 Technical Content**

Commercialization of SBIR research results is an important factor in the evaluation of all proposals. Because of the nature of the "TT" subtopics, special attention must be given to identify not only the technical approach to the research problem identified in the subtopic but the proposed means for commercializing the core NIST technology being exploited through the proposed research.

Beginning on **page 3 of the proposal**, include the following items with headings as shown:

(a) **Identification and Significance of the Problem or Opportunity.** Make a clear statement of the specific research problem or opportunity addressed, its

innovativeness, commercial potential, and why it is important. Show how it applies to a specific subtopic in Section 9.

(b) **Phase 1 Technical Objectives.** State the specific objectives of the Phase 1 effort, including the technical questions it will try to answer, to determine the feasibility of the proposed approach.

(c) **Phase 1 Work Plan.** Include a detailed description of the Phase 1 feasibility research plan. The plan should indicate what will be done, where it will be done, and how the research will be carried out. The methods planned to achieve each objective or task should be discussed in detail. This section should be at least one-third of the proposal.

**NIST technical support or assistance will be available to awardees in the conduct of the research only if specifically provided for in the subtopic description.**

(d) **Related Research or R&D.** Describe research or R&D that is directly related to the proposal, including any conducted by the principal investigator or by the offeror. Describe how it relates to the proposed effort, and describe any planned coordination with outside sources. The purpose of this section is to demonstrate the offeror's awareness of recent developments in the specific topic area.

(e) **Key Personnel and Bibliography of Related Work.** Identify key personnel involved in Phase 1, including their related education, experience, and publications. Where resumes are extensive, summaries that focus on the most relevant experience and publications are suggested. List all other commitments that key personnel have during the proposed period of contract performance.

(f) **Relationship with Future R&D.** Discuss the significance of the Phase 1 effort in providing a foundation for the Phase 2 R&D effort. Also state the anticipated results of the proposed approach, if Phases 1 and 2 of the project are successful.

(g) **Facilities and Equipment.** The conduct of advanced research may require the use of sophisticated instrumentation or computer facilities. The offeror should provide a detailed description of the availability and location of the facilities and equipment necessary to carry out Phase 1. **NIST facilities and/or equipment will be available for use by awardees only if specifically provided for in the subtopic description.** All related transportation/shipping/insurance costs shall be the sole responsibility of the contractor. If expressed in the subtopic description that access to NIST resources will be made available, then under mutual agreement between awardee and NIST staff, arrangements will be planned prior to NIST labs visits, samples testing or exchange, and any collaborative discussions.

(h) **Consultants and Subcontracts.** The purpose of this section is to show that: research assistance from outside the firm materially benefits the proposed effort,

and arrangements for such assistance are in place at time of proposal submission..

Outside involvement in the project is encouraged where it strengthens the conduct of the research. Outside involvement is not a requirement of this solicitation. Outside involvement is limited to no more than 1/3 of the research and/or analytical effort in Phase 1, per [Section 1.05](#).

1. Consultant - A person outside the firm, named in the proposal as contributing to the research, must provide a signed statement confirming his/her availability, role in the project, and agreed consulting rate for participation in the project. This statement is part of the page count.

2. Subcontract - Similarly, where a subcontract is involved in the research, the subcontracting institution must furnish a letter signed by an appropriate official describing the programmatic arrangements and confirming its agreed participation in the research, with its proposed budget for this participation. This letter is part of the page count.

Absence of such documents explaining such a consultant or subcontract, if cited elsewhere in the proposal and/or the budget, may disqualify the offeror from consideration.

No individual or entity may serve as a consultant or subcontractor if they:

Had any role in suggesting, developing, or reviewing the subtopic; or

Have been the recipient of any information on the subtopic not available to the public.

(i) **Potential Commercial Application.** Describe in detail the commercial potential of the proposed research, how commercialization would be pursued and potential use by the Federal Government.

(j) **Cooperative Research and Development Agreements (CRADA).** State if the offeror is a former or current CRADA partner with NIST, or with any other Federal agency, naming the agency, title of the CRADA, and any relationship with the proposed work. An Agency may not enter into, nor continue, a CRADA with an awardee on the subtopic of the award.

(k) **Guest Researcher.** State if the offeror or any of its consultants or subcontractors is a guest researcher at NIST, naming the sponsoring laboratory.

(l) **Cost Sharing.** Offerors may propose cost-sharing. Except where required by other statutes, NIST does not require or give preference to offerors proposing cost sharing in Phase 1. NIST will not consider whether an offeror proposes cost sharing in its evaluation of proposals

### 3.03.03.01 Similar Proposals or Awards

**NOTE** - While it is permissible, with proposal notification, to submit identical proposals or proposals containing a significant amount of essentially equivalent work for consideration under numerous Federal program solicitations, it is unlawful to enter into funding agreements requiring essentially equivalent work. If there is any question concerning this, it must be disclosed to the soliciting agency or agencies before award.

If an offeror elects to submit identical proposals or proposals containing a significant amount of essentially equivalent work under other Federal program solicitations, a statement must be included in each such proposal indicating:

- (i) The name and address of the agencies to which proposals were submitted or from which awards were received.
- (ii) Date of proposal submission or date of award.
- (iii) Title, number, and date of solicitations under which proposals were submitted or awards received.
- (iv) The specific applicable research topics for each proposal submitted or award received.
- (v) Titles of research projects.
- (vi) Name and title of principal investigator or project manager for each proposal submitted or award received.

If no equivalent proposal is under consideration or equivalent award received, a statement to that effect must be included in this section of the technical content area of the proposal and certified within the Cover Sheet.

### 3.03.03.02 Prior SBIR Phase 2 Awards

If the small business concern has received more than 15 Phase 2 awards in the prior five fiscal years, it must submit in its Phase 1 proposal: name of the awarding agency; date of award; funding agreement number; amount of award; topic or subtopic title; follow-on agreement amount; source and date of commitment; and current commercialization status for each Phase 2 award. **This required information shall not be part of the 25 page count limitation.**

NOTE: The Small Business Administration is mandated to establish an SBIR awardee database containing demographic, technical, outcome and output information on all SBIR awards. The database is being developed as of the date of release of this solicitation. When it becomes available, all NIST SBIR awardees

will be required to supply the required data in a timely fashion.

### **3.03.04 Proposed Budget**

NIST will not issue SBIR awards that include provisions for subcontracting any portion of the contract back to the federal government.

For Phase 1, a minimum of two-thirds of the research and/or analytical effort must be performed by the proposing small business concern. For Phase 2 a minimum of one-half of the research and/or analytical effort must be performed by the proposing small business concern.

Complete the **Proposed Budget** required form for the Phase 1 effort, and include it as the last page of the proposal. Some items of this form may not apply to every proposal. Enough information should be provided to allow NIST to understand how the offeror plans to use the requested funds if the award is made. A complete cost breakdown should be provided giving labor rates, proposed number of hours, overhead, G&A, and profit. A reasonable profit will be allowed.

The offeror is to submit a cost estimate with detailed information for each Line Item, consistent with the offeror's cost accounting system. This does not eliminate the need to fully document and justify the amounts requested in each category. Such documentation should be contained, as appropriate, within the proposal technical content.

**Lines A and B, Labor.** List the key personnel and consultants by name and function or role in the project. Other direct personnel need not be named, but their role, such as "technician," and total hours should be entered. Personnel whose costs are indirect (e.g. administrative personnel) should be included in Line D. Fringe benefits can be listed for each employee in the space provided, or they may be included within the indirect costs in Line G. The PI must be employed by the small business concern at the time of contract award and during the period of performance of the research effort. Additionally, more than half of the PI's time must be spent with the awardee during the contract performance.

**Line C, Equipment.** List items costing over \$5,000 and exceeding one year of useful life. Lesser items may be shown in Line E. Indicate if equipment is to be purchased or leased. Where equipment is to be purchased or leased, list each individual item with the corresponding cost. The inclusion of equipment will be carefully reviewed relative to need and appropriateness for the research proposed.

**Line D, Travel.** Itemize by destination, purpose, period and cost for both staff

and consultants. Budgets including travel funds must be justified and related to the needs of the project. Inclusion of travel expenses will be carefully reviewed relative to need and appropriateness for the research proposed. Foreign travel is not an appropriate expense.

**Line E, Other Direct Costs.** The materials and supplies, testing and/or computer services, and subcontracts required for the project must be identified. Specify type, quantity and unit cost (if applicable), and total estimated cost of these other direct costs.

**Line F, Total Direct Costs.** Enter the sum of Lines A through E.

**Line G, Indirect Costs.** Cite your established Overhead (OH) and General and Administrative (G&A) rate, if any. Otherwise include all indirect costs (e.g. facilities, shared equipment, utilities, property taxes, administrative staff) for the period of the project. Indirect costs are costs not directly identified with a single final cost objective.

**Line H, Total Costs.** Enter the total amount of the proposed project, the sum of Lines F and G.

**Line I, Profit.** The small business concern may request a reasonable profit.

**Line J, Total Amount of this request.** Enter the sum of Lines H and I. This amount must equal the amount entered in the Cover Sheet Form.

**Line K, Corporate/Business Authorized Representative.** A signature of someone with the authority to commit the company must be given.

## 4.0 METHOD OF SELECTION AND EVALUATION CRITERIA

### 4.01 Introduction

All Phase 1 and 2 proposals will be evaluated and judged on a competitive basis. Proposals will be initially screened to determine responsiveness. Proposals passing this initial screening will be technically evaluated by engineers or scientists to determine the most promising technical and scientific approaches. Each proposal will be judged on its own merit. NIST is under no obligation to fund any proposal or any specific number of proposals in a given topic. It also may elect to fund several or none of the proposed approaches to the same topic or subtopic.

### 4.02 Phase 1 Screening Criteria

Phase 1 proposals that do not satisfy all the screening criteria shall be returned to the offeror without further review and will be eliminated from consideration for award. Proposals may not be resubmitted (with or without revision) under this solicitation. The screening criteria are:

- (a) The proposing firm must qualify as eligible according to the criteria set forth in [Section 1.05](#).
- (b) The Phase 1 proposal must meet **all** of the requirements stated in [Section 3.0](#).
- (c) The Phase 1 proposal must be limited to one subtopic and clearly address research for that subtopic.
- (d) **Phase 1 total proposal budget must not exceed \$90,000.**
- (e) **The feasibility research duration for the Phase 1 project must not exceed 6 months.**
- (f) The proposal must contain information sufficient to be peer reviewed as research.

#### **4.03 Phase 1 Evaluation Criteria**

Phase 1 proposals that comply with the screening criteria will be rated by NIST scientists or engineers in accordance with the following criteria:

- (a) The scientific and technical merit of the proposed research (25 points)
- (b) Innovation, originality, and feasibility of the proposed research (20 points)
- (c) Relevance and responsiveness of the proposed research to the subtopic to which it is addressed (20 points)
- (d) Quality and/or adequacy of facilities, equipment, personnel described in the proposal (15 points)
- (e) Quality of the proposal's commercialization potential as evidenced by the offerors record of commercializing other research products; existence of outside, non-SBIR, funding or partnering commitments; or the presence of other indicators of commercial potential of the idea (20 points)

Technical reviewers will base their ratings on information contained in the proposal. It cannot be assumed that reviewers are acquainted with any experiments referred to, key individuals, or the firm. No technical clarifications may be made after proposal submission.

Final award decisions will be made by NIST based upon ratings assigned by

reviewers and consideration of evaluation of additional factors such as possible duplication of other research, the importance of the proposed research as it relates to NIST needs, and the availability of funding. In the event of a “tie” between proposals, manufacturing-related projects as well as those regarding energy efficiency and renewable energy system will receive priority in the award selection process. NIST may elect to fund several or none of the proposals received on a given subtopic. Upon selection of a proposal for a Phase 1 award, NIST reserves the right to negotiate the amount of the award.

#### **4.04 Phase 2 Evaluation Criteria**

During the feasibility study project performance period, Phase 1 awardees will be provided instructions for preparation and submission of Phase 2 proposals. Phase 2 proposals that comply with the screening criteria as stated in those instructions will be rated by NIST scientists or engineers in accordance with the following criteria:

1. Degree to which Phase 1 objectives were met (25 points)
2. The scientific and technical merit of the proposed research, including innovation, originality, and feasibility (25 points)
3. Quality and/or adequacy of facilities, equipment, personnel described in the proposal (25 points)
4. Quality of the proposal’s commercialization potential as evidenced by either the offerors record of commercializing other research products, existence of outside, non-SBIR, funding or partnering commitments, or the presence of other indicators of commercial potential of the idea. (25 points)

#### **4.05 Release of Proposal Review Information**

After final award decisions have been announced, the technical evaluations of proposals that passed the screening criteria will be provided to the offeror with written notification of award/non-award. The identity of the reviewers will not be disclosed.



## 5.0 CONSIDERATIONS

### 5.01 Awards

NIST will award **firm-fixed-price purchase orders and/or contracts** to successful offerors. A firm-fixed-price purchase order or contract identifies a price that is not subject to any adjustment on the basis of the contractor's cost experience in performing the effort. This agreement type places upon the contractor the risk and full responsibility for all costs and resulting profit or loss. It provides maximum incentive for the contractor to control costs and perform effectively and imposes a minimum administrative burden upon both parties. NIST also does not allow any advance payments to be made on its awards. The firm-fixed-price shall be inclusive of all transportation/shipping/insurance costs for government furnished property made available for use by awardee and all deliverables/prototypes to be furnished to NIST.

Contingent upon availability of funds, NIST anticipates making a total number of approximately 14 Phase 1 firm-fixed-price SBIR awards of no more than **\$90,000** each. The total performance period shall be no more than seven (7) months beginning on the contract start date. A period of one (1) month is allotted after the six (6) month R&D duration for the awardee to prepare and submit a final report.

Phase 2 awards shall be for no more than **\$300,000**. The R&D activity period of performance in Phase 2 will depend upon the scope of the research, but should not exceed 25 months. One year after completing the R&D activity, the awardee shall be expected to report on their commercialization activities. The total period of performance for Phase 2 is 37 months.

It is anticipated that approximately one-fourth of the Phase 1 awardees will receive Phase 2 awards, depending upon the availability of funds. To provide for an in-depth review of the Phase 1 final report and the Phase 2 proposal and commercialization plan, Phase 2 awards will be made approximately 5 months after the completion of Phase 1, contingent upon availability of funds.

**This solicitation does not obligate NIST to make any awards under either Phase 1 or Phase 2. Furthermore, NIST is not responsible for any monies expended by the offerors before awards are made.**

Upon award, the awardee will be required to make certain legal commitments through acceptance of numerous clauses in Phase 1 funding agreements. The outline that follows is illustrative of the types of clauses to which the contractor would be committed. This list is not a complete list of clauses to be included in Phase 1 funding agreements, and is not the specific wording of such clauses. Copies of complete terms and conditions are available upon request.

These statements are examples only and may vary depending upon the type of

funding agreement used.

- (1) Standards of Work. Work performed under the funding agreement must conform to high professional standards.
- (2) Inspection. Work performed under the funding agreement is subject to Government inspection, evaluation, and acceptance at all times.
- (3) Examination of Records. The Comptroller General (or a duly authorized representative) must have the right to examine any pertinent records of the awardee involving transactions related to this funding agreement.
- (4) Default. The Government may terminate the funding agreement if the contractor fails to perform the work contracted.
- (5) Termination for Convenience. The funding agreement may be terminated at any time by the Government if it deems termination to be in its best interest, in which case the awardee will be compensated for work performed and for reasonable termination costs.
- (6) Disputes. Any dispute concerning the funding agreement that cannot be resolved by agreement must be decided by the contracting officer with right of appeal.
- (7) Contract Work Hours. The awardee may not require an employee to work more than 8 hours a day or 40 hours a week unless the employee is compensated accordingly (for example, overtime pay).
- (8) Equal Opportunity. The awardee will not discriminate against any employee or offeror for employment because of race, color, religion, sex, or national origin.
- (9) Affirmative Action for Veterans. The awardee will not discriminate against any employee or application for employment because he or she is a disabled veteran or veteran of the Vietnam era.
- (10) Affirmative Action for Handicapped. The awardee will not discriminate against any employee or offeror for employment because he or she is physically or mentally handicapped.
- (11) Officials Not To Benefit. No Government official must benefit personally from the SBIR funding agreement.
- (12) Covenant Against Contingent Fees. No person or agency has been employed to solicit or secure the funding agreement upon an understanding for compensation except bona fide employees or commercial agencies maintained by the awardee for the purpose of securing business.

(13) Gratuities. The funding agreement may be terminated by the Government if any gratuities have been offered to any representative of the Government to secure the award.

(14) Patent Infringement. The awardee must report each notice or claim of patent infringement based on the performance of the funding agreement.

(15) American Made Equipment and Products. When purchasing equipment or a product under the SBIR funding agreement, purchase only American-made items whenever possible.

## 5.02 Reports

Progress reports scheduled periodically during the Phase 1 and Phase 2 periods of performance will include all technical details regarding the research conducted up to that point in the project and will provide detailed plans for the next stages of the project. The acceptance of each progress report will be contingent upon appropriate alignment with the solicited and proposed milestones. Consideration will be given to changes from the solicited and proposed milestones if results from experimentation warrant a deviation from plan. Inclusion of proprietary information within the progress reports and final report may be necessary in order to effectively communicate progress and gain appropriate consultation from NIST experts regarding next steps. All such proprietary information will be marked according to instructions provided in section 5.05.03.

An R&D final report on the Phase 2 project shall be submitted to NIST within 30 calendar days after completion of the two-year Phase 2 R&D activity period. A commercialization update report on the SBIR project shall be submitted to NIST within 30 calendar days three years after the Phase 2 award date, i.e. one year after the completion of the two-year Phase 2 R&D activity period. The total period of performance for Phase 2 is 37 months.

Final reports submitted under Phase 1 and Phase 2 shall include a single-page project summary as the first page, identifying the purpose of the research, and giving a brief description of the research carried out, the research findings or results, and the commercial applications of the research in a final paragraph. The remainder of the report should indicate in detail the research objectives, research work carried out, results obtained, and estimates of technical feasibility.

All final reports must carry an acknowledgment on the cover page such as: "This material is based upon work supported by the National Institute of Standards and Technology (NIST) under contract \_\_\_\_\_. Any opinions, findings, conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of NIST."

The commercialization update report will include the target markets and customers that have been identified for the technology developed under the SBIR project. The report shall include details about additional activities that have been planned and executed along with future plans to derive revenues from the technology; these may include but are not limited to: pricing, partners, licensing, production plans, manufacturing partners, follow-on R&D funding. Resources committed by the awardee to effectively commercialize technologies developed under the SBIR project will be clearly demonstrated as well as projections for further commercialization. Further details regarding the exact requirements for the commercialization update report will be provided during the Phase 2 period of performance.

### **5.03 Deliverables**

Offers submitted in response to subtopics that require delivery of a prototype should state in the proposal, the plan to develop and deliver the specified prototype. Notwithstanding the absence of such an explicit statement in the offeror's proposal, delivery of the developed prototype as called for by the solicitation subtopic is required.

### **5.04 Payment Schedule**

The specific payment schedule (including payment amounts) for each award will be incorporated into the purchase order and/or contract.

No advance payments will be allowed.

NIST will allow the Phase 1 award amount to be paid on a bimonthly interim basis upon delivery and technical acceptance of three progress reports that describe services performed, and one final payment upon delivery and technical acceptance of the final report.

NIST will allow the Phase 2 award amount minus \$10,000 to be paid in five equal increments on an interim basis upon delivery and acceptance of four progress reports (at the 2<sup>nd</sup>, 6<sup>th</sup>, 12<sup>th</sup>, and 18<sup>th</sup> months of the project) that describe services performed, and one final equal increment payment upon delivery of the final R&D report and prototype, if applicable per subtopic requirement, at the 25<sup>th</sup> month of the project. The final \$10,000 will be paid upon delivery and acceptance of the commercialization update report at the 37<sup>th</sup> month of the project. Failure to submit the report within thirteen months of the completion of the R&D activity period for Phase 2 will result in a de-obligation of the \$10,000.

## 5.05 Proprietary Information, Inventions, and Patents

### 5.05.01 Limited Rights Information and Data

Information contained in unsuccessful proposals will remain the property of the offeror. Any proposal which is funded will not be made available to the public, except for the "Project Summary" page.

The inclusion of proprietary information is discouraged unless it is necessary for the proper evaluation of the proposal. Information contained in unsuccessful proposals will remain the property of the offeror. The Government may, however, retain copies of all proposals. Public release of information in any proposal submitted will be subject to existing statutory and regulatory requirements. If proprietary information is provided by an offeror in a proposal, which constitutes a trade secret, proprietary commercial or financial information, confidential personal information or data affecting the national security, it will be treated in confidence, to the extent permitted by law. This information must be clearly marked by the offeror with the term "confidential proprietary information" and the following legend must appear on the first page of the technical section of the proposal:

"These data shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed in whole or in part for any purpose other than evaluation of this proposal. If a funding agreement is awarded to this offeror as a result of or in connection with the submission of these data, the Government shall have the right to duplicate, use, or disclose the data to the extent provided in the funding agreement and pursuant to applicable law. This restriction does not limit the Government's right to use information contained in the data if it is obtained from another source without restriction. The data subject to this restriction are contained on pages \_\_\_\_ of this proposal."

Any other legend may be unacceptable to the Government and may constitute grounds for removing the proposal from further consideration, without assuming any liability for inadvertent disclosure. The Government will limit dissemination of such information to within official channels.

Examples of laws that restrict the government to protect confidential/proprietary information about business operations and trade secrets possessed by any company or participant include: Freedom of Information Act (FOIA)—5 U.S.C. § 552(b); Economic Espionage Act—18 U.S.C. § 1832; and Trade Secrets Act—18 U.S.C. § 1905.

In view of the above, proposers are cautioned that proposals are likely to be less competitive if significant details are omitted due to the proposer's reluctance to reveal confidential/proprietary information.

### **5.05.02 Copyrights**

The contractor may normally establish claim to copyright any written material first produced in the performance of an SBIR contract. If a claim to copyright is made, the contractor shall affix the applicable copyright notice of 17 U.S.C. 401 or 402 and acknowledgment of Government sponsorship (including funding agreement number) to the material when delivered to the Government, as well as when the written material or data are published or deposited for registration as a published work in the US Copyright Office. For other than computer software, the contractor gives to the Government, and others acting on its behalf, a paid-up, nonexclusive, irrevocable, worldwide license to reproduce, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, by or on behalf of the Government.

For computer software, the contractor gives to the Government a paid-up, nonexclusive, irrevocable, worldwide license for all such computer software to reproduce, prepare derivative works, and perform publicly and display publicly, by or on behalf of the Government.

### **5.05.03 Rights in Data Developed Under SBIR Contracts**

To preserve the SBIR data rights of the awardee, the legend (or statements) used in the SBIR Data Rights clause included in the SBIR award must be affixed to any submissions of technical data developed under that SBIR award. If no Data Rights clause is included in the SBIR award, the following legend, at a minimum, should be affixed to any data submissions under that award:

#### **SBIR RIGHTS NOTICE**

“These SBIR data are furnished with SBIR rights under Contract No. \_\_\_\_\_ (and subcontract No. \_\_\_\_\_ if appropriate), Awardee Name \_\_\_\_\_, Address, Expiration Period of SBIR Data Rights \_\_\_\_\_. The Government may not use, modify, reproduce, release, perform, display, or disclose technical data or computer software marked with this legend for (choose four (4) or five (5) years). After expiration of the (4- or 5-year period), the Government has a royalty-free license to use, and to authorize others to use on its behalf, these data for Government purposes, and is relieved of all disclosure prohibitions and assumes no liability for unauthorized use of these data by third parties, except that any such data that is also protected and referenced under a subsequent SBIR award shall remain protected through the protection period of that subsequent SBIR award. Reproductions of these data or software must include this legend.”

#### **(END OF NOTICE)**

The Government's sole obligation with respect to any properly identified SBIR data shall be as set forth in the paragraph above.

#### **5.05.04 Patents**

Small business concerns normally may retain the principal worldwide patent rights to any invention developed with Government support. The Government receives a royalty free license for Federal Government use, reserves the right to require the patent holder to license others in certain circumstances, and requires that anyone exclusively licensed to sell the invention in the United States must normally manufacture it domestically. To the extent authorized by 35U.S.C. 205, the Government will not make public any information disclosing a Government supported invention for a minimum 4-year period (that may be extended by subsequent SBIR funding agreements) to allow the awardee a reasonable time to pursue a patent.

##### **5.05.04.01 NIST-Owned Patented Background Inventions**

SBIR awards made subsequent to “TT” subtopics in this Solicitation, will, upon the request of the awardee to a NIST licensing officer, include the grant of a non-exclusive research license to use NIST-owned patented background inventions which are specifically identified within the subtopic being awarded. SBIR offerors are hereby notified that no exclusive or non-exclusive commercialization license to make, use or sell products or services incorporating the NIST background invention is granted until an SBIR awardee applies for, negotiates and receives such a license. Awardees of solicited subtopics that identify specific NIST-owned patented background inventions will be given the opportunity to negotiate a non-exclusive commercialization license to such background inventions. If available, awardees may be given the opportunity to negotiate an exclusive commercialization license to such background inventions. License applications will be treated in accordance with Federal patent licensing regulations as provided in 37 CFR Part 404.

Any invention developed by awardee during the course of the SBIR contract period of performance is subject to the terms of section 5.05.04.

##### **5.05.05 Invention Reporting**

SBIR awardees must report inventions to the NIST SBIR Program within 2 months of the inventor’s report to the awardee. The reporting of inventions may be accomplished by submitting paper documentation, including fax or through the iEdison Invention Reporting System at [www.iedison.gov](http://www.iedison.gov).

#### **5.06 Additional Information**

(1) If there is any inconsistency between the information contained herein and the terms of any resulting SBIR funding agreement, the terms of the funding agreement are controlling.

(2) Before award of an SBIR funding agreement, the Government may request the offeror to submit certain organizational, management, personnel, and financial information to assure responsibility of the offeror.

(3) The Government is not responsible for any monies expended by the offeror before award of any funding agreement.

(4) This program solicitation is not an offer by the Government and does not obligate the Government to make any specific number of awards. Also, awards under the SBIR Program are contingent upon the availability of funds.

(5) The SBIR Program is not a substitute for existing unsolicited proposal mechanisms. Unsolicited proposals will not be accepted under the SBIR Program in either Phase 1 or Phase 2.

(6) If an award is made pursuant to a proposal submitted under this SBIR Program solicitation, a representative of the contractor will be required to certify that the concern has not previously been, nor is currently being, paid for essentially equivalent work by any Federal agency.

(7) The responsibility for the performance of the principal investigator, and other employees or consultants who carry out the proposed work, lies with the management of the organization receiving an award.

(8) Cost-sharing is permitted for proposals under this program solicitation; however, cost-sharing is not required. Cost-sharing will not be an evaluation factor in consideration of your Phase 1 proposal.

### **5.07 Research Projects with Human Subjects, Human Tissue, Data or Recordings Involving Human Subjects**

Any proposal that includes research involving human subjects, human tissue, data or recordings involving human subjects must meet the requirements of the Common Rule for the Protection of Human Subjects, codified for the Department of Commerce at 15 CFR Part 27. In addition, any proposal that includes such research on these topics must be in compliance with any statutory requirements imposed upon NIH and other federal agencies regarding these topics, all regulatory policies and guidance adopted by NIH, FDA, and other federal agencies on these topics, and all Presidential statements of policy on these topics. Any questions regarding these requirements should be addressed to Melissa Lieberman at (301) 975-4783 or [melissa.lieberman@nist.gov](mailto:melissa.lieberman@nist.gov).

**IRB Education Documentation.** A signed and dated letter is required from the Organizational Official who is authorized to enter into commitments on behalf of



the organization documenting that appropriate IRB education has been received by the Organizational Official, the IRB Coordinator or such person that coordinates the IRB documents and materials if such a person exists, the IRB Chairperson, all IRB members and all key personnel associated with the proposal. The NIST requirement of documentation of education is consistent with NIH notice OD-00-039 (June 5, 2000). Although NIST will not endorse an educational curriculum, there are several curricula that are available to organizations and investigators which may be found at: <http://grants.nih.gov/grants/guide/notice-files/NOT-OD-00-039.html>.

### 5.08 Research Projects Involving Vertebrate Animals

Any proposal that includes research involving vertebrate animals (including fish) must be in compliance with the National Research Council's "Guide for the Care and Use of Laboratory Animals" which can be obtained from National Academy Press, 2101 Constitution Avenue, NW, Washington, D.C. 20055. In addition, such proposals must meet the requirements of the Animal Welfare Act (7 U.S.C. 2131 et seq.), 9 CFR Parts [1](#), [2](#), and [3](#), and if appropriate, [21 CFR Part 58](#). These regulations do not apply to proposed research using pre-existing images of animals or to research plans that **do not** include live animals that are being cared for, euthanized, or used by the project participants to accomplish research goals, teaching, or testing. These regulations also do not apply to obtaining animal materials from commercial processors of animal products or to animal cell lines or tissues from tissue banks.

### 5.09 Technical Assistance For Proposal Preparation and Project Conduct

Proposers may wish to contact the NIST Hollings Manufacturing Extension Partnership (MEP), a nationwide network of locally managed extension centers whose sole purpose is to provide small- and medium-sized manufacturers with the help they need to succeed. The centers provide guidance to high-technology companies seeking resources and teaming relationships. To contact an MEP center, call 1-800-MEP-4-MFG (1-800-637-4634) or visit MEP's website at [www.mep.nist.gov](http://www.mep.nist.gov).

Proposers may wish to contact independent state, regional, or area specific resources, for example, economic development agencies for additional assistance and resources.

## 6.0 SUBMISSION OF PROPOSALS

### 6.01 Deadline for Proposals

**Deadline for Phase 1 SBIR proposal receipt is 3:00 pm on Friday, January 22, 2009 at the Contracts Office address below.**

**NIST does not accept electronic submission of proposals.**

All Offerors should expect delay in delivery due to added security at NIST. It is the responsibility of the Offeror to make sure delivery is made on time.

Because of the heightened security at NIST, USPS, FED-EX, UPS or similar-type service is the preferred method of delivery of proposals.

If proposals are to be hand delivered prior to the due date, delivery must be made by the actual deadline date and a 24-hour notice must be made to the NIST Contracts Office prior to delivery. All Offerors must notify Maria Gray at 301-975-5577 or [maria.gray@nist.gov](mailto:maria.gray@nist.gov). The name of the individual or courier company making the delivery must be included in the notification.

NIST will not evaluate proposals received after the stated deadline or that do not adhere to the other requirements of this solicitation (see checklist in section 8.04).

**Federal Acquisition Regulation** (FAR 52 215-1) regarding late proposals shall apply.

Offerors are cautioned to be careful of unforeseen delays, which can cause late arrival of proposals at NIST, resulting in them not being included in the evaluation procedures. No information on the status of proposals under scientific/technical evaluation will be available until formal notification is made.

### 6.02 Proposal Submission

**If courier delivered**, the Offeror must submit the Proposal Packages (**four (4) copies**) as defined in **Section 3.03** to:

National Institute of Standards and Technology  
Acquisitions and Management Division  
Attn: Mario Checchia, NIST-10-SBIR  
100 Bureau Drive STOP 1640 Building 301, Room B129  
Gaithersburg, MD 20899-1640

Phone Number: (301) 975-3976

**Hand delivery will be accepted ONLY at the following location on the due date, Friday, January 22, 2010, from 8:00 AM EST until closing time at 3:00 PM EST:**

National Institute of Standards and Technology  
100 Bureau Drive (Off Clopper Road)  
**Visitor Center ONLY**  
Gaithersburg, MD 20899

**Photocopies will be accepted.**

Acknowledgment of receipt of a proposal by NIST will be made. All correspondence relating to proposals must cite the specific **proposal number** identified on the acknowledgment.

(a) **Packaging--Secure packaging is mandatory. NIST cannot process proposals damaged in transit. All 4 copies of the proposal must be sent in the same package. Do not send separate "information copies," or several packages containing parts of a single proposal, or two packages of 4 copies of the same proposal. Clearly mark the bottom right-hand corner of the package with the subtopic number to which the proposal is responding.**

(b) Bindings--**Do not use special bindings or covers.** Staple the pages in the upper left hand corner of each proposal. Separation or loss of proposal pages cannot be the responsibility of NIST.

## **7.0 SCIENTIFIC AND TECHNICAL INFORMATION SOURCES**

Background information related to the NIST research programs referenced within the subtopics may be found within the NIST website at: [www.nist.gov](http://www.nist.gov). The NIST Virtual Library, [http://nvl.nist.gov/](http://nvl.nist.gov) may also provide valuable scientific and technical information resources. Wherever possible, reference citations are provided within the individual subtopics.

## 8.0 SUBMISSION FORMS

**8.01** Click on this link: [Cover Sheet](#) in order to access the required form (2 pages) in pdf format.

**8.02** Click on this link: [Project Summary](#) in order to access the required form in pdf format.

**8.03** Click on this link: [Proposed Budget](#) in order to access the required form in pdf format.

**8.04 Checklist of Requirements** Please review this checklist carefully to assure that your proposal meets the NIST requirements. Failure to meet these screening requirements will result in your proposal being returned without consideration. **Four copies of the proposal must be received by 3:00p.m. EST January 22, 2010.**

1. The [COVER SHEET](#) (both pages combined count as one toward page count) has been completed and is **PAGE 1** of the proposal.
2. The [PROJECT SUMMARY](#) is **PAGE 2** of the proposal.
3. The **TECHNICAL CONTENT** of the proposal **begins on PAGE 3** and includes the items identified in [SECTION 3.03.03](#) of the solicitation. The technical content section of the proposal is limited to 22 pages in length.
4. The SBIR PROPOSAL [PROPOSED BUDGET](#) has been completed and is the **LAST PAGE** of the proposal.
5. The entire proposal, including forms and the technical content, is **25 PAGES OR LESS** in length.
6. The proposal is limited to only **ONE** of the subtopics in Section 9.
7. The proposal budget is for **\$90,000 or LESS**. No more than one-third of the budget is allocated to consultants and/or subcontractors.
8. The abstract contains **no proprietary information** and does **not exceed** space provided on the Project Summary.
9. The proposal contains only pages of 21.6cm X 27.9cm size (8 ½" X 11").
10. The proposal contains an **easy-to-read font (fixed pitch of 12 or fewer characters per inch or proportional font of point size 10 or larger) with no more than 6 lines per inch**, except as a legend on reduced drawings, but not tables.
11. The P.I. will be employed by the company at least 51% time during the award

period.

12. If proposal addresses a subtopic that depends on patented background NIST technology, a non-exclusive, royalty-free patent license [application](#) is required. One signed original application is to be sent along with the proposal package. Each subtopic that references patented background technology and requires a license application is denoted with an asterisk.

NOTE: Offerors are cautioned to be careful of unforeseen delays that can cause late arrival of proposals, with the result that they **WILL** not be forwarded for evaluation.

**Potential offerors are advised to sign up within <http://www.fedbizopps.gov> to receive notification of any amendment to the solicitation that may be released after opening date. Also, potential offerors are advised to check the public Q&A website located at [www.nist.gov/sbir](http://www.nist.gov/sbir) for up to date information concerning specific subtopics that may be posted during the Solicitation open period.**

## 9.0 RESEARCH TOPIC AREAS

### 9.01 Advanced Biological and Chemical Sensing

#### 9.01.01.3-TT Microfluidic Palette for Cellular Response to Chemical Stimuli

*\* This subtopic requires that a license [application](#) be submitted in conjunction with the proposal. Be sure to include one, signed copy along with the proposal package.*

Microfluidic devices hold great promise for advancing measurements of cellular response to environmental stimuli. Previous methods for measuring cell motility toward a chemical stimulus, called chemotaxis, have required bulk measurements of community response with little information on individual cell dynamics. NIST has recently developed an innovative device called the microfluidic palette that produces multiple, steady-state chemical gradients in a miniature chamber about the diameter of a pinhead. The tool can be used to study the complex cellular responses critical in cancer metastasis, wound healing, biofilm formation and other fluid-related processes. The advantage of the NIST system is that the gradients are generated by diffusion and due to the unique configuration of the chamber, individual cell dynamics can be observed. NIST is soliciting proposals to develop this technology to a commercially viable stage. Aspects to be considered are optimizing fluid handling capabilities to facilitate integration of the palette into automated cell imaging systems and microarray readers resulting in faster and cheaper measurements of biological response to chemical gradients while maintaining

individual cell resolution.

Research needed to develop this into a commercial technology:

1. Optimize world-to-chip interfacing to reduce the complexity of the current palette design;
2. Optimize fluid handling design to reduce sample and reagent consumption;
3. Optimize palette design to enhance the interface with mature imaging technologies including microarray readers, cellular imaging and microscopy, histology and pathology tools and integration with cellular measurement protocols;
4. Optimize scalability through a design that promotes ease of manufacturing and handling

Phase 1 deliverables:

1. Report and demonstrate a prototype design for reduced fluid handling and world-to-chip interfacing; reduce device footprint by 50%.
2. Report and demonstrate a prototype design capable of integrating with accepted and mature imaging capabilities.

Phase 2 deliverables:

1. Report and demonstrate palette integration with imaging capabilities currently used for histology and pathology as well as to adapt to developed technologies marketed with limited application, microarray readers, which can be utilized for measurements of cell dynamics.
2. Report and demonstrate ease of manufacturing through nominal material use and time for construction, while maintaining capabilities achieved in phase 1.

References:

J. Atencia, J. Morrow and L.E. Locascio. The microfluidic palette: A diffusive gradient generator with spatio-temporal control. Lab on a Chip, Online June 22, 2009, 9(10): p. 2707-2714.

\* Provisional Patent Application Filed. Atencia J., Locascio L., "Microfluidic palette for the simultaneous generation of multiple chemical gradients" NIST Docket Number: 08-013, Federal Register, Vol. 74, No. 73, page 17819 (April 17, 2009).

### 9.01.02.3-TT Multi-well Cell Culture Plate for Oxygen Measurement

\* *This subtopic requires that a license [application](#) be submitted in conjunction with the proposal. Be sure to include one, signed copy along with the proposal package.*

Recently, NIST has developed a thin film oxygen sensor capable of monitoring changes of in vitro oxygen levels during culture [1]. In comparison with available commercial products, the NIST oxygen sensor is compatible with conventional cell imaging techniques (i.e. phase-contrast and quantitative fluorescence microscopy) allowing simultaneous monitoring of oxygen levels and other cell behavior. In addition, this sensor exhibits high sensitivity ( $K_{SV} = 584 \pm 71 \text{ atm}^{-1}$ ) and is capable of detecting small changes in oxygen level due to cellular oxygen consumption. The NIST sensor design employs a multiple layers that eliminate dye cytotoxicity and is compatible with multi-well cell culture plates used in conventional cell culture methods. However, the current design required the sensor to be individually placed in each well, and was labor-intensive for multi-well plates.

#### Motivation and Research Goals:

Cells based assays are a powerful tool widely utilized in the study of diseases and the development of new therapeutics and pharmaceuticals. By isolating cells from their native tissue, researchers can examine cell behavior and responses under controlled conditions. Due to the complexity of the biological response, these experiments must be performed with many replicates, and multi-well plate formats enable high throughput cell culture experiments.

A number of parameters defining the cell culture environment are monitored and controlled (e.g. temperature, pH, CO<sub>2</sub> partial pressure). In contrast, oxygen tension is rarely considered, even though oxygen is tightly regulated in vivo and can significantly affect cell function (e.g. wound healing, necrosis). Rather, current cell culture methodology generally calls for atmospheric oxygen levels (21%) that are much higher than the in vivo environment (3%-5%). Recent research has shown important systems where this practice leads to misleading conclusions (e.g. HIV infection, stem cell differentiation). These findings point to the critical need of monitoring and controlling oxygen levels in cell culture.

#### Research Goals:

The primary goals of the current SBIR is to develop a high throughput fabrication method to incorporate the NIST oxygen sensor into multi-well cell culture plates in a cost effective manner.

#### Milestones for Phase 1

The overall goal of the Phase 1 SBIR is to develop a strategy of incorporating NIST oxygen sensor into multi-well cell culture plates.

1. Design a high throughput method for placing an oxygen sensor in each well of a multi-well cell culture plates. This method should be fast and automated to minimize cost.
2. Establish and demonstrate a robust measurement protocol for sensitive determination of oxygen level that is compatible with conventional high throughput plate reader formats.

#### Milestones for Phase 2

The overall goal of the Phase 2 SBIR is the development and testing of multi-well cell culture plates with oxygen sensor.

1. Test fabrication method on 6, 12, 24, 48 and 96 well plates.
2. Demonstrate comparable cell culture on the oxygen sensing multi-well plates as compared to non-sensing control plates (no cytotoxicity).
3. Determine the sensitivity and reproducibility of the oxygen level measurement in each multi-well plate size.
4. Utilize the new design to monitor oxygen levels during live cell culture.

#### NIST Involvement

During Phase 1, NIST authors on this solicitation will be available to address questions about the previous oxygen sensor development and help evaluate proposed new sensor designs and measurement strategies.[1] Further, samples of earlier oxygen sensors will be made available. During Phase 2, NIST authors will expect to test prototype multi-well plate sensors for comparison to previous designs and are willing to assist with screening the new sensors during live cell culture (4th milestone).

#### References:

P. C. Thomas, M.Halter, A. Tona, S. R. Raghavan, A. L. Plant and S.P. Forry. A Noninvasive Thin Film Sensor for Monitoring Oxygen Tension during in Vitro Cell Culture, Analytical Chemistry, online publication October 27, 2009.  
<http://pubs.acs.org/doi/abs/10.1021/ac9013379>

\* US provisional patent application has been filed on the background NIST technology, Docket # 09-036, "Highly Sensitive Oxygen Sensor For Cell Culture."



## 9.02 Analytical Methods

### 9.02.01.3-R Signal Processing Methods for High-Dimensional Microsensor Data Streams

There exists a growing need for gas phase chemical analyses that can be performed reliably by portable systems. The application areas driving these needs are highly diverse, ranging from long-term environmental monitoring and process control to homeland security and medical diagnostics. Sensors and microsensors are expected to fulfill the detection role for many of the numerous application sectors, often because instruments (even when they can be miniaturized) are too expensive and/or labor intensive, and because they cannot be easily configured into network monitoring schemes.

This demand for sensors creates a significant set of challenges for sensor and microsensor performance. They must also be able to work under differing background conditions and identify a wide variety of target species. In fact, many applications (e.g. - personal safety or breath analysis for health screening) require that very low levels (~ 1 ppb to 100 ppb) of target compounds be tracked against complex and dynamic backgrounds that are mixtures of 10's to 100's of chemicals. Recognition, classification and quantification of the target analytes in such situations by sensors (not spectroscopic instruments) can require extremely rich datastreams as well as signal processing techniques that extract critical analytical information efficiently, rapidly and successfully.

NIST seeks the design and development of high performance signal processing routines to mate with microsensor technology being developed at its Gaithersburg, MD campus. Rich signal streams are produced from multielement (9 to 36) arrays, which are controlled and interrogated via circuitry that can individually address each element and also modulate the transduction properties of each microsensor within the arrays. Varied sensing materials populate the arrays so that differing responses are produced [1]. An example of "higher dimensionality" modulation of the elements is temperature programming (over a range of ~ 450 °C in 10 s), which temporally alters interfacial phenomena contributing to orthogonal signals coming from the sensor elements [2]. Data from a 16-element array can be obtained at a rate of up to ~ 200/s, with tests lasting weeks or even months. Training/testing sequences can also be rich in the variety of conditions they seek to examine (moving through ~ 40 conditions with specific exposure times of minutes). Signal processing methods are required that can model responses under known conditions, and then use those models for recognition of species during test sequences. It is expected that successful signal analysis will also require signal preprocessing subroutines that adapt to certain levels of signal offset

and drift in order to track useable response (shape) features. The models and signal analysis must quickly probe the rich datastreams to locate the most useful data for recognizing chemical events in time, discriminate between test flow constituents, and then identify and quantify target compounds. Certain aspects of the NIST technology can also benefit from software capabilities for tracking microsensor element "fatigue." Ultimately, the signal processing software would be refined to operate with the sensing hardware for near-real time detection and quantification. Many mathematical approaches can be considered to achieve these tasks, but it is imperative that the selected components work effectively together in the assembled signal processing system.

NIST researchers will work closely with awardee to provide databases that will be used in the development project.

Databases will be delivered for both training and testing experiments. Provided data will be accompanied by full descriptions of the experimental protocol and an explanation of any special operational aspects programmed into the microsensors in order to enrich or supplement the signal stream. During Phase 1, the awardee would develop methods for determining the most valuable portions of the data as a means of constructing recognition algorithms, and as appropriate, target libraries. Recognition models would be delivered to NIST, initially for off-line testing, and after refinements including integration with the NIST sensor control system, for on-line testing. Success would be measured by percentage of target analyte recognition the model allows (for multiple "on-off" presentations of from 3 to 4 compounds) in on-line testing demonstrations under a variety of backgrounds (including several interferences). Recognition from the coupled hardware-signal processing system must be indicated within 6 operational cycles (typical cycles running from 15 s to 30 s).

Phase 2, if awarded, would seek to improve the performance of the signal processing software, in terms of both percentage of proper recognition of targets, and the speed with which those assignments are made (down from 6 operational cycles to 3 cycles). In addition, NIST would require the demonstration of a number of other features, including a target quantification software module, flexibility to respond to adaptive operational modes, and a sensor fatigue tracking metric. Close collaboration with NIST researchers is envisioned for optimization of the system efficiency.

#### References:

1. K. D. Benkstein and S. Semancik "Integration of Nanostructured Materials with MEMS Microhotplate Platforms to Enhance Chemical Sensor Performance", *Journal of Nanoparticle Research* 8, 809-822 (2006).
2. D. C. Meier, J. K. Evju, Z. Boger, B. Raman, K. D. Benkstein, C. J. Martinez,

C. B. Montgomery, and S. Semancik, "The Potential for and Challenges of Detecting Chemical Hazards with Temperature-Programmed Microsensors", Sensors and Actuators B 121, 282-294 (2007).

### **9.02.02.3-TT Ultra-rapid Microtiter Plate Reader with "Detectorless" Electrophoresis Detection**

*\* This subtopic requires that a license [application](#) be submitted in conjunction with the proposal. Be sure to include one, signed copy along with the proposal package.*

The ability to acquire large amounts of high quality data very rapidly is increasingly important for progress in the biological sciences (e.g. drug discovery and systems biology). Capillary electrophoresis (CE) has a number of advantages that make it well suited to provide the kind of quantitative assays that are necessary in this area. In particular, it is relatively fast, requires only small amounts of sample and reagents, and can be applied to a wide variety of biochemical analysis problems. Although capillary array electrophoresis systems have been described for high throughput operation, they are complicated, expensive, and difficult to operate.

NIST has recently described a new approach to multiplexed electrophoresis which is much simpler and less expensive than conventional CE. It is expected that this approach will provide the ability to read an entire microtiter plate in less than one second, with no optical components, and without the need for expensive fluorescent or colorigenic reagents. In the new approach, the complex and expensive optical detection system of the conventional plate readers or CE systems is replaced by an array of very short (30-300  $\mu\text{m}$  long) electrophoresis channels (1-10  $\mu\text{m}$  diameter) and an array of electrical resistors used to measure the current through the electrophoresis channels. Measurements can be made by dipping the electrophoresis channel array into the samples to be analyzed and applying a controlled pressure and voltage to the array. The electrophoresis device can be easily and inexpensively arrayed into a format compatible with existing robotic systems for high throughput microtiter plate based measurements.

The "detectorless" electrophoresis approach is an implementation of the gradient elution moving boundary electrophoresis (GEMBE) technique with very short channels. With GEMBE, a combination of an electric field and controlled, variable buffer counterflow is used to achieve high resolution separations of multiple analyte species. Typically, the polarity of the applied voltage is set so that the analytes of interest are driven by electrophoresis from the sample toward the separation channel. At the beginning of a separation, the counterflow is high so that none of the analytes of interest will enter the channel. Over the course of the separation, the counterflow is gradually

reduced so that each analyte, in turn, will enter the channel as a moving boundary or step<sup>2</sup>. With very short channels, only one step at a time is present in the channel, and the channel current can be used as a detector signal, with minimal detector hardware. The time derivative of the current is then equivalent to a conventional electropherogram. Because of the simplicity of the hardware used, the “detectorless” electrophoresis approach is simple and inexpensive to multiplex; making it ideally suited to high throughput measurements.

NIST seeks the design and construction of a prototype apparatus for multiplexed, microtiter plate-based “detectorless” electrophoresis. NIST is willing to work collaboratively with the awardee on all aspects of the project. A proof-of-concept apparatus will be developed for evaluation for Phase 1. The Phase 1 apparatus will be capable of automated electrophoretic analysis of at least 16 samples simultaneously.

Phase 2, if awarded, will involve the design of an improved prototype taking into account the results obtained with the Phase 1 apparatus. The Phase 2 prototype will be integrated with a robotic system for automated sample mixing and will be capable of automated analysis of at least 96 samples simultaneously.

#### References:

1. D. Ross and J.G. Kralj, *Anal. Chem.* 2008, 80, 9467–9474.
2. D. Ross and E.F. Romantseva, *Anal. Chem.* 2009, 81, 7326–7335.
3. J.G. Shackman, M.S. Munson, and D. Ross, *Anal. Chem.* 2007, 79, 565-571.

\* US Patent Applications have been filed, NIST Docket #06-011 and #06-011CIP, "Gradient Elution Moving Boundary Electrophoresis"

### **9.02.03.1-R Pulse Tube Cryocoolers Optimized for Cooling Massive Payloads**

Pulse tube cryocoolers capable of reaching temperatures of 4 K or below have enabled a new generation of liquid cryogen-free refrigerators that are the tools of choice for a wide variety of medical and scientific applications. These cryostats often use the pulse tube to cool a massive payload, such as a superconducting magnet for magnetic resonance imaging, or an additional refrigeration stage to reach yet lower temperatures. NIST is particularly interested in the use of pulse tubes to precool an adiabatic demagnetization or dilution refrigerator. These two-stage systems provide reliable, robust access to 50 mK, and are increasingly used to cool sensors for applications ranging from materials analysis to measurements of the cosmic microwave

background. In all these scenarios, a significant amount of thermal mass is attached to the 4 K pulse tube and, as a result, the initial cool-down from room temperature is long: about 14 hours in small sensor systems used for homeland security applications and several days for large astronomical instruments. A key constraint on the speed of the initial cool-down is the low cooling capacity of the pulse tube's 4 K stage at higher temperatures.

NIST seeks pulse tube cryocoolers with design improvements that significantly reduce the cool-down time of massive loads (>10 kg) on the 4 K stage. Suggested methods for this include, but are not limited to, adjustable or switchable orifices, variable rotary valve speeds, and the use of heat pipes or heat switches between the pulse tube stages.

Secondary goals of this project are the reduction of vibrations and better power efficiency. Presently, the primary source of vibrations is not elongation of the cold head. Instead, the dominant source is the pressure wave in the flexible line between the remote valve and cold head. Alternative line materials and geometries that reduce this vibration are of interest. To improve efficiency, dynamic compressor settings are of interest to provide peak power when cooling and reduced power during steady-state operation. Dynamic compressor behavior may also reduce vibration in the line between the remote valve and cold head during steady-state operation. Alternative techniques to reduce vibrations, improve efficiency, and reduce cool down times are also of interest.

NIST is willing to work collaboratively with the awardee. In particular, NIST will provide representative data on cryostat requirements, such as typical thermal masses and steady state heat loads.

Milestones for the project are:

Phase 1: Proof-of-concept demonstration of techniques to reduce the cooling time to 4 K of massive payloads. Demonstrations of reduced vibration and higher efficiency are also desirable.

Phase 2: Development of commercializable hardware, including final design and fabrication of components and design and fabrication of a controller and compressor. A functioning 4 K pulse tube system that incorporates the design improvements described above will be delivered to NIST for its retention and ownership.

## 9.03 Healthcare and Medical

### 9.03.01.2-TT Semi-Autonomous, Articulated Forklift (SAAF) in Close Proximity to Workers

\* *This subtopic requires that a license [application](#) be submitted in conjunction with the proposal. Be sure to include one, signed copy along with the proposal package.*

The NIST HLPR Chair [1, 2, 3, 4] was developed based on forklift technology. The HLPR Chair included a unique articulation design allowing “lift-from-above” patient transfer, positioning, and mobility. Replacing the chair with the original forks or a gripper, HLPR provides much more than a forklift with load: accessibility, acquisition, rotation, measurement and transport capabilities of boxes and other heavy (up to 250 Lbs.) and bulky loads. HLPR, built using a manual forklift frame with added rear drive and steer, and wheel encoders, can be manually or computer controlled. Typically in manufacturing and distribution facilities, humans inefficiently or unsafely access, lift, maneuver and carry boxes, bags, and other loads causing worker injuries similar to patient lift and maneuverability by healthcare workers. Manual and powered lift devices and carts are available but, require humans to awkwardly maneuver loads throughout facilities. Workers knowledge and load accessibility are required to keep material handling costs down, although these operations could be safer and more efficient with intelligent, robotic worker-assistance. Therefore, lacking is a crossover between manually-controlled, powered forklift technology (improved with sizing comparable to humans and forks/gripper articulation for better load access) and automated guided vehicle technology with safe vehicle use around humans and in unstructured environments. Hence, a Semi-Autonomous, Articulated Forklift (SAAF) is needed. Manually accessing a load and then autonomously sending the load to another worker, equipment rack, truck or other area would eliminate many inefficient worker activities and reduce worker injuries if the vehicle can be made safe between loading and unloading areas. Also lacking is perception of the environment required for semi-autonomous vehicle technology to be used around humans. Manually-controlled forklifts are notorious for being unsafe since forklift framing and loads block driver views putting both the driver and pedestrians at risk. [5] 3D LIDAR (light detection and ranging) sensors are becoming useful for measuring volumes in tanks. These sensors also have potential for vehicle application although they have not been integrated and tested on forklift or other industrial vehicles. Similarly, ceiling- or wall-mounted absolute position measurement technology is new and untested on semi-autonomous vehicle technology. Therefore, research that is needed to advance SAAF toward the marketplace includes:

- Applying HLPR to access box, bag or palletized loads from + 90° to - 90° of the HLPR front while lifting/stacking loads from/onto shelves (articulation of forks or gripper) and supporting the load for safe, autonomous mobility

- 3D measurement of humans, equipment, and overhanging obstacles in the vehicle path integrated with SAAF
- Model based 3D recognition of doorways (human passageways and truck doors) and other path attributes for safe, efficient vehicle navigation.
- Point-to-point, load transfer around humans and through unstructured environments with knowledge of absolute vehicle position for navigation and tracking.
- Semi-autonomous control using developed open-source NIST control technology advanced with manual-to-autonomous and autonomous-to-manual control modes allowing human/robot intervention.

NIST is willing to work collaboratively with the awardee to help with evaluation of the operating parameters, but will not be involved in actual software development and vehicle testing. The awardee(s) will work closely with NIST staff members who are developing manufacturing vehicle standards by providing consultation, drawings, and prototype assistance with background knowledge of the device. Prototype modifications are to be made by the awardee.

Phase 1 will include design and demonstration of interchangeable and articulated forks and box gripper with robust load measurement ready for integration into the SAAF computer control system; design of the SAAF vehicle control code using MOAST [6, 7] ready to accept: absolute positioning sensor (APS) inputs, obstacle detection inputs from a 3D LIDAR sensor, and reactive vehicle control based on APS and 3D LIDAR inputs including vehicle stop and/or slow and modify vehicle path.

In Phase 2, a functioning SAAF, using HLPR 1, will be delivered to NIST for its retention and ownership, including:

- manually-controlled, powered, load measured, articulated pallet, box, bag lift and carry system with onboard, integrated vacuum gripper,
- fully functional SAAF vehicle control code using MOAST including:
  - sensor processing using wheel encoders, steering potentiometer, absolute positioning sensor (APS), and obstacle detection inputs from a 3D LIDAR sensor, model based door frame point cloud processing
  - world modeling showing path traveled and vehicle tracking, model based door frame recognition
  - behavior generation reacting to input commands (e.g., go to loading

dock or robot workcell) and processed world models to control SAAF to carry an onboard load or unloaded vehicle from one end of the building to another and dock with a shelf while adapting to humans in and along the path to apply: vehicle stop, modify vehicle path, and/or drive slow. Reacts to door frames as obstacles rotating to the right or left as needed to pass through.

Example plan execution will be as follows:

Worker A loads SAAF with boxes using onboard vacuum gripper and secures load to the vehicle; commands vehicle with a pushbutton command to carry load to the loading dock from current robot workcell position.

SAAF traverses out of robot workcell, down the hallways making turns as needed and stopping or avoiding humans, overhanging obstacles or other obstacles along the way to the loading dock

SAAF stops at the loading dock, is unloaded by Worker B onto shelves or in a truck; worker B commands through a pushbutton to return the SAAF back to worker A at the robot workcell.

Phase 2 Demonstration will occur at NIST in the Shops Building between the robot workcell and the loading dock.

**Figure 1** – Concept for box loading (left and middle) onto the SAAP and then (right) sending the vehicle on its way to another location. Only 2D LADAR is shown (red dotted line on right figure).

References:

[1] Roger Bostelman, James Albus, "Home Lift, Position and Rehabilitation (HLPR) Chair" (patent pending) , filed January 2009. NIST Docket #08-002

[2] "Static and Dynamic Stability Measurements of the Home Lift, Position and Rehabilitation (HLPR) Chair/Forklift," Joshua Johnson, Roger Bostelman, NISTIR, October 2009.

[3] Roger Bostelman, James Albus, "HLPR Chair – A Service Robot for the Healthcare Industry," 3rd International Workshop on Advances in Service Robotics, Vienna, Austria, July 7, 2006.

[4] Roger Bostelman, James Albus, Tommy Chang, Tsai Hong, Sunil K. Agrawal, Ji-Chul Ryu, "HLPR Chair: A Novel Indoor Mobility – Assist and Lift System," DETC-35295, Proceedings of IDETC/CIE 2007, ASME 2007 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, September 4-7, 2007, Las Vegas,



Nevada.

[5] Roger Bostelman, "White Paper – Towards Improved Forklift Safety," PerMIS 09 Special Session, October 2009.

[6] Balakirsky, S. Carpin, G. Dimitoglou, B. Balaguer, "From Simulation to Real Robots with Predictable Results: Methods and Examples," in: R. Madhavan, E. Messina, and E. Tunstel (Eds.), Performance Evaluation and Benchmarking of Intelligent Systems, Springer, 2009.

[7] Balakirsky, F. Proctor, C. Scrapper, T. Kramer, "An Integrated Control and Simulation Environment for Mobile Robot Software Development," Proc. of the ASME Computers and Information in Engineering Conference. New York, August 3, 2008.

\* US Patent Application #20090144895, Home Lift Position and Rehabilitation (HLPR) Apparatus <http://appft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&p=1&u=%2Fnethtml%2FPTO%2Fsearchadv.html&r=1&f=G&l=50&d=PG01&S1=20090144895&OS=20090144895&RS=20090144895>

## 9.04 Homeland Security

### 9.04.01.2-R RFID-Integrated Sensor Systems

Background:

Radio Frequency Identification (RFID) technologies are rapidly emerging as a means for tracking products and assets. Sensors can provide information about the condition of the products. The IEEE 1451.7 standard [1] was developed to provide methods for interfacing transducers (sensors or actuators) to RFID tags, and for reporting transducer data within the RFID and IEEE 1451 infrastructure.

Scope:

Innovative solutions are sought that create new ways to integrate RFID with networked sensor systems based on the IEEE 1451.7 standard. The IEEE 1451.7 standard provides a command set for accessing IEEE 1451.7 transducer data and parameters, such as the transducer electronic data sheet (TEDS) and timestamp information, but does not dictate use of a particular air interface format. Proposals submitted under this subtopic may address access to or cooperation with NIST staff. NIST is willing to work collaboratively with the awardee(s) to help with the evaluation of operating parameters, but will not be involved in the system design.

A successful Phase 1 awardee will deliver to NIST a prototype IEEE 1451.7 RFID-integrated wireless sensor network consisting of at least one network capable application processor (NCAP) with a transducer interface module (TIM) (see Appendix D of Reference 1), and at least two IEEE 1451.7 transducers. The NCAP/TIM must include a PC-compatible Ethernet network interface, a microprocessor-based command generator, and a radio-frequency (RF) unit for the UHF (902-928 MHz) or SHF (2.4 GHz) RFID frequency bands to communicate with the IEEE 1451.7 transducers. A partial list of standardized commands that must be supported include:

- (1) Read-Sensor-Identifier,
- (2) Read-Primary-Characteristics-TEDS,
- (3) Write-Sample-And-Configuration,
- (4) Read-Sample-And-Configuration, and
- (5) Read-Single-Memory-Record, as defined in the IEEE 1451.7 standard.

Each IEEE 1451.7 transducer must include a compatible RF unit, a microprocessor-based command interpreter, memory for the TEDS data accessed by the required commands, at least two sensors (e.g., temperature and vibration), and the means to digitize the sensor output with at least 8-bit resolution. Fully licensed Windows-compatible software and source code for demonstration of all required capabilities must also be delivered for NIST use.

A successful Phase 2 awardee would deliver to NIST a full function prototype IEEE 1451.7 RFID-integrated wireless sensor network NCAP/TIM and six IEEE 1451.7 transducers, along with software and source code for demonstration of all required capabilities in the standards.

**Motivation:**

RFID is rapidly emerging as a means for tracking products and assets. RFID standards are being developed to address these needs. Sensors can provide information about the condition of the products. There is a great need to provide sensor data as part of the supply chain reporting. Therefore combining an RFID tag into a sensor system consisting of sensors and actuators would not only identify a product, but also determine the conditions and health of the products for public safety. Development of the requested innovative solutions will help accelerate the implementation and widespread use of the new IEEE 1451.7 standard and will advance the state of RFID-integrated sensor systems.

**Reference:**

1. IEEE P1451.7D1.1 - Proposed Standard for a Smart Transducer Interface for Sensors and Actuators - Transducers to Radio Frequency Identification (RFID) Systems Communication Protocols and Transducer Electronic Data Sheet Formats (available from the IEEE website).

## 9.05 Information Technology

### 9.05.01.9-R Sound Static Security Analyzer for Software

Software is crucial in modern society for operations as diverse as jet planes, cell phones, heart pacemakers, electronic commerce, national infrastructure (like water or electricity SCADA), manufacturing machinery, and factories. Many of these have external digital interfaces, for instance to set parameters or control operation.

Severe security vulnerabilities are still frequently found in new code, even for bugs we've known about for decades, like buffer overflow or hard-coded passwords.

Special programs called "static analyzers" have been developed to report some vulnerabilities in software [1]. Unfortunately finding vulnerabilities can be arbitrarily complex, because of the difficulty of analyzing millions of lines of code, looking for dozens of different kinds of vulnerabilities, and explaining findings so programmers can quickly determine appropriate remediation. The challenge of meeting all these goals and others with limited budgets leads developers of static analyzers to use approximations and heuristics.

NIST is investigating software assurance methods to detect, remove, mitigate, or prevent vulnerabilities. Analogous to physical reference measurements, we want to be certain that types of vulnerabilities are (or are not) present in a piece of software. Since perfect manual review is impractical, we need a static analyzer which is sound [2].

That is, if it reports that a vulnerability is present, it is present with mathematical surety. If it reports that it is absent, it is assuredly absent. (Theoretical limitations mean all analyses must sometimes answer "unknown".)

Research is needed to (A) find a theoretical and mathematically sound foundation for the semantics of computer programs, (B) apply such a foundation to an actual programming language, and (C) implement analysis of realistic programs, such as those in the SAMATE Reference Dataset (SRD) [3].

Phase 1 of this research should demonstrate a prototype of such an analyzer for the C programming language, along with delivering a report giving the theoretical foundation of the sound analysis used.

Proposals submitted under this subtopic may address access to NIST's software tools and staff. NIST is willing to work collaboratively with the awardee to help evaluate the scope of analyses which can be handled.

In Phase 2 a functioning system for sound analysis of C programs for at least three of the Common Weakness Enumeration (CWE [4]) vulnerabilities listed below will be delivered to NIST for its retention and ownership.

CWE 78 OS Command Injection

CWE 89 SQL Injection

CWE 121 Stack-based Buffer Overflow (or CWE 122. CWE 121 and 122 cannot be counted as two vulnerabilities.)

CWE 134 Uncontrolled Format String

CWE 170 Improper Null Termination

CWE 244 Failure to Clear Heap Memory Before Release

CWE 259 Hard-coded Password

CWE 401 Failure to Release Memory

CWE 415 Double Free (or CWE 416 Use After Free. CWE 415 and 416 cannot be counted as two vulnerabilities.)

CWE 457 Use of Uninitialized Variable

References:

[1] "Static Analyzers in Software Engineering", CrossTalk, The Journal of Defense Software Engineering, 22(3):16-17, March/April 2009.

[2] "Source Code Security Analysis Tool Functional Specification Version 1.0", NIST Special Publication 500-268, May 2007.

[3] "Software Assurance with SAMATE Reference Dataset, Tool Standards, and Studies", Oct 2007, 26th Digital Avionics Systems Conference (DASC).

[4] <http://cwe.mitre.org/>, MITRE.

#### **9.05.02.4-R Analysis of New WWVB Modulation Schemes for Future Broadcast**

NIST radio station WWVB broadcasts a low frequency (60 kHz) time and frequency signal that delivers accurate time-of-day information to millions of radio receive devices across the United States. The modulation is an Amplitude Shift Keying (ASK) pulse width modulation conveying 1 bit per second. Further details of the WWVB modulation scheme and the data encoding are documented in NIST Special Publication 432, "NIST Time and Frequency Services" (<http://tf.nist.gov/timefreq/general/pdf/1383.pdf>).

Future low-frequency radio broadcasts are proposed using other transmitters elsewhere in the U.S. We solicit proposals to study and analyze potential future modulation schemes. This includes a detailed analysis of the present ASK technique and possible improvements to its format or form to improve radio

reception and processing. It also includes analysis of different modulation schemes such as digital minimum shift keying (MSK), quadriphase shift keying (QSK), and other methods of modulation of a low-frequency carrier. The analysis should detail advantages and disadvantages, including broadcast complexity and power usage, and reception complexity, power usage, and processing gain.

The potential improved broadcast technology could be complemented by improved receivers exploiting the different modulation schemes. These improved receivers could be commercialized to broaden the market for WWVB time code receivers.

Phase 1: The awardee will develop and deliver to NIST a report detailing possible improvements to the existing WWVB modulation schemes to be used on future broadcasts. Also the report shall detail other modulation schemes possible for future low frequency broadcasts and examine advantages and disadvantages of the broadcast from the transmission perspective and from the receivers' perspective. The proposed new modulation schemes should be backwards compatible with existing WWVB ASK broadcast techniques.

Phase 2: The awardee will develop a working modulator based upon results of the Phase 1 report. This modulator will be a fully developed and assembled circuit board with detailed schematics that will be capable of immediate implementation into a transmission operation. The awardee will also develop at least one prototype receiver based on the improved modulation scheme. The prototype receiver must demonstrate a clear potential for being compatible with existing commercial WWVB receivers in terms of size, power requirements, and other salient features, to enable the receiver to potentially augment the commercial market for WWVB receivers.

#### **9.05.03.9-R Ontologies for Enterprise Level Security Metrics**

Currently, it is difficult to answer simple questions such as “are we more secure than yesterday” or “how should we invest our limited security budget.” Decision makers in other areas of business and engineering often use metrics for determining whether a projected return on investment justifies its costs. Spending for new cyber-security measures is such an investment. Therefore, security metrics that can quantify the overall risk in an enterprise system are essential in making sensible decisions in security management.

Information Security is a critical part for any enterprise. Often wrong decisions are made due to insufficient knowledge about the security domain, threats, possible countermeasures and the company's assets. There are several reasons for this. First, security terminology is not precisely defined, which leads

to confusion among the security experts and the customers who should be served. Security ontologies are a viable solution for this problem because they allow a precise definition of the entities and their relationships to each other. Secondly, decisions about security are based on intuition rather than a thorough cost/benefit analysis. The main goal of the ontology is to develop a data model that has knowledge about which threats endanger which assets and which counter measures can reduce the probability of damage.

Proposals should include what sort of things that we need to measure for security and how to gather the data to compute the metrics. It should also include a data model using entities and relations for enterprise level security metrics. NIST is willing to work collaboratively with the awardee to help in the design and reference implementation. Phase 1 will demonstrate the feasibility of the design of ontology for enterprise level security metrics. In Phase 2 a functioning and tested implementation using OWL will be completed.

#### **9.05.04.9-TT Technology Transfer of Multimodal Biometric Application Resource Kit (MBARK)**

Despite existing efforts, building modern biometric applications (or clients) that are flexible with respect to changes in sensors, workflow, configuration, and responsiveness remains both difficult and costly. The Multimodal Biometric Application Resource Kit, or MBARK reduces the complexity and costs of implementing such an application. MBARK is public domain source code that may be leveraged to develop the next-generation of biometric and personal identity verification applications.

Incorporating the MBARK libraries can yield a variety of enhancements critical for the success of any real-world system. For example, MBARK provides a usability-tested and consistent user interface. MBARK provides operators means to quickly recover from both minor mistakes and major hardware failures. In addition, the use of Extensible Markup Language (XML) facilitates true sensor interoperability via plug-ins and allows for changes in workflow on-the-fly.

NIST seeks innovative proposals that would facilitate the technology transfer of MBARK. Potential activities include:

- Integration of commercial or research sensors
- Removal of third-party components and dependencies
- Migration to additional computing platforms (such as Mono, <http://www.mono-project.com>)

- A comprehensive suite of unit, integration, interaction, and/or user acceptance tests

Applicants are encouraged to propose technology transfer activities not listed above—all reasonable activities will be considered. NIST is prepared to collaborate closely with the applicants should the proposed activity warrant so.

MBARK was developed at the National Institute of Standards and Technology (NIST) by employees of the Federal Government in the course of their official duties. Pursuant to Title 17 Section 105 of the United States Code, this software is not subject to copyright protection and is in the public domain. Proposals should clearly describe the disposition of any generated intellectual property. Applicants are encouraged to include a component that returns both major and minor changes to the core MBARK source-code back to the public domain. Applicants are encouraged to use an open source license for their value-added components, although this is not a hard requirement of the proposal.

Delivery is expected in two phases. Source code, documentation, and accompanying tools are the expected deliverables for both phases. Phase 1 should demonstrate the technical feasibility of the proposed research. Phase 2 is the full development and implementation phase. Should the proposal be accepted, the applicant should expect to collaborate with NIST to further refine the phases to better reflect the particular activity proposed.

## 9.06 Intelligent Control

### 9.06.01.6-R Self-Calibrating Camera Networks for Rapid Deployment

Camera networks have been recently proposed as a new sensor modality to provide 3D tracking for manufacturing, construction, and research applications. A major obstacle in commercializing camera networks is the expensive and time-consuming calibration process.

This project calls for the development of an integrated hardware/software solution that comprises a network of cameras that can robustly self-calibrate.

Requirements for the solution include:

- 1) Automatic measurement of intrinsic parameters, including focal length, image center, and lens distortion parameters
- 2) Automatic measurement of extrinsic parameters, including rotation and translation values. Together with (1), these measurements capture

the camera's projection matrix  $P$ .

- 3) A method to synchronize all cameras to a common time
- 4) Total calibration time < 10 min
- 5) At least 4 cameras in the network
- 6) Successful solutions may include auxiliary devices to aid in calibration (beacons, targets, pan/tilt heads, etc.)

The ultimate vision of this project is to be able to place cameras throughout a work volume and begin 3D tracking operations within minutes, rather than hours as is the current practice. The realization of this goal will substantially reduce the barrier to entry by allowing the end user without advanced calibration training to quickly get a camera network operational.

NIST will work collaboratively with the awardee by providing feedback through testing the system in various environments (laboratory as well as field scenarios).

Phase 1: As a minimum demonstration of feasibility, the awardee will develop and deliver to NIST one prototype system meeting the above requirements. This prototype will contain the cameras, any external devices, and algorithms needed to perform the calibration. This portion may be completed in a simulation. NIST will test and evaluate the prototype calibration accuracy and setup time, and use these data to inform the review process for Phase 2 proposals.

Phase 2 (if awarded): The awardee will then proceed with refined development of the system, and construct a physical prototype if Phase 1 was conducted in simulation only.

#### **9.06.02.2-R Dynamic Six Degree of Freedom (6DOF) Vision System**

Automated assembly systems in factories typically measure the pose of an object only in highly constrained situations, such as when parts move at a fixed speed in a rigid conveyance, or by stopping an assembly line to sense the position of the part. Next generation flexible and reconfigurable automation processes will remove these constraints using sensor technology that can perceive the position of an arbitrary part under unconstrained motion to either inspect the part or direct a robot to manipulate it while still in motion. This advanced, dynamic six degree of freedom pose sensing technology will promote flexibility and cost savings by replacing expensive fixed installations



with more intelligent combinations of sensing and automation, and enable human operators to work and collaborate in close proximity to robots using validated 6DOF sensing. The technology will enable US manufacturers to compete more effectively with foreign firms where greater investments have been made recently in robotic technology.

The goal of this SBIR topic is to build a robust 6DOF parts/object measurement system for next generation agile manufacturing. The system must: 1) self-calibrate when combined with a robot arm or an arm attached to a rail (i.e., 7 DOF arm and rail) or when disconnected from the robot; 2) continuously measure the 6DOF location and orientation of an unconstrained moving object; and 3) report location and orientation for use by a supervisory level computer used to send high level commands to work cell factory equipment such as a robot arm, an automated vehicle, and conveyers. Part location and orientation information must be in the form of x, y, z, roll, pitch, yaw parameters or an equivalent representation suitable for locating the part in the larger workspace.

Phase 1 deliverables will include a detailed document describing the proposed approach to each of the steps above, together with results of experiments for each subcomponent providing evidence that the approach is feasible. NIST researchers will be available to work with the awardee(s), and NIST will make laboratory and measurement facilities available to support this work.

Phase 2 deliverables will include a prototype system that carries out the dynamic 6DOF measurements in unstructured environments, ready for testing at NIST facilities.

## **9.07 Manufacturing System Integration**

### **9.07.01.2-R Decision Support Tools for Sustainable Manufacturing**

Sustainable Manufacturing is a systems approach for the creation and distribution (supply chain) of innovative products and services that minimizes resources (inputs such as materials, energy, water, and land), eliminates toxic substances, and produces zero waste that in effect reduces carbon (including carbon equivalent) intensity across the entire lifecycle of products and services. Sustainable manufacturing stresses the importance of understanding manufacturing as a science of producing things taking into account sustainability factors during design, manufacture, distribution (supply chain and reserve supply chain), use, and post use. Traditional engineering tools such as CAD/CAM/CAE/PDM/PLM relied heavily on mathematical algorithms (geometry), information modeling, and interoperability standards to enable data aggregation, analysis, and decision support system.

In order to include total lifecycle synthesis and sustainability in to the early design stage of products we need to develop appropriate information infrastructure, and tools. Current LCA tools are mainly suitable for post-design, production, and distribution. However, in order to do “what-if” analysis and synthesis in the early design phase it is critical to integrate environmental aspects into product design and development, product lifecycle management and total lifecycle analysis. This SBIR solicitation seeks development of a tool that uses identified data and defined analysis and synthesis procedures to support interoperability among design engineering tools (such as CAD, CAE, CAM, PDM, PLM), enterprise business tools (such as ERP, SCM, CRM) and LCA tools. Such a tool should support energy and material monitoring, recyclability and reuse analysis, as well as other methods to measure the impact of a product and process on the environment.

The awardee will work with NIST staff members involved in sustainable manufacturing R&D to develop requirements for lifecycle assessment (LCA) tools to calculate GHG (green house gases, including CO<sub>2</sub>) footprints and integrate with design tools.

A successful Phase 1 awardee will deliver to NIST:

- Requirement analysis and data models to integrate environmental aspects that is beyond regulatory compliance into product design and development, product lifecycle management and total lifecycle analysis.
- Survey analysis of LCA tools and its scope
- Proof of concept case study to demonstrate the integration of design tools with LCA tools

A successful Phase 2 awardee will deliver to NIST:

- Develop necessary standards based application programming interfaces (APIs) between design tools, business tools, and LCA tools.
- Maximize the application of available standards such as PLCS (ISO 10303-239), BPMN, ebXML etc.
- Develop service oriented architecture based solution for such integration.
- Enable open standards for interfacing design tools, business tools, and LCA tools.

### **9.07.02.1-R Printed Circuit card Assembly (PCA) Testability Coverage Analysis in a Three-Dimensional Visualization Environment**

Printed Circuit Board Assembly technology is trending towards higher complexity, many boards have significantly more components and solder joints today than just a few years ago. In addition, board assembly process variations may lead to board failures due to the change of process parameters. The sooner process and electrical defects are caught, the lower the total cost of ownership will be. Defect detection early in the manufacturing process is critical to lower cycle time and cost for high-volume production. Therefore, a key challenge facing electronics manufacturers of high complexity boards is the issue of board testing; no single test technology is capable of providing full test coverage

High-density printed circuit card assemblies that mix digital, video, and RF technologies require multiple coordinated approaches to achieve sufficient test coverage to ensure proper operation. Currently it requires at least three different testing methodologies to achieve minimal testing coverage. Firstly, boundary-scan (IEEE Std 1149.1) supports digital integrated circuits. The second, "in circuit and flying probe" support analog circuits, including video. And lastly, RF functional testers support RF circuits. An application is desired that can integrate data from all three testing methodologies and provide a combined schematic and layout level display of test coverage of the entire circuit board; so the results are easily interpreted visually. Artificial coloring for the contribution from each testing methodology to the solution set should be displayed visually. Geometrically accurate three-dimensional component models will allow detailed examination of cases where simple rule based model declares the component untestable in a flying probe tester. SMEs shall be able to feed this test analysis tool with design information in the form of rich AP210 product models (the ISO 10303 standard for electronics). This effort shall apply these general techniques to create capabilities that will aid printed circuit board (PCB) fabricators and designers in the electronics domain.

NIST is soliciting proposals for innovative software and technology infrastructure that will overcome these challenges. The following capabilities are required:

Phase 1: Integrate flying probe rules results with boundary-scan results in a 3-D visualization showing in the layout the coverage achieved by each methodology (signified by different colors).

Phase 2: Integrate RF test coverage and cost models into the visualization. Combine the schematic and layout into the visualization. Provide back annotation to the layout tool of proposed changes.

The result of this effort will be a software tool, (can be web based) with the

above capabilities. Awardee will provide prototype version in phase 1. It is expected that NIST will collaborate extensively with awardee.

### **9.07.03.2-R Standard OWL Reasoning Support for Physical Quantities and Units**

The OWL Web Ontology Language [1] is emerging as an important tool to enable manufacturing enterprises to manage their information intensive activities such as product design for sustainability, supply chain planning, and systems and information integration. What OWL brings to this environment is the ability to capture knowledge in a precise way that then can be reasoned over by software systems. This reasoning can support merging of data and detection of inconsistencies among other capabilities. Previous NIST supported work has enhanced these capabilities by providing an additional formal interpretation and associated tooling that extends OWL such that it can be used as a schema language. OWL is now a nearly complete tool for model driven integration.

However, for use in technical domains and for eBusiness environments, it still has some weaknesses. Values describing physical quantities such as length or electric current are key elements of data in these domains. Physical quantity values are associated with aspects of things or phenomena, and logically contain both a numerical component and a unit (although the unit may be implicit or assumed). Physical quantities can be represented using many different units yet indicate the same value, and machine reasoning is needed to properly recognize when these values are the same, inconsistent, or out of range. Currently OWL has only basic support for expressing and reasoning over plain numerical values and no means to operate on physical quantity values with unit components. While there are ways to work around this, to be useful for manufacturing applications, these ways need to be standardized and support reasoning such as simple forms of dimensional analysis. There have been various models proposed for handling units in OWL, but none have any widespread use or generally available reasoning support. Without a full and explicit handling of units in OWL, OWL based reasoning will not fully understand technical data used in product design or supply chain planning and management. This may lead to missed opportunities, from lack of recognition of compatible values, or it may lead to disaster due to lack of recognition of different or incompatible values.

This subtopic seeks a model for units and measures for OWL that:

- supports physical quantities such as length, electric current, luminous intensity, etc. as supported by the International System of Units (SI) [2,3],

- supports all units and quantities in SI,
- is largely consistent the International Vocabulary for Measurement – VIM [4],
- can support additional units and quantities needed for commerce, including alternative unit systems, counts, mixtures of counts and quantities, and ratios, and
- maintains information about quantity kinds in ratios and other quantities despite the dimension vector (e.g., torque and work must be distinguishable).

The standard model must also be accompanied by software capable of machine reasoning that extends OWL description logic reasoning and supports:

- the detection of inappropriate comparison of quantity kinds,
- detection of incompatible use of quantity kinds in the model (as in subsumption relationships or OWL domain or range constraints),
- correct interpretation of sets of quantity values with different numerical values, but with units of measure such that they represent the same values (e.g., 2.54 CM and 1 inch) [5] to work with OWL cardinality restrictions (a.k.a. number restrictions) and
- that supports a data range extension for OWL such as the OWL 2 Data Range Extension: Linear Equations <http://www.w3.org/TR/2009/WD-owl2-dr-linear-20090611/> .

Some of the issues and a suggested approach for quantities and units in OWL are discussed in a paper at the OWLED 2008 workshop entitled “Quantities in OWL” by Bijan Parsia and Michael Smith [6] that respondents may find helpful.

Phase 1 awardee would deliver to NIST:

- a specification of an extension to OWL and/or the OWL model used to support physical quantities, units, and quantity values as described above,
- a paper explaining the extension, its means of extensibility, and any issues expected in tool implementation to support reasoning over quantity types and quantity values, and
- a proof of concept implementation of quantities with units reasoning that works with existing or emerging OWL reasoners such as Pellet or

Hermit.

Phase 2 awardee would deliver to NIST:

- a specification for an extension to OWL that adds the expressivity and reasoning support for quantities, units, and quantity values described above that is sufficiently complete to be used as the basis for a future revision of OWL,
- a robust beta version of the quantities and units reasoning implementation integrated with one or more of the popular OWL reasoners.

References:

1. <http://www.w3.org/TR/owl-ref/>
2. International System of Units, SI Units - [http://www.bipm.org/en/si/si\\_brochure/](http://www.bipm.org/en/si/si_brochure/)
3. The International System of Units (SI), NIST Special Publication 330, 2008 Edition, Barry N. Taylor and Ambler Thompson, Editors - <http://physics.nist.gov/Pubs/SP330/contents.html>
4. International Vocabulary of Metrology, VIM (3rd ed, 2008) <http://www.bipm.org/en/publications/guides/vim.html>
5. Note that this capability requires unit conversion across systems of units, and not merely within a system of units.
6. [http://www.webont.org/owled/2008/papers/owled2008eu\\_submission\\_34.pdf](http://www.webont.org/owled/2008/papers/owled2008eu_submission_34.pdf)

#### **9.07.04.2-R Sustainable Manufacturing Maturity Modeling Tool Development**

Sustainable manufacturing (SM) uses advanced manufacturing sciences and technologies that span the entire lifecycle of products and services to minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers, and are economically sound. Yet progress toward SM is hindered as industry lacks the quantifiable measurement techniques, data and tools to objectively evaluate progress against selected aspects of product lifecycle. This includes aspects such as energy efficiency, emissions, key process technologies, modeling and simulation and standards and associated regulatory requirements. Companies

need new tools to plan effectively for the near, intermediate and long-term and to objectively evaluate their progress toward their SM goals. We envision an evolving SM maturity model that includes a set of performance indicators that can be quantifiably measured with derived uncertainties. This maturity model will facilitate effective planning and standards conformance. The model will be useful beyond just measuring a single manufacturing process. It will allow one to prioritize activities and view progression within the enterprise towards the goal of becoming sustainable. It will also allow decision makers to compare the impact of one decision versus another on the enterprise.

The maturity model is expected to provide useful management insight through objective evaluation of initial and evolving states with regards to SM. It will promote the integration of traditionally separate organizational functions, set process improvement goals and priorities, provide guidance for quality processes, and provide a point of reference for appraising sustainability in current manufacturing processes. It will further promote:

- identification of complex intertwined issues,
- use of statistical controls/methods,
- use measurement principles to allow reporting/conformance to standards,
- meet/control requirements thus supporting cost and schedule control,
- support mutual understanding of requirements by product development and manufacturing team members,
- support implementation of new technologies and processes with ability to evaluate performance,
- promote continuous improvement culture, and
- support to interface with appropriate standards

This SBIR solicitation seeks development of a tool that uses identified data and defined analysis procedures to support functionality described in the preceding paragraph. A successful Phase 1 submitter would deliver to NIST:

- Specification for the tool and framework for a sustainable manufacturing maturity model, and
- Beta-level tool that illustrates its functionality and ability to provide measure of a company's SM maturity level through a case study demonstration.

Phase 2 deliverables:

An initial tool and toolkit that will provide useful management insight through objective evaluation of initial and evolving states of a company's evolution to achieving SM goals. The tool will also incorporate key functionality stated in the SBIR description.

A comprehensive industry case study/s that demonstrates the capabilities of the tool/toolkit in evaluating a company's overall performance, expected direction, and SM maturity. Further, this will include the company's perception regarding the impact of the tool on meeting the company's SM goals.

The awardee(s) will work with NIST staff members involved in sustainable manufacturing R&D to develop requirements for evaluating the tool functionality and performance against industry needs

#### **9.07.05.2-R Sustainability Performance Analysis Tools for Evaluating Manufacturing Processes**

Sustainable indicators and metrics provide the measurement foundation to evaluate the performance of manufacturing processes. Many sustainable indicators and metrics have been published by the Global Reporting Initiative (<http://www.globalreporting.org>) as well as some others, such as Dow Jones Sustainability Index (<http://www.sustainability-index.com>). However, specific indicators and metrics for evaluating the sustainability performance for specific manufacturing processes are rarely available. Software tools for analyzing the sustainability of a given manufacturing process are necessary for factory management to identify problem areas within the process. With this information, managers can make the necessary changes or improvements to the manufacturing process to achieve performance goals in sustainability. These tools would also be useful data for anyone using a sustainability manufacturing maturity model.

This SBIR solicitation seeks development of tools implementing publicly available indicators that are relevant to manufacturing and identify any missing indicators that are necessary to be included, and implement those too. Analytical capability enables manufacturing companies to benchmark current performance against company goals or regulations, track performance in time, and identify problems.

Phase 1 Milestones:

- A set of indicators used to evaluate sustainability performance in



manufacturing processes

- A set of benchmark metrics corresponding to the above mentioned indicators
- Prototype of an analysis software toolset
- A detailed project plan for developing software tools

Phase 2 Milestones:

- A ready-for-commercialization software toolset for the performance analysis of and reporting sustainability
- Document of the software architecture, functions, limitation, and user manual of the toolset
- Demonstration of the toolset using a selected manufacturing process

The awardee(s) will work with NIST staff members who are involved in sustainable manufacturing measurement and testing to develop requirements for performance analyses.

## 9.08 Materials Characterization

### 9.08.01.5-R Tensile Pulse Generator for Heated Kolsky Bar Apparatus

The Kolsky Bar technique, also known as a Split Hopkinson Pressure Bar [1], is the method of choice for obtaining the stress-strain response of metals at high rates of strain. NIST has developed a unique electrically pulse-heated Kolsky bar facility [2] for measuring the compressive strength of metals subjected to rapid loading at high temperature, such as occurs in machining. These measurements are needed for advancing the state-of-the-art in high speed machining modeling and control. NIST is currently expanding our measurement capability in this area to include a pulse-heated tension Kolsky bar, which will enable measurements of ductility and failure of metals subject to machining-like conditions and thereby enhance confidence in material models developed for machining simulations from the data. NIST currently seeks the development of tensile pulse generator hardware for the tensile pulse-heated Kolsky bar we are currently constructing out of maraging steel.

NIST requires the pulse generator to consist of a pneumatically driven striker bar, following methods described in [1], which will require mechanical coupling to the existing NIST tensile Kolsky bar hardware and conform to the following specifications:

- (1) The projectile must be made from maraging steel and must be impedance matched to the NIST tensile Kolsky bar. At present, the NIST Kolsky bar diameter has yet to be finalized, but it will be in the range of

15 mm to 25 mm. (All necessary technical information regarding the NIST bar design will be made available to the awardee on the award date).

(2) The striker velocity must be repeatable within  $\pm 0.2$  m/s and user-selectable up to 25 m/s at impact.

(3) The pulse duration must be selectable by being able to use different striker bar lengths, up to a maximum length of 0.5 m.

(4) The pulse shape must be adjustable using engineered pulse shaping materials placed at the striker impact surface to obtain constant strain rate tests for a wide variety of test materials. Software for the design of the pulse shaper material and dimensions must be supplied.

(5) The pulse generator must be electrically isolated from the struck bar at all times.

(6) The pulse generator must be triggered electrically, both from a push-button and a suitable control voltage signal.

(7) The striker velocity must be measured each test.

(8) The pulse generator must not, through design or performance, cause the test specimen to be optically obstructed in any way.

(9) The design will eliminate the need for any significant unsupported length of the incident bar, which can result in non-planar tensile pulses.

Note that it is expected that NIST will collaborate extensively with awardee(s) on the development of this device and its integration into the NIST tensile Kolsky bar.

Phase 1 Milestones:

Delivery to NIST of prototype pneumatic pulse generator with pneumatic actuator, one striker bar, firing mechanism, striker velocity measurement, and coupling hardware and mating threads for integrating into the NIST tensile Kolsky bar. The actuator will then be integrated into the NIST system and preliminary tests will be conducted to assess the design

Phase 2 Milestones:

Phase 2 will be to complete the design including any modifications that may be suggested by the preliminary test results. Final actuator design including multiple striker bars, pulse shaping design software, and any modifications that

have been incorporated as the result of Phase I testing. Tests to assess striker bar repeatability, pulse width and pulse shaping design will be conducted on a variety of materials, both with room temperature and elevated temperature samples using pulse-heating.

#### References:

[1] Gray III, G.T., Classic Split-Hopkinson Pressure Bar Testing, ASM Handbook, Vol. 8, Materials Park, Ohio, 1990, pp.462-476.

[2] S.P. Mates, R. Rhorer, E. Whinton, T. Burns and D. Basak, "A Pulse-Heated Kolsky Bar Technique for measuring Flow Stress of metals Subjected to High Loading and Heating Rates," Exp. Mech., 48 (2008), 799-807.

### **9.08.02.5-R Integrated Actuator for Contact Resonance AFM**

Contact resonance force microscopy (CR-FM) is an emerging technique for nanoscale materials characterization that utilizes the atomic force microscope (AFM). In CR-FM, one or more resonant vibrational modes of the AFM cantilever are excited while the tip of the cantilever is in contact with a material. By measuring the frequency of the resonant mode in contact, surface mechanical properties can be determined. NIST is developing advanced CR-FM methods to quantitatively image the spatial distribution in nanomechanical properties [1,2]. The resonant cantilever modes are typically excited using an external piezoelectric actuator mounted beneath the sample. This requires two-sided access to the sample: the top for the AFM cantilever tip, and the bottom for the actuator. However, two-sided access is either unavailable or undesirable in many applications. Single-sided access would also facilitate widespread use of CR-FM techniques. A possible solution to this problem involves the "tuning" or "shake" piezoelectric element within the AFM head or cantilever holder [1,3]. However, this element was designed for another purpose (intermittent contact mode) and produces inferior results when used for CR-FM. In particular, spurious signals are often observed that may result from plate modes of the element. Also, the output vibration amplitude of this element for a given input voltage is usually highly dependent on frequency. Therefore, it can be difficult to detect resonant peaks across a wide range of frequencies.

NIST solicits proposals to develop an improved means to excite the cantilever in CR-FM experiments. The device must be integrated into the AFM head or cantilever holder so that two-sided sample access is not required. Although its initial use will be in a NIST laboratory environment, the approach must be suitable for eventual implementation in an industrial or commercial setting. NIST will provide the awardee with information regarding CR-FM technology development. NIST will also work with the awardee to test the device during

development in order to provide feedback regarding its performance.

At the end of Phase 1, the awardee will deliver to NIST a prototype device suitable for use in laboratory CR-FM experiments with the following characteristics:

- Able to be used on one of NIST's existing AFMs.
- Able to be used with a wide range of commercial cantilevers. Self-actuating cantilevers will be considered, but the geometry of a self-actuated cantilever must not preclude the use of CR-FM analysis models.
- Capable of driving the cantilever with a continuous sine wave vibration at arbitrary frequencies in the range of approximately 10 kHz to 2 MHz (higher if possible).
- Capable of exciting the cantilever's resonant modes with sufficient amplitude for CR-FM experiments (typical photodiode output voltages of 0.05 to 0.5 mV at resonance).
- Easy to adjust and control the excitation frequency and amplitude in software, for instance to perform a frequency sweep. Control within the AFM software is preferred, but control by external commercial software (e.g., LabView) will be considered.

At the end of Phase 2, the awardee will provide NIST with a refined device suitable for commercial use. In addition to the required specifications for the laboratory prototype created in Phase 1, the Phase 2 device should have the following refinements:

- Improved flatness of vibration amplitude – as flat as possible over the entire frequency range. For comparison, the amplitude of bottom-mounted actuators used in current experiments typically decreases by approximately 50 % (-6 dB) at  $\pm 50$  % of the center frequency.
- Demonstrable reduction in both number and amplitude of spurious modes compared to existing top-mounted actuators (and to the prototype device, if possible).
- Able to be easily substituted for an existing component of a commercial AFM (e.g., cantilever holder) by someone trained in AFM use but without specialized expertise.

References:

1. D. C. Hurley, in Applied Scanning Probe Methods Vol. XI (Springer-Verlag, Berlin, 2009), Ch. 5, pp. 97-138.
2. D. C. Hurley, K. Shen, N. M. Jennett, and J. A. Turner, J. Appl. Phys. 94, 2347 (2003).
3. K. Yamanaka, K. Kobari, and T. Tsuji, Japanese J. Phys. 47, 6070 (2008).

#### **9.08.03.5-R Elevated Temperature Microbalance Instrument for Nanomaterial Characterization**

Carbon nanotubes will enable future electronics, composites, and biomedical devices, among many other applications. Determining nanotube chemistry, purity, homogeneity, and extent of surface coverage of functional moieties is challenging due to the extremely small dimensions coupled with the small quantities of these materials that are often available for analysis. Determining these chemical parameters is particularly important for materials analysis, as many different carbon-containing species can be produced under similar thermodynamic conditions. Subtle changes in nanotube composition and geometry can lead to substantial differences in performance (e.g., multi-walled vs. single-walled tubes). As a result, new methods are needed to quickly assess nanotube quality and homogeneity during purification processes.

As the need for high-purity and well-characterized nanotube samples grows, it is anticipated researchers and manufacturers will need methods to characterize samples on the small scale. Quartz crystal microbalances (QCMs) offer significant promise for characterization of nanotubes in a similar manner to thermogravimetric analysis with significant reduction in sample size. These devices are highly sensitive mass detectors and can determine changes on the order of picograms. Currently, however, most QCM devices are operated at or near ambient temperature conditions to avoid measurement error. We seek proposals for new fixtures and instrumentation that enable elevated temperature operation of QCMs in controlled environments to investigate material behavior in small volume. Control and equilibration of temperature prior to measurement are highly desired. Ease of application of the test material (e.g., via automated drop casting), rapid analysis of results, and the potential for either re-use (or ease of replacement) of the mass sensor are important metrics for future adoption of the approach in nanotube characterization. The potential to adapt the instrument for other nanoparticle characterization (e.g., iron oxides, gold nanoparticles, etc.) is also desirable.

Temperature ranges of interest include: 25-250 °C for analysis of organic materials and surface species; 100-500 °C for comprehensive decomposition studies. Acquisition of data in temperature increments of 1 °C is required, with

0.25°C increments preferred.

#### Phase 1 Milestone

At the completion of the Phase 1, the awardee will deliver a QCM test fixture to NIST with the following specifications:

- Capability to heat the microbalance from room temperature to 500 °C.
- Capability to measure and record temperature during heating (1 °C increment preferred) .
- Capability to control the heating rate from 1 °C/min to 20 °C/min.
- Capability to monitor QCM impedance during heating using standard electrical connections (e.g., BNC to impedance analyzer).
- Capability to access the top surface of the QCM prior to analysis to apply coatings, reagents, etc.
- Capability to minimize mechanical stress at the QCM edge (i.e., clamping) to avoid reduction in Q factor.

#### Phase 2 Milestone

At the completion of the Phase 2, the awardee will deliver a QCM instrument to NIST that includes the Phase 1 fixture with the following additional attributes:

- Capability to record and display all measurement parameters in real-time.
- Software to analyze acquired data and generate mass change vs. temperature graphs.
- Capability to flow fluids (liquid or gas) across the QCM surface during measurement.
- Capability to uniformly deposit specimens onto the crystal surface using an automated mechanism (e.g., micro-pipette).
- Capability to independently address and control at least 5 QCM sensors simultaneously via a multiplexed arrangement.

#### **9.08.04.3-R Instrument for Characterization of Environmental Soot Aggregates**

Particulate matter in the environment is known to have a significant influence on the climate, air quality, and population health. We are currently developing a program to investigate nano-particle effects on health. One of the diagnostic tools to be used in this project is laser-induced incandescence (LII), which can provide quantitative information on particle primary size and volume fraction. We currently have a turn-key system to provide real-time, nonintrusive measurements of these soot characteristics; however, LII measurements are unable to provide information on the soot aggregate characteristics. The current state of the art characterizes the aggregate fractal nature by using Rayleigh-Debye-Gans light scattering theory. Thus, development of an instrument that estimates soot aggregate size, concentration, and other relevant characteristics, and can be integrated into the LII design would represent a more comprehensive particulate characterization. Thus, we seek an innovative approach for a diagnostic system that provides state-of-the-art analysis of aggregate/agglomerate characteristics (e.g., distributions of particle size and volume fraction via the fractal dimension) for particles as large as 10  $\mu\text{m}$ , and the hardware will function in conjunction with our current LII system. The software must provide access to the raw data so that post processing of statistical information and graphing of data can be carried out on other computing platforms.

Phase 1 should demonstrate the feasibility of this new diagnostic to meet the stated criteria. The objective of Phase 2 is the delivery of a functioning instrument that is integrated into our current LII system. It is expected that this new measurement capability will find immediate commercial applications for a wide range of environmental and health-related technologies.

#### **9.08.05.5-TT Development of a MEMS Oscillatory Parallel-Plate Rheometer**

A MEMS Oscillatory Parallel-Plate Rheometer has been developed and demonstrated to measure viscoelastic properties (specifically, viscosity and viscous and elastic moduli) of fluids and gels.

Growing numbers of applications including proteomics, cosmetics, and thin film coatings use novel viscoelastic materials that derive their rheological properties from micro scale structure created by the inclusion of long chain molecules, nano particles and dispersed fluids. These applications also often involve flow through confined geometries which deform the micro structure, altering the materials' rheology and limiting their effectiveness. Characterization of these novel materials is often difficult due to the small volumes initially formulated. Therefore, "micro rheology" and thin film rheology techniques have been employed to characterize these materials. Micro rheology commonly refers to

analyzing the motion of micro probe particles to measure fluid response at small length scales. This method examines a small area around the probe particle, ignoring a fluid's micro structure. A number of methods exist to study thin films, but they rely on complex modeling of probe geometry, contact area and material properties to extract anything more than the elastic modulus of a film.

We demonstrate a MEMs parallel plate rheometer for micro rheology that confines viscoelastic materials to length scales on the order of a micrometer, but probes the entire material response to dynamic oscillatory shear. The MEMs Parallel Plate rheometer uses a 1 mm square nano positioner stage to apply a controlled sinusoidal strain, with displacement up to 15 micrometers. The instrument monitors two displacements on the MEMS platform, which measure the stress and strain in the sample. The device is suitable therefore for strain- or stress-controlled operation. Through physical modeling of the system, both storage and loss moduli can be extracted for a wide range of frequencies, from 0.5 to 500 Hz. The confinement of the fluid is set by adjusting the gap between the stage and a transparent cover plate that allows optical observation. By decreasing this gap, the increasing effects of confinement can be observed. Because the strain is applied to the entire fluid body, this device examines the effects of confinement on the entire micro structure. Furthermore, this device uses less than 1 nL of material, which is beneficial for these types of novel experimental materials. The current NIST design can be found at [www.nist.gov/msel/polymers/complex\\_fluids/upload/Christopher-09-SoR-MEMS-rheom-poster-v2.pdf](http://www.nist.gov/msel/polymers/complex_fluids/upload/Christopher-09-SoR-MEMS-rheom-poster-v2.pdf) (see [www.nist.gov/msel/polymers/complex\\_fluids/index.cfm%20](http://www.nist.gov/msel/polymers/complex_fluids/index.cfm%20)). Awardees will be able to consult with the technical contact about the design and most current developments.

Some developments are needed before commercialization. Primarily, higher-resolution displacement sensors are needed to extend the dynamic range of the rheometer. Currently with micrometer-scale resolution afforded by optical observation, the minimum measurable viscosity is approximately 0.1 Pa s. Implementation of real-time electronic sensors approaching nanometer-scale resolution is also needed. Optimization should include the device stiffness in and out of plane. Optimization of sample loading is also required. Accordingly, NIST is soliciting proposals from small companies to meet these challenges and bring the product to market.

Phase 1 deliverable:

- Develop a full design of a linear translational parallel-plate device, including mechanical drawings, displacement sensor components, and specifications for in-plane and out-of-plane device stiffness, sensor resolution, control algorithms and property measurement range.



- Develop a full design of a torsional parallel-plate device, including mechanical drawings, displacement sensor components, and specifications for in-plane and out-of-plane device stiffness, sensor resolution, control algorithms and property measurement range.
- Development of a commercialization plan for the instrument.

Phase 2 deliverables:

- Construction and demonstration of a prototype device able to measure viscosity as low as 0.001 Pa s, and dynamic moduli as low as 1 Pa.
- Measurements from the two sensors will be monitored in real-time, so that both stress- and strain-controlled measurements may be obtained.
- Temperature control. Two implementations: 5 °C to 40 °C and 30 °C to 200 °C.
- Demonstration of the device to the Technical Contact.

Reference: [MEMs Parallel-Plate Rheometer for Oscillatory Shear Micro Rheology Measurements](#), Christopher GF, Dagalakis N, Hudson SD, Migler KB, Society of Rheology, 81st Annual Meeting, Madison, WI, October 18-22, 2009.

#### **9.08.06.5-TT Resonance Tracking Electronics for Scanned Probe Microscopy**

Contact resonance force microscopy (CR-FM) is an emerging technique for nanoscale materials characterization that utilizes the atomic force microscope (AFM). In CR-FM, one or more resonant vibrational modes of the AFM cantilever are excited while the tip of the cantilever is in contact with a material. By measuring the frequency of the resonant mode in contact, information about near-surface properties such as elastic modulus can be determined. Instrumentation and software for CR-FM measurements while the cantilever tip remains stationary are relatively straightforward to implement with commercial methods. However, such methods are not suitable for CR-FM imaging, which requires rapidly detecting and “tracking” the resonant frequency as the cantilever is scanned. Off-the-shelf methods typically cannot simultaneously provide sufficient frequency resolution and practical scan speeds. One reason is that the resonant frequency can shift significantly as the tip is scanned across regions with different properties.

NIST has developed advanced CR-FM methods to track the resonant frequency during imaging [1,2]. In the NIST approach described in Ref. 1, a

swept-frequency sinusoidal signal is applied to a piezoelectric actuator. As the actuator drives the cantilever through its resonant frequency, the AFM photodiode detects the cantilever's vibration amplitude and sends it to a digital signal processor (DSP) circuit. The circuit constructs a complete resonance curve as each sweep completes and finds the frequency corresponding to the maximum amplitude. A feedback-control loop adjusts a voltage-controlled oscillator (VCO) to tune the center frequency of vibration to maintain the cantilever response curve centered on resonance. A voltage corresponding to the resonant frequency is also sent to an input port of the AFM instrument for image acquisition. Each pixel in the resulting image thus contains a value representing the resonant frequency at that position.

Interpretation of CR-FM data involves models for both the cantilever's vibrational response and the tip-sample contact [2]. Standard models usually yield values for the elastic properties of the sample. However, with more sophisticated models and/or additional measurements besides frequency, CR-FM experiments can yield other material properties. For instance, experimental proof of concept has been demonstrated for CR-FM viscoelastic measurements (storage and loss modulus) [3]. Demonstrating the value of CR-FM methods in nanoscale materials characterization has just begun by NIST and other institutions. However, there is currently significant duplication of effort as each research group develops their own software and hardware. NIST would like to facilitate more rapid adoption of CR-FM methods by a broader research community in order to realize its full potential for a wide variety of applications.

Therefore, NIST solicits proposals to develop a commercial system for CR-FM imaging for materials characterization. The system should leverage the NIST approach, but is expected to far exceed its original capabilities to provide a flexible platform for a range of applications. For instance, some electronic components in the original system are now obsolete and must be replaced with either direct substitutes or parts based on new concepts. Other aspects could be improved or refined, such as direct digital synthesis (DDS) to replace the VCO for frequency sweeping. NIST will work collaboratively with the awardee to provide feedback and help with issues such as evaluation of the operating parameters, device needs, and operating performance. NIST will provide the awardee with current information regarding CR-FM technology development.

At the end of Phase 1, the awardee will provide NIST with designs and documentation for CR-FM imaging electronics and software with the primary characteristics as follows:

- Able to be used in conjunction with any commercial AFM that contains a high-frequency photodiode PD output and an auxiliary image input
- Standalone module that is not integrated into a specific AFM or AFM component

- Standalone control software that makes it easy to adjust and control operating parameters. Compatible with Windows operating systems
- Approximate operating bandwidth 10 kHz to 2 MHz, higher (~3 MHz) if possible
- Capable of operating at scan speeds of at least 0.3 Hz per line, faster if possible
- Platform architecture that is sufficiently versatile (e.g., DSP, field programmable gate array, embedded processor) to permit upgrades and modifications in response to new research directions (e.g., signal processing to determine peak frequency or Q-factor)
- Capability to provide at least two output voltages simultaneously (e.g., two resonant frequencies, one resonant frequency and Q-factor)
- Adjustable output voltage to actuator, maximum peak voltage at least ~2 V.

Phase 2 involves manufacture and testing of a commercial prototype based on the Phase 1 design. The work will be achieved with the cooperation of the NIST staff. In order to assist in this work, a functioning device will be delivered to NIST for its retention during Phase 2.

#### References:

1. A. B. Kos and D. C. Hurley, "Nanomechanical mapping with resonance tracking scanned probe microscope," *Measurement Science and Technology* 19, 015504 (2008).
2. D. C. Hurley, "Contact Resonance Force Microscopy Techniques for Nanomechanical Measurements," in *Applied Scanning Probe Methods Vol. XI* (Springer-Verlag, Berlin, 2009), Ch. 5, pp. 97-138.
3. P. Yuya, D. C. Hurley, and J. A. Turner, "Contact resonance atomic force microscopy for viscoelasticity," *Journal of Applied Physics* 104, 074916 (2008).

## 9.09 Micro- and Nano-fabrication Micromachining

### 9.09.01.2-R Avoiding Parasitic Currents on MEMS Devices

Micro Electro Mechanical System (MEMS) devices are often built on semiconductor surfaces that are conducting because they are doped. When multiple devices, located on the same semiconductor surface, are simultaneously electrically actuated they may form parasitic electrical paths, which connect the electrical pads of these devices. These parasitic electrical paths can generate parasitic currents that result in undesirable cross talk errors.

**Figure 1** shows a planar two degree of freedom NIST MEMS nanopositioner capable of high precision motions along XY orthogonal axes. This device is actuated by two thermal actuators (electrostatic, piezoelectric, etc., actuators could have also been used). Electrical command signals are provided through the four electrical pads in the image (white rectangles). The electrical pads are electrically insulated from their surrounding, but the actuator beams are not, so any electrical potential difference has the potential to generate parasitic electrical currents through the device mechanism that will generate undesirable motion. The beams of the actuators can be insulated from each other with trenches filled with insulating material, but that complicates the fabrication process and weakens the device mechanism, thus a power amplifier solution is more desirable.

Objective:

Phase I work should include the design and fabrication of a prototype power amplifier that can minimize or completely eliminate these parasitic currents. The prototype should be delivered to NIST and tested by the awardee for the actuation of a MEMS device with at least two actuators. NIST researchers will be available to work with the awardee(s)

A successful test should meet the following performance criteria:

- A reduction of the measured parasitic cross talk error by at least 50%.
- No dynamic frequency response change below 10 kHz.
- Power capability of 0.5 W per actuator.

A successful Phase 2 awardee is expected to deliver a power amplifier that can minimize or completely eliminate parasitic currents for up to eight MEMS actuators.

### 9.09.02.1-R Common Platform for MicroRobotics Research

NIST is developing untethered MEMS devices, also referred to as microrobots. These MEMS-scale microrobots have dimensions that are measured in 100's of micrometers and mass measured in nanograms. These microrobots operate by wirelessly broadcast power and control signals from externally applied electrostatic or electromagnetic fields and are fabricated using highly customized MEMS processes to provide specific materials for their stress and/or electromagnetic characteristics. Although a MEMS foundry process may be used to partially process these devices, fabrication cannot now be completed solely using commercially-available processes, but requires non-standard post-processing. This processing could be done at any number of user facilities including NIST's CNST Nanofab, see for example: <http://cnst.nist.gov/nanofab/nanofab.html>.

The NIST research has two goals: The first is research in this nascent technology while the second is using microrobots as a testbed to develop solutions to a range of MEMS metrology needs. In parallel with these internal goals, NIST has organized international competitions to provide a forum for university-based microrobotics researchers to demonstrate the results of their research to others in the field.

Motivation:

NIST's research and community leadership efforts have both been hampered by the research challenge of developing new types of functioning microrobots. This challenge is in two areas: process development and microrobot design. Each research group interested in entering this field typically develops their own MEMS process to allow the production of functional microrobots. These development efforts are time consuming, the resulting microfabrication processes are often not easily transferable between different laboratories. Further, the resulting processes are highly focused and applicable only to a single type of microrobot.

The desired Phase 1 outcome of this SBIR is a standard process that will allow production of multiple classes of microrobotic device by different laboratories of a multi-project wafer basis. NIST staff will assist the awardee in identifying key process steps needed to successfully fabricate the different classes of microrobot. In Phase 2 the awardee will demonstrate different types of standard platform microrobots fabricated using the standard process developed in Phase 1. This package would include the microrobotic devices as well as any required substrate or operating environment. Successful completion of this SBIR would put the awardee in the position to serve a role in the microrobotics community similar to the role that MOSIS (<http://www.mosis.com>) plays for the CMOS community, serving as a virtual microrobotics foundry with well-defined processes and design rules.

Successful accomplishment of this two-phase program would provide NIST with the ability to acquire microrobots, either of our own design or a standard design, to use in our metrology program. In a much wider application, this SBIR will provide universities and other research organizations a quick entry into microrobotics research. Through our outreach activities we have observed that there are a number of universities who would like to enter this nascent field, but who lack the processing expertise and/or tools. This program would overcome this obstacle.

Phase 1 deliverables:

1. Delivery of microrobot fabrication process flow specification including preliminary design rules and identifying the source of each process step.
2. Proof-of-concept demonstration of functional electrostatic and electromagnetic microrobots co-fabricated in the process defined in Deliverable 1.

Phase 2 deliverables:

1. Demonstration of different types of functional, standard platform microrobots using current “best-in-class” processing technology. Successful demonstration will include any needed substrate or operating environment.
2. Delivery of final microrobot design rules and process specification.

#### **9.09.03.4-R Miniaturized Magneto-Optical Trap for Advanced Timing Applications**

NIST seeks to develop technology to enable demonstration of a microfabricated laser-cooled atomic clock that could lead to low-cost, mass-produced precision time and frequency standards. Our ultimate goal is to improve by a factor of 1000 the performance of existing miniature standards. Success on this project could lead to a crucial component of low-cost, mass-produced, precision time and frequency standards, with the potential for a large market in a variety of portable electronic applications, including navigation, telecommunications, and compact gyroscopes and gravimeters.

Our present focus is in the production of miniaturized magneto-optical traps (MOTs). We would like to ultimately produce MOTs in millimeter-scale vapor cells with vacuum chambers (including pumps) with sizes of order a cubic centimeter. In this solicitation, NIST seeks advances in the miniaturization of the MOT apparatus that would lead to a size reduction of a factor of ten over

current small-scale systems that could sustain background vapor pressures of  $10^{-8}$  torr or lower.

Since the number of atoms trappable in a vapor-cell MOT scales as the size of the laser beams to the fourth power, we plan to enhance the atom number by loading the atoms from a laser-cooled atomic beam, which must also be integrated into the design. We intend to cool the longitudinal beam velocity using laser beams directed along the axis of the atomic beam, thus optical access from all sides of the vacuum chamber is required. The transverse velocity of the atomic beam will be determined by apertures in the atomic beam path. Design features enabling magnetic microtraps within the vacuum chamber are expected to be an integral part of the design. [1]

Deliverables:

For Phase 1, the awardee shall provide:

1. A detailed drawing of the instrument
2. Results of simulations and detailed modeling of the apparatus that indicate that the design meets functionality described in the requirements for the Phase 2 deliverable.

For Phase 2, the awardee shall provide:

1. A functioning dual-chamber Rubidium Magneto-Optical Trap delivered to NIST for testing. The instrument is expected to:
  - a. Arrive under a vacuum of at least  $10^{-8}$  torr in the science chamber demonstrated by MOT lifetime.
  - b. Have a total volume of  $200 \text{ cm}^3$  or less (including the vacuum pump)
  - c. Have an integrated dual-chamber design for loading the MOT from an atomic beam
  - d. Have optical access along the axis of the atomic beam from both directions, and should have enough optical access on the MOT side of the chamber to produce a MOT with 5 mm diameter laser beams.

Reference:

[1] J. Reichel et al., "Applications of integrated magnetic microtraps," Appl. Phys. B 72, 81–89 (2001).

#### **9.09.04.2-TT Monolithic Highest Precision Planar Two Degree of Freedom and Three Dimensional Space Six Degree of Freedom Nanopositioners**

*\* This subtopic requires that a license [application](#) be submitted in conjunction with the proposal. Be sure to include one, signed copy along with the proposal package.*

Planar nanopositioner that can be built to any scale that can deliver x-y linear motion from a fraction of a nanometer to 500 micrometers with an angular deviation of less than a tenth of what is currently available in the market. The new design developed by National Institute of Standards and Technology researchers makes use of a dual parallel pairs of levers to generate perfectly straight line motions. This design has negligible wobble and crosstalk error thus eliminating the need for corrective motion action.

Remarkable benefits of this novel design include the use of embedded safety steps (door stops), which prevent the destruction of the deformable kinematic mechanism if it is accidentally overloaded. A displacement sensor can be embedded into the device along the axis of the actuator, thus eliminating Abbe sine displacement measurement error. Zero backlash and stiction are uniquely available due to the patented monolithic design.

Many dozens of these devices have been built and tested in the NIST Laboratories along with various types of controllers and actuators (piezoelectric, thermal, electrostatic and electromagnetic). Their size range from the macroscale (300 mm x 300 mm) ([http://www.isd.mel.nist.gov/meso\\_micro/MicPosModStdy.pdf](http://www.isd.mel.nist.gov/meso_micro/MicPosModStdy.pdf)), mesoscale (70 mm x 90 mm, see [Figure 1](#)), to MEMS- scale (3 mm x 3 mm, see [Figure 2](#), [http://www.isd.mel.nist.gov/meso\\_micro/GormanIMECE2006\\_16190.pdf](http://www.isd.mel.nist.gov/meso_micro/GormanIMECE2006_16190.pdf), [http://www.isd.mel.nist.gov/meso\\_micro/NIST\\_micropositioner.avi](http://www.isd.mel.nist.gov/meso_micro/NIST_micropositioner.avi), [http://www.isd.mel.nist.gov/meso\\_micro/video/NIST\\_micropos2\\_SEM.avi](http://www.isd.mel.nist.gov/meso_micro/video/NIST_micropos2_SEM.avi)). Materials used include aluminum, titanium, Invar®, steel, brass to single crystal silicon for the MEMS devices. Capacitance displacement sensors have been embedded into the macro- and meso- scale devices, interferometers into the MEMS microscale devices.

Computer Assisted Designs (CAD) drawings exist for all the above mentioned devices and would be available to licensee(s). Likewise, lithography mask designs for the MEMS devices are also available. A fully equipped laboratory is available to assist with the testing of the devices.

Six degree of freedom three dimensional (3D) space monolithic nanopositioner can be built to any scale that can deliver x- y- x linear and angular motions from a fraction of a nanometer to 500  $\mu\text{m}$ . The new design developed by National Institute of Standards and Technology (NIST) researchers makes use of a monolithic hexapod. Remarkable benefits of this novel design include the use of embedded safety steps (door stops) which prevent the destruction of the



deformable kinematic mechanisms if accidentally overloaded. A sensor assembly can be embedded into the device underneath the payload and measure the translational and angular motions about the xyz axes.

Zero backlash and stiction are uniquely available due to the patented monolithic design. A few of these devices have been built and tested in the NIST Laboratories along with various types of controllers. Their size range from the macroscale (300 mm x 300 mm x 300 mm, see [Figure 3](#), [http://www.isd.mel.nist.gov/meso\\_micro/kinematic\\_modeling.pdf](http://www.isd.mel.nist.gov/meso_micro/kinematic_modeling.pdf)) to MEMS- scale (6 mm x 6 mm x 3 mm, see [Figure 4](#)). Materials used include aluminum, steel, and single crystal silicon for the MEMS devices. Capacitance displacement sensors have been embedded into the macro- and meso- scale devices, optical into the MEMS microscale devices. Computer Assisted Designs (CAD) drawings exist for all the above mentioned devices and would be available to licensee(s). Likewise, lithography mask designs for the MEMS devices are also available. A fully equipped laboratory is available to assist with the testing of the devices.

Possible applications:

Research and Development in the Physical, Engineering, and Life Sciences.

Manufacturing of Reproducing Magnetic and Optical Media.

Semiconductor and Other Electronic Component Manufacturing.

Communications Equipment Manufacturing.

Pharmaceutical and Medicine Manufacturing.

Objective:

Phase I work should include the design and fabrication of a prototype.

#### **Figures 1 - 4**

References:

\* US Patent # [6,467,761](#), Positioning stage

\* US Patent # [6,484,602](#), Six-degree of freedom micro-positioner

## 9.10 Microelectronics Manufacturing

### 9.10.01.4-R Vertical Cavity Surface Emitting Lasers for Atomic Clocks

Vertical cavity surface emitting lasers (VCSELs) are a critical component in compact, low-power atomic clocks. The low threshold current of these devices combined with their high modulation bandwidth and large mode-hop-free tuning range makes them uniquely suited for this application. At present there are no U.S. suppliers of commercial VCSELs at the wavelengths of interest for atomic clocks and having the needed operating characteristics listed below. Because the criticality of VCSELs to the compact clock technology, we solicit proposals that would lead to a domestic source of supply.

Critical characteristics are as follows:

- Lasing wavelength of 795.0 nm, 894.6 nm, or 769.9 nm. The exact wavelength should be achieved at a device temperature between 25 °C and 90 °C and at an injection current sufficient to produce the power as specified below
- Threshold current below 3 mA
- Single longitudinal and transverse laser mode when the laser is operated at the current and temperature required to reach the design wavelength listed above
- Single stable polarization mode when the laser is operated at the current and temperature required to reach the design wavelength listed above
- Laser linewidth below 100 MHz when the laser is operated at the current and temperature required to reach the design wavelength listed above
- Output power of more than 0.5 mW when the laser is operated at the current and temperature required to reach the design wavelength listed above

In Phase 1, we anticipate that a VCSEL design will be developed in collaboration with NIST, if needed. At the end of Phase 1, the vendor must provide five prototype lasers to NIST for testing and evaluation, which will become the property of NIST. The prototypes must have been tested at the awardee's facility with respect to the criteria listed above and the data provided to NIST.

At the end of Phase 2, three wafers of lasers are to be delivered to NIST, with

at least 1 % of the lasers falling within the wavelength range described above. These lasers become the property of NIST. The wavelength distribution across the wafer will have been sampled and this data, along with measurements of the above parameters should have been carried out for some devices on the wafer.

#### **9.10.02.1-R Massively Parallel High Temperature Probe System for Wafer-level Reliability Testing**

Integrated circuit technology is already in the nanometer regime and advancing rapidly. Many aspects of the technology are pressing against limits set by the laws of physics. To overcome these limitations, new materials and new structures are being introduced in rapid pace. A natural consequence of nanoscale devices is that their properties cannot be controlled precisely. Variability is a growing problem. Long-term stability and reliability of advanced integrated circuit require statistical projection resulting from putting a larger number of devices under long term stresses. When the device properties are tightly controlled, this is already a challenging task that requires extensive testing resource. When the device properties are less well controlled, they will increase the uncertainty of the reliability projection. The only way to improve the reliability projection is to increase the number of devices being stressed drastically. Large sample size and long-term reliability test are fundamentally in conflict with each other. The problem is worse when a large number of tests are needed and each test requires multiple stress conditions. Testing thousands of devices for many months for each stress condition is simply too costly even for the biggest of manufacturers. As a result, long-term reliability is poorly understood and is a crisis in the making. A wafer-size probe card that can simultaneously contact several thousand devices and can interface with the control/measure electronics directly without wiring would revolutionize long-term reliability qualification. If the probe-card/electronic system can handle high testing temperatures, the same system can be used for a wide variety of tests and thus lower the cost drastically.

NIST is actively working with several major US semiconductor companies to develop reliability characterization methods and physical models to predict time-dependent dielectric breakdown in advanced gate dielectric materials. Currently, NIST can only test a few tens of devices simultaneously at the wafer-level to obtain electrical and reliability parameters. This process is tedious and inhibits the ability to gather a significant statistical sample size. Therefore, NIST desires a high temperature long term stress technology that will allow the testing of several thousand devices simultaneously and allow the easy replacement of individual probes in event they are damaged. In phase 1, NIST staff will assist the awardee to complete a feasibility study of fabricating the probe card including engineering of the interconnect system to allow electrical

connections between each probe and instrumentation existing in NIST facilities.

Phase 2 work would include the construction and testing of a prototype having five thousand probes on 12 inch wafer. The phase 2 prototype will be tested and characterized on a NIST probe station at test temperatures up to 400 oC with the cooperation of the NIST staff. The ability to align the probes with on wafer 50 um x 50 um probe pads at all temperature will be evaluated. The thermal stability and planarity of the card will be evaluated over long test times. Finally, reliability data will be collected using the card on a 12 inch wafer.

#### **9.10.03.1-R High-efficiency Photomixers for CW Terahertz Generation**

NIST seeks the design and construction, (including in Phase 2 the delivery of prototypes, to be tested in NIST Boulder laboratories) of novel semiconductor photomixers with terahertz bandwidth. The designs are to be optimized for high efficiency in CW, rather than pulsed, operation, and must be compatible with coupling of the output power either quasi-optically (through a planar antenna) or via a planar transmission line. Carrier recombination time must be engineered to provide a 3 dB rolloff frequency of 1 THz or greater. Specific attention should be paid to maximizing the efficiency (i.e. the THz output current for a given optical pump power) through various forms of semiconductor bandgap engineering that, for example, enable higher electrical bias to be maintained. Specific attention should also be paid to efficient dissipation of heat from the optical pump lasers.

The awardee will work collaboratively with NIST staff in the Boulder laboratories to design appropriate input and output coupling structures to enable testing over a continuous 100-2000 GHz band. Test structures must be included to enable identification of the limiting factors on efficiency. Phase 1 of this research should demonstrate, primarily through detailed simulation, the feasibility of significant improvement (>5 dB) in output power over current implementations of THz photomixers. It should also include a demonstration of feasibility of the growth of any novel semiconductor heterostructure required for the design. If phase 1 is successful, phase 2 will include the patterning, packaging, and testing of devices made from the heterostructures.

#### **9.10.04.1-R 3-Dimensional Visualization of Printed Circuit Card Assembly (PCA) Tin Whisker Risk Assessment**

One key to enhance the competitiveness of U. S. small and medium-sized enterprises (SMEs) is their ability to simulate the physical behavior of products during the manufacturing process. Being able to predict problems in the design phase, before the actual manufacturing process has started can greatly reduce

manufacturing costs due to products have to be re-manufactured due to defects such as “Tin Whiskers”. Using software analysis tools on the design specification, SMEs can greatly impact products by optimizing their performance, judging design alternatives, and improving manufacturing yields. However, industry often does not benefit from such simulations due to the lack of easy-to-use product-specific capabilities. This situation is exacerbated in SMEs where limited resources typically preclude having in-house analysis tools and staff. Yet SMEs need analysis capabilities, as they are often the ones with the precise product and process knowledge required to realize improvements.

Tin plating has been, and continues to be, the preferred surface coating for the leads on electronic components. Tin-based plating can be susceptible to the formation of needle-like protrusions, or whiskers. If whiskers grow to critical lengths in service, they can cause electrical shorts, disruption of moving parts, and/or degraded RF/high-speed performance. For decades, small amounts of lead have been added to the tin to prevent the growth of whiskers, but elimination of lead has stimulated a review of the risks associated with the use of pure tin. Tin whisker growth is an acknowledged risk for high-density electronics equipment during the manufacturing process. This SBIR will lead to the development of an analysis tool that will analyze three dimensional path based distance measurements between electrically functional metallic structures in a design, to predict potential tin whisker growth. The metallic structures to be considered include, but are not limited to, the electrical component terminals, the interconnect substrate component termination locations, and metallic mechanical components (e.g., fasteners and covers). The analysis tool will support proprietary algorithms while being based on standard product and material models. It should enable property mapping between proprietary tin whisker models and standard product models and open technical dictionaries. The analysis tool will display the results of the risk analysis in a three dimensional visualization, in the context of the assembly and interconnect substrate layout, so problem areas are easily identified and design changes can be made to mitigate the potential problem. SMEs shall be able to feed this analysis tool with design information in the form of rich AP210 product models (the ISO 10303 standard for electronics). This effort shall apply these general techniques to create capabilities that will aid printed circuit board (PCB) fabricators and designers in the electronics domai

Phase 1: Provide a software tool that computes a path based distance calculation and displays the result in a three-dimensional visualization including accurate interconnect metallization, electrical and mechanical component models.

Phase 2: Provide mapping methodology to map proprietary algorithm and property definitions to standard modeling language (e.g., SysML parametrics) and standard property models (e.g., ISO 29002) and standard product models (e.g., ISO 10303-210<sup>3</sup>). Provide methodology to transfer suggested changes to

the layout tool.

References:

1. Center for Advanced Life Cycle Engineering
2. Systems Integration for Manufacturing Applications (SIMA) program. <http://www.nist.gov/sima/>
3. Infrastructure for Integrated Electronic Design & Manufacturing. - <http://www.eeel.nist.gov/812/IEDM/index.html>
4. ISO 10303-210 - Electronic Assembly Interconnect and Packaging Design standard for electronics. - <http://www.ap210.org/>, <http://www.wikistep.org>

## 9.11 Nanofabrication

### 9.11.01.1-R Vertically Aligned Carbon Nanotubes for Thermal Detectors

Researchers recently documented the “World’s Darkest Substance” made from vertically aligned carbon nanotubes (VACNTs) [ref. 1]. The practical application of such a material is valuable to programs at NIST and elsewhere. All of the standards for radiometry are based on thermal detectors and in every case; these detectors have some sort of black absorption coating (nickel phosphorous, carbon paint, metal blacks). Measurements for climate change and monitoring solar irradiance require thermal detectors with improved black coatings. Devices for ‘clean energy’ such as thermoelectric converters or solar-thermal power generators will be improved by better black coatings. The functional properties of the coating are important as is the practical challenge of producing consistent coatings on a regular basis. In related fields, development of high efficiency absorbers may be used as high-efficiency emitters for applications of thermal management.

We have demonstrated vertically aligned multiwall carbon nanotubes (VAMWCNTs) chemical vapor deposition (CVD) on a thermal detector [refs. 2, 3]. Work is required to improve the absorption efficiency to that of the ‘world’s darkest substance’ and to do it in such a way that it is consistent and scalable for commercial production. Some technical challenges for optimizing the coating include: improve the deposition of catalyst metal, optimize surface properties of the substrate (that is, the platform material such as copper, silicon, lithium tantalate and diamond) and to optimize process parameters for nanotube growth.

It is possible to achieve values of detector reflectance as low as 0.1 % in the

visible and infrared spectrum. Since thermal detectors are capable of operating over a broad wavelength range, we usually want our black coating to have approximately 100 % absorption efficiency across the electromagnetic spectrum (from 100 nm to 100  $\mu$ m). In addition, a detector ideally having 100 % absorption efficiency is inherently spatially uniform. This is important for the next generation of standards for measuring optical power.

What is missing:

I. A method and means for creating large-area vertically aligned carbon nanotubes on various detector platforms. Such platforms include copper, silver, diamond, silicon, silicon carbide, lithium tantalate and others.

II. Determination of the optimal tube length and spacing for broad and uniform wavelength absorption ranging in wavelengths from the ultraviolet (UV) to the far infrared (Terahertz).

III. Optimization of the thermal diffusivity while decreasing thermal contact resistance between the tube and the detector substrate.

Milestones for Phase 1. Large-area vertically aligned carbon nanotubes on various detector platforms. Such platforms include copper, silver, diamond, silicon, silicon carbide, lithium tantalate and others. Optimize catalyst deposition to uniformly coat cavity structures and demonstrate a uniform and reproducible nanotube growth process.

Milestones for Phase 2. Determine and demonstrate optimal tube length and spacing for broad and uniform wavelength absorption ranging in wavelengths from the ultraviolet (UV) to the far infrared (Terahertz). Optimize thermal diffusivity while decreasing thermal contact resistance between the tube and the detector substrate (demonstrate, for example, with thermal conductivity measurements, detector frequency-response measurements).

References:

1. Yang, et. al, Nano Lett. Vol. 8, No. 2 446-451 (2008).
2. Lehman, et al, Infr. Phys & Tech 47 246–250 (2006).
3. Theocharous, et. al, 45, APPL. OPT. 1093-1097 (2006).

### 9.11.02.5-R Anion Exchange Resins for Chirality-based Separation of Single-wall Carbon Nanotubes

Single-wall carbon nanotubes (SWCNTs) have many potential commercial applications. Since the physical/chemical properties of SWCNTs are critically dependent on their structure, many SWCNT application developments require populations of single-chirality tubes that current SWCNT syntheses can not provide. Recent progress in SWCNT separation has demonstrated the possibility of using anion exchange stationary phase and specific ssDNA sequence wrapped SWCNT to obtain numerous single chirality tubes (ref. 1). Making such materials widely available should greatly enhance industrial application developments. However, the efficiency of the DNA-based single chirality SWCNT purification process, and therefore the amount of the purified materials, is limited to a very large extent by the anion exchange resin, which has been developed for the separation of DNA oligonucleotides, and does not provide optimal resolution and recovery for the separation of DNA-wrapped SWCNTs.

This call solicits research and development of new anion exchange resins that can deliver both higher recovery and higher resolution than what is currently available for the separation of DNA-wrapped SWCNTs. The research should entail development of new surface functionalization chemistry to control surface charge density, surface hydrophobicity and hydrophilicity, and reproducible batch processes for large scale production of the anion exchange resin.

Specifications:

1. Recovery: > 80% of the injected material is eluted from the column;
2. Resolution: capable of resolving in a single pass (9,1) and (6,5) from commercial SWCNT starting materials with narrow diameter distribution.

Phase 1 milestone: Demonstrate design concept by producing anion exchange columns that meet the above specifications; deliver the columns to NIST lab for testing and validation.

Phase 2 milestone: Develop reliable processes for large batch production of the new anion exchange columns, deliver the large batch production columns to NIST for testing and validation, commercialize the new anion exchange column technology.

Reference

1. Tu, X., Manohar, S., Jagota, A. & Zheng, M. DNA sequence motifs for structure-specific recognition and separation of carbon nanotubes. *Nature* 460, 250-253 (2009).



### 9.11.03.2-R Nanoscale Sidewall Imaging

One of the few ways to measure nanoscale features non-destructively in three dimensions is to use a critical dimension atomic force microscope (CD-AFM). The CD-AFM, unlike other AFMs has a dual excitation capability, and uses a special probe to unambiguously measure feature linewidth and sidewall angle with low uncertainty. Increasingly, the semiconductor industry is moving towards non-planar structures. New architectures such as finFETS, and tri-gates increase the shape complexity of semiconductor structures and require full knowledge of the profile. This places a great burden on the metrology.

In addition, parameters such as thickness and composition of films on feature sidewall are difficult to measure non-destructively. One instrument that could meet this challenge is the CD-AFM. Regular AFMs can identify different materials using modes such as scanning capacitance, scanning spreading resistance imaging, and electrostatic force microscopy among others. The CD-AFM in its current implementation only measures topography and displacement, albeit at very high resolution.

To meet the challenges of measuring the properties of non-planar gates on nanoscale features needed for nanomanufacturing, Phase 1 will demonstrate feasibility to extend the capabilities of 3D-AFM to integrate materials and length metrology. This will build on previous NIST work on traceable linewidth and sidewall dimensional metrology using CD-AFMs.

If successful, the Phase 2 deliverables will include: Manufacture and test of a prototype CD-AFM for sidewall topography and material characterization. The system shall include one of the following imaging modes: scanning capacitance, electrostatic force, or surface potential. The system will be delivered to NIST for its retention and ownership.

#### References:

1. Orji N. G., Dixon R. G., Martinez A., Bunday B. D., Allgair J A., Vorburger T V., "Progress on implementation of a reference measurement system based on a critical-dimension atomic force microscope," J. Micro/Nanolith. MEMS MOEMS 6(2), pp 023002-4 (2007).
2. Dixon R. G. et al. "Traceable calibration of critical-dimension atomic force microscope linewidth measurements with nanometer uncertainty," J. Vac. Sci. Technol. B 23, pp. 3028–3032. (2005)
3. Dixon R., Guerry A., Bennett M., Vorburger T., and Bunday B., "Implementation of a reference measurement system using CDAFM," Proc. SPIE 5038, pp. 150–165 (2003)
4. Dixon R. and Guerry A., "Reference metrology using a next generation CD-AFM," Proc. SPIE 5375, pp. 633–646 (2004).
5. Orji N. G., Dixon R. G., Bunday B. D.; Allgair J. A. "Accuracy

considerations for critical dimension semiconductor metrology” Proc. SPIE Vol. 7042 (2008)

6. Orji N. G., Dixon R. G., Bunday B. D.; Allgair J. A. “Toward accurate feature shape metrology” Proc. SPIE Vol. 6922 (2008)
7. Orji N. G. et al. “TEM Calibration Methods for Critical Dimension Standards” Proc. of SPIE Vol. 6518, 651810, (2007)

General project information: <http://www.nist.gov/mel/ped/smm/wafm.cfm>

#### **9.11.04.2-R Filling the Gaps in Nanoscale Length Standards**

Currently there are gaps in the availability of traceable physical standards at nanometer length scales. Traceable step height standards are available commercially in the United States with heights ranging from 50 micrometers or more down to 8 nm, and silicon (Si) (111) step standards are available with a height of 0.3 nm, but there is nothing available at 2 nm to 3 nm range, 1 nm, or (the ultimate limit) 0.1 nm. Analogously, for gratings, traceable commercial gratings are available with pitch spacings down to 100 nm and Si lattice planes with 0.3 nm pitch may be used with transmission electron microscopes, but there are no traceable, commercial gratings available in this country with pitches in between: approximately 1 nm, 3 nm, 10 nm, and 30 nm.

Phase 1 will demonstrate feasibility to develop traceable grating or step-height standards for any of the size-scales indicated above.

A successful Phase 2 awardee will accomplish the following:

- (1) Manufacture of four prototype step samples ranging from 1 nm to 3 nm in height
- (2) Manufacture of four prototype step samples with a height of approximately 0.1 nm
- (3) Manufacture of four prototype gratings with pitches of 1 nm, 3 nm, 10 nm, and 30 nm.
- (4) Each sample should be at least 2 cm by 2 cm, and will be delivered to NIST for retention and ownership.

## 9.12 Optics and Optical Technology

### 9.12.01.6-R High-frame Rate, Foveated 3D Imaging System

The National Institute of Standards and Technology (NIST) requires a 3D imaging system for effective control of machinery, specifically for docking operations when placing manufactured construction components. A 3D imaging system that is needed would most likely be a laser scanning type metrology instrument capable of fast beam steering in order to achieve foveal “vision.” Foveal “vision” refers to the ability of the instrument to concentrate its measurements within a small field-of-view (FOV) in order to get a higher resolution image of an object (or part of an object) of interest. This foveal “vision” is in addition to a wide FOV that must be achieved by the same instrument.

Requirements for the solution include:

1. Illumination Source: Eye Safe (1500 nm)
2. Wide FOV: > 60 deg x 60 deg
3. Foveated FOV: < 10 deg x 10 deg
4. Range Resolution: 1 mm @ 15 m; 3 mm @ 5 m to 100 m
5. Angular Resolution: < 0.03 deg
6. Frame Update Rate: > 10 Hz
7. Size: < 20 cm x 20 cm x 30 cm
8. Weight: < 15 kg

Although the above attributes can be met by certain existing systems individually, there is no present solution that meets all of the attributes combined.

Phase 1: As a minimum demonstration of feasibility, the awardee will develop a design for a prototype system meeting the above requirements. The design should include details about the mechanical, electronic, and optical design of the instrument as well as the data processing and control algorithms needed. Demonstrations of how foveal vision will be achieved (e.g., using galvo motor-mounted mirrors, MEMS mirrors, etc.) are encouraged. NIST will evaluate the design (and possible demonstrations), and use these data to inform the review process for Phase 2 proposals.

Phase 2 (if awarded): The awardee will then proceed with refined development of the system, and construct a physical prototype, which will be delivered to NIST.

### 9.12.02.6-R 3D Imaging Sensor System for Robotic Platform

The National Institute of Standards and Technology (NIST) has a requirement for a high frame-rate 3D imaging system (herein referred to as “the SENSOR SYSTEM”) that delivers both range image data and co-registered video for mobile robot control applications. The range and video cameras must be mounted together and co-registered on a pan-and-tilt mechanism to provide an expanded operational field of view. A common, integrated interface for sensor control, data access, and pan-and-tilt control must be provided.

Requirements for the system include:

1. 3D Imaging: The SENSOR SYSTEM must include a high frame-rate 3D imager (a.k.a. range camera) that meets the following minimum characteristics:

- a. Design: Solid state.
- b. Safety: Eye-safe.
- c. Resolution: minimum of 170 pixels x 140 pixels.
- d. Field of view: Greater than or equal to 40 degrees x 30 degrees.
- e. Range: Minimum range less than or equal to 0.3 meters. Maximum range of greater than or equal to 5 meters.
- f. Frame rate: Greater than or equal to 30 frames per second.
- g. Data: 3D imager provides both intensity and range image data.
- h. Triggering: In addition to being able to trigger the 3D imaging sensor through software via the communications interface, an external input to trigger the sensor must also be provided

2. Machine-Vision Camera: The SENSOR SYSTEM must include a camera meeting the following minimum characteristics:

- a. Image output: RGB color with 8 bits per channel or greater.
- b. Resolution: Greater than or equal to 1280 pixels x 1024 pixels.
- c. Frame rate: Greater than or equal to 30 frames per second.
- d. Triggering: In addition to being able to trigger the camera through software via the communications interface, an external input to trigger the camera must also be provided.

3. Pan and Tilt mechanism: The SENSOR SYSTEM must include an integrated pan and tilt mechanism which meets the following minimum characteristics:

- a. Horizontal rotation (pan) limit: Greater than or equal to 330 degrees of panning motion.
- b. Vertical rotation (tilt) limit: Greater than or equal to 100 degrees of tilting motion. Unit must have a minimum of -80 degrees tilt (i.e., look down capability).

- c. Position resolution: Less than or equal to 0.05 degrees.
- d. Minimum pan and tilt speed: Less than or equal to 0.05 degrees per sec.
- e. Maximum pan and tilt speed: Greater than or equal to 250 degrees per sec.
- f. Sensor mounting and calibration: The sensors must be able to be removed from the pan and tilt mechanism. A method for recalibrating the sensors once reinstalled must be provided.
- g. Power: Single 12-24V power supply.
- h. Payload: Must support the specified 3D imaging sensor and the camera.

4. Control Software: The SENSOR SYSTEM must include integrated control software and an application programming interface (API) which provides capability to send outputs to actuators and read inputs from the sensors. The following capabilities must be provided:

- a. Send configuration parameters to the 3D imager and the camera (e.g., setting frame rate, resolution, and etc.).
- b. Communications interface: USB 2.0, Firewire 800, or Ethernet (Ethernet preferred).
- c. Read data from the 3D imager, the camera, and the pan and tilt mechanism.
- d. Diagnostic software for reading all of the system parameters/status and for testing all available functionality.
- e. Cross-platform operation (Windows, Linux, Mac).
- f. Set motion control parameters (e.g., range of angular motion limits, angular rotational speed limits, etc.)
- g. Programming capability for basic behaviors such as homing, repetitive movement, etc.
- h. Real-time control at up to 30 commands/sec enabling both absolute and relative positioning.

Phase 1: As a minimum demonstration of feasibility, the awardee will develop and deliver to NIST one prototype system meeting the above requirements. This prototype will contain one (1) SENSOR SYSTEM, peripherals, which include but are not limited to control software and an application programming interface (API), manuals, and schematics

Phase 2 (if awarded): The awardee will then proceed with refined development of the system, and construct a second prototype, which will be delivered to NIST.

#### **9.12.03.4-R Compact Parametric Down Conversion-Based Source Of Entangled Photon Pairs**

We solicit an integrated, narrow band quasi continuous wave source of degenerate entangled photon pairs tunable over the Rubidium D2 line at 780 nm. Such a source would be of significant interest to the field of quantum information, as it allows for the interaction between photonic qubit states and material qubit states, which is a key need of many quantum computation and communication schemes. We envision a nonlinear crystal-based optical-parametric-oscillator with an integral stable resonator design source for the output light. We expect this to employ a parametric down conversion (PDC) crystal with built-in reflectors forming a cavity to achieve the narrow linewidth (this might be, but is not limited to, a waveguide design with built-in Bragg reflectors or a bulk crystal design using curved crystal surfaces). The linewidth of generated photons (FWHM) should be 5 MHz or less. When used as a heralded source of single photons, the normalized heralded autocorrelation function ( $g(2)$ ) should be less than 0.25 at a 100 kHz heralding rate. The number of photons generated by a PDC process should be greater than 85 % of all single photons generated at the same frequency (that is, background single photon fluorescence should be no more than 15 % of the total signal in the 5 MHz bandwidth). The source output must be single-spatial-mode, so that it can be coupled to a single-mode fiber with an efficiency of better than 50 %. Any additional losses in extracting the photon pairs from the crystal source such as due to spectral filtering, reflective or absorptive losses must be less than 20 %.

At the end of Phase 1, 5 prototype crystal sources shall be delivered to NIST. After demonstrating this source at 780 nm in Phase 1, the awardee will extend this capability to a range of other wavelengths needed by quantum information applications.

#### **9.12.04.4-R High Resolution Hyperspectral Image**

Compact hyperspectral imagers, with spectrally tunable acousto-optic or liquid-crystal filters, are commercially available for environmental remote-sensing and military surveillance applications. At best, these devices offer 3 nm spectral resolution. However, this is not adequate for biomedical imaging, which requires better than 1 nm spectral resolution for molecular specificity. Currently, dispersive optical systems meet this resolution requirement, but spatial scanning is required to acquire a hyperspectral image.

NIST wishes to have developed an imager with at least 1 nm spectral resolution that could be used both in wide field and in microscopy to enable better interrelation of data at these different spatial scales for biomedical

research. This spectral resolution should be adequate both for clinical applications and for cellular and tissue microscopy. We envision a non-spatially scanned hyperspectral imager that could be alternately outfitted with a camera lens for wide-field applications or coupled to a commercial microscope, with only minor optical changes. For this project to succeed, those optical designs are needed along with the coupling of the lenses and the filter to the camera, in addition to the development of the software to synchronize the filter spectral tuning with the camera image acquisition.

We believe that the spectral resolution requirement can be attained using volume holographic filters. These are now commercially available with continuous spectral tuning capability.

The expected research output is a working non-spatially scanned hyperspectral imaging device prototype to be provided to NIST for evaluation. It must have the following features: (1) spectral coverage from 400 nm to 1000 nm in 1 nm steps or less, (2) spatial resolution of at least 1024 x 768 pixels, (3) optics to allow the imager to be used both for wide-field imaging (i.e., as a typical camera) and for attachment to a standard optical microscope, (4) software to control the operation of the spectral tuning element and to synchronize it with image acquisition, (5) system-level quantum efficiency of 30 % or better over the entire spectral range.

Expected deliverables for Phase 1:

1. Volume holographic filter assembly with mounting hardware for coupling with a CCD camera (For testing purposes, NIST would loan a CCD camera to the awardee if needed).
2. Software, or at least, a dynamic link library to enable spectral tuning of the spectrally tunable filter.
3. Optical design specifications for the semi-custom camera lens, taking into account the additional filter thickness.
4. Design for a separate optical relay that would enable coupling to a commercial microscope.

Expected deliverables for Phase 2:

1. Procurement of the designed camera lens, optical relay for microscope and camera for testing the prototype.
2. Operating software for the compact hyperspectral imager, synchronizing the filter spectral tuning with the camera image acquisition.

#### **9.12.05.1-R High Efficiency, Photon Number Resolving Visible Light Photon Counters (VLPC)**

To characterize new types of quantum states of light, highly efficient single photon detectors are needed. At NIST, we are interested not only in detecting single photons but also in counting the number of photons in a pulse of light. Visible Light Photon Counters (VLPC) are a promising technology that could be embedded in systems to obtain very high system detection efficiency. At present, the technology has not been optimized for very many wavelengths or demonstrated in simple, turn-key systems.

In Phase 1, five prototype detectors that demonstrate both high efficiency (>85%) in the near IR (telecommunication wavelengths) and photon number resolving capability will be delivered to NIST. For Phase 2, NIST is willing to work collaboratively with the awardee to help measure the performance of the detectors more thoroughly to include, but is not limited to, measurements of dark counts, jitter, and maximum count rate. In addition, Phase 2 development will include extending the operating wavelength and packaging the device in a cryogen-free system. Other Phase 2 development may include optical packaging for large arrays of devices.

#### **9.12.06.4-R Improved VUV Lamp**

We seek development of improved lamp technology having broadband spectral output from the vacuum ultraviolet (VUV) into the visible. Such lamps have use in a wide variety of applications, including transfer standards for lamp calibrations, metrology instruments for nanotechnology, bio-analytical, and other instrumentation, and for general use in research and development.

Available in the market today are deuterium lamps and arc lamps—both are widely used. Deuterium lamps extend to wavelengths as short as 120 nm, however the spectral brightness is extremely low and the lifetime is typically less than 1000 hours, declining steadily from initial turn-on. Arc lamps are not available below approximately 180 nm, and they also have limited spectral brightness and a limited lifetime.

The proposed lamp must meet the following performance characteristics:

Wavelength Range: 120 nm to 600 nm

Radiance: 3 mW / (nm mm<sup>2</sup> sr) (wavelengths shorter than 250 nm)  
20 mW / (nm mm<sup>2</sup> sr) (wavelengths of 250 nm or longer)



Irradiance (measured 50 cm from source):  
0.3 mW / (m<sup>2</sup> nm) (wavelengths shorter than 250 nm)  
8 mW / (m<sup>2</sup> nm) (wavelengths of 250 nm or longer)

Source Size: less than 500 μm diameter

Source Position Stability: ±100 μm

Intensity Stability: ±1 % while running; ±5 % restart

Lifetime: 10,000 hr

Phase 1 deliverable: A lamp that can be demonstrated to meet the performance characteristics.

Phase 2 deliverable: A reliable, commercializable version of the lamp that could be utilized by secondary standards laboratories and in industrial applications.

#### **9.12.07.1-R Non-linear Crystals for Photon Pair to be Efficiently Coupled into Single Mode Optical Fiber**

There has been significant research activity in the area of photon pair generation using non-linear crystals. In particular, there is significant in using photon pairs as a source of entanglement that could be used for enhanced information processing (e.g. quantum computing), secure communications, and better metrology. However, for these applications to be successful, the photon pairs must be efficiently extracted from the sources and coupled to other optical components. At NIST, we are interested in using both ultra-fast (i.e. mode-locked Ti:Sapphire) and CW lasers as pump lasers to generate photon pairs around 1550nm that can be coupled in to fiber with efficiencies >90%. We would like to use crystals that are type II and make degenerate photon pairs.

In Phase 1, four crystals will be delivered to NIST. Two crystals will be suitable for pumping by an ultra-fast pulsed laser. The other two crystals will be suitable for pumping with a CW laser. We will work collaboratively with the awardee to ensure that the crystal is designed for high coupling efficiency in to fiber. For Phase 2, NIST is willing to work collaboratively with the awardee to help measure the performance of the crystals more carefully. For example, NIST will measure the joint spectral density to verify the agreement between predicted and actual crystal performance. Other Phase 2 development may include coupling the crystals to NIST high efficiency single photon detectors to demonstrate the suitability of these detectors for quantum information applications.

### 9.12.08.5-R High Speed and High Sensitivity Quadrant Photodetector

NIST requires develop quadrant photodetector to measure displacements on MEMS or NEMS cantilever beams that form part of advanced instrumentation and measurement systems. The detector should have a bandwidth of at least 50 MHz and a signal to noise ratio (SNR) of at least 80 dB.

This type of detector is of interest for measurements applying laser based position detection over large displacement ranges (0.1 nm resolution over 1  $\mu\text{m}$  displacement range). It is expected that this technology will be useful for a variety widespread applications, including next generation atomic force microscopes (AFM) capable of ultra-rapid operation, and devices for very rapid thermal characterization of materials.

This call solicits research and development of new quadrant photodetectors that can deliver both higher measurement speed (while maintaining low noise and high SNR) than conventional quadrant photodiodes. The research should entail development of a new detector system to maximize response speed and limit noise. Major specifications are listed below.

Specifications:

1. Quadrant photodetector with a 2 x 2 array of pixels; signal outputs provided for each pixel; additional signal outputs for the differences between pixels may be provided (i.e. left-right, top-bottom).
2. Maximum detector bandwidth of at least 50 MHz.
3. Signal to noise ratio of at least 80 dB OR, expressed in different units, a displacement resolution of at least 0.1 nm over a displacement range of at least 1  $\mu\text{m}$ ).
4. Sensitivity: capable of position detection with incident spot power of 100 pW or less.
5. Variable Gain, with maximum signal gain of at least 1000
6. Quantum Efficiency greater than 70% between either 630 to 690 nm OR Quantum Efficiency greater than 70% between 850-1000 nm.
7. Contain all necessary power supplies, detectors, circuitry, cables, etc. to operate from wall power (115 VAC, 1 phase) to generate voltage outputs proportional to position.

Phase 1 milestones:

Demonstrate design concept by producing prototype detector meeting the specifications above and operating with SNR of at least 80 dB with a bandwidth of 50 MHz; deliver the prototype detector to NIST for testing and validation.

Phase 2 milestones:

Producing second generation prototype detector operating with a SNR of at least 100 dB with a bandwidth of 50 MHz AND a SNR ratio of at least 80 dB with a bandwidth of 100 MHz. In addition, the second generation detector should have commercial features (e.g. USB interface and software drivers) that enable the detector to be integrated with other instrumentation via laboratory automation software. The second generation prototype detector will be delivered to NIST for testing and validation.

#### **9.12.09.1-R Ultra-thin NbN Films for Superconducting Detectors**

Recently, there has been significant research and development of high speed single photon detectors using ultra-thin (4nm) superconducting films of NbN. However, one of the limitations in the performance of these devices is the poor detection efficiency. In particular, there has been limited success in embedding these films in the appropriate dielectric structures to enhance the absorption of single photons in to the NbN film. The main limitation has been the development of a process to deposit NbN films on to substrates other than sapphire or MgO which are lattice matched to the NbN. It is possible to obtain thin films (4nm) from a Russian vendor on sapphire. But it would be highly desirable to obtain superconducting 4nm thick NbN or NbTiN on a dielectric oxide or nitride (SiO<sub>2</sub> or SiN) that could then be patterned by NIST in to a superconducting detector.

In Phase 1, the awardee will provide one wafer of superconducting NbN or similar material of 4nm thickness and three or more wafers with 4nm thick NbN or similar material on top of a dielectric that has been deposited or grown on a 3 in silicon wafer. If necessary, NIST can provide the wafers for growing/depositing the NbN. For Phase 2, NIST is willing to work collaboratively with the awardee to help with the design and fabrication of the appropriate optical structure to increase the detection efficiency of these devices from the few percent level to the ninety percent efficiency level. Other Phase 2 development may include the development and fabrication of single photon detectors from these films.

#### 9.12.10.4-R Table-Top Broadband VUV Source for Radiometry

We seek development of an affordable and compact vacuum ultraviolet source with sufficient flux and spectral coverage to be used for standards purposes by both NIST and secondary standard laboratories. This wavelength range is important for diverse fields, from astronomy to national defense to the fabrication of microprocessor and memory chips. The proposed source must have the following performance characteristics:

Wavelength Range: 115 nm to 600 nm

Output Power: greater than 100  $\mu\text{W}$  / nm into a monochromator with a horizontal acceptance angle of 65 mrad ( $f/\# = 15$ ) and a vertical acceptance angle of 6 mrad ( $f/\# = 167$ )

Source Size: less than 500  $\mu\text{m}$  diameter

Source Position Stability:  $\pm 100 \mu\text{m}$

Intensity Stability:  $\pm 1 \%$

Furthermore, the proposed source must produce a continuous emission spectrum, i.e. one that contains emission at every wavelength in the specified wavelength range at the specified power level. Some wavelength-dependent structure in the emission is acceptable, but smooth spectra are preferred over “spiky” structures. The proposed unit should be reasonably compact (no more than 25 cm in linear dimensions with not more than one rack of support equipment and electronics) and should be air-cooled. While source size (and hence brightness) is not a critical requirement, a small source size (and high brightness) will be viewed as a favorable characteristic.

Phase 1 deliverable: A laboratory vacuum ultraviolet source that can be demonstrated to meet the performance characteristics.

Phase 2 deliverable: A reliable, commercializable version of the source that could be utilized by secondary standards laboratories.

### 9.12.11.9-TT Single Photon Sensitive Spectrometer for Infrared Signals

Researchers at NIST published details [1] of a technique for single photon infrared spectrometer to measure the spectrum of a very low infrared light signal (single photon level). This single photon infrared spectrometer uses an up-conversion module, also developed by this group[2,3], to convert single photons in the infrared region to visible light where they were easily detected. This system will have an enormous effect on research and development in a number of areas including quantum communications, low light spectrum analysis, chemistry, nano-photonics, forensics and more.

Until now, the primary method for the spectral analysis of infrared signals was to ensure that a stronger infrared signal was available for measurement. In order to generate sufficient infrared light, for example, in photoluminescence or Raman spectroscopy, an often destructively high power pump beam was required to generate the infrared signal for measurement using less sensitive spectrometers. That technique often leaves samples damaged or even destroyed. Furthermore, in some cases the generation of a sufficiently high power signal was not possible, making these signals inaccessible with existing technology. The up-conversion infrared spectrometer offers a potential breakthrough for such applications since it is in the order of 1000 times more sensitive than existing optical spectrum analyzers. This system will impact both laboratory level research and product development by providing better spectral sensitivity at a low cost.

We propose to transfer this technology to US industries through the SBIR program.

Phase 1: The goal of the feasibility study is the design and development of a bench top spectrometer prototype suitable for low (single photon) intensity infrared light, using an up-conversion module with a performance matching NISTs development. Milestones include:

- develop expertise and facilities to build a working bench top low light spectrometer suitable for use in the IR light range based on the same principle as described by the NIST paper and with the same performance (see detailed specifications below);
- theoretically study and practically estimate the limitations of the spectral measurement range, sensitivity and resolution due to the fundamental characteristics of the materials and processes used;

Phase 2: The goal of the R&D phase will be to thoroughly characterize the performance and specification limitations for a viable commercial product

based on this technology and the production of a compact prototype suitable for commercialization. Milestones include:

- improve the performance of the phase 1 prototype up-conversion spectrometer;
- verify experimentally and characterize the performance of the system including the limits on the spectral range, sensitivity and resolution for a viable commercial product based on this technology;
- eliminate spectral artifacts (e.g. false 'side peaks' described in the NIST paper);
- develop a compact IR spectrometer prototype, with all the controls and design features typical of commercial spectrometers – this prototype will be delivered to NIST for its retention;
- provide a detailed method to expand the spectrometer for other spectral ranges.

Minimum specifications of frequency up-converter, detector and spectrometer:

Frequency up-converter:

Input pump: 1550 nm tunable.  
Input signal central wavelength: 1310 nm.  
Noise (dark counts): < 2000 counts per second.  
Internal conversion efficiency:  $\geq 95\%$   
Waveguide technology for frequency up-converter should be US developed.

Single-photon detector:

Operating modes: Polarization sensitive free running and optical pulse gating modes.  
Overall quantum detection efficiency:  $\geq 20\%$ .

Spectrometer:

Sensitivity: -126 dBm  
Spectral resolution: 0.2 nm  
Spectral range:  $\geq 20$  nm  
Central measurement wavelength: 1310 nm (initially).

It is the expectation of the quantum communication project at NIST that this will be a collaborative effort and will involve significant technical interaction

between our researchers and the company's researchers and developers to work out many of the specific details. The company will have access to the NIST campus to perform any required testing and development, when agreed to by us. Specifically, the company will have access to the NIST Quantum Network Laboratory.

#### References:

[1] Lijun Ma, Oliver Slattery, and Xiao Tang, "Experimental study of high sensitivity infrared spectrometer with waveguide-based up-conversion detector<sup>1</sup>," Opt. Express **17**, 14395-14404 (2009).

<http://www.opticsinfobase.org/oe/abstract.cfm?uri=oe-17-16-14395>

[2] H Xu, L. Ma, X. Tang, " [Low noise PPLN-based single photon detector](#) ", Proceedings of SPIE, Vol. 6780, Page 67800U-1 (2007).

[3] Lijun Ma, Oliver Slattery, Tiejun Chang and Xiao Tang, " [Non-degenerated sequential time-bin entanglement generation using periodically poled KTP waveguide](#) ", Optics Express, Vol. 17 Issue 18, pp.15799-15807 (2009).

## 9.13 Technologies to Enhance Fire Safety

### 9.13.01.6-R Barrier Fabrics for Fire Safe Furniture and Mattresses

Current barrier fabrics based on organic polymers (poly acrylonitrile (PAN), cotton, rayon, novoloid) function by self-extinguishing due to flame retardant coatings. However, this approach often fails due to poor resistance to exposure to water. Another mechanism is due to fiber pyrolysis during a fire which leaves behind a carbonaceous fabric; this protects underlying flammable materials such as foam and fibers. This later mechanism does not suffer from water exposure, but the char yields for the low cost polymers are not 100%, so as the polymer chars the fabric shrinks and this causes cracks in the carbon fabric that expose the underlying foam and allows ignition and fire growth. At high flux exposures this problem is more severe.

New approaches to development of barrier fabrics are solicited. Potential topics may include application of nano-based flame retardants, new polymer, or high char-yield additives within the fiber or as a coating or as a blend with conventional fabrics. Careful consideration should be made as to the methods for material preparation, characterization and flammability property measurement when proposing a program for this subtopic.

Phase 1 deliverable: The awardee should document through the results of pyrolysis experiments that candidate polymer fibers can produce large char residues. Cone calorimeter tests should be used to demonstrate improved flammability properties (e.g., reduced heat release rate and/or longer times to ignition) of the candidate polymer fiber.

Phase 2 deliverable: The awardee should document the improved thermal stability and flammability properties of the barrier fabrics they have developed. Sufficient fabric materials should be provided to NIST at the end of the award period to allow follow-on testing.

## 9.14 X-ray System Technologies

### 9.14.01.1-R Superconducting, Flexible Printed Circuits

NIST is developing arrays of superconducting transition-edge sensors (TESs) for a variety of applications, including: x-ray spectroscopy at synchrotrons for analysis of photovoltaic materials and organic semiconductors; gamma-ray spectroscopy for nuclear-fuel-rod assay; and mm-wave polarimetry of the cosmic microwave background. The TES detectors are read out by SQUID-multiplexed current amplifiers. For maximum sensitivity, the detectors and amplifiers are operated at about 100 mK.

NIST presently builds TES arrays by tiling the detector chips and the separate amplifier chips in a plane, and then interconnecting them with aluminum wirebonds. These silicon chips are 10's of mm on a side. The scales of arrays built in this way are limited to a few hundred TES pixels by the geometrical constraints of tiling the chips and of constructing adequate magnetic shielding around these large planes.

Kilopixel- and larger-scale arrays are desired for all applications, so as to increase collecting area, count rate, and sensitivity. A possible geometry for these larger arrays is a 3-D arrangement in which the detector chip is not coplanar with the readout chips. Such geometry would require an interconnect that does not yet exist: a flexible, high-density, wirebondable printed circuit in which each line has very low or zero resistance. NIST is inviting proposals to develop such a circuit and refine its manufacturing. A large section of the cryogenic detector community, including NASA, will be interested in purchasing circuits like these when they are commercially available.

Desired circuit properties include:

- bending radius of 5 mm or smaller. A base material like 25  $\mu\text{m}$  polyimide would probably be a good starting point



- circuit must be able to be bent to the minimum radius and be straightened again over a minimum of 5 cycles without affecting trace resistance
- single-sided traces on a 200  $\mu\text{m}$  pitch (100  $\mu\text{m}$  trace and 100  $\mu\text{m}$  space) or finer.
- easy and repeatable bondability with standard 25  $\mu\text{m}$  aluminum wirebonding wire. This likely will require a stiffening scheme at the ends. The circuit must be able to be stored under normal laboratory conditions for at least 6 months without degrading wirebondability. Protective coatings on otherwise active metals may be proposed.
- at least 128 traces side by side, with trace runs of at least 50 mm
- resistance lower than 10  $\mu\text{ Ohm}$  along the traces, including parasitic resistance from the wirebond interfaces. Superconducting (zero resistance) traces preferred. If the traces are superconducting, the critical current must exceed 10 mA at 100 mK
- circuit metal must be metallurgically compatible with aluminum, so the wirebond interfaces do not degrade over time

An obvious candidate for the trace metal is aluminum, as it is superconducting at the temperatures of interest, and will not develop bad interface chemistry with the aluminum wirebonds. However, aluminum may be difficult to etch chemically to the required trace/space tolerances. Other possible materials include, but are not limited to, niobium, titanium, niobium-titanium, tin, molybdenum, and tantalum. Proposals to plate or deposit appropriate metals onto flexible copper traces will also be considered. Common adhesion materials such as nickel and chromium are unlikely to be acceptable, due to their magnetic properties.

While the primary goal of this subtopic is to produce flexible circuit materials that will connect two chips at 100 mK, a similar, secondary application that has even greater potential for commercialization is a flexible circuit material that can carry signals between cryogenic stages of different temperatures. In this case, low thermal conductivity of the circuit is crucial, so a thinner base material and a thinner metal layer of a higher-temperature superconductor like niobium, niobium-titanium, or tantalum would be required. Such interconnects could eliminate the need for bulky and expensive wire harnesses in cryogenic apparatuses. Proposers may address this secondary problem as well; proposed solutions to the primary and second problems do not necessarily have to include the same metallization schemes.

NIST will work extensively with the awardee to assess possible materials, conduct wirebonding tests, verify the above circuit properties, refine the circuit

design as manufacturing capabilities evolve, and assess commercial opportunities within the cryogenic-detectors field. Proposers are not required to have previous experience with the properties of superconducting materials.

Milestones for Phase 1: Test candidate materials to determine how they etch and check suitability to achieve the other desired circuit properties. Settle on a production material. Deliver 8 prototype circuits for use in NIST synchrotron detector system.

Milestones for Phase 2: Refine production techniques, move flexible circuit toward commercialization.