Extreme Manufacturing Workshop

Frontiers of manufacturing science: Self-assembly and Biomanufacturing

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Why are the Frontiers of Manufacturing Science Important?

Rationales and Mechanisms for Revitalizing U.S. Manufacturing R&D Strategies

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The importance of the development or acquisition of technology combined with its effective utilization cannot be overstated. Economic studies over several decades have demonstrated the essential role of technology in economic growth. ***Essentially, the high-income economy must be the high-tech economy.***

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Tassey's Recommendations

(1) Increase the average R&D intensity of the domestic manufacturing sector to 6 percent.

(2) Adjust the composition of national R&D *to emphasize more long-term, breakthrough research* and increase the amount sufficient to fund a diversified portfolio of emerging technologies commensurate with the size of the U.S. economy.

(3) Improve the efficiency of R&D performance and subsequent technology diffusion by increasing the number of science parks and regional technology clusters and the use of research portfolio and stakeholder management techniques in order to facilitate person-to-person knowledge exchange so critical to innovation.

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Self-assembly and Biomanufacturing

- Physical Manufacturing Processes:
  - Produce new materials with useful properties
  - Improve manufacturing precision
  - Platform “Generic” technologies
  - High Flexibility
  - Reduced waste and energy consumption
- Value added to US economy
  - Minimize impact of labor cost
  - Take advantage of sophisticated infrastructure
  - Require large capital investments

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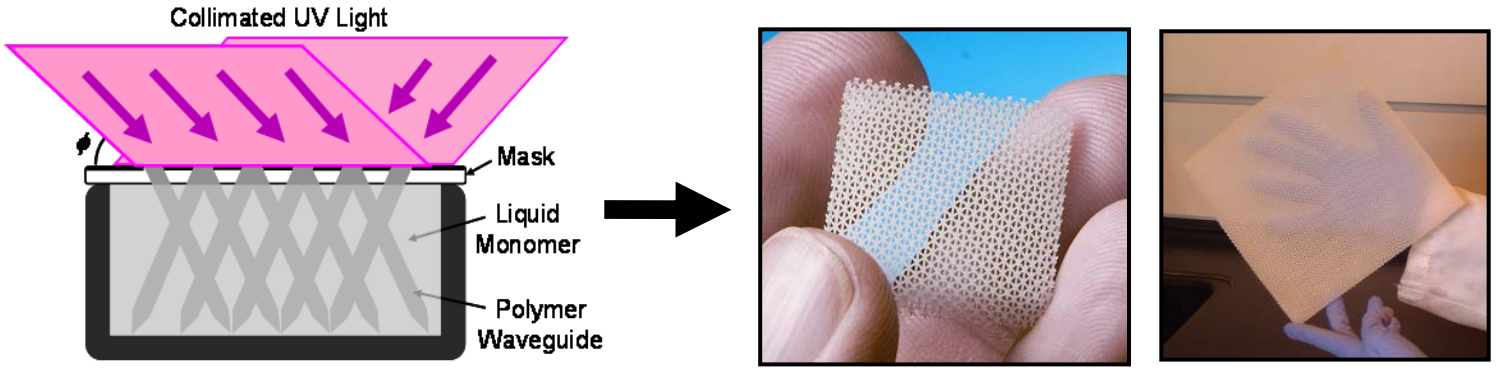
New material process example:
Micro-scale Truss Material - Alan J. Jacobsen, HRL



- Customizable material properties
  - Anisotropic
  - Designed spatial variation
  - Highly flexible, scalable, low cost production
  - Platform technology enabling many products
  - Mass customization potential
  - Additive process - minimal waste

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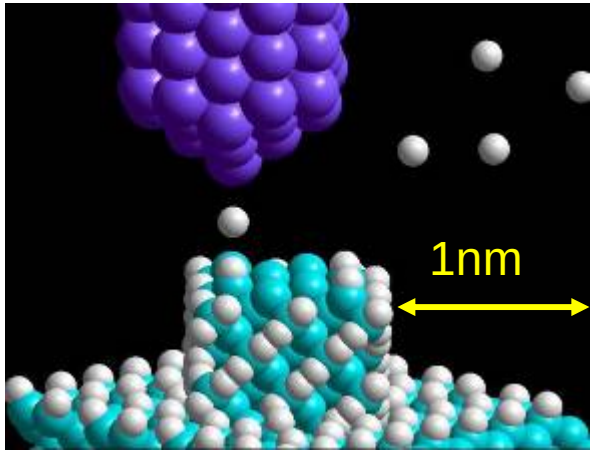
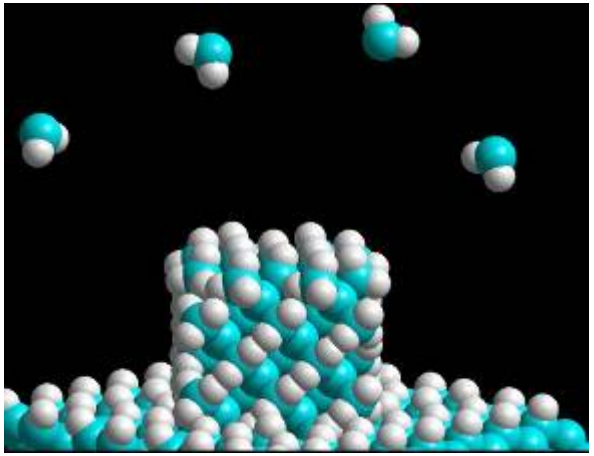
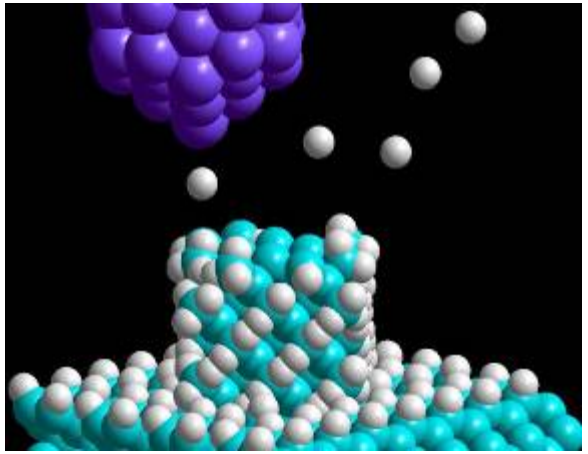
Atomically Precise Manufacturing: Our Technology Approach



Invariant **atomically-precise STM tip**, with closed loop computer control, inside UHV system, removes H from Si surface with atomic precision



In deposition phase, gaseous SiH_2 radicals deposit one Si atom wherever H atom is removed (**patterned Atomic Layer Epitaxy**)



After each deposition cycle, SiH_2 is evacuated and patterning step is repeated to create **designed 3D structure**

- APM is the integration of two known experimental techniques:
  - The atomic precision removal of H atoms from a silicon surface
  - Atomic Layer epitaxy: the deposition of a single layer of Si atoms
- The process which happens in an ultra high vacuum consists of removing H atoms with a scanning tunneling microscope and then introducing a Si containing gas that deposits a single layer of H protected Si atoms.
- The process is repeated to build up 3D structures.

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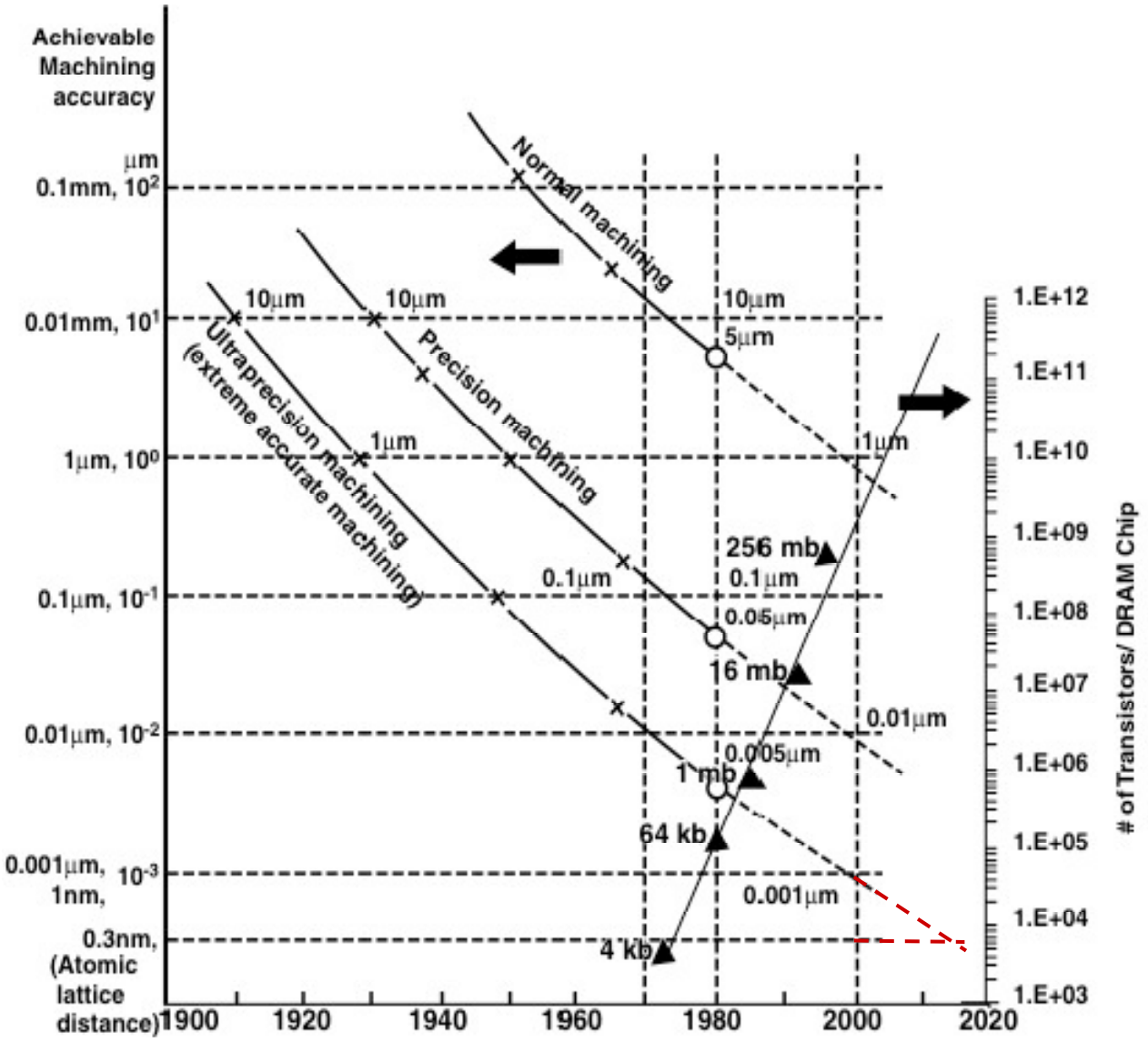
Norio Taniguchi's Precision Chart



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Atomically Precise Manufacturing
Desirable attributes

- Ultimate in Precision
- Digital manufacturing
- Platform technology
  - Atomically precise CNC Mill
  - Extensible to many material systems
- Additive process – minimize waste material
- Scalable
- Even with a very slow process the nano-scale volume of near term products with large impact will start another fortuitous cycle:
  - products, investments, improved manufacturing efficiency, and a wider range of products, investments, improved manufacturing efficiency, . . .

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Why am I here?

- Atomically Precise Manufacturing will happen, the question is **where**?
- The Semiconductor Industry is not going to do it
  - It will start in very small markets
  - Digital electronics won't need atomic precision
- Asian laboratories are already dabbling in Atomically Precise Manufacturing science
- We are a small and dedicated company that even with DARPA support cannot do this in a vacuum
- Our approach might not work
- There should be a large program to fund many efforts such as ours to develop Atomically Precise Manufacturing and the infrastructure to support it.

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What are my hopes

- US Policy makers enact Tassey's recommendations
- We identify manufacturing science and technology gaps that could make a large impact to the future of the US
- We recommend that the US Government fund programs that are a partnership of National Labs, Industry, and Universities to assure that US companies and workers benefit.
- In terms of logistics for such programs:
  - Tassey: most R&D funding agencies mission is not commerce
  - I like the DARPA model
- We also encourage the USGOV to:
  - Work to strengthen the international IP protection laws
  - Provide funds to see that the IP developed will be filed internationally
  - Ask for a proportional payback of funds if the technology is used offshore

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