A CRITICAL NATIONAL NEED IDEA

Advanced Manufacturing Technologies

A Solution for Manufacturing High Volume Precision Micro Scale Components

Submitted by:

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1. Overview

Manufacturing today is faced with a new paradigm that is rapidly changing the scope of machining processes. This paradigm can be best characterized by the phrase “smaller is better”. It is most clearly expressed in the field of electronics where over the past 40 or more years there has been a steady decrease in component and product size with a corresponding increase in product capability. As we move into the 21st century, this paradigm is increasingly impacting other technologies, which, in turn, is driving manufacturing to new miniaturized processes. Machining technologies are included in this drive toward the production of miniature components. Machined micro/meso scale components (often less than 50 mm^3) with micro scaled features (ranging between10 microns and 100 microns) are increasingly required for products in many industries including aerospace, defense, electronics, bio-medical, power generation and propulsion. Many of these components have feature accuracy requirements in the range of 10^{-3} inches to 10^{-5} inches. These miniature components are currently very difficult to manufacture often requiring new and innovative machining processes along with new tools.

Micro & Meso Scale Components

Initially, industry responded to this challenge by using macro scale machine tools to produce micro scale components. Currently, macro scale CNC milling machines and Swiss style machines are often the tools of choice and currently produce nearly all small parts and micro scale parts. However, the economics of this approach are not favorable, often resulting in costly parts that limit the market penetration of products using these components. Additionally, current machining methods sometimes cannot produce the desired part accuracies. The scale of macro machine tools relative to the miniature parts they produce often compromises the machining processes and the quality of the components produced. Macro scale part tolerances fall easily within the error budgets of these machines. However, micro scale components have far more demanding tolerances, which are difficult or impossible to meet with macro machines. For example, if a macro machine with a 1-meter cube work zone has a linear positioning accuracy of +/- 0.010mm, then a micro machine with a 10mm work cube, to hold the same relative accuracy, must have an accuracy 1/100th of the macro machine. This is a positioning accuracy of 0.0001 mm or 0.1 micron. In addition to positioning accuracy, the ability to position the cutter within the work zone (volumetric accuracy) becomes increasingly difficult with the size of the machine. Volumetric work zone accuracy is significantly affected by Abbe errors, thermal changes, large moving masses, bending moments and vibration. For a 1-meter cube work zone the volumetric error (volumetric positioning accuracy) may easily exceed 0.005 inches along each axis. Because of adverse economics and accuracy deficiencies associated with macro scale machines, there is increasing interest in the development of machining technologies based micro scale machine tools commonly known as Micro Machines.

Typical Micro Machines

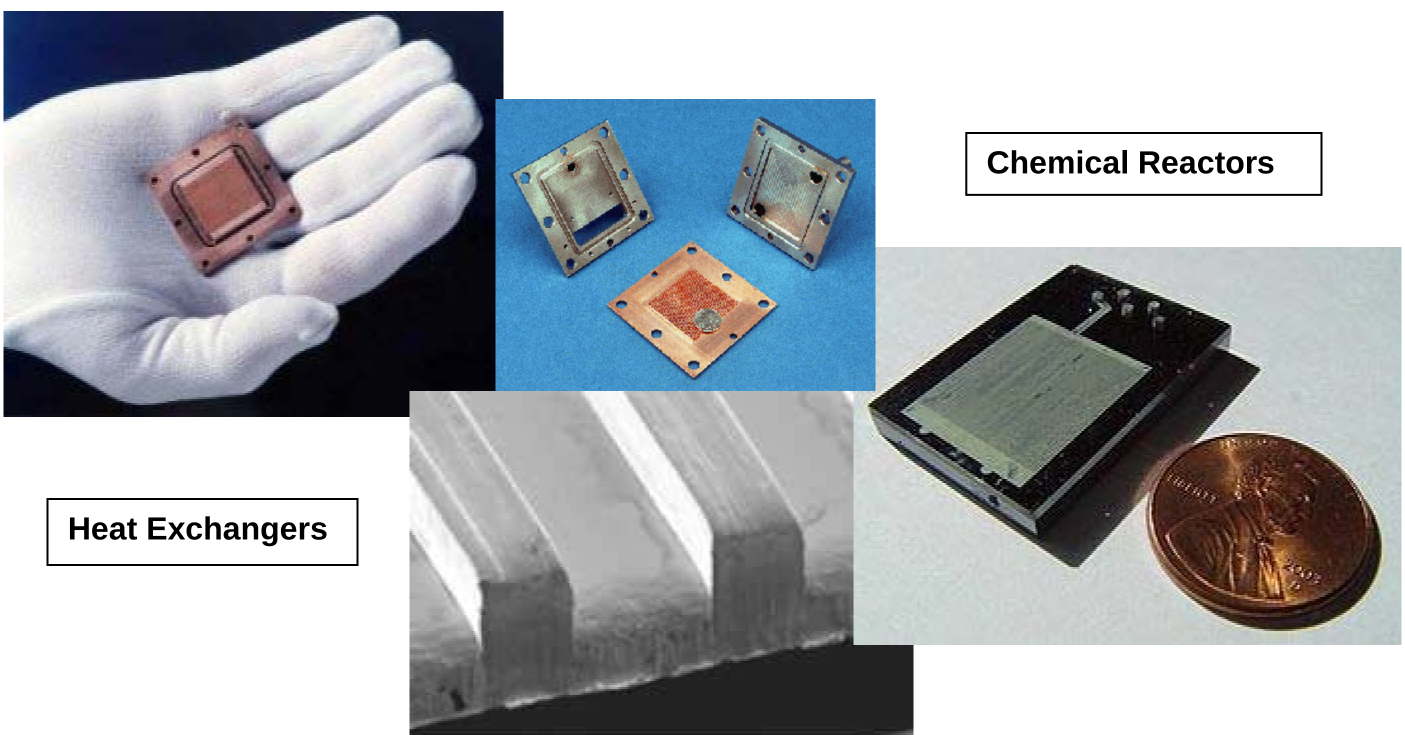
Generally, Micro Machines can be classified by work zone size, accuracy and capability. Most machines have a work zone less than 150 mm^3 and are available with a wide range of accuracies. All of the commercially available Micro Machines are general purpose CNC machines with 3 to 5 axis contouring capability. Studies show they consume approximately 10% of the energy, floor space and capital of equivalent macro scale machines resulting in a corresponding decrease in part manufacturing costs. Machines are available today in a wide range of accuracies ranging from engraving machine accuracy to accuracies well into the sub micron realm.

Although Micro Machining technology has seen slow growth in the U.S. there are active and growing markets in Germany, Japan and Korea with a number of Micro Machine builders serving these markets. The primary focus of the technology has remained general purpose applications with a focus on prismatic parts requiring 3, 4 and 5 axis machining capability.

2. High Volume Micro Scale Part Production

Although existing Micro Machine technology offers solutions for both the economic and accuracy deficiencies of macro scale machining, it is missing a very significant market for micro scale components. The current generation of Micro Machines, from both foreign and domestic machine tool builders, is focused on general purpose machining applications. These machines are well suited for producing one-off or low volume prismatic components. In high volume applications, component manufacturing time and cost becomes problematic. However, there is a particular class of components that will be needed in very high volumes and these parts cannot currently be produced by either macro scale machine tools or Micro Machines.

Within the past 10 years there have been significant developments in a wide range of



Chemical Reactors

Heat Exchangers

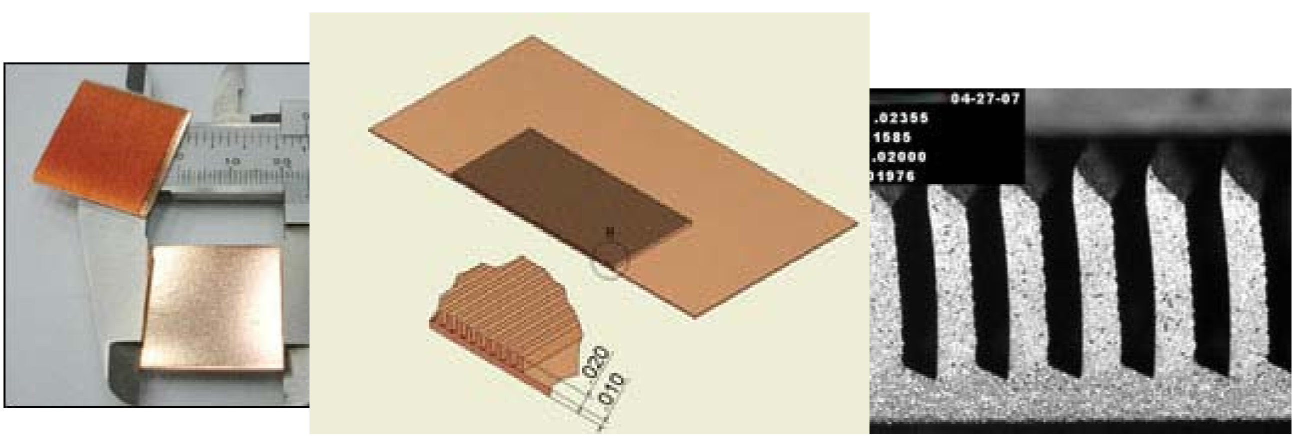
Micro Channel Components

micro fluidic devices that are based on a rapidly developing technology known as micro engineering. This technology uses thousands of micro channels in laminated assemblies for heat or mass transfer. These devices are found in a wide range of applications including biomedical, energy, chemistry, electronics and water purification.

The micro channels used in these applications often have a precise rectangular cross section with dimensions less than 0.100 mm X 0.10 mm arranged at a pitch of 0.300mm or less. Thousands of these channels make up one layer in a laminated assembly. Currently micro channels are machined, skived, laser cut or micro formed in thin metal sheets. By layering these channels, a device with an extremely large surface area can be created in a very small volume. This feature of the technology makes it ideal for a variety of applications where space is critical to the product's function, cost and marketability.

Micro fluidic devices based upon micro channel technology include micro heat exchangers, chemical reactors, microelectronics cooling, blood analysis systems, kidney dialysis, small fuel cells and a variety of other similar devices that operate using heat and/or mass transfer.

The function of these devices is based upon Micro Process Engineering. This is the science of conducting chemical or physical processes inside small volumia, typically inside channels with very small cross sections. These processes are carried out in a continuous flow mode allowing high volume, rapid reaction processes within a small volume. The advantages of microstructured reactors are enhanced heat transfer and enhanced mass transfer due to the large surface to volume area ratio. For example, in a reactor, the efficient mixing of reactants can be achieved in milliseconds. In micro heat exchangers temperature can be precisely controlled.



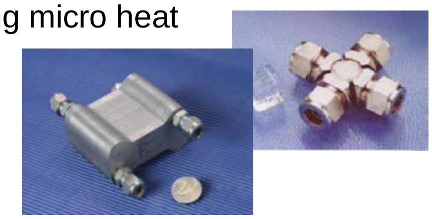
Micro Channel Technology

Micro channel technology has the potential to revolutionize a number of existing technologies. For example, currently the development of more powerful microprocessors and integrated circuits is constrained by the ability to efficiently remove heat from the chip's surface. A significant research effort is underway to develop an economical solution to this problem and one promising solution is the development of micro fluidic heat exchangers that use micro channel technology. Prototype systems have been developed that utilize a micro scale pump, fluid media and radiator to remove heat directly from the integrated circuits. These systems are 20% to 30% more efficient than current cooling system technology. In addition, they are easily incorporated into existing circuit board technology. Their design allows heat from the integrated circuit to be exhausted at the most optimum location in the computer. Other similar examples exist for a wide range of products, from medical instruments to fuel cells.

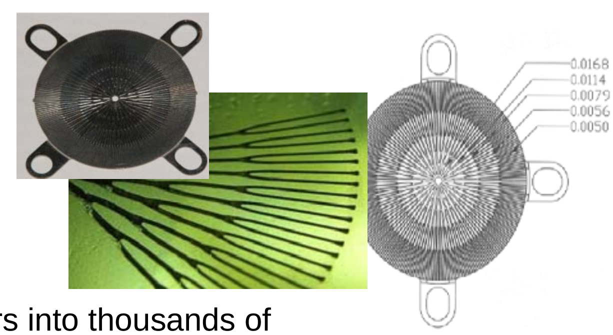
3. Examples of Micro Channel Devices

Although micro channel technology has only recently seen the development of commercial applications, there are many examples of its potential impact. Some products are in commercial production while others are in the research and/or prototype stage. Following are a few examples of current products and research activities.

<u>Micro Heat Exchangers</u>



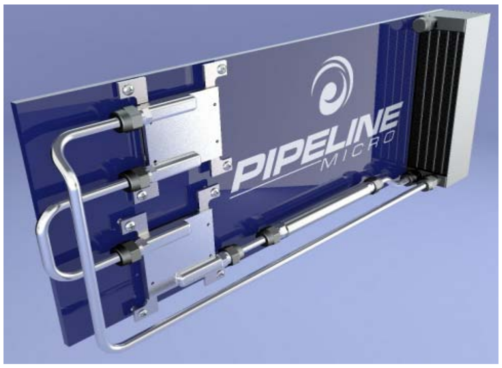
Industrial Applications - A number of companies are producing micro heat exchangers for industrial applications. Generally these devices are designed for applications where space is at a premium and cost constraints are less important. Market penetration of these devices has been limited due to high manufacturing costs.

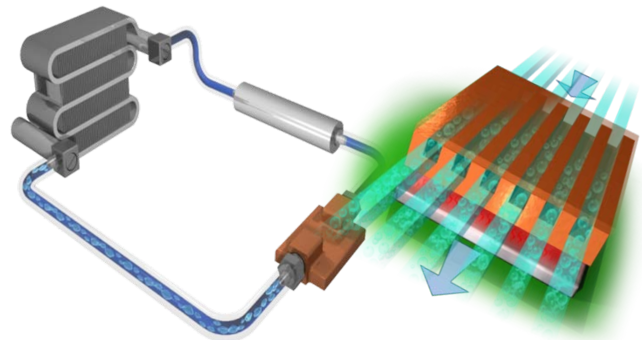


Military Applications – Within the past two years, the U.S. Army engaged Oregon State University to develop a heat exchanger for the personal cooling requirements encountered by soldiers in desert environments. Although the prototype designs yielded excellent performance, manufacturing costs were excessive. Micro machining of the channels in metal substrates drove the cost of the heat exchangers into thousands of dollars with manufacturing cycle times of over 24 hours for a single lamination. Clearly, this is not an acceptable manufacturing solution for a device that is to be produced in the 100's of thousands units.

Microelectronic Cooling – Today, the main constraint to micro processor and integrated circuit development is the ability to cool the chip. Unless more efficient cooling systems can be developed, designers will be unable to increase micro processor speed and capability. A similar constraint is inhibiting the development of more powerful integrated circuits.

Companies ranging from IBM to a startup company - Pipe Line Micro - are developing





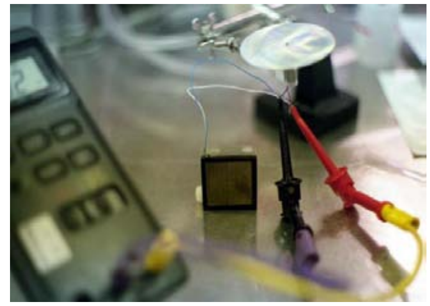
micro channel fluid based cooling system. The compact size of these systems and their ability to transfer heat off the circuit board make them ideal for microprocessor cooling. This application requires high volume production of micro channel laminations in the millions of units. The market for this application alone is estimated to be $5B per year and is anticipated to double within the next 5 years.

Micro Chemical Reactors

Overview – A micro reactor is a highly efficient device for thermally controlling reagents. The large surface area per volume gives high thermal conductivity to a micro channel based reactor, allowing quick and accurate control over the chemicals inside. The small size shortens the molecule diffusion time for fast and efficient reaction. Pressed by a need to streamline costs and reduce environmental damage, many of the biggest names in fine chemicals, specialty chemicals, pharmaceuticals and consumer products are developing applications for micro reactors.

Chemical and Pharmaceutical Production – Micro Reactors are currently being developed for not only specialty chemicals and pharmaceuticals but also for bulk chemicals. It seems counterintuitive that a micro reactor could produce 10,000 tons of a chemical, but micro reactors are not batch technology. Because they employ flow chemistry – a continuous process – the principals governing their operation and economics are fundamentally different. It is estimated that within the next 10 years over 30% of all fine chemicals and pharmaceuticals will be produced by micro reactors.

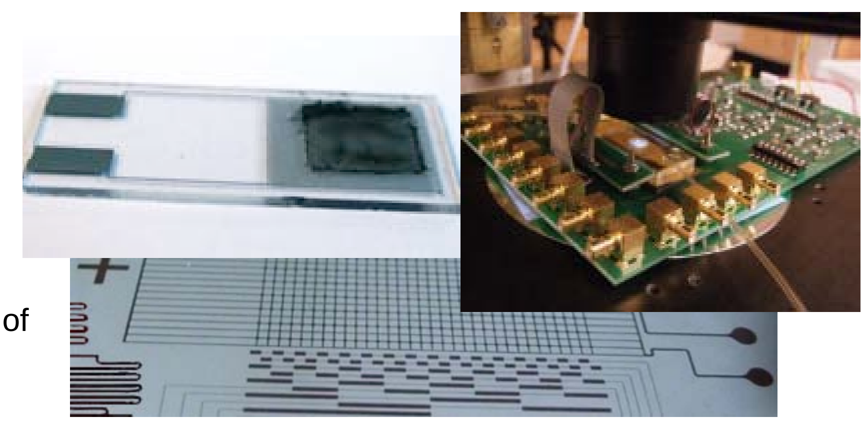
Micro Fuel Cells



Overview - The operation of a fuel cell involves the chemical interaction between hydrogen and oxygen to produce water, heat and electrical energy. Typically, a fuel cell consists of a pair of electrodes (the 'anode' and the 'cathode') separated by a membrane that allows protons (hydrogen ions) to pass through the membrane but does not allow an electric current to pass. A main objective of current research is the application of micro scale fuel cells to portable electronic devices such as cell phones and computers.

Portable Fuel Cells - The main problem with applying fuel cell concepts to mobile devices is that the power source (battery or fuel cell) must be able to deliver around 300mA of current at 3.6V and it must not occupy a volume of more than around 12 cubic centimeters. However, the output current of a fuel cell is directly related to the common surface area between the electrodes and the membrane and to obtain 300mA of current using conventional fuel cell technologies would require a surface area of around 60 square centimeters, much larger than is available in a mobile phone. Important progress has been made in overcoming this problem by developing new technologies in which the fuel cell could be implemented as a 3D structure containing thousands of buried micro channels that maximize the contact area between the gases, the catalysts and the electrodes.

Biomedical Devices



Overview – There are a number of wide ranging applications for micro channel technology within the biomedical fiels. They range from small portable dialysis systems to blood filters to asay instruments. In many of these appliations laminated assemblies of micro channels are seperated by semi perimable membranes that function as filters or media seperators or reactors.

Kidney Dialysis – Portable dialysis systems based on micro chanel technology are currently under study. They offer the possibility of reducing or eliminating the amount of time paitents need to spend in conventional dialysis centers.

4. High Volume Production Research

The key to unlocking the full potential of micro fluidic devices is the development of an effective and economical manufacturing process for creating micro channels in a variety of substrate materials. Current manufacturing processes include micro milling, micro forming, skiving, photo etching, electro discharge machining, micro forming and in some instances injection molding. However, these processes have generally not proven to be economical for producing high volume commercial products such as micro processor coolers, micro fuel cells or personal cooling systems. They are batch processes that produce one component at a time or low volumes of components. To produce micro channel parts for these high volume applications, a low cost continuous manufacturing process is required.

Consider the basic requirements to produce cooling systems for micro electronics. Assuming a production requirement of 10,000 units per month, all of the parts for each unit must be manufactured and assembled within approximately 24 seconds. The cost of the manufacturing process also has to be quite low, perhaps less than $1 per micro channel lamination, to keep the system cost within an acceptable range. Only a continuous, as opposed to a discreet, process can meet these requirements.

In addition to the volume and cost requirements, some micro channel based devices are very sensitive to the precision of the channel. Where laminar flow is a requirement, the channel surfaces must be straight with smooth surfaces. Also, if the channels can be produced with sharp corners, the surface area can be increased, which increases the efficiency of the device.

Research has to a large extent demonstrated the potential of micro channel technology based devices. Unfortunately, the technology is currently limited to low volume, high cost applications due to manufacturing constraints. Research needs to be applied to developing economical manufacturing processes that produce the components for these devices in high quantities with the precision required.

It is clear that many commercial applications of micro channel technology will require a continuous manufacturing process rather than the current batch processes. There are a number of areas that need to be researched. The manufacturing process itself needs to be studied. While micro milling is often used to produce prototype micro channel parts this batch process is not suited for high volume production. Cycle times, tool consumption and capital investment all adversely impact the economics of high volume part production. Other metal working processes such as skiving, broaching, sawing or micro forming are more amenable to a continuous manufacturing process. However, it will require a significant research effort to select the best process and develop equipment that will produce parts at the required rate with acceptable precision and cost. Other areas of research may deal with critical issues such as stresses within the laminate material, material handling, in-process inspection, and integration of the manufacturing process with assembly of the device.

5. The Need for NIST Funding

A majority of the research devoted to micro fluidics and more specifically to micro channel technology has been to demonstrate the potential of the technology. Today there are many examples of how this technology could revolutionize many important commercial and inustrial products. However, in spite of a concentrated effort on the part of some researchers, very little progress has been made on the manufacturing issues that are inhibiting high volume, low cost production of these products. To some extent this is due to the background of the researchers. In many cases these researchers come from academic, medical or basic research backgrounds and are not familiar with manufacturing technologies. REALLCo believes that a NIST funded initiative can demonstrate to industry that the manufacturing problems associated with the commercilization of this technology have viable solutions. This research could be the catalysist that moves this important technology forward and jump starts the development many of the products that have been demonstrated in the laboratory.