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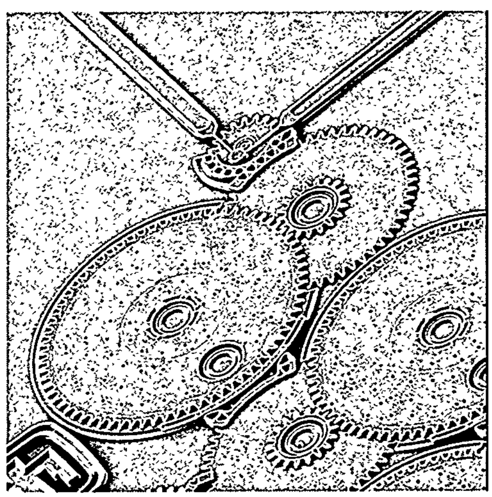
Microsystems – The Next Big Thing

Micro-Electro-Mechanical Systems (MEMS) is a big name for tiny devices that will soon make big changes in the way we live and work. These and other types of microsystems range in size from a few millimeters to a few microns, much smaller than a human hair. These microsystems have the capability to enable new ways to solve problems in commercial applications ranging from automotive, aerospace, telecommunications, manufacturing equipment, medical diagnostics to robotics, and in national security applications such as nuclear weapons safety and security, battlefield intelligence, and protection against chemical and biological weapons. This broad range of applications of microsystems reflects the broad capabilities of future microsystems to provide the ability to sense, think, act, and communicate, all in a single integrated package.

Microsystems have been called "the next silicon revolution", but like many revolutions, they incorporate more elements than their predecessors. Microsystems do include MEMS components fabricated from polycrystalline silicon processed using techniques similar to those used in the manufacture of integrated electrical circuits. They also include optoelectronic components made from gallium arsenide and other semiconducting compounds from the III-V groups of the periodic table. Microsystem components are also being made from pure metals and metal alloys using the LIGA process, which utilizes lithography, etching, and casting at the micron scale.

Generically, microsystems are micron scale, integrated systems that have the potential to combine the ability to sense light, heat, pressure, acceleration, vibration, and chemicals with the ability to process the collected data using CMOS circuitry, execute an electrical, mechanical, or photonic response, and communicate either optically or with microwaves.



Polysilicon micromachine components made using a five-level process developed at Sandia National Laboratories. Photo courtesy of P. McWhorter, Sandia National Laboratories.

Microsystems are already becoming part of our lives. If you drive an automobile, you are probably using a microsystem-based accelerometer package that will trigger your airbag in the event of a wreck. This system, made by Analog Devices, costs less than $5, versus the $50 cost of previous systems. Over 50 million of these systems are now in operation without a single reported failure.

Existing microsystems can also spit out ink from your ink jet printer, monitor your blood pressure, adjust the fuel-air mixture in your automobile engine, and project your transparencies to audiences.

Different physics at the microscale

Because of their extremely small size, microsystems are not significantly affected by inertia, momentum, or gravity. This means that they can be extremely resistant to mechanical shock. For instance, microsystems

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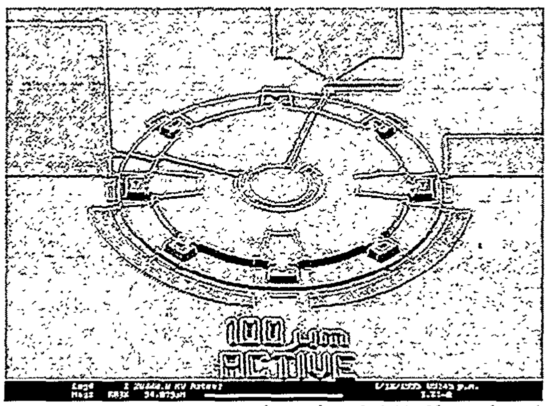
embedded in artillery shells have survived shock environments with accelerations exceeding 10,000 g's without failure. Micro-gear sets can run at up to 350,000 rpm with the capability to reverse instantly and operate efficiently with gear ratios of a million-to-one.

The other side of this coin is that microsystems are strongly affected by interfacial forces such as stiction. Stiction is the tendency for surfaces to adhere to each other due to van der Waals, polar, capillary, and other forces between surfaces. One way to overcome stiction problems is to apply self-assembling monolayer coatings on problem surfaces. This use of nano-scale coatings illustrates the synergy between microsystems and new advances in nanotechnology. Other concerns in the use of microsystems include wear, fatigue, and friction on the microscale. Advances in the understanding of the physics of surfaces on the nano-scale will be an important element in the commercialization of microsystems.

Applications of microsystems

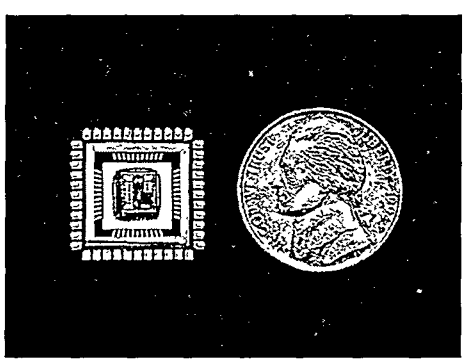
Microsystems have demonstrated the capability to sense most physical quantities, including light, temperature, pressure, acceleration, vibration, and the chemical environment.



A pressure sensor made using MEMS technology.

Photo courtesy of P. McWhorter, Sandia National Laboratories

The development of new and more capable microsensor packages is an important key to the widespread use of microsystems. Microsensors are now being developed to optically detect multiple chemical species for applications such as detection of chemical or biological weapons. This can be accomplished in several ways; by combining Surface Acoustic Wave Detectors with thin surface coatings that are sensitive to specific chemicals, by the use of chemiresistive coatings, by micro-optical techniques, or by the use of microscale gas-chromatograph columns. Integrated "chem-lab-on-a-chip" sensor systems may someday perform the work of an entire analytical chemistry lab in a package the size of a quarter.



A single IC with a 3 axis accelerometer and on-chip electronics.

Photo courtesy of D. Plummer, Sandia National Laboratories.

Combinations of sensors are also being developed to predict upcoming system failure in applications ranging from automobiles to washing machines. One technique in this area is the use of micro-arrays of accelerometers and application-specific integrated circuits (ASICS) to detect and interpret vibration signatures characteristic of upcoming failure. Acceleration sensors and microgyros, now in the prototype stage, will enable small, lightweight navigational systems for missiles or cars.

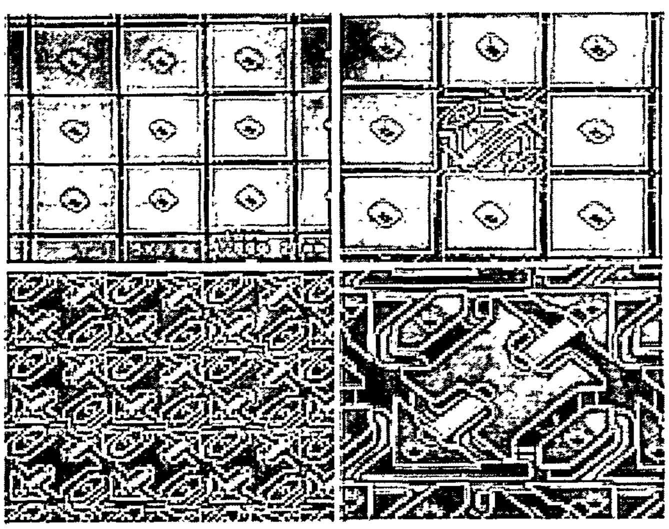
New capabilities in the MEMS area are being introduced rapidly due to advances in design and fabrication techniques. The new SUMMiT 5 process (http://www.mdl.sandia.gov/micromachine/summit5.html), developed at Sandia National Laboratories, now enables the production of 5 layer, self-assembling polysilicon components incorporating complex geometries and shapes. Components that can be produced using this process include gears, locks, timing devices, pop-up mirrors, microscopic relays, and optical shutters. One application that can result from the integration of these and other components with on-board ASICs capability is the creation of programmable locking devices that can prevent tampering with anything from your automobile to your checking account.

Disruptive Technology

An important driver for the rapid growth of microsystems usage in the marketplace is their ability to provide new types of solutions to problems that cannot be solved using present technology. These "disruptive" capabilities will by-pass present technology barriers, enabling rapid advances.

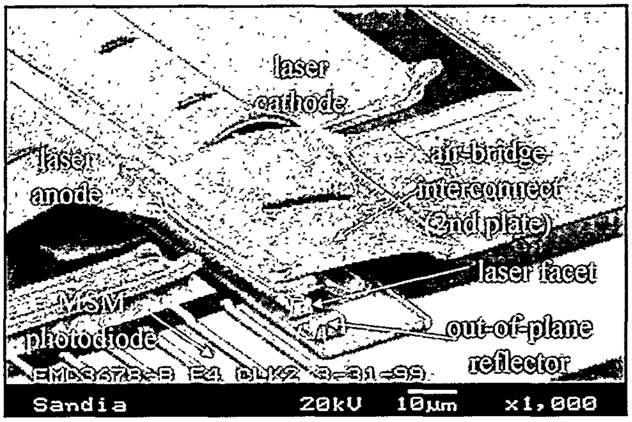
Although microsystems have been around in their simplest forms for several years, they are now evolving into forms sophisticated enough to justify the term "disruptive technology". This is typified by the new capability, coming on-line within the next few years, to make bundled sensors with the on-board processing to blend the sensor inputs, make "decisions" about the results, and communicate these decisions using optical or RF techniques. Such devices will be useful in applications ranging from counter-terrorism, to environmental remediation, to monitoring of the medical condition of patients in their own homes.

Another example of disruptive technology is the rapidly emerging capability to use microsystems to do direct optical switching in fiber optic-based telecommunication networks. Present switching systems must convert light in fibers to electrical signals that are then reconverted to light in a second fiber. Building on microsystems technology pioneered by Texas Instruments for digital projection applications, it is now possible to use millions of micron-size, MEMS-based movable mirrors to actively direct light from one fiber to another. This can remove the need for electrical conversion and potentially provide 10x faster switching speeds at 10x lower cost. Regarding this application, David Bishop of Lucent Technologies says "Five years from now, the winner will be the one that got MEMS out fastest, and the losers will be the ones that didn't."



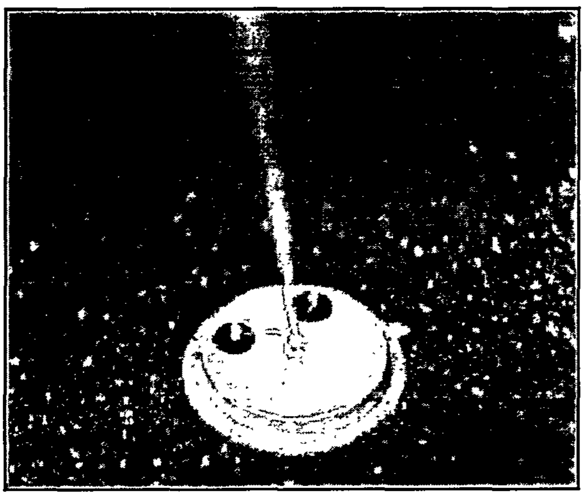
Texas Instruments' digital micromirror device.

Another important technology advance is the capability now being developed to combine the Vertical Cavity Surface Emitting Lasers (VCSELs) (Kent D. Choquette, J. Vac. Sci. and Tech. B., V. 11, p. 1844, 1993) with other optical and mechanical components to create photonic integrated circuits (http://www.mdl.sandia.gov/photonics/CCST7.html). One applications of such circuits may be in low power, lightweight communication links for nanosatellites.



A Photonic Integrated Circuit.

(Photo courtesy of T. Zipperian, Sandia National Laboratories)



A Vertical Cavity Surface Emitting Laser (VCSEL).

(Photo courtesy of A. Owyoung, Sandia National Laboratories)

The business case for microsystems

Now that initial applications are growing and the capabilities of microsystems are becoming better known, companies are taking a closer look at the growing microsystems market. The small size of MEMS parts and the ability to use standard, lithographic fabrication tools and techniques adapted from the semiconductor industry will enable thousands of microsystems to be fabricated on a single wafer at costs that can ultimately be as cheap as present microelectronics chips.

Although MEMS and other microsystems components can be fabricated using similar processes to those used in microelectronics, they do not require the extremely small feature sizes of the latest generation of microelectronics. This enables greatly reduced capital equipment cost because previously retired fabrication equipment, 1-2 generations behind that presently being used for microelectronics, can be used for microsystems. This will allow microelectronics fabricators to use their old equipment that would otherwise be discarded, to make MEMS components with little additional capital cost.

More than 600 organizations worldwide are now developing microsystems technology, with about one quarter of these pursuing commercialization. According to Roger Grace, a San Francisco-based market analyst, the annual market for microsystems was $4-6 billion dollars in 1998, with expected growth to $10-20 billion in 5 years. This demand for microsystems will probably be satisfied by the combination of microsystem fabrication facilities provided initially by existing microelectronics producers, together with dozens of new start-up companies introducing new designs and packaging concepts for a wide range of applications. The development of new packaging solutions for microsystems will be an important enabling activity in the growth of commercial microsystems applications.

To help jump-start new, microsystems-based solutions for national security applications, a new microsystems facility is being planned for construction at Sandia National Laboratories. This facility, called the Microsystems and Engineering Sciences Applications (MESA) facility, will provide the capability to design, model, fabricate, and package polysilicon MEMS components, GaAs electro optical components, silicon microelectronics, and hybrid combinations of the three. The technical teams working in the MESA facilities will also help to develop the technology and packaging options needed to produce useful and reliable systems for both national security and commercial applications. Other capabilities and techniques are being developed under sponsorship of several organizations including the Defense Advanced Research Projects Agency (DARPA) and the National Science Foundation. University research at institutions such as the University of California at Berkeley and the Massachusetts Institute of Technology is also playing an important role in advancing the state of microsystems technology.

The Future

Within the next few years the growth of microsystems capabilities and profitability will unleash a flood of new applications. Future applications of microsystems are limited only by the imagination. Within the national security areas, microsystems will enable unmatched battlefield intelligence and provide early warning against chemical and biological weapons. Sensor fusion combined with artificial intelligence will make just-in-time preventive maintenance standard throughout the transportation and manufacturing sectors. Low cost microsystems will ensure the integrity of our critical infrastructures, from the power grid to bridges and buildings.

Chem-lab-on-a-chip capability will lead to "med-lab-on-a-chip" for rapid, low cost diagnostics capability, either in a clinic or in your own home. Other biomedical applications will include microscopic surgical tools, implantable microsystems for medical diagnostics or delivery of medication, and microsystems and sensors to restore impaired sensory functions such as hearing.

For industry the message is clear; "Get involved, the revolution is starting!" For the rest of us, microsystems promise to play an important role in creating a more secure, healthier, and wealthier tomorrow.

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