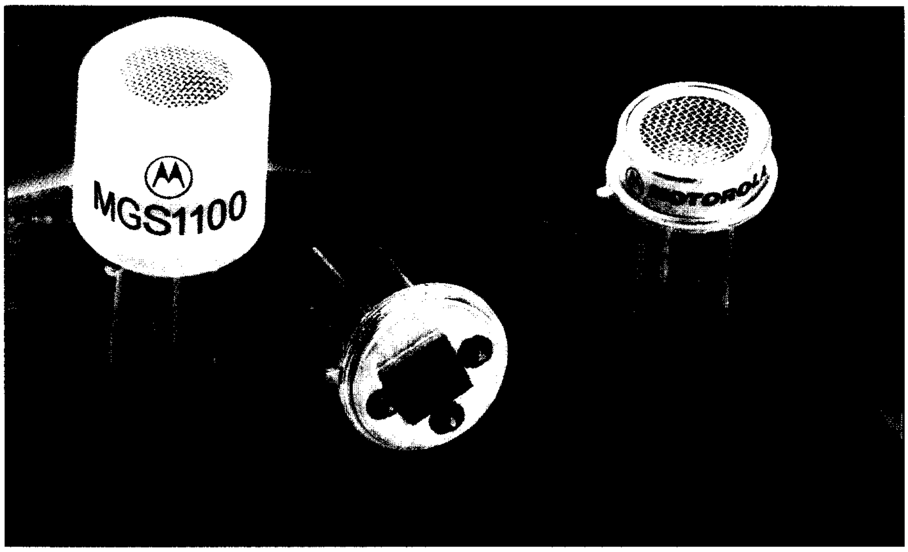
# MEMS: Another Fast-moving Target for the Compounds to Track

**by Jo Ann McDonald, US Correspondent**

*MEMS are the manipulative little devices that have wormed their way to the top of the list of interesting "new" technologies this fall. When looking into the increasing number of MEMS initiatives, one conjectures that their popularity is because MEMS offer systems designers the opportunity to marry the "smaller, faster, smarter" philosophy with old fashioned facts of mechanical and human life.*

Where silicon leads, the compounds inevitably follow. Siliconers are hot on the MEMS trail these days, and as soon as systems designers start demanding more of their MEMS devices (more light, faster speed, radiation hardness, higher temperatures, etc...), we may see viable niches for MEMS based on III-Vs and the wide bandgap materials.

When announcing DARPA's recent $50 million MEMS initiative, Dr. Kaigham (Ken) J. Gabriel defined Microelectromechanical Systems (MEMS) as: "an enabling technology that merges advances in information processing, storage, and display with advances in sensors and actuators to bring about a revolution in the way we both perceive and control the environment."




Motorola's SENSEON™ Carbon Monoxide Chemical Gas Sensor.

Formerly the program manager for DARPA's MEMS effort, Ken has recently assumed the directorship of DARPA's Electronic Technology Office, replacing Lance Glasser who entered the commercial sector. The two names are familiar ones to the US compound semiconductor R&D community. Ken went on to note that, "MEMS is a natural progression in the capabilities of semiconductor devices. The ability of MEMS to gather and process information, decide on a course of action, and control the environment through actuators increases the affordability, functionality, and number of smart systems. The enhanced capability of smart systems enabled by MEMS will increasingly be the product differentiator of the 21st century, pacing the level of both defense and commercial competitiveness."

MEMS are getting smarter. Sandia Laboratories in Albuquerque is setting a fast pace and calling the MEMS they design and fabricate, "intelligent multipurpose micromachines." According to Sandia's science writer, Neal Singer, "a smart micromachine is better than a dumb one, just as a car with a gas indicator, speedometer, and cruise control is easier on a driver than one that merely runs. An intelligent micromachine can signal for more power, communicate that it is operating too fast or too slow, or even perform actions on an automated basis." According to Paul McWhorter, manager of the effort at Sandia's Microelectronics Development Laboratory (MDL), "This will

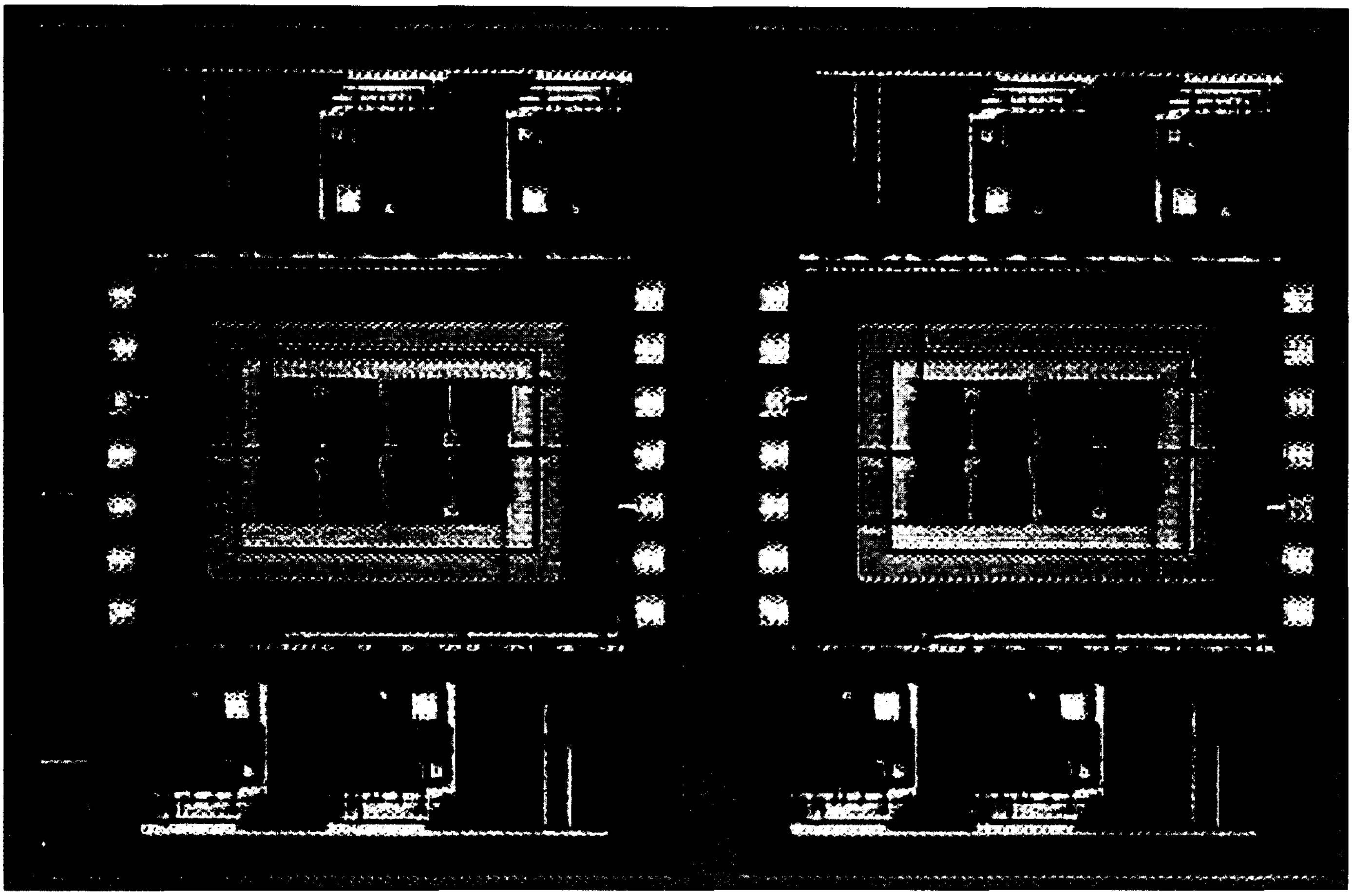

be a big enabler for a variety of new products to be produced that are small, smart and cheap," underscoring that by using the semiconductor industry's fab methods, "we've created a generic manufacturing process."

The Sandia process etches tiny trenches in silicon chips and fabricates the machines within these depressions like pool tables in sunken living rooms. The machines, heat-treated, are then submerged—like the Alpine Iceman, preserved in the interior of a glacier – in a tiny hardening sea of silicon dioxide. "If you first sink the machine in a trench and then fill in around it, in effect you've recreated a pristine wafer for doing electronic processing," said Steve Montague, inventor of the approach.

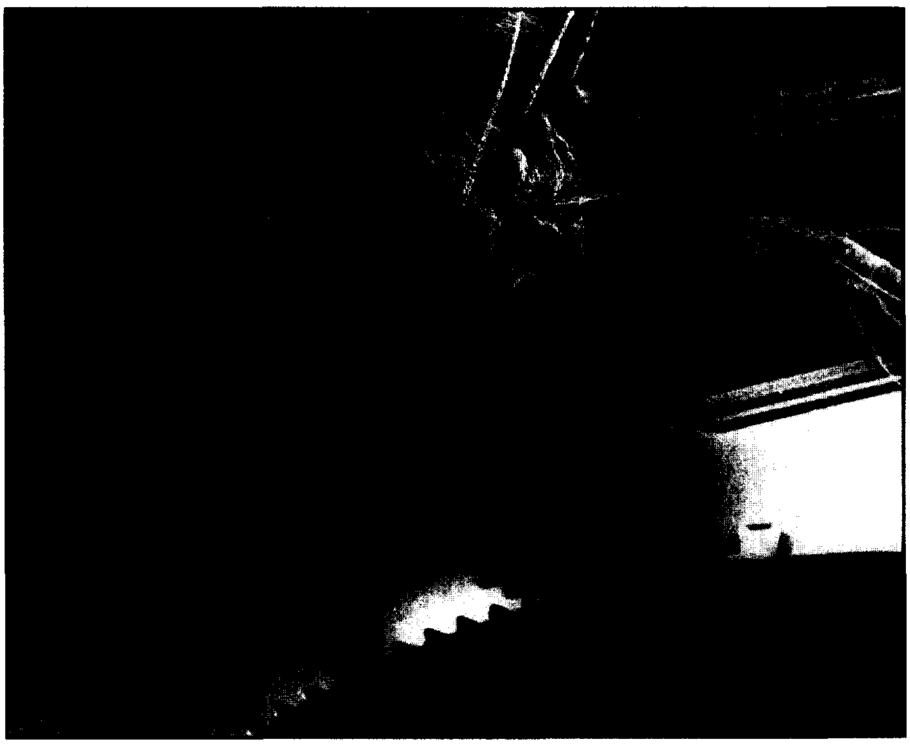
The hardened silicon dioxide recreates a level chip surface upon which circuitry is fabricated by photolithography. Removal of the silicon dioxide at the end of the process frees the microengines. Working systems are manufactured with a 78% success rate – a reasonably high measure of production yield. The process can produce a wide range of micromachine systems because it allows independent optimization of micromachine and microcircuit performances, achieving the "paradoxical but desirable result of larger, more powerful micromachines with smaller transistors," says Paul McWhorter.

While the machines and electronics now are completely fabricated at Sandia, another option is to continue fabrication of the machines and chips at the Labs' Microelectronic Development Laboratory, but permit novel circuitry to be added at other integrated circuit facilities. An effort is currently underway at Sandia to transfer the technology to industrial partners for large scale production. Telephone contact for Paul McWhorter for more details is 505/844-4683.

MEMS are not really all that "new." Automotive airbag systems are based on MEMS technology, as is Texas Instrument's Digital Micromirror Device. Sometimes the nomenclature is confusing. Not only have all the hyphens thankfully been removed from "microelectromechanical," but the term "micromachining" is also involved. Two of the common MEMS fabrication processes are bulk micromachining and surface micromachining, so we'll be seeing terms like "microfabrication" relating to MEMS. Orbiting around space technology conclaves are the terms "nanoscale" and "nanotechnology," terms especially familiar to Eastern European scientists and engineers. A "nanometre" is one billionth of a meter, and has become the preferred unit of measure among scientists working at the atomic scale in biology, electronics, and materials sciences. No matter how small, or what you call them, MEMS present a new opportunity to cleverly combine the advantages of miniaturization and the



**Integrated Accelerometers (50,000 g Rating). Sandia's integrated and 3-level poly surface micromachines.**



**Dust mite = 300 microns. Human hair = 75 microns long. Small driving gear = 50 microns wide. Large gear = 1600 microns wide (These photos courtesy of Steve Montague of Sandia National Labs). Contact: Paul McWhorter, Manager of Integrated Micromechanics, Microsensors and CMOS Technology Dept. tel: [1] 505 844-4683.**

integration of multiple components into one system, using the manufacturing process steps learned from microelectronic fabrication.

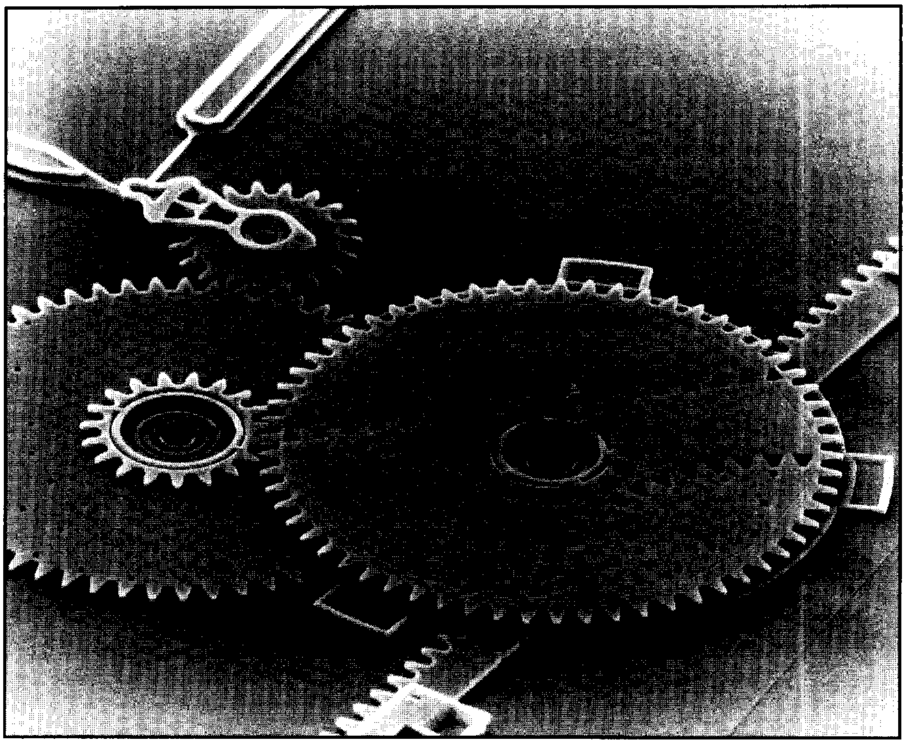
## Market forecasts

Current estimates are that today's MEMS market is around the $2 billion sales mark, and predominantly sensor based. By the year 2000, more than 50% of MEMS will be actuator based. By that time, the total worldwide MEMS market will rise to around $14 billion, but it will take until 1999 to realize that rampup. An SPC MEMS market study that DARPA has cited forecasts that market segments by the year 2000 will break out to: 25% pressure sensors, 21% optical switching, 20% inertial sensors, 19% fluid regulation and control, and 6% mass data storage, leaving 9% for various smaller niches.

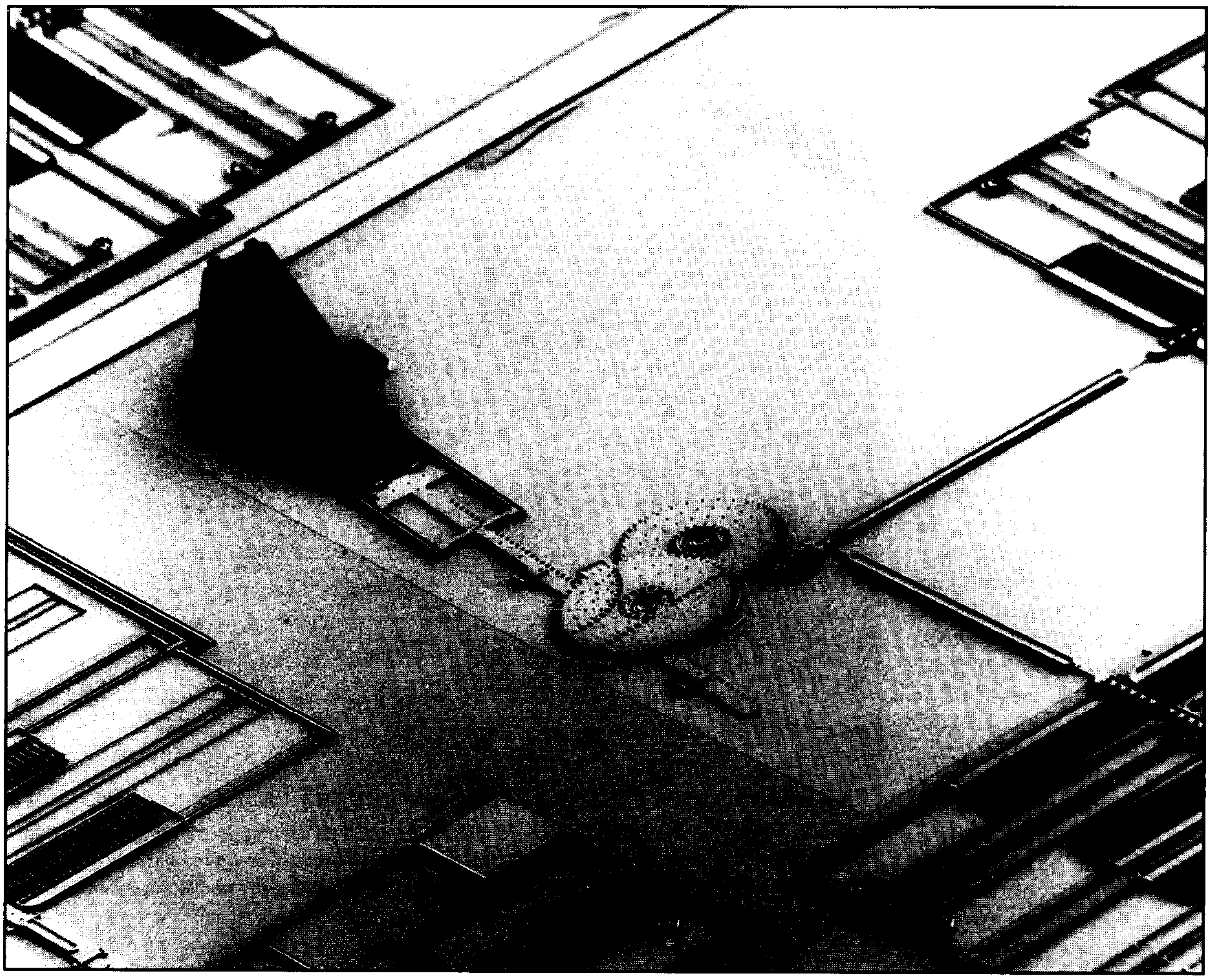
## Motorola defines state of the art commercial environmental sensors based on MEMS carbon monoxide device

Ideally typical of commercial efforts that are fielding state of the art MEMS now is Motorola's launch of their "Senseon" chemical sensor family, touting how silicon micromachining offers "uncompromising performance for air quality and environmental monitoring." The product will be officially introduced at Sensors Expo, 22 October 1996, in Philadelphia, Pennsylvania, see photos.

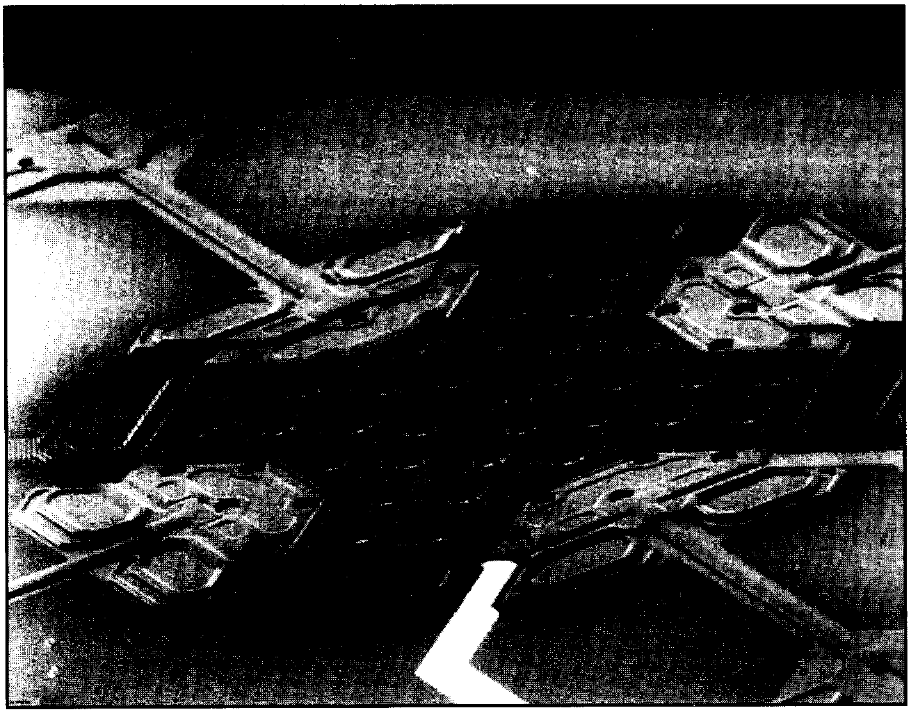
The SENSEON MGS1000 series of chemical gas sensors is based on thin film MOS technology, manufactured under license of Microsens SA in Switzerland. The series features an embedded heater layer to raise the temperature of the metal oxide film in order to be more sensitive to the



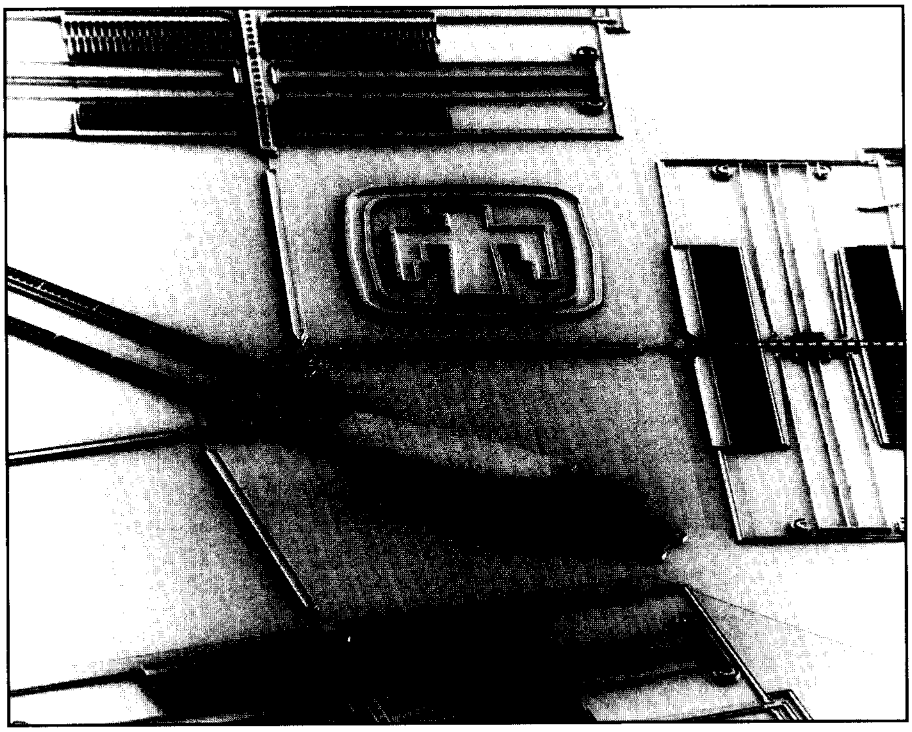
Nested drive gears in 3-level technology (generates more torque). Courtesy of Sandia National Labs.



3-level poly-powered, surface micro-machined mirror for optical interconnects. (Courtesy of Sandia National Labs.)



Motorola SENSEON in close up.



Micromachined mirror w/drive motors for optical interconnects (Rack and pinion drive). Courtesy of Sandia National Labs.

target gas, combined with a micromachined silicon diaphragm for reduced power consumption. Designed to support the most current standards for residential CO detectors, the device is fitted with a stainless steel mesh and an active charcoal filter for protection against damaging elements, and to selectively screen out noise gases. The sensors are priced at under $10 each in low quantities. Complete research, development, and manufacturing of Motorola's chemical sensors is being implemented in Motorola's existing facility in Toulouse, France. Future products from the MGS1000 series will include the 1200 methane sensor

## DARPA's newest $50 million MEMS initiative

As of July, proposals are in and are now under consideration at DARPA for their newest $50 million MEMS initiative (Issue: PSA 1565, SOL BAA 96-19). Quoting from the BAA: "The long-term goal of DARPA's MEMS program is to merge computation, sensors, actuators, and mechanical structures to radically change the way people and machines interact with the physical world. As military information systems increasingly leave command centers and appear in weapons and in the pockets and palms of combatants, they are getting closer to the physical world, creating new opportunities for perceiving and controlling the battlefield environment.

"This phase of the DARPA MEMS program will build advances in MEMS devices, device integration, and fabrication resources to develop and demonstrate new system concepts and resulting capabilities." DARPA seeks proposals in three broad technology areas:

i. MEMS systems developments and demonstrations, particularly but not exclusively in signal processing, control of distributed, multi-element (10,000 sensor) and actuator systems, and electromagnetic beam steering;

ii. MEMS manufacturing resource development, including but not limited to: MEMS electronic design aids, MEMS fabrication/processing equipment, generalized MEMS packaging techniques and tools, and visualization/analysis tools for MEMS device and systems;

iii. Integrated microfluidic systems for molecular processing and detection.

Recent accomplishments of DARPA's MEMS program to date include the demonstration of an accelerometer operating at near 80,000 g's, optical diffraction gratings that electromechanically switch light in 40 nanoseconds, and a fabrication service that has already provided hundreds of distributed users from diverse backgrounds with affordable access to micromachining processes at regular, scheduled intervals.

For the latest information via the web: http://eto.sysplan.com/ETO/MEMS/index.html and a control chip that features signal conditioning, output drivers, and interfaces, both planned for introduction in 1997.

Their technology road map includes such sensor refinements as sensitivity to new target bases and lower power devices.

Motorola's MEMS activities will also be featured in Philadelphia at an all day MEMS seminar on 23 October, chaired and organized by Roger Grace, President of Roger Grace Associates in San Francisco. The agenda includes global market overviews, university and research lab activities, and MEMS applications. For more information, Roger Grace can be contacted at tel: 415/821-6881 fax: 415/641-6156 email: rgrace1@aol.com

## MEMS headliners at big U.S. shows:

SEMICON/Southwest (Austin, Texas, 14-17 October) and IEDM (San Francisco, California, 8-11 December) SPIE's 1996 Symposium on "Micromachining and Microfabrication," held in conjunction with SEMICON/Southwest '96 will feature three days of MEMS related meetings, covering the entire spectrum of activities, worldwide.

Plenary presentations include: "MEMS in 3D" by Kristrofer Pister of UCLA, "CAD & CAE for MEMS: Emergence from the Dark Ages" by Selden Crary of the University of Michigan, "Commercializing MEMS–Too Slow or Too Fast?" by Steven Walsh of the New Jersey Institute of Technology, and "Application of Micro-Machining Technology to Optical Devices and Systems" by Hiroyuki Fujita of the University of Tokyo. Detailed information is available from SPIE over the web: http://www.spie.org/ or by tel: 360/676-3290, fax: 360/647-1445, email: spie@spie.org

The 2000 engineers present at this year's IEDM in San Francisco will hear about MEMS as one of the three plenary presentations. Kicking off

## Challenges in packaging MEMS

How MEMS are packaged is critical, especially for space applications. Many of the potential applications for MEMS devices will likely be in "hostile" environments, for which they seem well-suited. MEMS are already in use in high temperature electronic (HTE) applications. As stated above, the chapter by James Lyke on "Packaging Technologies for Space-Based Microsystems and Their Elements" is a comprehensive overview of the entire field of study, and should be on everyone's "must read" list. At Phillips Lab, James Lyke and his colleagues have sponsored approximately 27 SBIR programs in the area of relevant advanced packaging, resulting in the development of over three dozen MCM designs. Phillips works largely with companies that are doing leading edge work, although, according to Lyke, "there are many shades of grey in packaging." For example, "what was normally called the chip and wire hybrid technology, which we use as a commodity item in a design if it is required, in many cases is a case of pushing the advancement of that technology to a further degree."

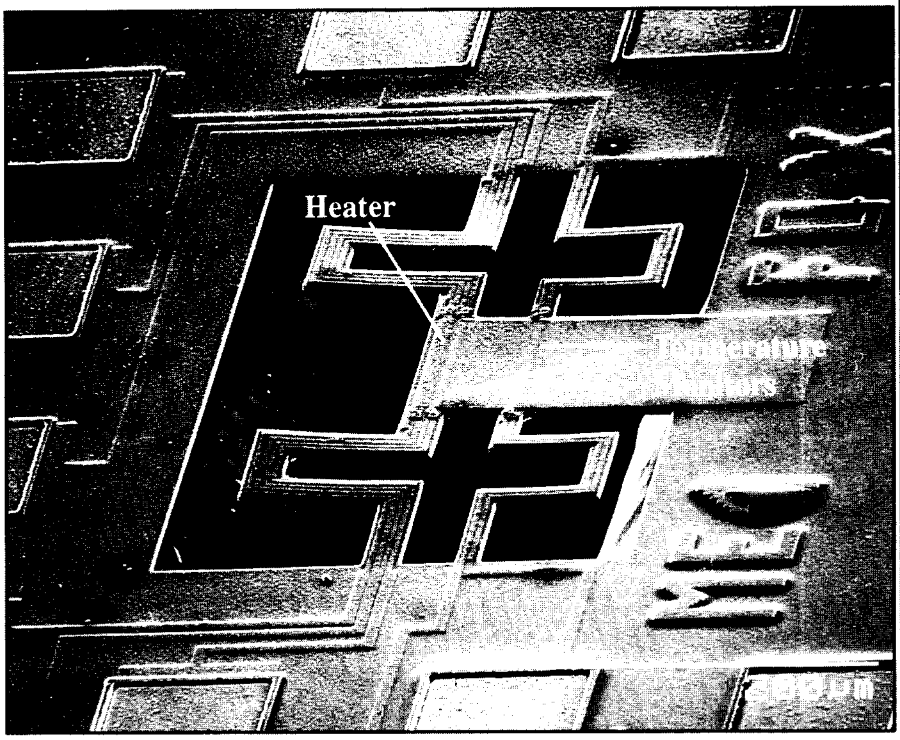



Photo courtesy of Dr O. Paul, Physical Electronics Laboratory, ETH Zurich, Switzerland.

Where are the current sights and focus in packaging? "The areas of packaging that we're most interested in today involve cost reduction in 2D packaging, 3D heterogeneous packaging, and there's a new frontier, and not a lot of work being done, in the advancement of the next generation of 2D packaging," Lyke continues. "There are questions that involve the very foundation of designing ICs for more optimal performance, that involve the design and development of complementary packaging technologies which we call Ultra High Density Interconnect. In our spare time, Capt. Ken Merkel and I are trying to develop papers directed to this new, exciting area." Lyke's chapter in the Aerospace Corporation report, cited above, builds on the heritage of the last decade of research and packaging, and it contains the philosophies and taxonomies from which to build future MEMS systems that will clearly change packaging technologies as we know them today.

## Catching MUMPS at MCNC

This sort of "MUMPs" is quite different than the well-known childhood ailment. MUMPs is one of the MEMS processes referred to above, and is the acronym for Multi-User MEMS Processes. MUMPs was put in place under the funding and direction of DARPA at the MEMS Technology Applications Center at the Microelectronics Center of North Carolina (MCNC in Research Triangle Park, North Carolina). The director of the program is Karen Markus. Another good contact is David Koester, Member of the Technical Staff.

Contact is via email at: mems@mcnc.org. The MUMPs program is designed to provide low-cost MEMS process technology to the industry, academic, and government research and development communities in the US and Canada. The front end support activities and access to the technologies are provided by MCNC's Electronic Technologies Division. Participants may purchase a 1 cm x 1 cm die site for a nominal fee (about $180 US) with approximately 15 unreleased dice delivered. Layout service and die release are available for an additional fee.

MUMPs is a three layer polysilicon surface micromachining process designed to be as general as possible to provide the user with the greatest process flexibility. Polysilicon is used as the structural material, deposited oxide (PSG) as the sacrificial material, and silicon nitride for electrical isolation from the substrate.

The process is derived from work performed by the Berkeley Sensors and Actuators Center at the University of California at Berkeley. Devices fabricated using the MUMPs process include linear comb drives, rotary side drive motors, wobble motors, and resistive fuse links. Detailed information on the Center, the process, and results are available over the MCNC website: http://mems.mcnc.org/mumps.html

will be Professor Kensall Wise, Director of the Center for Integrated Sensors and Circuits at the University of Michigan in Ann Arbor who's address is simply "MEMS SYSTEMS" There is also slated a special invited paper titled "IC MEMS Microtransducer" where researchers from ETH in Zurich, Switzerland, will review the interaction of microelectromechanical systems with IC technology, providing a roadmap of current technological approaches, a description of new microtransducer prototypes, a summary of recent progress in CAD tools, and a critical evaluation of MEMS product potential sen photo. (Paper #20.1, H Baltes et al., ETH). Other MEMS-related papers will also be heard at IEDM. For registration and other information, IEDM now has a website as well: http://his.com/~iedm or contact Melissa Widerkehr, IEDM Conference manager, at tel: [1] 301/527-0900, fax: [1] 301/527-0900.

## Aerospace corp reports authorized for public release

The dramatic progress in recent years is due to the combined efforts of hard working scientists in a number of sectors. For example, the U.S. space community has been working in the MEMS area for some time. The Aerospace Corporation, which functions as an "architect-engineer" for national security programs in the USA, gathered together a seminal report in 1993 (titled "Micro- and Nanotechnology Applications for Space Systems) that characterized this rapidly advancing technology. In late 1995, that report was updated and now serves as one of the guiding documents for MEMS development in the USA. Titled "Microengineering Technology for Space Systems," the present report recognizes that the term "nanotechnology" has evolved to represent the more basic research level of trying to grow nano materials, of which wide bandgap semiconductors play an important role.

According to the study's lead editor, Henry Helvajian of The Aerospace Corporation, the discipline now encompasses "the design, materials synthesis, micromachining, assembly, integration, and packaging of miniature 2-D and 3-D sensors, actuators, microelectronics, and MEMS for the development of intelligent microinstruments." The current report is a crash course on the field and an excellent read. Especially noteworthy is the treatment of the small nanosatellite'concept, based on MEMS technology, that totally changes our current approach to utilizing space.

The chapter on packaging, authored by James C. Lyke of the U.S. Air Force's Phillips Laboratory at Kirtland AFB in New Mexico, is an especially comprehensive packaging primer on earth-bound systems as well as for spacecraft. Recently, the U.S. government authorized the release of the pair of studies to the public, free of charge. They can be obtained through

Henry Helvajian, The Aerospace Corporation, P.O. Box 92957-M/S M5-753, or by faxing a request through 310/336-7680 or via email: henry_helvajian@qmail2.aero.org.

## MEMS clearninghouse

An especially helpful DARPA-backed service is the "MEMS Clearinghouse," which maintains a comprehensive online website. A scan of the "archives/newstuff" portion dates back to postings beginning in August of 1994 and is perhaps the quickest and most painless way of getting up to speed on international developments within the MEMS community. Despite (or perhaps due to) the informality of the format, the amount of information and ease of access is impressive. The site also includes listings of the various MEMS fabrication centers and company information on each (Lucas NovaSensor Company, Fraunhofer Gesellschaft...the list is growing quickly). The virtual clearinghouse also includes a listing of companies that are hiring MEMS developers and posts a wide variety of academic opportunities and staff openings in the U.S., as well as at many different international sectors and institutions. The URL for the clearinghouse is: http://mems.isi.edu/mems. Those without web access can contact the clearinghouse by email, directed to: info-mems@isi.edu, or by postal mail to: USC/Information Sciences Institute, 4676 Admiralty Way, Marina del Rey, CA 90292, USA.