BERKELEY SENSOR & ACTUATOR CENTER

# BSAC News

Summer 2003
Volume 19, No. 1

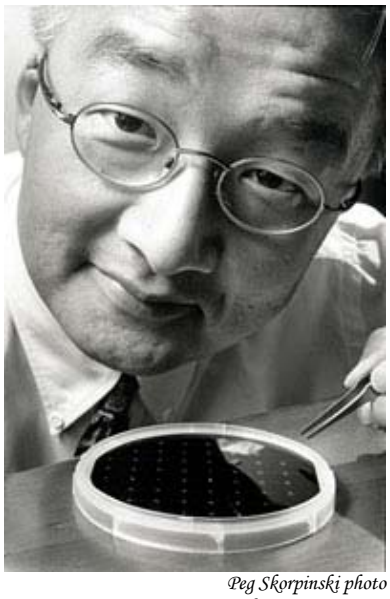
AN NSF INDUSTRY / UNIVERSITY COOPERATIVE RESEARCH CENTER
UNIVERSITY OF CALIFORNIA BERKELEY & UNIVERSITY OF CALIFORNIA DAVIS
FOUNDED IN 1986

## THE EYES OF MEMS

*Courtesy, David Pescovitz & UCB College of Engineering* ***Lab Notes***

Less than 2 years ago, BSAC Director and assistant professor of bioengineering Luke Lee promised a micro-CIA (microscale confocal imaging array), which would fit on the head of a pin. He also predicted then that this technology and its extensions would, someday, become the "eyes" of entire new classes of biophotonic devices, instruments, and even computer peripherals. You will have to come to the BSAC Fall 2003 IAB/Research Review to judge for yourself, but he and BSAC PhD students Sunghoon Kwon and Gang Liu, and undergraduate student Mike Liu feel they have fulfilled his promise and have begun work on the predictions.

The micro-CIA is part of a large class of devices known as BioPOEMS (Bio-Polymer Opto Electro Mechanical Systems). BioPOEMS merge the tiny machines of MEMS with micro-optics, diode lasers, photodiodes, and microfluidic devices. Fabricated by micromachining silicon or polymers in much the same way microchips are produced, BioPOEMS could ultimately cost only a few cents each when manufactured in large quantities.



*Peg Skorpinski photo*

***BSAC Director Luke P. Lee***

"We want to use these in many applications, from biowarfare pathogen detection to preventive, corrective, and diagnostic medicine," Lee says. "Once you can see what's going on inside the body on a single cell level, you could, for example, characterize a specific area as being cancerous. Then, perhaps you could use a laser tool along with the BioPOEMS to do true microscopic surgery. The optical qualities of BioPOEMS could lead to neuroprosthetic retinas, bringing sight to the blind."

A single micro-CIA is essentially a massively scaled-down confocal microscope—a $500,000 photocopier-sized tool used to study cellular mechanisms. Confocal microscopes work by shining a laser at a molecule that has been tagged with a fluorescent die. The laser "excites" the fluorescent molecule so it emits a specific color of light. In order to create a clear image of the sample, only one tiny point of the sample is illuminated at any moment. The laser scans the sample many times a second, imaging each tiny point, and a complete three-dimensional image is built.

*Continued on page 4*

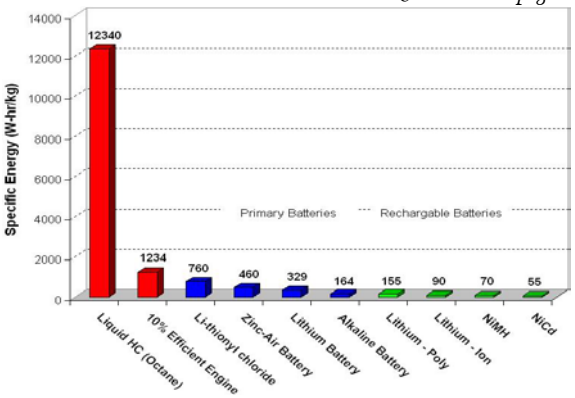
## THE BIG SPIN

### 12.9mm Rotary Engine Power System

*By D. C. Walther and A. P. Pisano*

The Rotary Engine Power System (REPS) is a liquid hydrocarbon-fueled portable power system using a rotary (Wankel) engine as the power source. The selection of liquid hydrocarbon is due to their higher available energy density when compared to even the very best conventional batteries, even after the conversion efficiency is considered. The ultimate goal of the project is to create a power system capable of producing ~10-100 W of electrical power in a dramatically smaller package than currently available. This engine would be the world's smallest Wankel-type rotary engine.

*Continued on page 4*




*Graph of energy density of various batteries vs liquid HC fuel.*

## ON THE MOVE

### UC Davis ECE Chair Norman Tien Receives UC Berkeley Joint Appointment

*Norman C. Tien*

BSAC Director Norman Tien became Chair of the UC Davis Department of Electrical and Computer Engineering (ECE) on July 1. With responsibility for nearly 900 undergraduate, 200 graduate electrical engineering students, and a 33-strong faculty, Tien believes the ingredients are in place to accelerate the emerging UC Davis reputation into a premier EE teaching and research university.

His role as a BSAC Researcher and Director was also reinforced in July, with his joint appointment to the faculty of the UC Berkeley Department of Electrical Engineering and Computer Science (EECS). Professor Tien joined the faculty at UC Davis from Cornell University in 2001 and quickly assumed the position of BSAC Principal Investigator at UC Davis. The new joint appointment enables Professor Tien to also assume formal Principal Investigator role for BSAC research projects conducted at UC Berkeley. His interests involve work on silicon-based microelectromechanical systems (MEMS); his specific interest is in their application to micro-optical systems, wireless communications, RF components, and biomedical devices.

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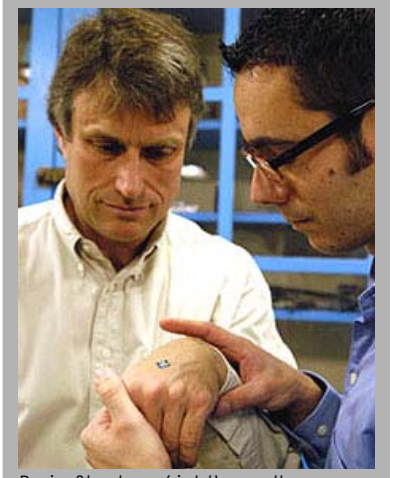
## A SHOT AT A NEW DRUG-DELIVERY SYSTEM

By David Pescovitz

Tomorrow's rural populations may be saved from deadly diseases like malaria and typhoid with a dose of freeze-dried medicine painlessly pushed directly into the skin by a friend or family member.



*Boris Stoeber (right) gently presses the MEMS chiclet on Dorian Liepmann's hand—all it takes to deliver a life-saving dose of antibiotics. (Peg Skorpinski photo)*

UCB Bioengineering professor Dorian Liepmann and postdoctoral researcher Boris Stoeber have developed a MEMS syringe, the size of a fingernail. Called a chiclet for its resemblance to a square of gum, the MEMS syringe delivers the freeze-dried drug stored inside through up to 100 microneedles. Fortunately, the targeted site in the skin is out of reach of sensitive nerve endings, making the drug delivery painless.

The MEMS syringe is designed to be shipped pre-loaded with a lyophilized, or freeze-dried, drug stored in its silicone rubber reservoir. Keeping the drug in its lyophilized state, Liepmann explains, ensures a long shelf life and negates the need for sterile water or electrically powered refrigerators to cool antibiotics like penicillin that are temperature sensitive once reconstituted.

The "shot" is delivered simply by pressing the device against the skin for a few seconds. The dry drug is pushed through the microneedles and into the skin where the body's own interstitial fluids assist in rapidly absorbing the drug directly into the bloodstream.

"By finding an alternative way to deliver drugs, we can open the door to more effective treatment of life-threatening illness," says Liepmann.

Labnotes full article available at: *www.coe.berkeley.edu/labnotes/0503/liepmann.html*

# MEMS "RESEARCHER FACTORY" HONORED

*By John Huggins*

What organism catalyzes (improved) renditions of itself every 4 months over a 40 year period, assembles a colony to continue its proliferation, and is subservient only to a smaller, more attractive counter-organism? If you guessed *the adaptive viral-bacterial colony of the best-selling novel* Prey, guess again. We refer to our own Professor Richard S. Muller.

On June 28, a distinguished group of former students and colleagues of Richard Muller assembled in honor of his 41st year on the faculty of UC Berkeley, his 46th wedding anniversary, and his 70th birthday.

Richard's wife, "counter-organism" Joyce Muller, demonstrated her control by luring the unsuspecting Professor to the surprise event which was organized by BSAC Grant Administrator Helen Kim, along with a conspiracy of former Muller students.

The dinner attendees represented a virtual "who's who" of academics and top industrial researchers in MEMS. Jack W. Judy and Kirt Williams showed a "family tree" of Richard's academic descendants who have taken faculty positions at dozens of top U.S. and international universities. They also traced R.S. Muller's predecessors through a succession of faculty advisors from Richard's own CalTech advisor, R. David Middlebrook (in attendance), through, with some editorial license, Thomas Alva Edison (not in attendance). Those interested in reproductions of this family tree, or in an R.S. Muller BSAC Laboratory Gift fund, can contact Richard Lossing in the BSAC Office.

A first and lasting impression of Richard is that of congeniality borne of confidence; and intellect sharpened by challenge. He has brought prestige to Cal, credibility to the science, an army of researchers to the industry, and humility to those of us who wonder how he does it. We hope, for the benefit of all practitioners of MEMS, that Muller's mentorship continues for many years.

### A Tale of Two Titans

Great achievers often inspire other great achievers. It is interesting to contrast the duality of R. S. Muller's trajectory with that of Robert S. Pepper, who, in 1962, as a young aggressive visionary on the UCB faculty, was the person most responsible for attracting Richard to "Cal". After a period of academic collaboration with Muller, Professor Pepper decided to supplement academics with "a one year" industrial research sojourn at Sprague. Forty years later, Pepper is finally back, not on the faculty, but on the UCB College of Engineering Board of Advisors where his industrial experience helps guide the college to a balance of industrial relevance and academic aggressiveness. In the intervening 40 years, in between those intersections, Muller, through his pioneering academic achievements, helped launch a multi-billion dollar industry based on solid University-spawned applied science and engineering. And Pepper left a legacy of multi-billion dollar achievement and leadership in divisions of Analog Devices, RCA, Intel, and Level One. Dr. Pepper spoke at the event in honor of his long-term colleague. The two titans were, for one magic evening, together again.

# ENTREPRENEURIAL ACHIEVEMENT

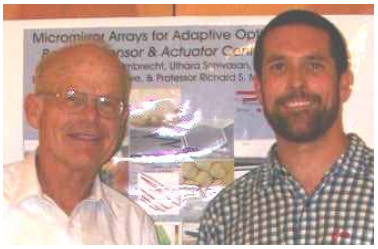
Imagine looking into a living human eye—the layers you would have to see through to view the retina. Flaws in the cornea and lens that cause common eye disorders often distort the picture of the retina, making it difficult to get a true clear image. Now, what if MEMS technology could sharpen that image by adapting optically to the corneal and lens imperfections?

Well, that technology is being made possible by BSAC and start-up venture, Iris AO. Inspired by the BSAC research conducted for the Center for Adaptive Optics (CfAO), Iris AO is developing the technology, and creating a market for low-cost deformable mirrors and adaptive optics systems.

The purpose behind deformable mirrors is to improve free-space communication by eliminating aberrations. Already used in astronomy, such as in the Hubble Telescope, Iris AO is looking to use the deformable mirrors on a larger, less expensive level for vision science and health, improving the examination process for optometrists. The potential benefits include early eye disease detection, prevention, and correction, including customized LASIK surgery. The deformable mirrors have the potential to correct vision to 20/10. The long-term goal of the field is to make adaptive optics useable and affordable in any optical system, including household CD players.

Iris AO was founded in 2001 (incorporated in 2002) by BSAC graduates, Michael Helmbrecht (PhD) and Cliff Knollenberg (MS); UCB Haas School of Business graduate, Matthew Campbell (MBA); and University of Durham, UK graduate, Nathan Doble (PhD). The young company has funded itself through business plan competitions, taking first place in the UC Berkeley Business Plan Competition (2002), the national MBA Jungle Business Plan Challenge in New York (2002), and the Purdue University's Life Science Business Plan Competition (2003). They also received an honorable mention at the Innovator's Challenge in 2002.

Helmbrecht, president of Iris AO, credits the interaction with and experiences of BSAC industrial members as major contributing factors to the development of the company, especially at IAB where



*Professor Richard S. Muller & President Michael A. Helmbrecht*

manufacturability is a prime concern. He cited the experiences of BSAC graduates Mark Lemkin, Thor Juneau, and Bill Clark, who founded Integrated Micro Instruments (IMI), which was then acquired by Analog Devices, Inc, as examples of entrepreneurial spirit.

The first images of the actuators for the Micromirror Arrays for Adaptive Optics were presented by Helmbrecht, then a graduate student under Professor Richard Muller, at IAB in Fall 2000 and at every IAB since. Helmbrecht and Muller continue to work together closely, IrisAO often supplying test structures for the BSAC research team.

Helmbrecht says, "My personal goal is to carry the project from conception to manufacturing—to see the full cycle. The project is really 'my baby'."

# RESEARCHERS DEVELOP TECHNIQUE FOR FASTER NANOTECH COMMERCIALIZATION

*By Sarah Yang, UC Berkeley News (23 June 2003)*

Engineers at UC Berkeley, have found an innovative way to grow silicon nanowires and carbon nanotubes directly on microstructures in a room temperature chamber, opening the doors to cheaper, faster commercialization of a myriad of nanotechnology-based devices.

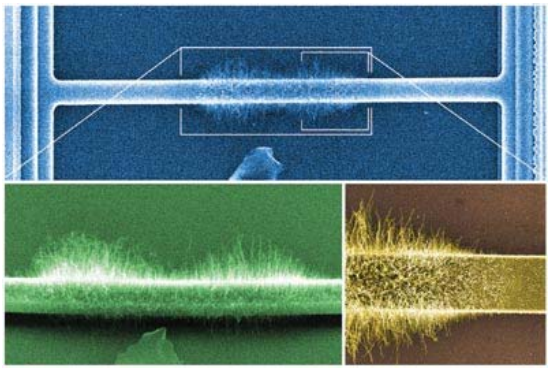
The researchers were able to precisely localize the extreme heat necessary for nanowire and nanotube growth, protecting the sensitive microelectronics—which remained at room temperature—just a few micrometers away.

The new technique, described in the June 24 online issue of the journal *Applied Physics Letters*, eliminates cumbersome middle steps in the manufacturing process of sensors that incorporate nanotubes or nanowires. Such devices suggest early-stage disease detectors that could signal the presence of a single virus or an ultra-sensitive biochemical sensor triggered by mere molecules of a toxic agent.

"One very big problem right now is figuring out how to assemble these nanowires or nanotubes onto a microchip in a way that is commercially feasible," said Liwei Lin, associate professor of mechanical engineering at UC Berkeley.

UC Berkeley researchers Ongi Englander & Dane Christensen, used a gold-palladium alloy with silane vapor to create silicon nanowires, and a nickel-iron alloy with acetylene vapor to create carbon nanotubes.

Previously, nanomaterials have been produced in a separate high temperature thin film precipitation, then harvested with ultrasonic waves to loosen them from the wafer surface. Researchers must then sort through the billions of nanowires or nanotubes to find the few that meet the specifications they need for their sensor applications.



*An image of the technique featured on the cover of **Applied Physics Letters**, June 30 issue. – O. Englander, D. Christensen, and L. Lin, Appied Physics Letters 82, 4797 (June30, 2003).*

Instead of finding a way to produce nanomaterials separately and then connecting them to larger scale systems, the researchers decided to grow the silicon nanowires and carbon nanotubes *directly between patterned microstructures on the microchip*.

The UC Berkeley researchers used localized resistive heating by passing current through a wire to the specific locations on the microstructure where they wanted the nanowires or nanotubes to grow. "It's the same idea as the wires in a toaster," said Englander.

The experiments yielded silicon nanowires from 30 to 80 nanometers in diameter and up to 10 micrometers long, and carbon nanotubes that were 10 to 30 nanometers in diameter and up to 5 micrometers long.

"It's the immediate integration of the nanoscale with the microscale," said Christensen. "This is a very unique approach," said Lin. "This method allows the production of an entire nano-based sensor in a process similar to creating computer chips. There would be no post-assembly required."

The California State Nanotechnology Fellowship and the GAANN Fellowship helped support this research.

*Full article available at: http://newscenter.berkeley.edu/*


## FALL 2003 INDUSTRIAL ADVISORY BOARD MEETING

8-10 September 2003

Including a Member Poster Session for the First Time!

Register Online at: *www-bsac.eecs.berkeley.edu/iab/*

# REINVENTING BSAC

## BSAC Continues to Thrive with Successful 5-year Renewal as NSF I/UCRC

BSAC has successfully completed our 5-year renewal as The NSF Industry/University Cooperative Research Center on Micro Sensors and Actuators. This is the final 5-year renewal for which BSAC is eligible under the immensely successful NSF I/UCRC program, of which BSAC was an early (1986), highly visible participant. By 2008, we will adopt a new, to-be-determined, industry/university charter with the guidance and consent of our Industrial Advisory Board. In the meantime, we can say that by nearly any measure, the Center has been and continues to be successful for the faculty, students, and for our industrial members.

The largest of the 52 US I/UCRC Centers, as measured both by overall funding and number of researchers, BSAC is the only one dedicated to MEMS. And, our research productivity is accelerating.

If there is a "secret" to our application of the I/UCRC model, it is that BSAC has been able to offer our members multiple ways to find the "right" collaboration mode. Our members can sponsor specific research projects under arrangement with specific faculty; with sponsorship of a faculty Director, they can send Visiting Industrial Fellows for one-year on-campus immersion in the Center; they can make use of the Berkeley microfabrication facility for early process and device development; and they can even receive pass-through R&D funding as subcontractors on BSAC-originated federal grants. Whatever form BSAC assumes after 2008, it will be based upon a strong Industry-University "boundary spanning" model.

# U.S. Patents

U.S. Patents

The U.S. Patent and Trade Office has recently awarded the University of California four new patents with BSAC researchers as the named inventors. This multi-year process is generally undertaken by the University only for inventions with the very highest likelihood of significant commercial impact. BSAC member companies have immediate access to new disclosures filed by BSAC researchers.

***Microfabricated Filter***
Patent 6,478,974 –
Lebouitz, Howe, Pisano

***Angle-Measuring Gyroscope***
Patent 6,481,285 – Shkel, Howe

***Continuous Laminar Fluid Mixing***
Patent 6,520,197 –
Deshmukh, Liepmann

***Microfabricated Interventional Surgical Device***
Patent 6,547,803 – Seward, Pisano

Boston TRANSDUCERS '03

## BSAC PUBLISHES 22 PAPERS AT TRANSDUCERS '03

A number of BSAC member companies, including Analog Devices, Draper Labs, Corning Intellisense, Sandia National Laboratories, Bosch, Siemens, Eastman Kodak, Honeywell, Omron, Samsung, Yamatake, and Discera, authored or co-authored papers and posters at this biannual showcase MEMS International Technology Conference, for which BSAC Professor Roger Howe served as Technical Program Chair.

Beyond our member company contributions, BSAC was further distinguished, with 22 original works. Of course, BSAC Industrial Members had been watching the progress of these published research projects, sometimes years in advance, and had early access to the BSAC submissions from our web site.

**Photo Finish:** The top 3 institutions, including BSAC, each had up to 22 accepted, refereed papers and posters, accounting for more than 15% of the total reported research.

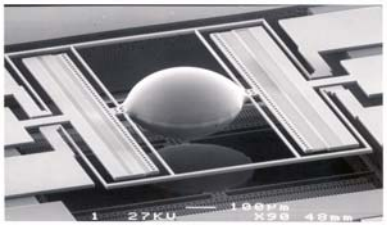
And the winner was…?
*The Transducers '03 attendees!*

## THE EYES OF MEMS

*Continued from page 1*

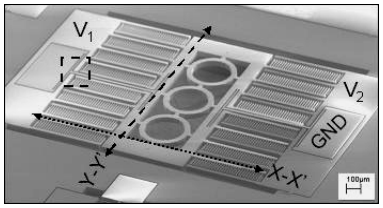
Inside the micro-CIA, the sample molecules or cells travel through a system of channels and reservoirs etched in the polymer or silicon microsystem where they can be highlighted with fluorescent tags or mixed with other materials to analyze biochemical reactions. Then, the molecules or cells flow under the lens of the microscope where they are illuminated with a laser diode.

In order to keep the light source tightly focused, a precise system of microlenses is necessary. And in the case of the micro-CIA and other BioPOEMS, it's no easy task to fabricate a lens as small as a few microns in diameter, twenty times thinner than a human hair. To do it, Lee and his team use a tiny drop of polymer that hardens when exposed to ultraviolet light. One way is to confine the liquid polymer to a small area by surrounding it with water-resistant material that controls the shape of the lens. The lens can also be focused by applying a small voltage to change its surface tension, the tendency of the liquid to spread. Another method is to dispense a pre-patterned lens-holder on a micromechanical platform that moves up and down, much like a simple desktop microscope is focused.



*A stacked 2D Microlens Scanner.*

With either solution, a series of rapidly moving mirrors inside the micro-CIA enables the beam to scan over the sample bit by bit just as with a full-size confocal microscope. Meanwhile, sensors act as eyes, looking for fluorescence and feeding that data to the computer controlling the micro-CIA. By analyzing that information, the computer can automatically detect and identify a single biomolecule in near future.




*Vertical Microlens Scanner*

Testing and system integration of the micro-CIA will be described at the upcoming BSAC Fall 2003 IAB Meeting & Research Review.

This program is supported by a grant from DARPA.

## THE BIG SPIN – 12.9mm engine

*Continued from page 1*

This type of rotary engine was initially developed by Dr. Ing. Felix H. Wankel and Walter Froede in the 1950s at NSU and was called the KKM This engine design consists of a triangular (trochoidal) rotor rotating within an epitrochoidal chamber. As the rotor rotates about the center of the epitrochoid, all three apex points of the rotor maintain contact with the walls, forming three sealed chambers when two axial ends are attached. In large-scale systems, elaborate sealing systems are used to prevent leakage paths either over the face of the rotor (face seals) or around the rotor ends (apex seals).

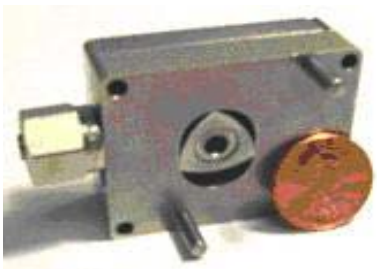
A rotary engine was selected for development due to several factors: 1) the planar design of the rotary engine lends itself to MEMS batch fabrication; 2) the rotor controls the timing of the intake and exhaust which removes the need for complex valving, 3) the power output is in the form of rotary motion of the shaft, facilitating lossless coupling to an electrical generator rotor.; and 4) rotary IC engines have the highest specific power when compared to other engines or electrochemical cells.

BSAC is separately pursuing several research avenues and phases necessary to produce the ultimate REPS package. Two primary engines are being developed, both of which are significantly smaller than any commercially available rotary engines. The larger 12.9mm rotary engine described here, has immediate application as an aggressively miniaturized liquid-fuel power generator. While this engine will make extensive use of MEMS for fuel delivery and control subsystems, it makes less use of semiconductor processing and materials than the smaller, 2.4mm silicon based rotary and has correspondingly fewer "batch processing" manufacturing economies. It does have predictive and simulation value useful in development of the MEMS-intensive 2.4mm engine. Research features include the design and fabrication of the micro-rotary internal combustion engine (including apex and face sealing technologies and an ignition module), internal thermal management, MEMS-enabled fluid delivery systems, and high bandwidth MEMS-based feedback control elements.

The 12.9mm engine has been constructed from steel using fine wire electrodischarge machining (EDM). With discharge wires as small as 20um in diameter, EDM (or uEDM) is one of the most accurate means of manufacture at this scale. Spark ignition was used to initially investigate the engine performance. However, actual operation of both of these engines will be by glowplug enhanced auto-ignition with a catalytically active material.

Reduction to engines of the millimeter scale requires simplified sealing mechanisms because of manufacturing and assembly cost and complexity goals. Another major feasibility issue with engines of this scale is sustaining combustion due to the increased heat losses of the high surface-to-volume ratio reactor, which acts to suppress ignition and quench the reaction. Prior research has demonstrated that reduction in heat losses from the reactor, preheating the fuel air mixture by creating nearly-adiabatic surfaces, and recuperating exhaust gas heat all increase the reaction rate, allowing sustained combustion to occur in volumes as low as a few cubic millimeters.

The 12.9mm engine is currently producing up to 4W of power at speeds up to 10,000 RPM, enough to power a bicycle headlight. Currently, the engine uses hydrogen as a fuel source, but in the future, liquid hydrocarbon fuels (such as butane) will be used. In the coming months, researchers will be working on improving the engine performance with the aim of producing the 50W of electricity required to power commercial electronic equipment. The improvements include improved sealing, modified rotors and housings, and increased manufacturing tolerances. Perhaps most importantly, the inclusion of MEMS based subsystems for fuel delivery and feedback control will enable efficiency gains which will allow for the successful development of the world's smallest Wankel type engine. Implementation of these enabling silicon based subsystems to traditional engine materials and environments is a difficult task which will be buoyed by several existing BSAC research efforts including the MEMS REPS (Pisano), MEMS Strain Gauge (Pisano), Micro Capillary Pumped Loop (Liepmann), and Chemical Sensing (White) projects.



*12.9mm Rotary Engine*

The 12.9mm (mini) REPS project is supported by grants from Chevron-Texaco Corporation & UC Discovery.

## DEGREES EARNED

**Robert Ashurst, PhD**
UC Berkeley
*Surface Engineering for MEMS Reliability*

**Xuesong Jiang, PhD**
UC Berkeley
*Capacitive Position-Sensing Interface for Micromachined Inertial Sensors*

**Michel Maharbiz, PhD**
UC Berkeley
*Electrochemical Gas Generation for Cell Culture*

**Dan McCormick, PhD**
UC Davis/Cornell Univ.
*Dielectric Fluid Enhancement of RF MEMS Devices & Micromachined Scanners for Optical Coherence Tomography Imaging*

**Yu-Chuan Su, PhD**
UC Berkeley
*Water-PoweredMicrofluidic Devices for Diagnostic & Drug Delivery Systems*

**Ye Wang, PhD**
UC Davis/Cornell Univ.
*A Lateral-contact Micro-relay for RF Applications*

## BSAC WINNERS AT INNOVATOR'S CHALLENGE 2003

**Category: IMPACT**

First Place Winner
Boris Stoeber & Stefan Zimmerman
*Diabetes Under Control: A Microneedle-Based Continuous Glucose Monitor*

**Category: ELEGANT SOLUTION TO A DIFFICULT PROBLEM**

Runner Up
Michel Maharbiz, Gerritt Van Roekel, & Chris Baker
*A Microfabricated Electrolytic Gas Generator for High-throughput Cell Cultivation*

**Category: TECHNICAL EXECUTION**

Runners Up
Michel Maharbiz, Gerritt Van Roekel, & Chris Baker
*A Microfabricated Electrolytic Gas Generator for High-throughput Cell Cultivation*

Sunghoon Kwon & Gang Liu
*MEMS Laser Scanning Confocal Microscopes for Point-of-Care Bioassay System*