AIR FORCE OFFICE of SCIENTIFIC RESEARCH [AFOSR]
Manager of the Basic Research Investment for the Air Force

Research HIGHLIGHTS

JUL AUG 02

New Instrumentation Allows Researchers To Probe Micro-scale Fluid Motion

A new instrument that will allow researchers to measure motion of fluid inside micro-fluidic devices at thousands of points simultaneously has recently been developed by Professor Carl Meinhart at the University of California Santa Barbara.

The device, a micron-resolution Particle Image Velocimetry (Micro-PIV) instrument, will enable scientists to better understand the basic physics of fluid motion at the micro-scale. It also will lead to improvements in the design of micro-fluidic devices.

The research was jointly-funded by the Air Force Office of Scientific Research and DARPA under the "MEMS for Flow Control" program (MEMS is an acronym for micro-electro-mechanical system).

While microfluidic devices are being used increasingly in commercial, medical and military applications, it has been difficult for scientists to measure the details of fluid motion inside these devices. The small scale of these devices make direct measurements inside of them with probes almost impossible. However, many complex fluid-surface interactions are not understood at the micro-scale, inhibiting the development and commercialization of micro-fluidic devices.

Micro-PIV works by making measurements of the displacement of small fluorescent particles in the flow. By tracking the displacement of these particles during a short time interval using two pulses of a laser beam, the fluid velocities in the device can be determined. Innovations in the imaging system, data processing, and seed particles were required to develop the micro-PIV system.

Recent market surveys indicate by the year 2003, worldwide sales for micro-fluidic devices will be \$3.8 billion, or about 40 percent of the total MEMS market. Worldwide sales are expected to grow at an annual rate of 25-35 percent. The majority of current sales are associated with inkjet printer heads, although new applications in a variety of fields are being developed.

In printer head applications, Micro-PIV has been applied to measure liquid flow through a micro-nozzle. Traditionally, inkjets have been designed based upon trial and error, empirical models and computer simulations of the fluid motion. Micro-PIV measurements provided the first detailed velocity measurements inside an inkjet printer head. The micro-PIV velocity field also can show the detailed motion and droplet formation during the ejection process. This gives insight into common problems such as non-uniform ejections, satellite droplets, cross talk between adjacent nozzles, and excessive relaxation times required between ejections.

Biotechnology researchers can also use micro-PIV to investigate the interaction between micro-scale fluid motion and cells. It has been reported that shear stress on endothelial cell walls cause them to change their shape, which has been associated with vascular disease.

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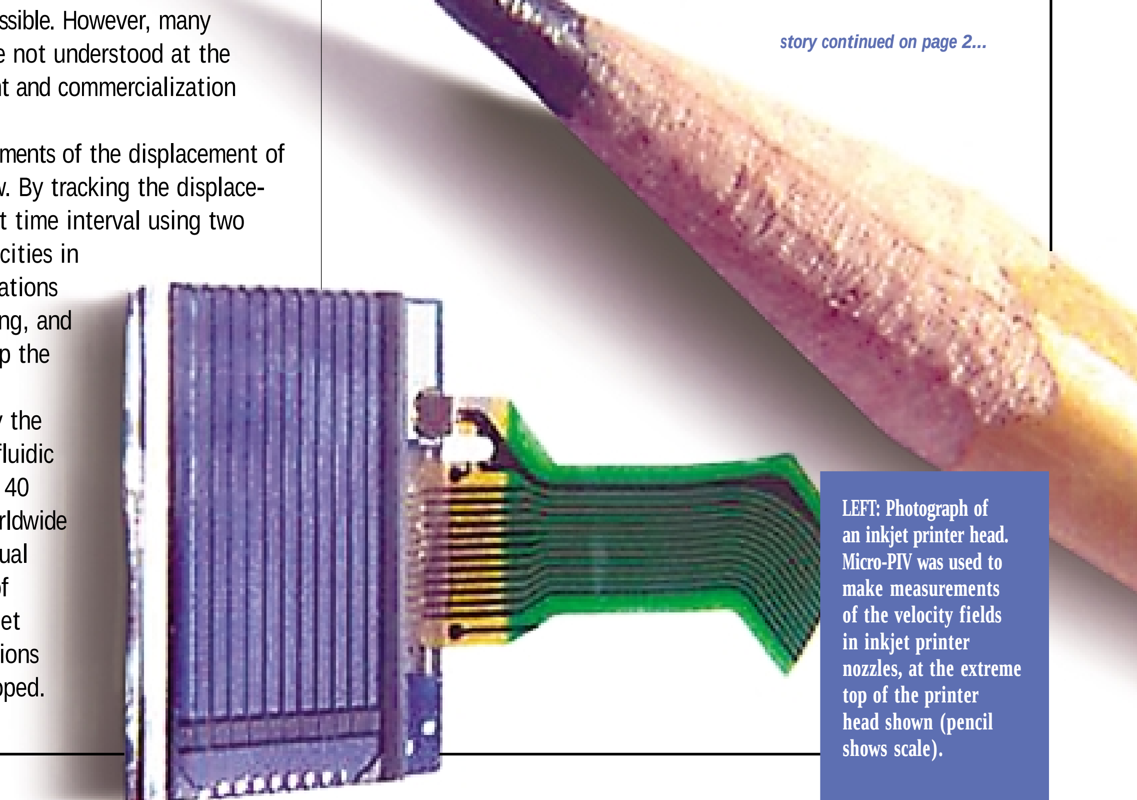

LEFT: Photograph of an inkjet printer head. Micro-PIV was used to make measurements of the velocity fields in inkjet printer nozzles, at the extreme top of the printer head shown (pencil shows scale).

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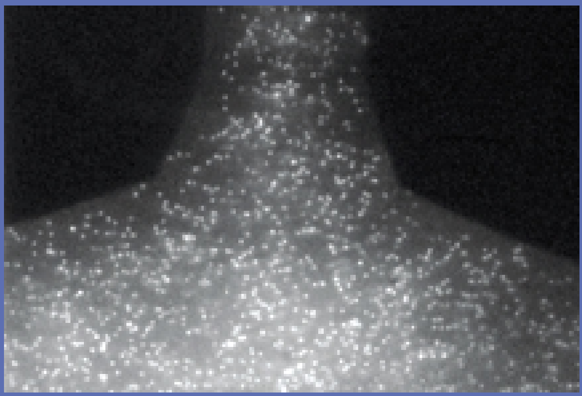
Micro-PIV has been combined with Atomic Force Microscopy to simultaneously measure the fluid motion and cellular shape around cultured endothelial cells.

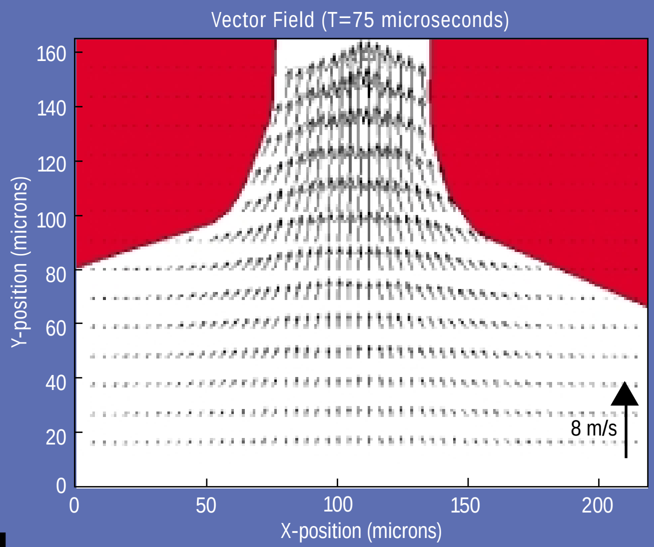
Micro-fluidic devices are currently being developed for use in biomedical diagnostics, biotechnology sensors, and for a variety of aerospace applications. An improved understanding of the details of fluid mechanics at the micro-scale, made possible with micro-PIV, may lead to more efficient mixing and response times in biological and chemical detection devices, more efficient and repeatable micro-thrusters for nanosatellite station keeping, more efficient heat exchangers for cooling electronic components, and a variety of other applications. Micro-PIV provides a revolutionary tool for measuring the fluid motion inside these devices, and the understanding required to optimize their performance.

Dr. Thomas Beutner, AFOSR/NA, (703) 588-6961



ABOVE: Camera image of particles in the nozzle shown in photo on cover.

BELOW: Velocity-vector fields showing the flow structure near the nozzle of the inkjet printhead during fluid ejection. The velocity fields are measured using micron-resolution Particle Image Velocimetry (Micro-PIV). The spatial resolution is 8.16 µm x 22 µm in the *x* and *y* directions, respectively.



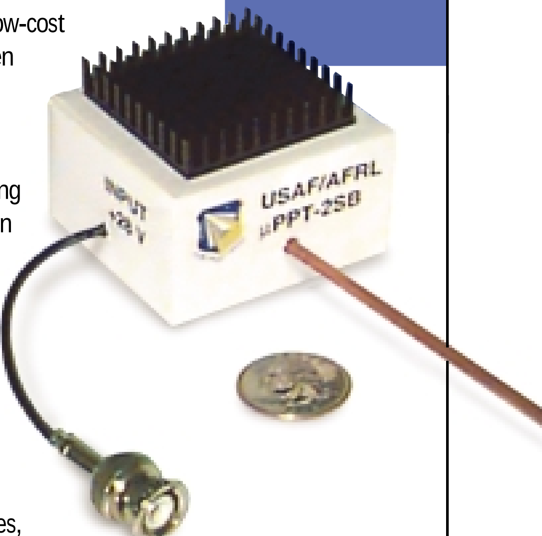
Micro-Pulsed Plasma Thrusters to Fly on Air Force Satellites

An invention by an Air Force Research Laboratory (AFRL) scientist will help pave the way for highly maneuverable micro-satellites to perform a variety of future space missions. Dr. Gregory Spanjers, a member of AFRL's electric propulsion group, recently invented a class of miniaturized electric propulsion thruster, called Micro-Pulsed Plasma Thruster or MicroPPT. This thruster is capable of providing primary thrust for on-orbit operations, as well as, thrust required to change the satellite's orbit. Spanjer's invention, supported by the Air Force Office of Scientific Research's Aerospace and Materials Sciences Directorate, will enable future "micro-satellites" to perform surveillance, on-orbit servicing, inspection and space control.

Triggered MicroPPT Design:

- Basic Research and Modeling led to long-life design
- Manifested on TechSat21 (2005) as technology demo
- Manifested on USAFA FalconSat (2005) to demonstrate propulsive Attitude Control System
- Mass reduction of 90% from conventional reaction wheels and torque rods
- 300 grams, 1-10 Watt, 5µN/Watt class

"Micro-satellites" are low-cost satellites weighing between 10-100 kilograms. In the future, fleets of micro-satellites weighing about 25 kilograms and operating independently, or flying in formation, are expected to perform numerous space missions.



Spanjer's MicroPPT device is important because it produces thrust by accelerating, with the use of electromagnetics, ionized propellant particles, which are ablated from the face or surface of the solid Teflon propellant. The use of solid propellant reduces the satellite weight and size by eliminating the propellant feed system. The use of electromagnetic acceleration to create thrust leads to a higher specific impulse (or thrust per unit time) for the thruster, compared to chemical propulsion systems.

The MicroPPT evolved from a radical re-engineering of the Pulsed Plasma Thruster, originally developed in the 1970s. By removing all nonessential hardware and simplifying the electronics, the MicroPPT represents improvements that are about 50-times greater than capabilities of current, state-of-the-art designs. The finished product weighs only 660 grams, with experimental lab models weighing even less — well under 100 grams. This allows the MicroPPT to be well suited for microsatellite propulsion applications requiring high values of specific impulse.

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Designing Semiconductor Active Materials Prior to Wafer Growth and Device Fabrication

Scientists will now be able to characterize semiconductor single and multiple quantum well optical properties prior to wafer growth and device fabrication thanks to a recent breakthrough.

As a result of funding provided by the Air Force Office of Scientific Research's Mathematics and Space Sciences Directorate, researchers at the Arizona Center for Mathematical Sciences (ACMS) developed a rigorous and self-consistent theory and simulation capability for studying semiconductor lasers. A critical aspect of this work is the capability to compute and predict the optical properties of semiconductor Quantum Well (QW) materials under varying operating environments in a running laser.

The ACMS group collaborated with the Marburg University's Theoretical Physics Institute in Germany on developing an experimentally validated, fully-microscopic theory of the semiconductor optical response. This theory was verified by experimental measurements of optical gain, refractive index, and line width enhancement spectra for semiconductor QW materials spanning emission wavelengths from the infared to visible.

While the findings were encouraging, there was a need to actively engage materials growers to demonstrate explicitly that a reliable QW active structure design phase could be completely decoupled from and precede the actual material growth and device fabrication.

That loop was closed as a result of a recent collaboration with scientists T.R. Nelson, J.E. Ehret and W.J. Siskaninetz, members of the AFRL's Materials and Sensors Directorate at Wright Patterson AFB, Ohio. The trio was able to see the connection between photoluminescence (PL) spectral peaks measured from the wafer and gain spectra peaks in the running laser device. The AFRL group experimentally measured the PL spectra for this structure from the wafer at different excitation densities and sent this data to the Arizona group. In the meantime, cleaved wafers were sent to the laboratory of Dr. Martin Hoffman at the University of Bochum in Germany to measure gain spectra.

The Arizona group took the nominal growth parameters and calculated the absorption spectra at different excitation densities for a homogeneously broadened ideal crystal lattice.

The devices were then shipped to Professor Hoffmann in Germany. He measured the gain using the classical Haki-Paoli method and sent the data back to Arizona. The experimentally measured gain spectra were then compared directly to the theoretical gain spectra. The agreement was remarkable. Not only did the peak gain show the correct position and shift with increasing carrier density, but the lineshapes map precisely to one another within the rather small experimental uncertainties of the measurements.

The fully microscopic many-body approach developed jointly by the Arizona and Marburg groups can be applied to a broad variety of existing and new semiconductor QW materials.

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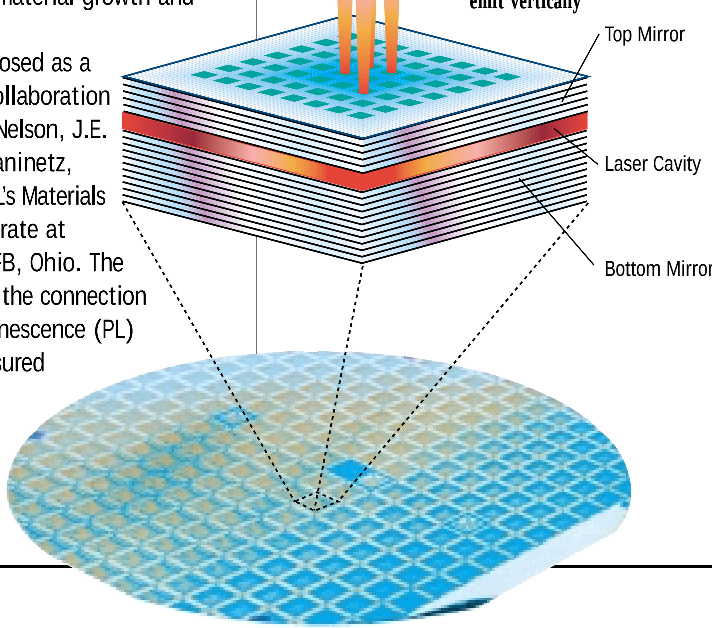
BELOW: VCSEL array showing multiple emitters. Laser beams emit vertically



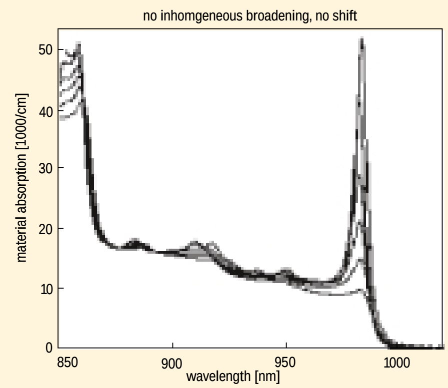


FIGURE 1: Low density OnGaAs absorption spectra at different carrier densities showing exciton features.

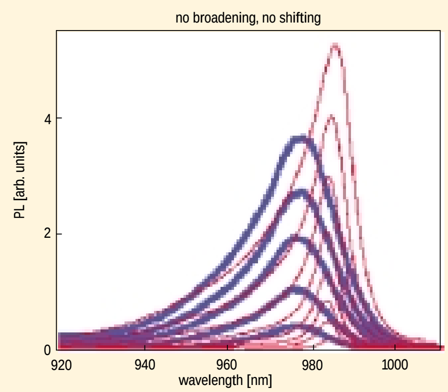


FIGURE 2: Experimentally measured PL spectra (blue) at different excitation densities and compared and computed PL spectra for nominal structure parameters.

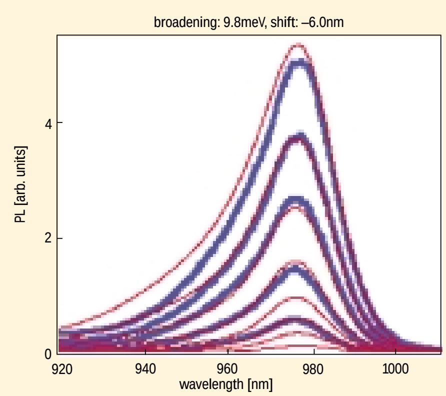
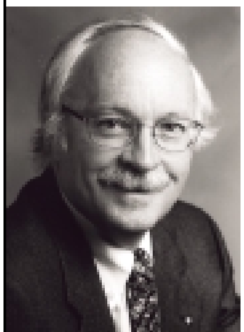


FIGURE 3: Computed PL with adjusted parameters. Experimental spectra are shown in blue.

AWARDS



Dr. David McLaughlin, funded by the Air Force Office of Scientific Research's Aerospace and Materials Sciences directorate for more than 10 years, has been recognized with two prestigious honors: a promotion from mathematics department chairman at New York University to its Provost. He was also recently elected to the National Academy of Sciences.

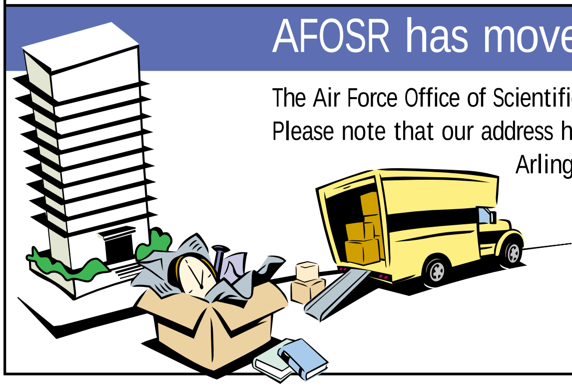
McLaughlin's decade-long research for AFOSR has focused on the area of nonlinear partial differential equations, with a particular emphasis on modeling/simulation of nonlinear optics. His most recent project involving nonlinear optics has been to better understand the interaction of ultrashort laser pulses with a class of materials (chromophores) believed to be most suitable for goggle lenses, as well as protection of sensors.

His election as a member of the National Academy of Science is considered one of the highest honors accorded a U.S. scientist or engineer. The Academy was established in 1863 by a Congressional Act of Incorporation, signed by Abraham Lincoln, that calls on the Academy to act as an official adviser to the federal government, upon request, in any matter of science or technology. There are currently 1,907 active members.

Dr. Howard Schlossberg, program manager for the Air Force Office of Scientific Research's Physics and Electronics directorate, was recently honored at the 2002 Lasers and Electro-optics/Quantum Electronics & Laser Science (CLEO/QELS) Conference in Long Beach, Calif.

Schlossberg, whose influence was critical to the success the CLEO/QELS symposium enjoys today, was recognized for more than 30 years of work in the electro-optics and quantum electronics field. He also is credited with spearheading the Air Force's efforts in these areas. Schlossberg's vision of where the future was going, and his early direction for research programs, gave rise to the current CLEO/QELS conference series.

AFOSR has moved!



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Research Highlights

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