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VISIONS

Iowa Advanced Technology Laboratories

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THE UNIVERSITY OF IOWA

Optical Science and Technology Center

From the Director...

This is an exciting time for the Optical Science and Technology Center (OSTC). Our membership continues to increase, our research scope continues to expand, our facilities and instrumentation continue to improve, and our level of external funding continues to grow. In my view, however, the most exciting advance is the research programs being established by our young faculty. These programs are so exciting because these young faculty are doing research at the forefront of important scientific disciplines and they represent the future of the OSTC.

The previous, current and next issues of *Visions* are dedicated to the OSTC Assistant Professors. This group of dedicated faculty is working hard to establish independent research programs with contributions from the strong students and postdoctoral associates in their groups. The last issue of *Visions* included a description of Allan Guymon's research program to develop nanoscale materials through photopolymerization processes. This issue of *Visions* highlights the budding research programs of three Assistant Professors: John Prineas, Markus Wohlgenannt, and Chris Cheatum. The next issue will feature the research programs headed by Julie Jessop in Chemical and Biochemical Engineering and Len MacGillivray in Chemistry.

Reading over these research descriptions, I was struck by two things. First, these researchers

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John Prineas—Semiconductor Heterostructures

Assistant Professor John Prineas did his graduate work at the Optical Sciences center at the University of Arizona and postdoctoral work at the Max Planck Institute for Solid State Research in Stuttgart, Germany. Prineas joined the Optical Science and Technology Center (OSTC) and the Department of Phyics and Astonomy in 2001.

Prineas leads two labs in the OSTC, a Molecular Beam Epitaxy (MBE) facility and an ultrafast spectroscopy lab. Molecular beam epitaxy is a state-of-the-art technique for growing semiconductor heterostructures one atomic layer at a time. “It's like spray painting with atoms,” Prineas says. “By mixing layers of different kinds of semiconductors you can engineer the solid on the atomic level.” This technology is used to create optoelectronic devices and photonic structures. The MBE facility is expensive to run because it consumes over 200 gallons of liquid nitrogen each day. The nitrogen is used to create an extremely low pressure inside the MBE chamber, which is necessary for very high purity semiconductor growth. Prineas' second research facility is designed for ultrafast spectroscopy based on a 40 femtosecond pulsed Ti-Sapphire laser. The short pulses allow the study of phenomena on that timescale: “It's kind of like having a fast shutter speed on your camera,” Prineas says. “We can spectrally and temporally resolve pulses and see how they interact with structures on the femtosecond (10^{-15}) time scale.” An undergraduate student involved in this research, Tony Link, created a pulse shaping device which can, Prineas says, “sculpt light.” Prineas' research team also includes another undergraduate, one postdoctoral student, and three graduate students.

Professor Prineas and Saravanan Veerasamy work on the MBE machine

During his three years at

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New Members

The Optical Science and Technology Center continues to grow in terms of the scope of research and the number of participants. In this issue of *Visions*, we welcome Professor Gary Small from the Department of Chemistry, Professor Bill Eichinger from the Department of Civil and Environmental Engineering, and Professor Alan Kay from the Department of Biological Sciences.

Professor Small just arrived on campus in August from the University of Ohio and his research program focuses on the development of novel analytical methodologies with an emphasis on real-time vibrational spectroscopy for passive remote sensing, *in vivo* biomedical sensing and infrared imaging. Innovative data analysis techniques are developed to isolate selective spectral signatures for targeted components within complex environmental or biological sample matrixes.

Professor Eichinger is a long time member of the faculty in the College of Engineering at The University of Iowa and his research program involves multiple aspects of environmental engineering with an emphasis on understanding and characterizing atmospheric pollution for the purpose of control and remediation. Students in his group develop and implement novel optical sensors for real-time and in the field measurements of selected atmospheric constituents.

Professor Kay is a neurobiologist on the faculty in the Department of Biological Sciences. His research centers on the characterization of synaptic chemistry with a strong interest in the role of zinc in the synaptic process. These research interests demand the development of: 1) novel optical probes to monitor zinc and other transition metals during synaptic processes, 2) fluorescent reagents for imaging neural activity, 3) novel imaging techniques, and 4) nanoscale structures for delivering analytical reagents to specific cellular populations.

Recent Funding

Kay—$568,000 from NINDS, "Defining the roles of metals in synaptic transmission."

Arnold/Small—$550,000 from NIH, "Instrumental designs for near infrared glucose monitors."

Gillan—$355,000 from NSF, "From unstable precursors to metastable nitrides: Azidothermal synthesis of binaries and beyond."

Grassian/Larsen—$225,000 from Army Research Office, "Development of nanocrystalline zeolite materials for the decontamination of chemical warfare agents."

Kleiber/Grassian/Young—$488,181 from NSF, "Toward a greater understanding of direct radiative forcing: Laboratory studies of the impact of physicochemical processing on the optical properties of mineral dust aerosol".

Prineas—$2.7 million from DARPA, "Slow light and induced transparency in resonant periodic semiconductor nanostructures."

Prineas—$300,000 from NSF, "Gap solitons and spin-dependent polarization modulation in resonant photonic bandgap structures."

Cheatum—$35,000 from ACS Petroleum Research Fund, "Two-dimensional infrared spectroscopy of proton-transfer complexes in solution."

Cheatum — $291,000 from Roy J Carver Charitable Trust, "Photon echo measurements to study the role of enzyme dynamics in catalysis."

Larsen—$98,858 from NSF/NUE, "NUE: Illuminating nanoscience with semiconductor quantum dots."

Guymon—$50,000 from University of Iowa Bio-Sciences Pilot Grant, "Multi-disciplinary development of nanostructured microvascular stent."

MacGillivray—$75,000 from Honda, "Gas storage within inverted metal-organic frameworks."

Markus Wohlgenannt - Organic LED's

Assistant Professor Markus Wohlgenannt came to study in the United States from a small town near the Austrian Alps; where he received his Ph.D and completed his postdoctoral research at the University of Utah. In fall 2002, Wohlgenannt joined The University of Iowa Physics and Astronomy Department and the Optical Science and Technology Center.

Professor Wohlgenannt and Omer Mermer work using the glovebox.

Wohlgenannt is a semiconductor physicist, but rather than studying silicon, his research group fabricates transistors and other electronic devices from synthetic, organic materials called pi-conjugated molecules and polymers. These plastic-like materials have the advantage of cheap fabrication and other features associated with plastics, such as flexibility. According to Wohlgenannt, "we live in the Plastic Age–plastic materials are industrially produced in the largest quantity of all materials." The most promising applications for these organic semiconductors are flexible display panels and photovoltaic cells. This research and technology will lead to ultra-thin TV screens that can be rolled up like a plastic bag and also to the creation of electronic devices housed in self-contained plastic solar power sources or photoelectric cells.

Wohlgenannt has expertise in the field of optical spectroscopy (experiments that use light) and condensed matter physics, the discipline that studies the properties of solids and liquids. In particular, Wohlgenannt explores the electrical properties of solids. There is a distinction between electric conductors such as metallic wires, and insulators such as ceramics, paper, or synthetic

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plastic materials. In between these two extremes exists the important class of semiconductors, which are insulators whose electrical conductivity can be strongly enhanced by the controlled introduction of chemical impurities—a process called "doping." The most common semiconductor is silicon, which is used to make transistors as well as computer chips and virtually all electronic devices. "I guess our time can also be called the "Silicon Age," Wohl-

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Prineas...continued

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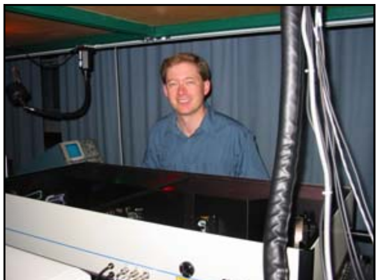
The University of Iowa, Prineas has engaged in a vigorous research program, having recruited grants from several sources and forming collaborations with researchers within the OSTC and beyond. One of Prineas' research interests is in near- to far-infrared optoelectronic devices created from antimonide compound semiconductors. Prineas' MBE facility is one of the few in the world with the ability to "grow" structures using antimonides. Optoelectronic devices are hybrid devices which use both photons and electrons. Such devices include optical detectors, light emitting diodes, and laser diodes, all which can be used in environmental and medical sensing, in addition to communications systems. For example, near- to far- infrared materials can be used to detect the presence of complex molecules. Prineas is currently working on a collaborative project funded by a 2.3 million dollar grant from the National Institutes of Health to create a continuous sensing blood glucose monitor (see *Visions,* volume 2,issue #2). In another project, Prineas collaborates with Professor Art Smirl from the Department of Physics and Astronomy and the Laboratory for Photonics and Quantum Electronics. In this collaboration, Prineas and Smirl are interested in finding ways to manipulate photons, the massless particles that form light, using photonic bandgap structures and gap solitons, which can, Prineas says, "catch a photon just like a baseball glove catches a ball." For many years, scientists have been incredibly successful at manipulating electrons in silicon and the result is an array of functional integrated circuits for electronic and computations. By analogy, Prineas and Smirl are looking to manipulate and control photons in semiconductor materials. This kind of manipulation could lead to an optical buffer that stores a light pulse for a short period of time, which could greatly reduce the complexity of all-optical communication networks. It could also lead to a very sensitive all-optical switch, which is an important basic technological building block. Prineas' role in this project is to synthesize innovative periodic structures by Molecular Beam Epitaxy. In addition, he will be doing ultrafast spectroscopy to characterize the gap soliton formation in the photonic bandgap structures. This project is funded by a $300K, three-year grant from the National Science Foundation and a five-year, 2.7 million dollar grant from the Defense Advanced Research Projects Agency (DARPA). "I'm really excited about this project," Prineas says. "I've been working on gap solitons since my postdoctoral research and with these grants I'll be able to work with a team of top researchers to actually observe solitons in action."

http://ostc.physics.uiowa.edu/~prineas

Christopher Cheatum - 2-D Vibrational Spectroscopy

Assistant Professor Chris Cheatum joined the Chemistry Department just last year, but has already begun to settle in at the Optical Science and Technology Center, where his research on enzymes is at the cutting edge of his field. After completing his Ph.D. at the University of Wisconsin at Madison, Cheatum went on to engage in two years of postdoctoral research at M.I.T. He has spent the past year setting up his lab at the Iowa Advanced Technology Laboratories facility thanks to what he calls a "very generous" seed grant from The University of Iowa. His lab includes an amplified Ti-Sapphire laser system pumping an optical parametric amplifier followed by a difference frequency generator. This cascade of nonlinear optics allows him to create the tunable table-top femtosecond infrared pulses used in two-dimensional vibrational spectroscopy, a technique that is only four to five years old. Only about twenty researchers in the world are doing these experiments, Cheatum says.



Professor Cheatum with his Ti-Sapphire laser system

Cheatum puts this lab set-up to work studying how enzymes work at the most fundamental levels. He calls himself a "vibrational spectroscopist" who looks at molecular vibrations to learn about chemical structure and dynamics. His research focuses on enzymes, the proteins that catalyze reactions in biological systems. "Enzymes are," Cheatum says, "designer solvents that make chemistry happen." Usually, he notes, enzymologists study enzymes using tools such as kinetics, NMR, and X-ray crystallography, but such technology can't do what Cheatum does which is, he says, to "look at how atoms explore the energy landscape in which they live." He is interested in observing how a chemical reaction evolves over time, how proteins move, how chemistry happens at the atomic level. And he doesn't want to see just a snapshot of a stage in the chemical reaction, he wants to see the entire dynamic process as it happens, which is how his spectroscopic technique differs from approaches such as crystallography, which allow only static pictures. Observing such dynamic reactions is important because enzymes are a key target of many pharmaceuticals, so understanding how they work can lead to new drugs to treat diseases.

Cheatum is currently focusing his energy on two main areas of research. The first is a collaborative project with Amnon Kohen from Chemistry and Bryce Plapp from Biochemistry. These scientists are looking at liver alcohol dehydrogenase, an enzyme related to the metabolism of alcohol. "We're asking," Cheatum says, "How does the enzyme work? What does the protein do to make this reaction go?" Previous studies of this enzyme could only infer significant features of the enzyme mechanism such as which molecular motions are involved in the reaction; Cheatum's two-dimensional infrared spectroscopy can quantify the interactions between molecular vibrations and measure the effect of the protein on those interactions. These measurements will reveal the shape of the potential energy surface for the reaction.

Optical table located in Professor Cheatum's lab

The second research project Cheatum is working on is studying small molecule systems with strong hydrogen bonds to look at proton-transfer reactions. This is chemistry at its most fundamental level. "I want to know," Cheatum says, "if I change the chemical structure how does it change the dynamics of proton transfer." Proton-transfer reactions are important in enzyme catalysis, so understanding the factors that determine the rate of these reactions will provide insights into the fundamental behavior of many enzymes.

"There is a huge unexplored landscape of applications for these techniques.

It's my dream to make these tools available to more researchers."

Cheatum has been assiduously pursuing funding opportunities. He received a grant from the Roy J. Carver Charitable Trust for $100K a year for three years; he will submit a revised proposal to the National Institutes of Health in November and plans to submit grant proposals next year to the Department of Energy and the National Science Foundation. He currently employs two graduate students and one postdoctoral student; an undergraduate student from Iowa State University worked in his lab over the summer.

In the future, he'd like to put some of his resources to work creating a femtosecond-laser user-facility available to any researcher on campus. Amplified laser systems are very difficult to maintain, but they are high powered and very flexible. "There is a huge unexplored landscape of applications for these techniques," Cheatum says. "It's my dream to make these tools available to more researchers."

www.uiowa.edu/~chemdept/faculty/cheatum

Selected Publications

FOR A FULL LISTING OF PUBLICATIONS VISIT OUR WEBSITE: www.ostc.uiowa.edu/publications

Kay, AR, "Detecting and eliminating zinc contamination in physiological solutions," *BioMed Central Physiology* **4:4** (2004).

Gundogdu, K, Hall, KC, **Boggess, TF**, Shchekin, OB, Deppe, DG, "Efficient electron spin detection with positively charged quantum dots," *Applied Physics Letters* **84**, 2793 (2004).

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Miller, DR, Swenson, DC, **Gillan EG**, "Synthesis and structure of 2, 5, 8-triazido-s-heptazine: An energetic and luminescent precursor to nitrogen-rich carbon nitrides," *Journal American Chemical Society* **126** (**17**), 5372-5373 (2004).

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Chatterjee, S, Ell, C, Moser, S, Khitrova, G, Gibbs, HM, Hoyer, W, Kira, M, Koch, SW, **Prineas, JP**, Stoltz, H, "Excitonic photoluminescence in semiconductor quantum wells: Plasma versus excitons," *Physical Review Letters* **92**, 067402-1 (2004).

Lee, TY, Kuang, W, Jonsson, ES, **Guymon, CA,** Hoyle, CE, "Synthesis and photopolymerization of novel multifunctional vinyl esters," *Journal of Polymer Science: Polymer Chemistry* **42** (**17**), 4424-4436 (2004).

Gao, X, Friscic, T, Papaefstathiu, GS, **MacGillivray LR**, "Crystal and molecular structure of rebek's imide," *Journal of Chemical Crystallograph* **34**, 171-174 (2004).

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Working together in research

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Founded in 1994, The Optical Science and Technology Center consists of faculty members from the University Departments of Chemistry, Chemical and Biochemical Engineering, Electrical and Computer Engineering, Civil and Environmental Engineering, Biological Sciences and Physics and Astronomy. Among the faculty are distinguished scientists who have developed international reputations for innovative research on the frontiers of optical science and engineering. Current research areas include: photonics and optoelectronics, laser spectroscopy and photochemistry, nanotechnology and nanoscience, ultrafast laser development, condensed matter physics, materials growth techniques, device physics and engineering, surface chemistry, chemical sensors, noninvasive monitors, environmental chemistry, polymer science, plasma physics, and nonlinear optics.

Future issues of *Visions*
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OSTC Symposium — February 18th

Optics, Lasers, and Nanoscale Materials in Environmental Science.

Wohlgenannt.....continued

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genannt noted.

Wohlgenannt's laboratory is focused on device fabrication. His laboratories include a large glovebox with an integrated spin-coater and evaporation chamber. The glovebox allows the transistor or display panel fabrication steps to be completed without exposure of the chemicals to oxygen, which would degrade the performance of the resulting devices. Spin-coating is a process used to deposit the organic polymer semiconductor onto a surface; an evaporation chamber is used to deposit the necessary metallic electrical contacts. In the future, Wohlgenannt hopes to extend his device fabrication ability to the nanoscale, which is about 1000 times smaller than current microchip technology.

Wohlgenannt and his students have recently discovered a novel type of sensor based on organic semiconductors and they are currently seeking a patent on this novel device. Wolgennant notes that "it would be very fulfilling for us to have developed a product that finds application in people's everyday lives." In addition, his research program has been awarded a grant from the National Science Foundation, which provides $210K in funding over three years for designing quantum computers and magnetic field sensors based on organic semiconductors. Currently, he is working with OSTC researchers Michael Flatté, Tom Boggess, and John Prineas on a proposal to develop hybrid semiconductor devices, using both inorganic and organic semiconducting materials. "I often consult with Professor Flatté's group to gain better insight into the theoretical explanations for some of our unexpected experimental results," Wohlgenannt says. "I am happy to be part of the OSTC, which greatly facilitates collaborations and discussions with other researchers."

http://ostc.physics.uiowa.edu/~wohlgenannt

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are developing first rate programs in highly significant areas of science and technology. John Prineas is developing novel semiconductor materials for photonic devices that will advance the general field of optoelectronics with applications in a wide variety of technologies, such as communications, chemical sensing, and computing. Markus Wohlgenannt is advancing the fundamental understanding of innovative organic semiconductor materials with a tremendously wide range of potential applications, including inexpensive, reliable, portable, and flexible information display panels. Chris Cheatum is applying state-of-the-art laser-based vibration spectroscopy to investigate fundamental chemical processes responsible for biocatalytic reactions, thereby advancing our knowledge of basic biochemistry and expanding potential targets for the next generation of pharmaceutical agents or "miracle drugs". Wow, these are exciting areas of exploration with the potential to greatly impact Society.

Second, I was struck by the extent of interdisciplinary research being pursued by these young scientists. Each is affiliated with other researchers both within and outside the OSTC. Actually, I'm not all that surprised by the interdisciplinary nature of these young research programs. The modern pursuit of scientific knowledge generally demands input and coordination from multiple disciplines. These bright and energetic investigators are sharp enough to acknowledge the need for multidisciplinary collaborations and they eagerly embrace this paradigm as the best way to advance their science.

Interdisciplinary research is a centerpiece of the OSTC. In my view, the most important objective of the OSTC mission is to establish an environment that enables and promotes the pursuit of interdisciplinary and multidisciplinary science. The assistant professors of the OSTC are a spirited group that strongly support and practice interdisciplinary research. Their commitment and dedication to science will help the OSTC flourish for many years to come.

I hope you enjoy reading about their research programs and I urge you to visit their websites for more information.