NSF ERC for EUV Science and Technology

news from the EUV ERC

Volume 2 Issue 3 June, 2010

R.W. Wood Prize awarded to Henry C. Kapteyn and Margaret M. Murnane

R. W. Wood Prize

Established by the Optical Society of America (OSA) in 1975 to honor the many contributions that R.W. Wood made to optics, this award recognizes an outstanding discovery, scientific or technical achievement, or invention in the field of optics. The accomplishment for which the prize is given is measured chiefly by its impact on the field of optics generally, and therefore the contribution is one that opens a new era of research or significantly expands an established one.

Professor Margaret Murnane and Professor Henry Kapteyn were awarded the prestigious Wood Prize at the recent CLEO conference in May. Henry and Margaret were recognized for their critical advances in the science and technology of high harmonic generation, with particular relevance to sub-femtosecond pulse generation and related attosecond-scale physics.

See: http://www.osa.org/Awards_and_Grants/Awards/Award_Description/rwwood/

Dr. Murnane is the Deputy Director of the EUV ERC and Dr. Kapteyn is a Center Principle Investigator and member of the executive committee.

For more information about Professors Murnane and Kapteyn, and their work, see: http://jjila.colorado.edu/kmgroup/

Volume 2 Issue 3

NSF Site Visit And Annual Review

May 4, 5 and 6, 2010
University of Colorado, Boulder

Thank you to the IAB

The support demonstrated by industrial members of the ERC was outstanding:

1. **14 of the 16 member companies were represented**
2. **18 people from member companies participated in the event**
3. **Three former students, now employed by industry member companies contributed presentations describing their experiences.**
4. **Members of the NSF site visit team commented on how impressed they were by the quality and content of the IAB support and feedback**

Jorge Rocca (Center Director), Bruno LaFontaine (IAB Chair) and Lynn Preston (NSF Leader of the ERC Program) discuss the review process.

ILO, Bob Bower, details the industry membership.

Wolf Law building on the CU campus

For further information please contact your Industrial Liaison Officer, Bob Bower, at Robert.Bower@ColoState.EDU

NSF Site Visit And Annual Review

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Andor becomes the EUV ERC's newest member. In the picture to the right, Domenic Bucci, Americas' Sales Manager; Research at **Andor** Technology, presents Andor's membership payment to Jorge Rocca, the EUV ERC Director.

Bruno LaFontaine from Cymer talks to graduate students Mark Berrill and Dale Martz at the Tuesday evening poster session.

Lunch in the Physics Building Tower

Travis Ayers, Luxel
Arnd Kruger, Newport/Spectra-Physics
Gabe Morgan, XEI Scientific

Dr. Rocca presents an EUV ERC overview to the NSF site visit team, representatives of the Industrial Advisory Board, Center Principle Investigators, Center students and staff.

For further information or assistance, please contact your Industrial Liaison Officer, Bob Bower, at Robert.Bower@ColoState.EDU

EUV ERC Calendar

Summer Program Short Course - *New Trends in Nano-Scale Metrology*
The course will be presented in the Engineering Research Center for Extreme Ultraviolet Science and Technology located in the Daryl B. Simons Building on the Foothills Campus from July 19 to July 23, 2010, 8:30 AM to 12:30 PM.
To register, please send an e-mail to marconi@engr.colostate.edu.

More information at http://euverc.colostate.edu/calendar/schoolannouncement2.pdf

Summer Programs
July 6th - Margaret Murnane gives the Summer EUV ERC Seminar, 11am CU Boulder
July 7th - CSU REU Co-op Seminar - Atmosphere group
July 12th - 15th RET Retreat in CA
July 13th - David Attwood gives the Summer EUV ERC Seminar 11am UC Berkeley
July 17th - Hiking trip for all summer participants
July 21 - CSU REU Co-op Seminar - The Graduate School - Horsetooth Room
July 30th - last day of RET program
August 4th - REU Poster session with CSU REU Co-op 5pm Marriott
August 6th - REU symposium at CSU 11am

For details of these events, please contact the Center's Education Director, Kaarin Goncz

July 2010 Presentations

Tenio Popmintchev et al, ",” Fourth International Conference on Frontiers of Nonlinear Physics, Nizhny Novgorod to St.-Petersburg, July 2010. Presented by Tenio Popmintchev.

R. Adam, P. Grychtol, C. La-O-Vorakiat, S. Mathias, M. Siemens, J. Shaw, H. Nembach, T. Silva, M. Aeschlimann, C. M. Schneider, H. C. Kapteyn, and M. M. Murnane, “Measurement of demagnetization dynamics at the M edges of Ni and Fe using a tabletop high-harmonic soft X-ray source,” 37th International Conference on Vacuum Ultraviolet and X-ray Physics, Vancouver, Canada, July 2010. Presented by R. Adam.

Poster Presentation Stefan Mathias, Chan La-O-Vorakiat, Patrik Grychtol, Roman Adam, Mark Siemens, Justin M. Shaw, Hans Nembach, Martin Aeschlimann, Claus M. Schneider, Tom Silva, Margaret M. Murnane, Henry C. Kapteyn, “Ultrafast, Element-Specific, Demagnetization Dynamics Probed Using Coherent High Harmonic Beams,” 17th International Conference on Ultrafast Phenomena, Snowmass, CO, July 2010. Presented by Stefan Mathias.

Robynne M. Lock, Xibin Zhou, Margaret M. Murnane, and Henry C. Kapteyn, “Elliptical Dichroism of High Harmonics Emitted from Aligned Molecules,” 17th International Conference on Ultrafast Phenomena, Snowmass, CO, July 2010. Presented by Robynne M. Lock.

M.-C. Chen, P. Arpin, T. Popmintchev, M. Gerrity, M. Seaberg, B. Zhang, D. Popmintchev, A. Bahabad, M. M. Murnane, H. C. Kapteyn, “Bright, Coherent, Attosecond Soft X-Ray Harmonics Spanning the Water Window from a Tabletop Source,” 17th International Conference on Ultrafast Phenomena, Snowmass, CO, July 2010. Presented by M.-C. Chen.

A. Bahabad, M. M. Murnane and H. C. Kapteyn, “Enhanced Single Attosecond Pulse Generation by Accelerating Quasi-Phase-Matching of High Harmonic Upconversion,” 17th International Conference on Ultrafast Phenomena, Snowmass, CO, July 2010. Presented by A. Bahabad.

Xibin Zhou, Predrag Ranitovic, Craig Hogle, Margaret M. Murnane, and Henry C. Kapteyn, “Ultrafast Control of Fragmentation Pathways of Soft X-Ray Driven Dissociation of Triatomic N 2 O Molecules,” 17th International Conference on Ultrafast Phenomena, Snowmass, CO, July 2010. Presented by Xibin Zhou.

Wen Li, Agnieszka A. Jaron-Becker, Craig W. Hogle, Vandana Sharma, Xibin Zhou, Andreas Becker, Henry C. Kapteyn and Margaret M. Murnane, “Visualizing Electron Rearrangement in Space and Time during the Transition from a Molecule to Atoms,” 17th International Conference on Ultrafast Phenomena, Snowmass, CO, July 2010. Presented by Wen Li.

Prestigious Laser Research Award Goes to EUV ERC Graduate Student on Laser's 50th Anniversary

Brendan Reagan, 27, recently won the prestigious Theodore Maiman Student Paper Competition for a paper based on his work with Dr. Jorge Rocca, and fellow graduate students Federico Furch and Alden Curtis and research scientist Brad Luther in an EUV ERC lab. Reagan obtained his bachelor's degree in electrical engineering at Colorado State in 2004. The technology involves the generation of short wavelength light in the extreme ultraviolet or soft X-ray range of the electromagnetic spectrum with wavelengths about 100 times shorter than visible light. These lasers can be used to "see" tiny features, create extremely small patterns and manipulate materials in ways that visible light can't. In the Maiman competition, Reagan was one of 21 semi-finalists selected from a record 944 student paper submissions. He won for his paper titled "Soft X-Ray Laser Pumped by a Joule-Class, All-Diode-Pumped Laser System" after he and two other finalists were judged on their innovation, research excellence and presentation ability. The competition comes with a $3,000 prize. "It's very nice that a lot of people from diverse areas in this important field recognize our research success," Reagan said.

Award Presentation
Brendan, far right

EUV ERC Graduate Student, Brendan Reagan

The Maiman Student Paper Competition honors American physicist Theodore Maiman for his amazing invention, the first working laser, and his other outstanding contributions to optics and photonics. It recognizes student innovation and research excellence in the areas of laser technology and electro optics. The award is endowed by a grant from HRL Laboratories LLC, the IEEE Photonics Society and the APS Division of Laser Science and is administered by the OSA Foundation

Pre-Press Publications

Until official publication of these papers, please do not distribute information outside of your company.

Extreme Ultraviolet Laser-based Table-Top Aerial Image Metrology of Lithographic Masks

Fernando Brizuela,1,2* Sergio Carbajo,1,2 Anne Sakdinawat,1,3 David Alessi,1,2 Dale Martz,1,2 Yong Wang,1,2 Bradley Luther,1,2 Kenneth A. Goldberg,3 Iacopo Mochi,3 David T. Attwood,1,3 Bruno La Fontaine,4 Jorge J. Rocca,1,2 and Carmen S. Menoni1,2

1National Science Foundation Engineering Research Center for Extreme Ultraviolet Science and Technology

2Electrical and Computer Engineering, Colorado State University, Fort Collins, CO 80526, USA

3Center for X-Ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA

4GLOBALFOUNDRIES, 1050 E. Arques Avenue, Sunnyvale, CA, 94085, USA

**brizuela@engr.colostate.edu*

Abstract: We have realized the first demonstration of a table-top aerial imaging metrology system (AIMS) capable of characterizing pattern and defect printability in extreme ultraviolet lithography masks. The microscope combines the output of a 13.2 nm wavelength, table-top, plasma-based, EUV laser with zone plate optics to mimic the imaging conditions of an EUV lithographic stepper. We have characterized the illumination of the system and performed line-edge roughness measurements on an EUVL mask. The results open a path for the development of a compact AIMS tool for high-volume manufacturing.

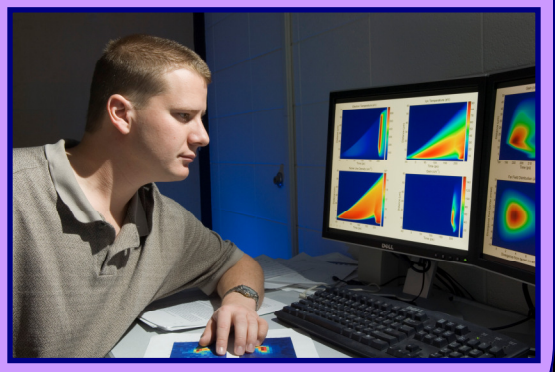
Fernando Brizuela

Improved beam characteristics of solid-target soft x-ray laser amplifiers by injection-seeding with high harmonics

M. Berrill1,2, D. Alessi1,2, Y. Wang1,2, S.R. Domingue1,2, D.H. Martz1,2, B. M. Luther1,2, Y.Liu1,3, and J.J. Rocca1,2,4

1. National Science Foundation ERC for Extreme Ultraviolet Science and Technology
2. Electrical and Computer Engineering Department, Colorado State University, Fort Collins, CO 80523
3. University of California at Berkeley, and Center for X-ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA 94720
4. Physics Department, Colorado State University, Fort Collins, CO 80523

Injection-seeding of solid-target soft x-ray laser amplifiers with high harmonic pulses is shown to dramatically improve the far-field laser beam profile and reduce the beam divergence. Measurements and 2-dimensional simulations for a 13.9 nm nickel-like Ag amplifier show that the amplified beam divergence depends strongly on the seed, and can therefore be controlled by selecting the divergence of the seed. The near-field beam size of both the seeded and unseeded lasers is shown to be determined by the size of the gain region and the divergence of the amplified beams.



Mark Berrill

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EUV ERC Summer Programs

Research Experience for Undergraduates

Program Goals

- Improve participants' understanding of EUV science by involving them in cutting-edge research projects with state-of-the-art equipment with top EUV researchers,
- Generate interest among participants in pursuing a graduate education and provide them with the information and skills needed to make a successful graduate school application
- Motivate women and URM students to enter careers in science and engineering

Dominique Everett (Morehouse College)

The objective of our research is to investigate new polymers for EUV laser nano-patterning. We cover substrates' surfaces with polyurethanes diluted in THF (Tetrahydrofuran which is our solvent), such that the solution can be at a liquid state to spin coat homogenously. Thus far we have discovered that the polyurethane has a reaction to UV light. The goal is to find the conditions that will allow EUV nano-patterning in the surface of these biocompatible polymers.

Dominique Everett (Morehouse College)

This summer, I am working with several different aspects of a 47 nm imaging system. I am developing an electronic amplifier to drive a piezo to demonstrate stop-action nano-scale imaging with this microscope. I also developed and tested a new electronics control circuit to remotely control the extreme ultraviolet laser that is used as the illumination light source for the microscope. I'm also working on zone plate software development to design lenses for the microscope. For side projects, I'm working with silicon nitride membranes.

Leigh Martin (University of Colorado, Boulder)

This summer I am building a feedback system to stabilize our laser setup. In higher harmonic generation, we require our laser to point directly into an extremely narrow, gas-filled fiber. By using extremely accurate movable mirrors and high speed electronics, I will compensate for much of the spatial instability in the laser and keep it pointed directly into this fiber. Hopefully, this will increase the repeatability of the light we create from these fibers, which could lead to higher-quality data.

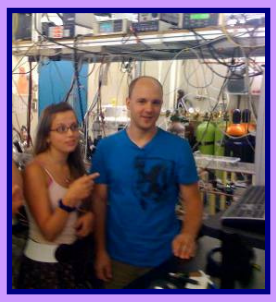
David N. Hill (Morehouse College)

My project will consist in studying the effect of EUV laser irradiation on dielectric coatings. I am also involved in a project that investigates biocompatible polymers that can possibly be patterned with EUV light. The project includes spin coating polyurethanes onto silicon wafers. Presently I am testing the spin coating conditions to find the protocol to generate homogeneous films to be exposed to the EUV.

Thaddeus Johnson (Colorado State University)

My main project has been working in the electronics for a fast laser switch. At first Derek (my REU co-worker) and I researched about light polarization, Pockels cells, EMI, RFI, and different types of filters. We then modified the power supply and control board to have improved EMI filtering. This was especially interesting because we had the opportunity to work through the entire process, designing the filters, simulating them, designing our pcb, selecting and ordering parts, and assembling the final circuit. I learned a lot about the differences between the ideals that we learn in school and what goes into making a board that actually does what you want it to. I have also learned a good deal of Solidworks and I have learned how to use the manual milling machine and the band saw.

Nina Popovic Basta (McGill University)



A pump probe uses the popular method of splitting and recombining light to experimentally discover properties of an molecule. For this project the time difference is an essential variable to the able to control and know. My set up will use a Michelson Interferometer set up to find a correlation between the time delay and a piezo-motor movement. The final product will be a labview program that can control the piezo motor movements to affect the time delay .

This is a sampling of the students involved in this year's program. Be sure to see the August newsletter in which we will feature additional REU students.

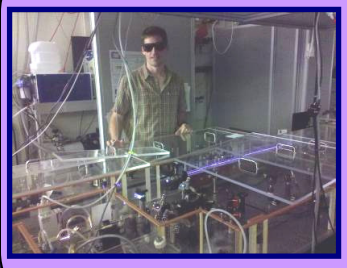
Research Experience for Teachers

Building long-term collaborative partnerships between K-12 STEM teachers and the Center programs

The long-term goals of the RET program are:

- Revitalize middle school science teaching by providing teachers with an EUV research experience, using state-of –the-art equipment in collaboration with top EUV researchers, who will generate excitement about scientific discovery
- Help teachers develop effective teaching approaches using a donated light/optics kit that will engage their students in self-directed experimentation and discussion
- Make a longer-lasting impact on middle school science education by following up with multiple in-class visits to help teachers with light/optics lessons using optics kits
- Attract more students (women and minorities in particular) to pursue careers in engineering and science by recruiting educators who teach at schools with large minority populations

Brian Riccatone (La Jara's Centauri Middle School)



The project I am currently working on has been to take apart and re-construct a couple different helmholtz coils to be used in an experiment to produce a uniform magnetic field to study the process of ultrafast magnetism on a sample. They are looking at the limits at which magnetism can occur on specific samples and what the limitations are for those samples. The coils I have working on surround the sample when it is probed by the EUV laser. I am also participating in another project in which researchers are using EUV lasers to measure how fast electrons are changing energy levels in various materials for applications such as the next generation of solar cells that can store and transfer energy more efficiently. My part in this so far has been that of observer but I have also been able to do mirror and lens adjustments to the laser while using the spectroscope to achieve the proper pulse rate for the laser.

Rob Behrens (Fort Lupton Middle School and Dominique Gauydn (University of Colorado, Boulder)

We are modifying a design to utilize a regular CCD (charged coupled device) to measure the spectrum of the soft x-ray output of the High Harmonics laser system. When in place, this would allow the laser user to tune to differing pressures of gases and know what kind of x-ray output is happening. Our job is to find if this setup is possible and could be implemented to all laser arrays in the group, allowing funds to be spent more efficiently.

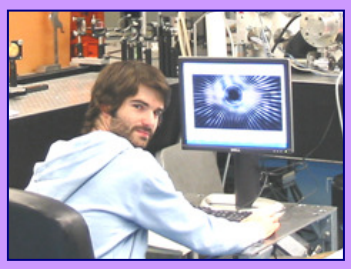
This is a sampling of the teachers involved in this year's program. Be sure to see the August newsletter in which we will feature additional RET teachers.

Graduating

Fernando Brizuela

Fernando joined the NSF Center in 2003 after receiving a B.S. in Materials Engineering from the University of Mar del Plate in Argentina. Within the center he has worked in developing zone plate-based microscopes using table-top EUV lasers. One of these microscopes received an R&D100 award in 2008. Fernando participated in several other projects within the center gaining broad experience in the field of surface and material science. His most recent project was the development of full-field microscope for actinic inspection of extreme ultraviolet lithography masks.

Fernando will complete this Ph.D. from Colorado State University summer 2010 and is interested in pursuing a career in Research and Development in the areas of lithography, optics, and materials sciences.



Jonathan Grava

Joining the NSF Center in 2003 after receiving a M.S. in Electrical Engineering from the University of Nice in France, Jonathan Grava is completing his Ph.D. in Electrical Engineering at Colorado State University. His group has conducted several dense plasma diagnostics experiments using a soft x-ray laser interferometry setup developed at CSU. He has gained broad knowledge in the fields of laser design and operation, optical systems and plasma physics.

Jonathan will complete his Ph.D. in May 2010 and is interested in pursuing a career in the industry using plasmas and involving laser systems, optics.

Brook L. Messler

Brooke joined the NSF Center in 2004 after receiving a B. S. in Engineering Physics from the University of California at Berkeley. As part of the center Brooke has helped run the x-ray transmission microscope, XM-1, at the Advanced Light Source in Berkeley, CA. Brooke has conducted several experiments at XM-1 focusing on magnetic spin dynamics in patterned magnetic samples. In addition to an understanding of current magnetism issues, she fabricated all her samples. Brooke has experience with micro and nanofabrication, particularly e-beam lithography, e-beam evaporation, and both dry and wet etching.
Brooke will complete her Ph.D from the University of California at Berkeley in 2010 and is interested in pursuing a career in fabrication either in the magnetic storage industry or in other computer technology industries.

The Extreme Ultraviolet (EUV) Engineering Research Center is one of 15 centers established in the United States through the National Science Foundation and supplemented by industry funding. Colorado State University (CSU) is the host institution with partner sites at the University of Colorado (CU), UC Berkeley and Lawrence Berkeley National Laboratory. The Center research mission is the development of compact coherent EUV sources and EUV-engineered systems that provide solutions to challenging scientific and industrial problems, including the development of new tools for nanotechnology and nanoscience. The Center has an important educational mission providing a unique environment for the training of students, young engineers and scientists. An Industry Advisory Board (IAB) with members, ranging from large - to small- capitalized companies, spanning instrumentation, semiconductor, lasers and optics, nanotechnology and the biological and chemical sciences actively participate in early access to technologies, joint research projects, directed research projects and the hiring of the some of the best students in the world in these areas.

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