NSF ERC for EUV Science and Technology

news from the EUV ERC

Volume 2 Issue 1 February, 2010

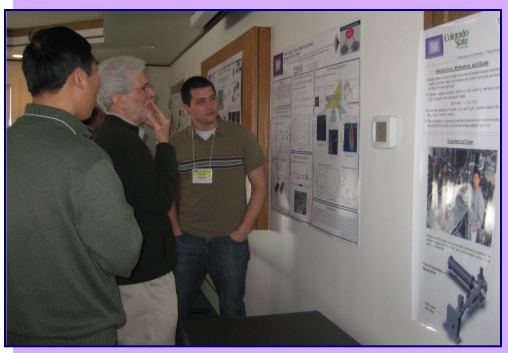
Annual Retreat 2010

Special Features

- NSF Site Visit
- Intellectual Property and Disclosures
- Patent Writing
- Industry Entrepreneur Experience
- Student Leadership Council Meeting
- Poster Session
- Industry Collaborations

Retreat Presentations

- *Coherent imaging* Paul Arpin
- *Aerial imaging and other recent progress in nano-scale imaging using EUV lasers* Fernando Brizuela
- *EUV lithography optics characterization* Ryan Miyakawa
- *Aerial imaging and other recent progress in nano-scale imaging using EUV lasers* Fernando Brizuela
- *Progress in the Development of EUV lasers.* Dave Alessi, Federico Furch, Mark Berrill
- *Progress in the Development of High Harmonic Sources* Tenio Popmintchev
- *Ultrafast Magnetic Dynamics, Nanoscale thermal transport* Dr. Stefan Mathias, Qing Li
- *Femtosecond Transient Absorption EUV Spectroscopy* Erik Hosler
- *Single Photon ionization mass spectroscopy* Feng Dong



In this Issue

Volume 2 Issue 1

EUV ERC Presentations

EUV ERC Trip to Albany, New York

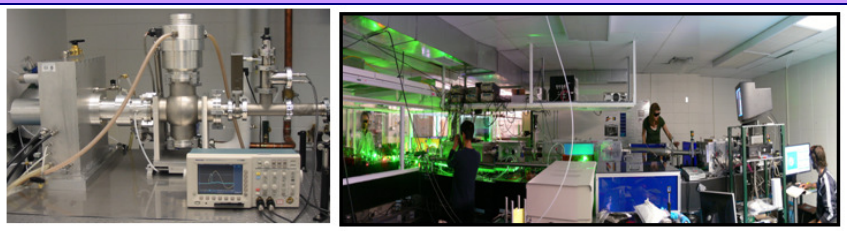
During the week of February 1st, a team of Principle Investigators from the EUV ERC traveled to Albany, New York to meet with SEMATECH, industry partners and people from the College of Nanoscale Science and Engineering at the University of Albany. The two-day visit consisted of information exchange meetings and presentations by members of the EUV ERC team. Of great interest were conversations exploring opportunities for collaboration.

Jorge Rocca, Director

Title: Progress in the Development of EUV Lasers

A major goal of the Center is the development of compact sources of EUV/soft x-ray radiation for applications. The Center has developed lasers with wavelengths spanning the spectral region between 46.9 nm and 10.9 nm. At the longer wavelength boundary very compact desk-top size and table-top lasers excited by a fast capillary discharge are now available for applications . These lasers, that produce average powers ranging from 0.1mW to more than 1 mW at 46.9 nm have been successfully used in applications that include ultrahigh resolution microscopy, nano-patterning, nano-machining, and single photon ionization mass spectroscopy. At shorter wavelengths, including the 13.5 nm region of interest actinic metrology of lithographic masks [1], bright table-top laser beams are generated from plasmas excited by optical lasers. The latest results include the increase of the average power in the vicinity of 13.5 nm to 20 μW, and the extension of these table-top lasers to wavelengths as low as 10.9 nm [2]. In another recent development geared towards increasing the repetition rate of these lasers the first EUV laser fully pumped by diode lasers was demonstrated [3].

1. F. Brizuela, Y. Wang, C. A. Brewer, F. Pedaci, W. Chao, E. H. Anderson, Y. Liu, K. A. Goldberg, P. P. Naulleau, P. Wachulak, M. C. Marconi, D. T. Attwood, J. J. Rocca, and C. S. Menoni, "Microscopy of extreme ultraviolet lithography masks with 13.2 nm tabletop laser illumination," Optics Letters **34**, 271 (2009).
2. D. Alessi, D.H. Martz, Y. Wang, M. Berrill, B.M. Luther, and J.J. Rocca, "1 Hz Operation of a Gain-Saturated 10.9 nm Table-Top Laser in Nickel-like Te," Optics Letters, **35**, 414, (2010).
3. F. Furch, B. Reagan, B. Luther, A. Curtis, S. Meehan, and J.J. Rocca, "Demonstration of an all-diode-pumped soft x-ray laser," Optics Letters **34**, 3352, (2009).



Left: Desk-top size discharge-pumped λ= 46.9 nm EUV laser. **Right**: Laser-pumped EUV producing laser beams in the λ=13.5 nm spectral region and at wavelengths as short as 10.9 nm. The laser seen interfaced to an actinic aerial imaging metrology tool operating at λ = 13.2 nm.

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

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Carmen Menoni, Professor and PI

Title: Nanoscale Imaging and Patterning Using Bright Beams of Soft X-ray Light from Table-top Lasers

The short wavelength, 10-47 nm, high coherent average power from table-top extreme ultraviolet lasers has enabled the demonstration of practical imaging and patterning systems with nanoscale spatial resolution. We have implemented and characterized full field microscopes that use table-top SXR lasers operating at 46.9 nm and 13.2 nm wavelength. [1,2] The microscopes, that operate in transmission and reflection configurations, have achieved a spatial resolution down to 38 nm. The 13.2 nm wavelength reflection microscope was used in the first demonstration, outside of a synchrotron facility, of an aerial imaging metrology system (AIMS). This microscope emulates the illumination conditions of a EUVL stepper. The system produces images of EUVL masks in tens of seconds where critical dimensions as small as 55 nm are resolved. The high quality of EUV images allows analysis of line edge roughness (LER) and consequently enables inspection of pattern and defect printability independently of resist response. (Fig. 1).

We have also demonstrated innovative nanopatterning tools that exploit the high spatial and temporal coherence of the compact SXR laser sources. SXR interferometric lithography was implemented to pattern resists with periodic arrays nano-scale pillars and holes with features as small as 59 nm. Using coherent Talbot nano-imprint we have also demonstrated printing of arbitrary patterns in resists. These patterns are printed in a matter of minutes over areas of approximately a square millimeter. These results open up new avenues for the patterning of for example, magnetic materials and metals for plasmonic devices. [2,4] (Fig. 2).

References

1. F. Brizuela, et al., Optics Letters, **34**, No. 3, 271-273, (2009).
2. C.A. Brewer et al., Optics Letters **33**, 518 (2008).
3. P.W. Wachulak, et al., Journal of Vacuum Science and Technology, B**25**, 2094, (2007).
4. A. Isoyan, et al., accepted for publications Journal of Vacuum Science and Technology, 2009.

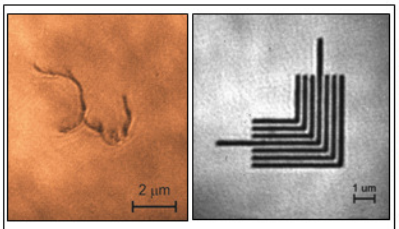

Fig. 1. Single shot EUV transmission image of an ensemble of carbon nanotubes (left). EUV reflection image of 180 nm dense elbow pattern on a EUVL mask captured with a 90 sec exposure (right).

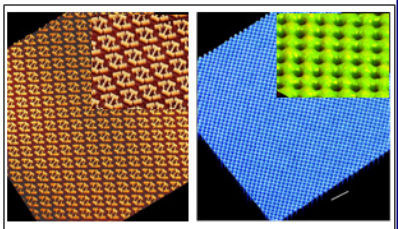

Fig. 2. EUV Coherent lithography was used to print arrays of arbitrary shape on resist using EUV Talbot optical nano-imprint (left). Periodic array of 100 nm holes obtained in resist by EUV interferometric lithography (right).

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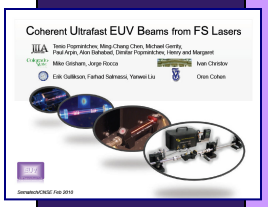
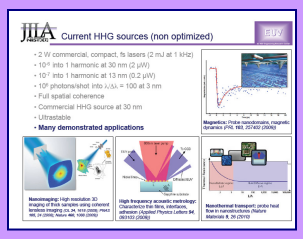


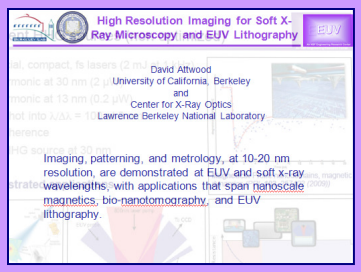
Margaret Murnane, Deputy Director
Title: Coherent Ultrafast EUV Beams from Femtosecond Lasers

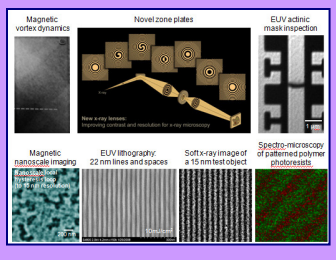
High harmonic generation is an extreme nonlinear process that upconverts femtosecond laser light into the extreme ultraviolet and soft x-ray regions of the spectrum. This light can be used for a variety of applications, including for coherent diffractive imaging with nanometer resolution. In this talk, I will discuss the optics and technology of this process, and show recent experiments that show promise for tabletop sources of coherent hard x-ray beams.



David Attwood, Associate Director
Title: High Resolution Imaging for Soft X-Ray Microscopy and EUV Lithography

Abstract: Imaging, patterning, and metrology, at 10-20 nm resolution, are demonstrated at EUV and soft x-ray wavelengths, with applications that span nanoscale magnetics, bio-nanotomography, and EUV lithography.





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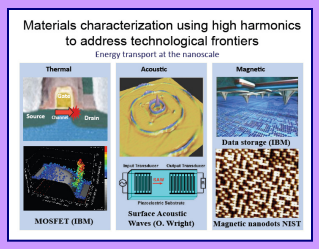
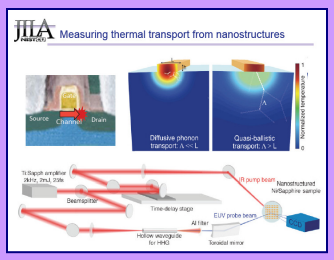
Henry Kapteyn, Professor and PI

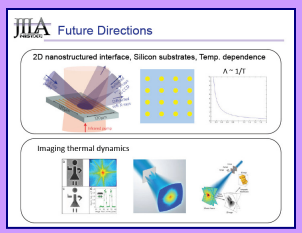
Title: Quasi-ballistic Thermal Transport at the Nano-interfaces

The generation of coherent light in the extreme ultraviolet region of the spectrum presents new opportunities for observing and characterizing nanoscale systems and phenomena. In this talk, I discuss two examples of recent work of particular interest for semiconductor design and fabrication. In the first work [1] we measured for the first time the "nanoscale heat sink" problem, where heat is conducted away from a nm-size "hot spot" into a bulk substrate. Using coherent EUV diffraction, we show that the finite mean-free path of the heat conducting phonons limits heat transport. In the second work [2], we show how dynamics in magnetic systems can be monitored in an element selective manner by using coherent EUV spectroscopy. This work holds the potential to allow for ultrafast imaging of magnetic dynamics with namometer spatial resolution-- a topic of interest for magentic recording and spintronics. Several other applications such as coherent diffractive imaging, and ultrafast photoelectron spectroscopy, are also mentioned.

[1] M. E. Siemens, Q. Li, R. G. Yang, K. A. Nelson, E. H. Anderson, M. M. Murnane, and H. C. Kapteyn, "Quasi-ballistic thermal transport from nanoscale interfaces observed using ultrafast coherent soft X-ray beams," *Nature Materials,* vol. 9, pp. 26-30, Jan 2010.
[2] C. La-O-Vorakiat, M. Siemens, M. M. Murnane, H. C. Kapteyn, S. Mathias, M. Aeschlimann, P. Grychtol, R. Adam, C. M. Schneider, J. M. Shaw, H. Nembach, and T. J. Silva, "Ultrafast Demagnetization Dynamics at the M Edges of Magnetic Elements Observed Using a Tabletop High-Harmonic Soft X-Ray Source," *Physical Review Letters,* vol. 103, pp. 257402/1-4, Dec 2009.







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Volume 2 Issue 1

EUV ERC Students

Graduating

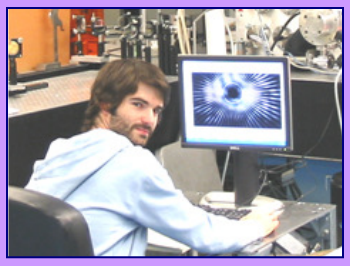
"It cannot be overestimated how important the educational aspect of the Center is for building a broad know-how base in fundamental understanding of EUV science and technology and in educating its future practitioners to provide the EUV engineering know-how the industry will need for successfully adapting EUV technology in all its potential applications." - IAB SWOT Analysis Report from the February 23, 2009 meeting

For contact information and resumes, e-mail your ILO: Robert.Bower@Colostate.EDU

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 in May 2010 and is interested in pursuing a career in Research and Development in the areas of lithography, optics, and materials



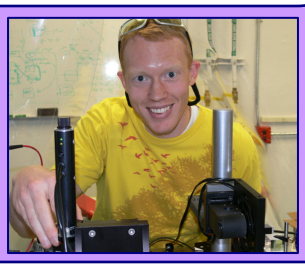
Jonathan Grava

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.

Erik Krous

Erik's work at the NSF EUV ERC includes large area multilayer dielectric diffraction gratings for chirped pulse amplification lasers and in-depth expertise on the growth and characterization of ion beam sputtered multilayer coatings for high power lasers. He gained expertise in thin film deposition and characterization of the interference coatings using a variety of chemical and optical probes. This work resulted in the demonstration of extremely low-loss, high-damage threshold optical coatings.



Erik Krous is graduating in May 2010 with a MS in Electrical and Computer Engineering and is looking to start an R&D career in materials and optical sciences. Erik is interested in a summer internship

NSF Site Visit Scheduled for May 4th - 6th

Mark Your Calendars

Due to the importance of this meeting, we ask that as many industry representatives as possible attend. The detailed agenda with maps and lodging recommendations will be provided with your invitation.

The NSF site visit team (SVT) will be at the University of Colorado, Boulder, campus for the evaluation of the EUV ERC to determine if the center will receive funding for the full 10-year term. NSF has designed these evaluations to answer critical questions about its ERCs. Among the topics considered are:

- What is the focus on transformative engineered systems?
- What is the quality and integration of research programs designed to achieve system goals?
- How well qualified, conceived and organized is the team to conduct the project?
- Does the activity promote discovery and understanding as well as teaching, training and learning?
- Does the pre-college program serve to motivate students to pursue engineering careers?
- Does the program broaden the participation of underrepresented groups?
- To what extent does the program enhance the infrastructure for research and education and infrastructure?
- **Is there a strong and active partnership with industry?**

We are working on the detailed agenda which will be provided with the invitations. Topics and focus will include the following:

- EUV ERC PI Presentations
  - Compact Sources
  - Imaging Metrology & Patterning
  - EUV Materials and Molecular Science
- Student Presentations and Poster Session
- Private SVT Meetings
- Industry Collaboration
- Education and Outreach
- Infrastructure and Tours
- EUV ERC Response to SVT Questions
- SVT Report Writing

New ILO

The research center has a new Industrial Liaison Officer. Please welcome Bob Bower who officially started work on February 1, 2010. In his first week on the job, he logged 3,563 air miles meeting with industry partners and key people at the NSF.

Bob brings 20 years of experience in high tech industry to the job as well as 13 years of experience working at academic institutions. More details are available at www.linkedin.com/in/BBower

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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 leading institution with partner sites at 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, laser and optics businesses, actively participate in early access of 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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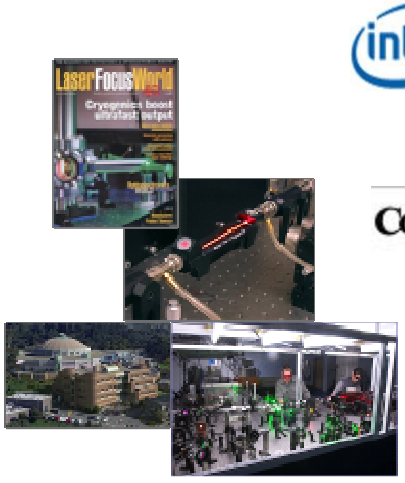

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