



## Mark Your Calendars for the NSF Site Visit and Review

**May 18th, at the University of California, Berkeley.  
All-day meeting starts at 8:00 AM**

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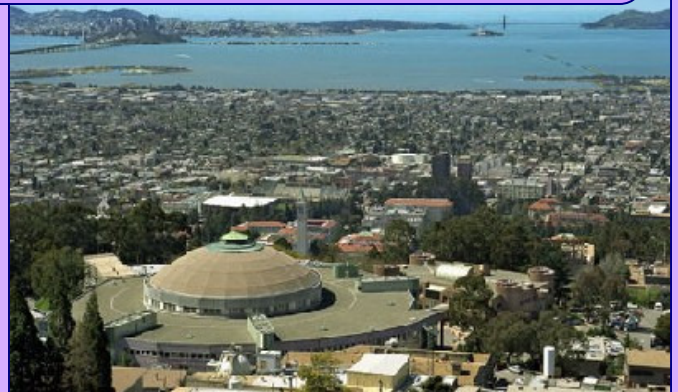
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About the EUV ERC

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The EUV ERC is asking Industrial Board Members to plan to attend this year's annual NSF site visit and review. The NSF review team was impressed by the strong show of support from IAB members attending last year's meeting. This year's meeting reviews programs over the next year as well as sustainability plans for the EUV ERC.



Presentations include overviews of research and Center accomplishments. This meeting is an excellent opportunity to gain a detailed overview of EUV work at all three of the Center's universities.

Industrial Advisory Board support and participation will go a long way towards making the 2011 review a success. The event will include:

- Presentations and updates by principal investigators, students and ERC staff
- Lab tours of the ERC facilities at Berkeley
- Student Poster Session
- Opportunities for one-on-one conversations with ERC personnel and industry peers.
- Lunch and refreshments

An agenda, maps and lodging recommendations will be provided to all IAB members. Please contact Bob Bower for more information at [Robert.Bower@colostate.edu](mailto:Robert.Bower@colostate.edu)

# Industrial Advisory Board Meeting



**Industrial Advisory Board Meeting February 28, 2011**

The Center held a face-to-face meeting with the Industrial Advisory Board on February 28<sup>th</sup>, in San Jose, during the SPIE Advanced Lithography meeting. 25 industry members and 3 industry guests from companies considering membership attended the meeting. A Principal Investigator from each campus presented updates on work and advancements in research realized over the last year. Following each presentation, there was a question and answer session. The ILO, Bob Bower, provided an overview and updates on the industry program over the last year and, in coordination with the IAB Chairman, Bruno La Fontaine of Cymer, introduced and explained the objectives for the SWOT analysis. In a closed meeting with IAB members, Dr. La Fontaine conducted the SWOT analysis obtaining input and comments from the IAB members. During that closed meeting, the Principal Investigators met with guests, potential new members, from Agilent Technologies and Hitachi Global Storage. Following the SWOT meeting, all participants returned to the meeting room and Dr. La Fontaine presented an overview of the analysis. The meeting wrapped up with informal discussions among the participants.

**Meeting topics included:**

- Welcome, introductions and networking opportunities
- Presentation followed by a question/answer period on EUVL research activities at LBNL
- Presentation followed by a question/answer period on Applications of Tabletop Coherent Soft X-Ray Beams from Femtosecond Lasers
- Presentation followed by a question/answer period on Progress in the Development of EUV Lasers and Applications
- Overview and updates on the EUV ERC Industry Program
- Discussion and preparation for the SWOT Analysis
- Closed meeting of IAB members to conduct the SWOT Analysis
- SWOT Analysis feedback and high level overview from the IAB to the EUV ERC



EUV ERC ILO, Bob Bower, discussing the Center's industry program at the IAB meeting in February.

Copies of the presentations are available on the EUV ERC website. Please contact Bob Bower at [Robert.Bower@Colostate.EDU](mailto:Robert.Bower@Colostate.EDU) for the URL to download these presentations.

**CLEO 2011**  
**Laser Science to Photonic Applications**  
**May 1-6, 2011**  
**Baltimore Convention Center**  
**Baltimore Maryland**

**May 2**

Location: Room 339 (Baltimore Convention Center) Time of Presentation: May 02 4:30 PM - 4:45 PM  
 Category: CLEO: Science & Innovation 6: Optical Materials, Fabrication and Characterization

**Talbot Effect: A Venerable Idea with New Applications in Nanofabrication**

*L. Urbanski1; P. Wachulak2; A. Isoyan3; A. Stein4; C. Menoni1; J. Roccal; M. C. Marconi1*

1. Electrical and Computer Engineering, Colorado State University, Fort Collins, CO, United States.
2. Institute of Optoelectronics, Military University of Technology, Warsaw, Poland.
3. Synopsys Inc, Hillsboro, OR, United States.
4. Center for Functional Nanomaterials, Brookhaven National Lab, Upton, NY, United States.

We describe a coherent nanolithography approach using the Talbot effect in combination with a table top EUV laser emitting at 46.9 nm. The method was used to print large areas of periodic features with nanometer resolution.

**May 3**

Location: Room 339 (Baltimore Convention Center) Time of Presentation: May 03 8:30 AM - 8:45 AM  
 Category: CLEO: Science & Innovation 6: Optical Materials, Fabrication and Characterization

**The reduction of laser damage resistance of optical coatings to subpicosecond pulse trains under vacuum**

*D. N. Nguyen1; L. Emmert1; W. Rudolph1; D. Patel2; C. Menoni2*

1. Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States.
  2. Electrical and Computer Engineering, Colorado State University, Fort Collins, CO, United States.
- Optical multilayer materials HfO<sub>2</sub> and SiO<sub>2</sub> exhibit subpicosecond laser damage thresholds of just 10% of their intrinsic value when tested in vacuum. A few Torr of water vapor is shown to remedy this effect.

Location: Room 324-326 (Baltimore Convention Center) Time of Presentation: May 03 9:30 AM - 9:45 AM  
 Category: CLEO: QELS Fundamental Science 7: High-Field Physics and Attoscience

**Spectral Linewidth Measurement of an Injection-Seeded Transient 18.9 nm Soft X-Ray Laser**

*D. Alessi1; L. Meng2; Y. Wang1; O. Guilbaud3; M. Berrill1; S. R. Domingue1; D. H. Martz1; B. M. Luther1; D. Joyeux4; S. De Rossi4; A. Klisnick2; J. Roccal*

1. Electrical and Computer Engineering, Colorado State University, Fort Collins, CO, United States.
2. ISMO, Univeristé Paris-Sud 11, Orsay, France.
3. LPGP, Univeristé Paris-Sud 11, Orsay, France.
4. LCFIO, Institut d'Optique-Graduate School, Palaiseau, France.

The linewidth of an injection-seeded 18.9nm molybdenum soft x-ray laser (SXRL) was measured to be significantly wider than seeded optical field ionization SXRLs that use gaseous targets, an advantage for the development of sub-picosecond SXRLs.

(continued on next page)

**May 3 (continued)**

Location: Room 315 (Baltimore Convention Center) Time of Presentation: May 03 11:30 AM - 12:00 PM

Category: CLEO: Science & Innovation 8: Ultrafast Optics, Optoelectronics and Applications

**Sub-30nm Spatial Resolution Imaging Using a Tabletop 13nm High Harmonic Source**

*M. D. Seaberg*<sup>1</sup>; *D. E. Adams*<sup>1</sup>; *W. F. Schlotter*<sup>2</sup>; *Y. Liu*<sup>3</sup>; *C. Menoni*<sup>4</sup>; *M. Murnane*<sup>1</sup>; *H. C. Kapteyn*<sup>1</sup>

1. Physics, University of Colorado at Boulder, Boulder, CO, United States.
2. SLAC National Laboratory, Menlo Park, CA, United States.
3. Center for X-Ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA, United States.
4. Electrical and Computer Engineering, Colorado State University, Fort Collins, CO, United States.

We report the highest spatial resolution (<30nm) imaging to-date using a tabletop x-ray microscope in any imaging modality. High-harmonic light at 13nm illuminates an object, with images retrieved by iterative phase retrieval of the scatter pattern.

**May 4**

Location: Exhibit Hall (Baltimore Convention Center) Time of Presentation: May 04 12:00 PM - 1:30 PM

Category: CLEO: Applications & Technology 3: Government & National Science, Security & Standards Applications

**Single-Shot Imaging of Nanoscale Dynamics by Extreme Ultraviolet Microscopy**

*S. Carbajo*<sup>1, 5</sup>; *F. Brizuela*<sup>1, 5</sup>; *A. Sakdinawat*<sup>3, 5</sup>; *Y. Liu*<sup>3, 5</sup>; *W. Chao*<sup>2, 5</sup>; *W. Chao*<sup>2, 5</sup>; *E. H. Anderson*<sup>2, 5</sup>; *A. Vinogradov*<sup>4</sup>; *I. Artiukov*<sup>4</sup>; *D. T. Attwood*<sup>3, 5</sup>; *M. C. Marconi*<sup>1, 5</sup>; *J. Rocca*<sup>1, 5</sup>; *K. Buchanan*<sup>1</sup>; *C. Menoni*<sup>1, 5</sup>

1. Colorado State University, Fort Collins, CO, United States.
2. Center for X-Ray Optics, Lawrence Berkeley National Laboratory, Berkeley, CA, United States.
3. ECE, University of California Berkeley, Berkeley, CA, United States.
4. Lebedev Physical Institute, Moscow, Russian Federation.
5. NSF ERC for EUV Science and Technology, Fort Collins, CO, United States.

Snap-shot imaging with nanometer spatial resolution and nanosecond temporal resolution is used to make movies of the interaction dynamics of nanostructures.

**May 5**

Location: Room 318-320 (Baltimore Convention Center) Time of Presentation: May 05 9:50 PM - 10:00 PM

Category: CLEO: QELS Fundamental Science 7: High-Field Physics and Attoscience

**Bright Coherent Attosecond-to-Zeptosecond Kiloelectronvolt X-ray Supercontinua**

*T. Popmintchev*<sup>1</sup>; *M. Chen*<sup>1</sup>; *D. Popmintchev*<sup>1</sup>; *S. Alisauskas*<sup>2</sup>; *G. Andriukaitis*<sup>2</sup>; *T. Balciunas*<sup>2</sup>; *A. Pugzlys*<sup>2</sup>; *A. Baltuska*<sup>2</sup>; *M. Murnane*<sup>1</sup>; *H. Kapteyn*<sup>1</sup>

1. JILA and University of Colorado at Boulder, Boulder, CO, United States.
2. Photonic Institute, Vienna University of Technology, Vienna, Austria.

We demonstrate bright coherent X-ray supercontinua generated by phase-matched upconversion of mid-IR laser light into the keV spectral region. The ultrabroad bandwidths can support few attosecond pulse durations, scalable to zeptosecond time scales.

**NSF Annual Review and Site Visit****May 18, 2011**

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

Annual Site Visit and Review

University of California, Berkeley

# EUV ERC Annual Retreat

Tamasag Center, Fort Collins, Colorado  
January 13-14, 2010



Industrial Advisory Board members and industry guests were invited to attend this year's retreat. In addition to viewing presentations covering research, intellectual property, the Center's industry program and the education and outreach program, attendees had numerous opportunities to interact and network. Presentation topics included:

**Center Vision** Jorge Rocca

**Imaging, Metrology, and Patterning**

- *Coherent imaging* Dan Adams/Paul Arpin
- *Broad area imaging with zone plates* Sergio Carbajo/ Isela Howlett
- *Multilayers for applications of compact EUV sources* Yanwei Liu
- *EUV Nanopatterning* Lukasz Urbanski
- *EUV interferometry: the challenges of wavefront sensing at short wavelengths* Ryan Miyakawa

**Industry Entrepreneur Experience** Chris Myatt, Precision Photonics  
**Intellectual Property**

- How and why to Disclose IP to your University Jeremy Nelson (CSU)
- *Writing a Patent Application* Jennifer Bales

**Compact Coherent EUV Sources**

- *Progress in the Development of EUV lasers* Dave Alessi/ Brendan Reagan
- *Progress in the Development of High Harmonic Sources* Tenio Popmintchev/Ming-Chang Chen/Henry Kapteyn

**Industry Collaborations** Bob Bower

**Education** *EUV ERC Outreach Program and Opportunities to Get Involved in ERC Outreach* Kaarin Goncz

**EUV Spectroscopies**

- *Ultrafast Materials Dynamics*, Stefan Mathias/Chan Laovorakiat
- *Nanoscale thermal and acoustic dynamics* Qing Li
- *Femtosecond Transient Absorption EUV Spectroscopy* Erik Hosler
- *Single Photon ionization mass spectrometry*, Jorge Filevich/Dr. Feng Dong/ Ilya Kuznetsov /Bryce Schroder



If you have further interest in any of these topics, please contact Robert.Bower@colostate.edu

## Publications and Presentations

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- P. Ranitovic, X. M. Tong, C. W. Hogle, X. Zhou, Y. Liu, N. Tushima, M. M. Murnane, and H. C. Kapteyn, "Laser-Enabled Auger Decay in Rare-Gas Atoms", *Phys. Rev. Lett.* **106**, 053002 (2011).
- F. Brizuela, S. Carbajo, D. Martz, D. Alessi, Y. Wang, B. Luther, A. Sakdinawat, W. Chao, E. H. Anderson, Y. Liu, K. A. Goldberg, D. T. Attwood, B. LaFontaine, J. J. Rocca, C. S. Menoni, and M. C. Marconi, "Table-top Microscope for the Actinic Aerial Imaging Inspection of Extreme Ultraviolet Lithography Masks", 54th International Conference on Electron, Ion and Photon Beam Technologies and Nanofabrication, EIPBN, June 1-4, Anchorage, Alaska, US. C.S. Menoni, "Movies of nanoscale dynamics by extreme ultraviolet microscopy," *Progress in Quantum Electronics Conference, Snowbird, UT, Jan.*, (2011).
- J.J. Rocca, D. Alessi, D.H. Martz, Y. Wang, B. Reagan, B.M. Luther, F. Furch, A. Curtis, K. Wernsing, M. Berrill, "Advances in compact high brightness soft x-ray lasers: sub-10 nm wavelengths and smaller size," 41st Progress in Quantum Electronics Symposium, Snowbird, UT, Jan. 2-6, (2011). Plenary Talk, Invited.
- M.G. Capeluto, M.C. Marconi and C. Iemmi "Design of a phase shifting interferometer in the EUV for high precision metrology," *Journal Of Physics: Conference Series* 274, (2011), 012026.
- S. Kohli, P.R. McCurdy, C.D. Rithner, P.K. Dorhout, A.M. Dummer, and C.S. Menoni, "Effect of Annealing on the Interfacial and Structural Properties of Amorphous Silicon-Hafnia Films," *Metallurgical and Materials Transactions a-Physical Metallurgy and Materials Science.* **42A**(1) 71 (2011).
- C.S. Menoni, "Movies of nanoscale dynamics by extreme ultraviolet microscopy," *Progress in Quantum Electronics Conference, Snowbird, UT, Jan.*, (2011).
- I.A. Vartanyants, A. Singer, A. P. Mancuso, O. Yefanov, A. Sakdinawat, Y. Liu, G. Williams, G. Cadenazzi, B. Abbey, H. Sinn, A. Scherz, J. Turner, W. Schlotter, D. Attwood, K. A. Nugent, E. Weckert, et. al. "Coherence properties of the single femtosecond pulses of an X-ray free-electron laser," *Journal of Physics B-atomic Molecular and Optical Physics* **43**, 19, 194016 (2011).
- M. Siemens, Q. Li, M. Murnane, H. Kapteyn, R. Yang, "Probing Nanoscale Thermal Transport using Extreme Ultraviolet (EUV)," *SPIE Photonics West '11 Conference, San Francisco, CA, Jan.*, (2011). Invited.
- M. Murnane et al, "Capturing Electron Dynamics in Materials using Bright Coherent X-Rays," 41st Winter Colloquium on the Physics of Quantum Electronics, Snowbird, UT, Jan., (2011) Plenary talk.
- H. Kapteyn et al, "Ultrahigh Resolution Imaging Using Tabletop Coherent EUV Light Sources," 41st Winter Colloquium on the Physics of Quantum Electronics, Snowbird, UT, Jan., (2011) Plenary talk.
- M. Murnane et al, "Science at the Timescale of the Electron - from Picoseconds to Zeptoseconds," *North-east Conference for Undergraduate Women in Physics, MIT, Jan.*, (2011). Invited.

(continued on next page)

If you have further interest in any of these topics, please contact Robert.Bower@colostate.edu

## Publications and Presentations

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- P. Naulleau, "Facing the challenges in EUV resists development," Applied Materials Inc. Internal Seminar, Santa Clara, CA, Mar., (2011). Invited.
- P. Naulleau, "EUV resists: illuminating the challenges," 2011 SPIE Advanced Lithography Conference, San Jose CA, Mar., (2011). Invited.
- P. Naulleau, "Challenges in EUV resists," Zeiss Technical Symposium, Oberkochen, Germany, Jan., (2011). Invited.
- P. Naulleau, "Using synchrotron light to accelerate EUV resist and mask materials learning," 27th European Mask and Lithography Conference, Dresden, Germany, Jan., (2011). Invited.
- P. Naulleau, "Breaking barriers in resolution," International EUV Resist Symposium, Osaka, Japan, Nov., (2011). Invited.
- P. Naulleau, "EUV microscopy," Samsung Mask Group Seminar, Suwon Korea, Nov., (2011). Invited.
- P. Naulleau, "EUV learning at LBNL: past, present, and future," The 2010 Lithography Workshop, 2010, Lihue, HI, Nov., (2011). Invited.
- P. Naulleau, "Nano-patterning research at LBNL: enabling new science and technologies," Workshop on Nanoscale Science, Technology, and Innovation, Rio De Janeiro, Brazil, Sep., (2011). Invited.
- P. Naulleau, "Contact size variations: Dissecting the sources," 2010 International Workshop on EUV Lithography, Maui HI, June, (2011). Invited.
- D. Attwood, Two Lectures at HERCULES (Higher European Research Course for Users of Large Experimental Systems) in Grenoble, France, March 1-2, 2011: 1) *Introduction to Synchrotron Radiation and its Applications*; 2) *High Spatial Resolution: X-Ray Microscopy*.
- D. Attwood, "Internet Courses for Career Path Redirections," APS meeting, Dallas, Texas, March 22-24, 2011. Invited.
- B. McClinton, "Physical and geometric optics models for mask roughness induced LER," SPIE 2011 Advanced Lithography Conference, San Jose, CA, March 2, 2011. Poster.
- B. McClinton, "LER Control and Mitigation: Mask Roughness Induced LER," SPIE 2011 Advanced Lithography Conference, San Jose, CA, March 2, 2011. Poster.
- B. McClinton, "Absorber Height Effects on SWA restrictions and 'Shadow' LER," SPIE 2011 Advanced Lithography Conference, San Jose, CA, March 2, 2011. Poster.
- D.N. Nguyen, L.A. Emmert, P. Schwoebel, D. Patel, C.S. Menoni, M. Shinn and W. Rudolph "Femtosecond pulse damage thresholds of dielectric coatings in vacuum," *Opt. Express* **19**, 5690 (2011)
- M. J. Abel, D. M. Neumark, S. R. Leone, and T. Pfeifer, "Classical and quantum control of electrons using the carrier-envelope phase of strong laser fields," *Laser Photonics Rev.* **25**, 1 (2011).
- T. Rohwer, S. Hellmann, M. Wiesemayer, C. Sohrt, A. Stange, B. Slomski, A. Carr, Y. Liu, L. Miaja Avila, M. Kalläne, S. Mathias, L. Kipp, K. Rosnagel and M. Bauer, "Collapse of long-range charge order tracked by time-resolved photoemission at high momenta", *Nature* **471**, 7339-490 (2011).

# EUV ERC

## *New IAB Member*

### New IAB Member, Agilent Technologies

Please welcome the EUV ERC's newest Industrial Advisory Board member, Agilent Technologies.

Agilent Technologies has joined the Industrial Advisory Board as a Principal Corporate Member. Instrumental to Agilent's joining the Center was the guest attendance of Agilent representatives from Agilent Labs and Agilent's University Relations office to the IAB meeting in San Jose on February 28<sup>th</sup>. The Center's expanded focus on chemical analysis and biological imaging provided motivation for Agilent's membership. Of particular interest to Agilent Labs is Dr. Carmen Menoni's use of the 46.9 nm capillary discharge, coherent, table-top system with a TOF-MS analyzer to image biological samples with extremely high spatial resolution. Potential applications of this system include sub-cellular imaging and chemical profiling of complex biochemical systems. Agilent views its Center membership as an initial step in future collaborations with the EUV ERC.



**Agilent Technologies**

The NSF's policy for ERCs is that at the end of the ten-to eleven-year cooperative agreement, NSF funding will cease and the centers are expected to become self-sustaining. The EUV ERC is in its 8th year as an ERC and is actively building a sustainability plan to guide and grow the post-graduation Center.

The future of the Center's industry program is among the components of that sustainability plan. IAB participation and ownership are key to the creation and implementation of the industry program plan.

Both in response to IAB interest and as a key part of the Center's planning process, the EUV ERC and the Center's IAB are planning a Sustainability Summit to be held later in 2011. In the coming weeks, we will focus on creating the summit agenda and determining the location and date for this meeting.

## Sustainability

### Topics for consideration:

What does the post-graduation Industry Program look like?

What are its goals and objectives?

What role does each industry member of the IAB play in the post-graduation EUV ERC?



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.

**Industry Members**



**Industry Affiliates**



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