The Center for Extreme Ultraviolet Science and Technology

Colorado State University (lead institution)

Bringing new light to science and nanotechnology

A National Science Foundation Engineering Research Center since 2003

Partner Institutions:

- ***University of Colorado***
- ***University of California-Berkeley***

As the size of the most advanced electronic circuits and nanoscale machines continues to shrink below the wavelength of visible light, conventional optical technologies are rapidly reaching their limits. As a result, light in the Extreme Ultraviolet (EUV) region of the spectrum (wavelengths approximately 5 to 50 nm) is poised to become a key element in technologies of critical importance to the national economy. Furthermore, exciting new opportunities in science will arise from the possibility of focusing EUV radiation to unprecedentedly small spot sizes, short pulse durations, and extremely high intensities. Development of EUV technologies will open up a variety of new areas of investigation, including surface, chemical, and materials dynamics studies, EUV nonlinear optics, biological studies, and the development of a new generation of nanoprobes. The Engineering Research Center for Extreme Ultraviolet Science and Technology (EUV ERC) is exploring the development and application of compact coherent EUV sources with the objective of making EUV technology widely available to solve challenging scientific and industrial problems.

Specifically, the EUV ERC will (1) advance the technology of small-scale and cost-effective coherent EUV sources; and (2) demonstrate their utility by integrating them into testbed applications. The motivating vision of the Center is that, at the end of a 10-year ERC effort, EUV radiation—now mostly limited to a handful of large national facilities—will be routinely used in a broad variety of settings for applications such as high-resolution imaging, spectroscopy, elemental- and bio-microscopy, and nano-fabrication. This vision will be realized through research, and by creating a diverse workforce trained in EUV optical technologies.

Research

The goals of EUV ERC research are the development of compact tabletop and desktop-size coherent EUV light source systems and their integration with EUV optics to develop engineered system testbeds for solving problems. Some testbeds have unique capabilities that will provide solutions to problems that no other systems can solve, irrespective of their size or cost. These testbeds integrate all of the following: a) a compact tabletop EUV light source; b) advanced EUV optics; c) a detection system; and d) components related to a particular application.

- The development of compact, cost-effective, coherent EUV light sources that provide unique capabilities
- The integration of these light sources into Application Testbeds that solve challenging engineering and scientific problems in unique ways
- Contributions of the EUV sources to fundamental knowledge in optics, laser, and EUV science and technology, and in plasma physics.

Researcher developing ultrafast, high repetition rate compact EUV lights sources through high harmonic generation techniques.

The Applications Testbeds will address a number of selected applications in imaging, microscopy, materials study and characterization, and optical metrology for nanometer-scale (10^{-9} meters) devices. Example testbeds include sub-hundred-nanometer-resolution EUV microscopes for nano-scale inspection/fabrication and biology; femtosecond (10^{-15} second) time-resolved spectroscopy systems for material and chemical analysis; and "workstations" for nanocluster spectroscopy and fabrication. These testbeds will be capable of probing atomic, molecular, and materials processes with sub-hundred nanometer spatial resolution and femtosecond time resolution.

The development of these testbeds requires small-scale coherent EUV sources with specific characteristics. Depending on the particular application, one might require some combination of high average power, high energy per pulse, femtosecond pulse duration, high repetition rate, and/or tunability. Many of these requirements will only be met by systems that are "testbeds" in themselves; i.e. systems using various combinations of high-energy discharges, ultrafast optical lasers, advanced optical components, vacuum systems, and control electronics. Two complementary approaches for intense coherent EUV light generation are being developed at the EUV ERC: compact EUV lasers and high-order harmonics. The first approach provides highly monochromatic EUV light with high pulse energy, and the second is a useful method for the production of ultrafast EUV light pulses at very high repetition rates. These EUV source systems will constitute one of the major deliverables of the center.

Education

The EUV ERC education plan is designed to have a broad impact, with activities for education at all levels. The education plan encompasses three major goals:

- Provide unique opportunities for multidisciplinary research projects that go beyond single research groups and involve significant teamwork
- Influence K-12 education
- Assist industry in creating a workforce proficient in EUV technology.

The Center will educate a workforce in the critical area of EUV technology. To ensure the active participation of underrepresented groups in this effort, we are working to integrate our programs with existing, successful state and national diversity programs, and are collaborating with several outreach institutions that predominantly serve underrepresented populations. Moreover, we have assembled a Center leadership team that is diverse in gender and ethnicity, a valuable resource for outreach activities that can help to bring members of underrepresented groups into engineering and science.

Graduate and undergraduate students team up in working at the LBNL ALS beamline chambers.

To support the new educational programs at the university level, the Center is offering courses addressing the foundations and applications of optical and EUV science, including EUV source physics, optical system implementation, and measurement techniques. In addition, the courses will integrate the latest advances in EUV science and technology developed at the Center.

The EUV ERC has developed a number of workshops for K-12 students and teachers to promote an interest in science in general, and lasers in particular. With the help of ERC researchers, graduate, and undergraduate students, K-12 students have the opportunity to participate in hands-on experiments to learn the basic properties of light and the fundamentals of optics. The Center has also developed "optics suitcases" available to teachers, so that educational activities can continue without the direct supervision of the ERC.

The university courses developed by the Center are open to industry personnel interested in EUV science. Additionally, the EUV ERC will provide advanced training of engineers, scientists, and technicians through the following:

- On-line and web-based courses on EUV sources, optical design and measurement techniques, and applications of EUV technology
- Opportunities for industry scientists and technicians to work at any of the three university research sites. This program will by complemented by internships for graduate and undergraduate students at industrial sites.

Industry

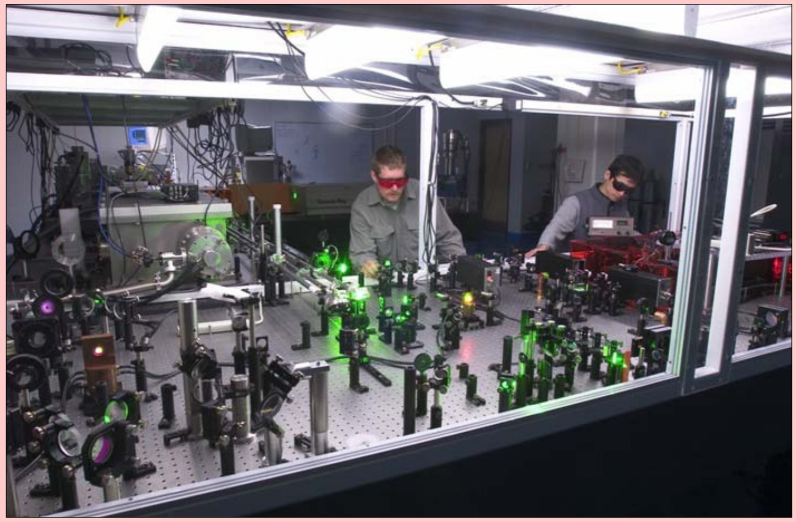
The goal of the EUV ERC is to have a broad impact on science and technology, from fundamental research to the development of tools that can assist large-scale manufacturing. Towards this end, the ERC is collaborating with industry members from small, medium, and large corporations, who have a broad spectrum of scientific and technical interests. The industrial members presently include laser manufacturers, instrument suppliers, semiconductor industries, and advanced optics manufacturers.

The widespread pursuit of nanoscience and nanoengineering benefits from the availability of radiation with comparable wavelengths for imaging, metrology, and characterization, and in some cases for direct nanopattern formation. As a consequence many new scientific and technological opportunities are emerging that require compact, widely available tools. A particular case, and a strong driver of the current expansion of activities, is that of EUV lithography for the high-volume manufacture of future computer chips. Current industry timelines call for this new technology to be used for the manufacture of 19 GHz microprocessors in the year 2009. To meet these ambitious goals, a substantial new infrastructure is required, including component vendors, as well as instrument suppliers small and large, all requiring a well-trained staff that the Center educational program can provide.

In the area of photophysics, photochemistry, and surface science, the high photon energy and unsurpassed temporal resolution of EUV light sources, that extends to the femtosecond and attosecond (10^{-18} second) regimes, provides unique opportunities to study ultrafast processes and chemical reactions in materials and surfaces. EUV spectroscopic tools will provide new insight on very important industrial catalytic processes. As the compact sources advance towards shorter wavelengths, applications to biology will become increasingly possible.

Facilities

The Center headquarters, located at Colorado State University (CSU) in Fort Collins, Colorado, has nearly 6500 sq ft of laboratory space and 12 offices located in the Engineering Research building on CSU's foothills campus. At the University of Colorado (CU) over 3600 sq ft of laboratory space is available, including 1000 sq ft of newly renovated laboratory space at the CU JILA building. A variety of EUV lasers and high harmonic EUV compact sources, several of them unique, are available at these laboratories for use in applications. Researchers at the University of California–Berkeley have access to beamlines at the Advanced Light Source synchrotron facility at the Lawrence Berkeley National Laboratories (LBNL), as well as advanced nanofabrication tools for the manufacturing of EUV diffractive optics. State-of-the-art thin film deposition systems for the manufacturing of EUV diffractive and reflective optics are available at all three Center campuses.



Researchers developing the technology for a high energy, compact, cost-effective, coherent EUV light source.

Center Organization and Leadership

Dr. Jorge Rocca (CSU) serves as Director of the EUV ERC, with Dr. Margaret Murnane (CU) as Deputy Director and Dr. David Attwood (UCB/LBNL) as Associate Director. This ensures that the three core institutions have a leadership stake in the EUV ERC and promotes good communication between the core partners. Dr. Carmen Menoni (CSU), Dr. Henry Kapteyn (CU) and Dr. Patrick Naulleau (LBNL) serve as members of the executive committee, advising the directors on matters of research and administration. Sheila Davis is the administrative director for the Center, working at CSU. Mr. Robert Bower is the industrial liaison officer.

EUV ERC students guide high school seniors through "Amazing Experiments with Light."

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