Brightness and Coherence Research at the Center for X-Ray Optics

David Attwood
University of California, Berkeley
Happy days in Berkeley
Happy Couple: Kwang-Je and Kyeong-Hwa aka Elizabeth
Happiness delayed
**LBL Starts World’s First Center For X-ray Optics**

*By Lynn Yuris*

The only one of its kind in the world, LBL’s new Berkeley Center for X-Ray Optics is scheduled to begin full operation in April, as part of the Accelerator and Fusion Research Division.

Under the leadership of physicist David Attwood, research at the new Center will focus on the use of radiation that falls between X-rays and ultraviolet light (about 10 keV to 10 eV) on the electromagnetic spectrum—often referred to as XUV radiation.

“The Center will serve as a national source of development and application of new techniques for the use of XUV radiation,” says Attwood. “Emphasis will be placed on emerging technologies, such as diffractive and reflective optics, necessary for the efficient transport, dispersion, focusing and detection of XUV radiation from synchrotron and other light sources.”

The relatively unexplored XUV spectral region has been called the last frontier of the electromagnetic spectrum. According to Attwood, “After a 30-year dormancy, interest in the region has suddenly come alive.”

The reason for this renaissance, he says, is a rapid advancement in technological capabilities, permitting exciting new applications of XUV radiation and optics in the fields of physics, chemistry, materials science, and the biological and life sciences.

Potential applications include the development of x-ray microscopes that could provide detailed views of materials and biological structures, such as cells, never before attainable, and the production of much smaller microcircuits for the electronics industry than is currently feasible.

In addition, says Attwood, devices, such as LBL’s Advanced Light Source, which is so rich in atomic resonance structure.”

The idea of a center specializing in the study of XUV radiation through x-ray optics was first proposed at the June 1981 Monterey Conference on Low-Energy X-Ray Techniques, sponsored by the American Institute of Physics. Organized by Attwood and University of Hawaii physicist Burton

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**Vish More of Plant Engineering (center, at desk) describes the laboratory facilities which will soon be available at LBL’s new Center for X-ray Optics. Behind More are, from left to right, David Attwood, consultant Gary Sommargren of Zygo Corporation, James Underwood, Kwang-Je Kim, Malcolm Howells and Al Thompson.**

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*Currents* 
University of California Berkeley, California 94720
Orange Data Book, April 1986
Kwang-Je Kim’s FEL designs

- Radiation couples to electron beam and modulates the density with period length $\lambda$.
- Coherent addition of radiation from different electrons — Intensity is proportional to $N_e^2$.
- Longitudinal coherence $l_c = L_e \left( \frac{\lambda}{\Delta \lambda} \right) \approx \frac{L_e}{\lambda} \approx 10^6$.
- Spatially coherent and tunable.
Kwang-Je Kim’s FEL designs

High-Gain, Single-Pass Free Electron Laser

- FEL interaction is so strong that an intense, coherent signal develops from noise in a single pass.
  - Mirrors are not required.
- Long undulator (~20 m; 500–1000 periods) with small gap (~3 mm) requires bypass operation.
- Tens of megawatts of peak power is expected.

An FEL Community White Paper Was Organized

Coherent X Rays and Vacuum–Ultraviolet Radiation from Storage-Ring-Based Undulators and Free Electron Lasers

December 1984
Tunable Coherent X-rays
David Attwood, Klaus Halbach, Kwang-Je Kim

The spectral region referred to as the XUV includes soft x-rays and ultraviolet radiation. Photon energies in this region extend from several electron volts (eV) to several thousand electron volts (keV). The primary atomic resonances of elements such as carbon, oxygen, nitrogen, and sodium, as well as resonances from many molecular transitions, appear in this region. In addition, the photon which emit radiation of longer wavelengths. Optical techniques, including reflection, dispersion, and imaging, suffer from photoelectric absorptive effects in this region. Between the wavelengths of about 10 and 1000 angstroms (Å) there are no materials that are both transmissive and capable of supporting an atmosphere of pressure over macroscopic dimensions.

Summary. A modern 1- to 2-billion-electron-volt synchrotron radiation facility (based on high-brightness electron beams and magnetic undulators) would generate coherent (laser-like) soft x-rays of wavelengths as short as 10 angstroms. The radiation would also be broadly tunable and subject to full polarization control. Radiation with these properties could be used for phase- and element-sensitive microporbing of biological assemblies and material interfaces as well as research on the production of electronic microstructures with features smaller than 1000 angstroms. These short wavelength capabilities, which extend to the K-absorption edges of carbon, nitrogen, and oxygen, are neither available nor projected for laboratory XUV lasers. Higher energy storage rings (5 to 6 billion electron volts) would generate significantly less coherent radiation and would be further compromised by additional x-ray thermal loading of optical components.

Substantial progress in the development of x-ray optical techniques has been made recently (7-6), largely as the result of the need for ever smaller microfabrication capabilities in the electronics industry. Research on x-ray emitting, hot resolution, initially developed to study energy transport in hot dense plasmas (7), are now commercially available.

In order to extend scientific and technological opportunities, a bright source of tunable, partially coherent, XUV radiation is needed. Coherence, in the limited sense used here, refers to the ability to form interference patterns when wave fronts are separated and recombined. Partially coherent radiation is capable of producing clear interference patterns (fringes), but only within limited transverse or longitudinal displacement (10). The longitudinal displacement within which fringes can be formed is called the coherence length $\ell_c$ (11), which is given by the wavelength $\lambda$ times the number of waves of coherence $\lambda/\Delta\lambda$ (spectral parity: $\ell_c = \lambda^2/\Delta\lambda$). For experiments that utilize phase-sensitive techniques, such as x-ray interferometry and x-ray microphotography, a radiation field with full spatial coherence and several micrometers (μm) of longitudinal coherence is often satisfactory.
November 1985 ALS workshop

Don Stevens
Judy Bostok
Klaus Halbach
Martha Krebs
Yuan Lee
Report of the Workshop on an 
Advanced Soft X-Ray and 
Ultraviolet Synchrotron Source: 
Applications to Science and Technology 
November 13-15, 1985 
Berkeley, California

Lawrence Berkeley Laboratory 
University of California 
Berkeley, California 94720

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098
ALS is in the budget

The American dream is a song of hope that rings through the night winter air. Vivid, tender music that warms our hearts when the least among us aspire to the greatest things — to venture a daring enterprise; to unearth new beauty in music, literature, and art; to discover a new universe inside a tiny silicon chip or a single human cell.
LBL’s World Class Accelerator Team (AFRD) Designs a State-Of-The-Art Low Emittance Machine

Director’s Technical Review of the Advanced Light Source

February 18-19, 1986

February 1986

Advanced Light Source Overview
Klaus H. Berkner

Photon Performance of ALS
Kwang-Je Kim

Storage Ring Design and Performance
Max Cornacchia

Advanced Light Source Injection System
Michael S. Zisman

ALS Vacuum System
Kurt Kennedy

Study of Chamber Impedance
Glen Lambertson

Magnet System Design and Performance
R.T. Avery

Control, Feedback & Power Systems
Henry Lancaster

ALS Program and R&D Issues
Jay Marx

1–2 GeV SYNCHROTRON RADIATION SOURCE
Conceptual Design Report — July 1986

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
Prepared for U.S. Department of Energy under Contract No. DE-AC03-76SF00098
2.3 Optical Characteristics of Synchrotron Radiation

The radiation spectrum from a bending magnet is smooth, centered around the center frequency $\omega$. Wiggler can be exploited as a sequence of bending magnets of alternating pole for. Thus, in addition to those from bending magnets, the spectrum can be further modified by wiggler radiation.

$$\Delta \omega = \frac{c}{\pi L} \left[ \frac{1}{k} \sqrt{1 - \frac{1}{k^2}} \right]$$

where $\Delta \omega$ is the full magnetic gap frequency, $\omega$ is the electron energy, and $L$ is the bending magnet length.

For bending magnets, $\Delta \omega$ in the above expression must be replaced by $\Delta \omega'$, where $\Delta \omega'$ is the magnetic field in the bending magnet. The angular distribution of the reduced power is

$$\frac{dP}{d\Omega} = T \frac{dP}{d\Omega}(\omega, \eta, \phi)$$

Ref. [11]
ALS Construction Begins, 1988
By Lynn Yarris

The Advanced Light Source, LBL’s newest, largest, and most technologically advanced accelerator, produced its first experimental light this week. During a Tuesday afternoon ceremony to mark the occasion, a phosphor-painted target glowed bright orange when it was struck by a beam of white x-ray light from bending-magnet port 10.3. Many of the people who made the moment possible watched the event on a video monitor.

The actual first light from the ALS came at 11:34 p.m., the previous night (Oct. 4), when the beamline was put through its final preparatory tests. Word of the success led the development of the beamline, which will serve as a fluorescent x-ray microprobe available for use by LBL groups to study material, biological, and geological samples. He opened Tuesday’s ceremony by thanking the staffs of the ALS and the CXRO, as well as LBL Materials Sciences Division (MSD) Director Daniel Chemla and acting ALS scientific adviser Phil Ross, who helped obtain funding for the beamline which came from the U.S. Department of Energy’s Division of Materials Science in Germantown, Md.

“We’re all celebrating this day!” Thompson enthused.

Bending-magnet port 10.3 features the longest beamline the concurrent running of independent experiments. For now, the single branch will be used by Thompson and his CXRO collaborators, Jim Underwood, Karen Chapman, Phil Batson, Ron Tadicaberry, Drew Kemp, and Steve Klingler to study trace elements in materials.

The ALS x-ray microprobe is capable of simultaneously detecting and measuring the presence of elements from potassium to zinc in amounts as small as a millihund of a billionth of a gram. Its first use will be to analyze the distribution of trace elements in ceramic materials in an effort to answer the age-old mystery of why ceramics are so brittle.
Best wishes to Kwang-Je on his 75th birthday