In this talk, a general overview of the Advanced Light Source (ALS) will be presented. The ALS is a third generation light source optimized for soft x-ray/ VUV science. Beamline 10.0.1 of the ALS is a good example of a VUV/EUV beamline. A detailed description of this beamline will be presented. This high resolution beamline splits in three branches serving two very different communities. One branch is dedicated to photoemission studies of highly correlated materials (solid state physics) and the other two branches are dedicated to photoionization/photoexcitation studies of atomos, molecules and clusters in gas phase. Recent research highlights conducted in all three branches will be presented in a second talk.

Primary authors : Dr. AGUILAR, Alejandro (LBNL-ALS)

Co-authors :

Presenter : Dr. AGUILAR, Alejandro (LBNL-ALS)
General overview of the Advanced Light Source: a soft x-ray/VUV facility

Alex Aguilar
LBNL-ALS
Beamline Scientist (10.0.1)
Index

• Little bit of history
• Parameters
• Bend magnets and Super-bend magnets
• Insertion Devices
  • In Vacuum
  • EPU and QEPU
• Top-Off mode
• Future upgrades
• Beamline 10.0.1
• Summary
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• Beamline 10.0.1
• Summary

For more information, contact
David Robin (DSRobin@lbl.gov)
Christoph Steier (csteier@lbl.gov)
A little bit of history…

Original building completed in 1942.


Was built to house Berkeley Lab's namesake E. O. Lawrence's 184-inch cyclotron (Nobel Prize in 1939).

Today, the expanded building houses the Advanced Light Source (ALS), a third-generation synchrotron and national user facility.
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Today, the expanded building houses the Advanced Light Source (ALS), a third-generation synchrotron and national user facility.
• 3rd generation synchrotron light source
• Commissioned in 1993, $99.5 million
  • Operating budget $25 million
  • 1500 users
• Present (2010)
  • Operating budget $52 million
  • 2800 users
• 1.9 GeV, 0.5 A electron storage ring
• 40 operating beam lines
• 50 possible beam lines
## Storage ring parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron beam energy</td>
<td>1.9 GeV</td>
</tr>
<tr>
<td>Injection energy</td>
<td>1.0-1.9 GeV</td>
</tr>
<tr>
<td>Beam current</td>
<td>500 mA in multi-bunch</td>
</tr>
<tr>
<td>Filling pattern</td>
<td>256-320 bunches; possibility of one or two 5-6 mA “camshaft”</td>
</tr>
<tr>
<td>Bunch spacing: multi-bunch</td>
<td>2 ns</td>
</tr>
<tr>
<td>Bunch spacing: 2-bunches</td>
<td>328 ns</td>
</tr>
<tr>
<td>Circumference</td>
<td>196.8 m</td>
</tr>
<tr>
<td>Straight sections</td>
<td>12</td>
</tr>
<tr>
<td>Insertion devices</td>
<td>11</td>
</tr>
<tr>
<td>Beam size in straight sections</td>
<td>310 µm horiz. x 16 µm vert.</td>
</tr>
</tbody>
</table>
ALS storage ring lattice

12 straight sections
- 12 arc-shaped sections
  - Bend magnets (B),
  - Quadrupoles (QFA, QDA, QF, and QD)
  - Sextupoles (SF and SD).
- Three of the arc sections contain superconducting bend magnets (superbends).
### Bending magnets and superbend magnets

#### 9 Bending magnets feeding 19 beamlines

<table>
<thead>
<tr>
<th>Infrared (IR) Spectroscopy</th>
<th>X-Ray Tomography</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-Ray Microscopy</td>
<td>Magnetic Spectroscopy</td>
</tr>
<tr>
<td>Materials Science</td>
<td>Diagnostic Beamlines</td>
</tr>
<tr>
<td>Atomic and Molecular Physics</td>
<td>Chemical Sciences</td>
</tr>
<tr>
<td>X-Ray Fluorescence Microprobe</td>
<td>Small Molecule Crystallography</td>
</tr>
<tr>
<td>EUV Lithography Mask Inspection</td>
<td>MicroXAS</td>
</tr>
</tbody>
</table>

#### 3 Super-bend magnets feeding 8 beamlines

<table>
<thead>
<tr>
<th>Protein Crystallography</th>
<th>Tomography</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Pressure</td>
<td>X-Ray Micro-diffraction</td>
</tr>
</tbody>
</table>
What is a super-bend magnet and what is it for?

- Expand the capability and capacity of the facility to serve the Hard X-ray community
- Do not compromise the ability of the facility to serve the UV and Soft X-ray community

Solution
- In 3 of the 12 ALS sectors, replace an existing 1.3 Tesla bending magnet with a 5 Tesla bending magnet
Super-bend magnets vs. Bend magnet

- Excellent source of hard X-rays — up to 40 keV
  - Well suited for protein crystallography and other hard X-ray applications
    - Small beamsize in the center bend ($\sigma_x = 100 \ \mu m$) is a good match for many crystals

- High Capacity
  - 3 Superbends yield up to 12 beamlines without using any straight sections

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Installing the first Superbend (Aug. 21, 2001)
Insertion Devices

1 Wiggler (11.4-cm-period) feeding 3 beamlines

Protein Crystallography

4 Elliptical Polarization Undulators. 3 are 5-cm-period and 1 is a 9-cm-period

<table>
<thead>
<tr>
<th>Magnetic Spectroscopy</th>
<th>Molecular Environmental Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Resolution spectroscopy of complex materials</td>
<td>Photoemission electron microscope and Soft X-ray scattering</td>
</tr>
</tbody>
</table>

7 Undulators. 2 (U3), 2 (U5), 1 (U8) and 2 (U10)

<table>
<thead>
<tr>
<th>Ultrafast/Femtosecond Dynamics</th>
<th>Surface, Materials Science</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Dynamics</td>
<td>Diffraction Imaging</td>
</tr>
<tr>
<td>Correlated Materials</td>
<td>Atomic and Molecular Physics</td>
</tr>
<tr>
<td>EUV testing and interferometry</td>
<td>ARPS</td>
</tr>
</tbody>
</table>
New Insertion Devices

Quasiperiodic Ellipically Polarizing ID (MERLIN)

In-Vacuum ID (Femtoslicing)

Ellipically Polarizing ID (PEEM-III)
In-Vacuum Insertion Device

Specifications
Magnetic gap 5.5 mm
Period 30 mm
No. periods 48
$B_0 = 1.45$ T

Smallest ID Gap
MERLIN QEPU

- Installed in Fall/Winter 2007
- Commissioned in January 2008
- First Light in February 2008

Initial Shimming Results are Very Encouraging

- Dynamic Multipole Shimming Close to Optimal
• Why a Quasi periodic Undulator (QEPU)
  – For low-energy undulators, the inability of monochrometers to distinguish integral multiples of the fundamental can result in unwanted excitations of electron states.
  – A QEPU is an efficient yet simple scheme is proposed that reduces the photon flux at integer multiples of the fundamental
MERLIN Quasi-periodic Undulator (QEPU) Reduces Flux in Higher Harmonics

Performance
At minimum gap
ALS upgrade parameters

1st
3rd
5th
EPU90
7th

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MERLIN Quasi-periodic Undulator (QEPU) Reduces Flux in Higher Harmonics

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ALS upgrade parameters

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R. Schlueter, S. Prestemon, S. Marks
MERLIN Quasi-periodic Undulator (QEPU) Reduces Flux in Higher Harmonics

Performance At minimum gap ALS upgrade parameters

1st 3rd 5th 7th

QEPU90

EPU90

5 times smaller 3rd Harm.
MERLIN Quasi-periodic Undulator (QEPU) Reduces Flux in Higher Harmonics

Performance
At minimum gap
ALS upgrade parameters

QEPU90
5th
EPU90
7th

~50 times smaller 5th Harm.

5 times smaller 3rd Harm.

1st
3rd

Photon energy [eV]

Ph/s/0.1%bw/mm²

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R. Schlueter, S. Prestemon, S. Marks
In top-off mode the plan is to run with
• 2 times higher time averaged current
• smaller vertical beam size – less than half the present size

**coupling**

*After Top-off*

\[
\delta i \quad \Delta t \quad \sigma_h \quad \sigma_v \quad \sigma'_h \quad \sigma'_v
\]

1.5mA 32.0s 298μm 8μm 22μrad 3μrad

Top-off mode
In top-off mode the plan is to run with
• 2 times higher time averaged current
• smaller vertical beam size – less than half the present size

Top-off mode has opened the door to large increases in brightness and improvements in beam stability
Brightness Before and After Top-off

![Brightness graph]

- **Brightests**
  - ALS, U50, 2004, 250 mA (avg)
  - ALS, U50, 2007, 250 mA (avg)
  - ALS, U50, 2008, 500 mA (top-off)

**E_{photon} [eV]** vs. **Brightness [Ph/Sec 0.1% BW mm^2 mrad^2]**

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### Before Top-Off

- **Injection at 1.5 GeV and then ramp**
- Inject with insertion devices open
- Average beam current was 250 mA
- Vertical emittance was 150 pm rad
- Lifetime was 8 hours at 400 mA
- Injection period every 2 to 8 hours
  - 1 Hz injection for 4 minutes
    - From 200 to 400 mA
- **Photon shutters were closed during injection**

### After Top-Off

- **Full energy injection (1.9 GeV)**
- Inject with insertion devices closed
- Average beam current is 500 mA
- Vertical emittance is 30 pm rad
- Lifetime is about 3 hours at 500 mA
- Injection period about every 30 seconds
  - 1 pulse
    - From 498.5 to 500 mA
- **Photon shutters remain open during injection**
Top-off Radiation Issues/challenges

Injected e- beam cannot exit the shielding

Non Top-off (present)– Inject with personnel safety shutters closed

This potential accident scenario has to be prevented

• Follow very similar approach to APS
• Extensive tracking and mitigation strategy
• New configuration control and interlock systems

Large collaboration between Accelerator / Engineering / EHS Staff

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From Tracking to Requirements

Begin with a beamline

Phase Space Results

Backtracking Simulator

Mitigation : Interlocks and aperture
Some upcoming upgrades at the ALS

Flexible Bunch Frequency

Terahertz

High Brightness Lattices

Superconducting IDs

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Optimized Lattice Settings

Global Lattice Exploration

Ultralow Emittance Lattice


Ultralow Emittance Lattice

Install New Sextupoles

- Horizontal emittance is reduced to 1/3 from 6.3 nm rad to 2.2 nm rad
- Brightness is inversely proportional to emittance

Emittance would be as low as any existing light source

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Modest Lattice Upgrade with Big Benefits

• **Brightness**
  — More than 3 times the brightness for central bend and Superbend beamlines
  — Up to 2 times (with more speculative lattices even more) the brightness for soft x-ray beamlines

• **Additional Benefits: Short Pulses**
  — 500 MHz picosecond pulses at reduced currents
  — Coherent Terahertz Radiation
Superbend Beamsize

Horizontal Beamsize at Superbends reduced to 30%

223 microns (FWHM)  68 microns (FWHM)
New sextupoles = increasing the brightness

Led by Christoph Steier and Arnaud Madur

- Horizontal emittance is reduced by factor of 3 to 2.2 nm rad

Of existing light sources, only PETRA-III has a lower emittance

- Brightness is inversely proportional to emittance
- Project received funding in summer 2009
- Passed comprehensive project review
- Close to awarding contract for magnets
- On track for completion of project by end of FY13

$5.8M (ARRA) funding from BES
U10 Undulator

- 10.0 cm period, 43 periods
- 12 – 1500 eV energy range (@ 1.9 GeV)

www.xfel.spring8.or.jp/cband/j/Undulator.htm
U10 Undulator
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Spherical Grating Monochromator

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**U10 Undulator**
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**Spherical Grating Monochromator**
- 3 gratings: 380, 925, and 2100 lines/mm

[Website](www.xfel.spring8.or.jp/cband/j/undulator.htm)
Beamline 10.0.1

U10 Undulator
• 10.0 cm period, 43 periods
• 12 – 1500 eV energy range (@ 1.9 GeV)

Spherical Grating Monochromator
• 3 gratings: 380, 925, and 2100 lines/mm
• 17 – 340 eV energy range

<table>
<thead>
<tr>
<th>Grating</th>
<th>Ruling (lines/mm)</th>
<th>Energy Range (eV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>380</td>
<td>17 – 75</td>
</tr>
<tr>
<td>Medium</td>
<td>925</td>
<td>40 – 170</td>
</tr>
<tr>
<td>High</td>
<td>2100</td>
<td>100 – 340</td>
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# Characteristics of Beamline 10.0.1

<table>
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<tr>
<th>Characteristic</th>
<th>Details</th>
</tr>
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<tbody>
<tr>
<td>Energy range</td>
<td>17 eV to 350 eV (73 nm to 5 nm)</td>
</tr>
<tr>
<td></td>
<td>11 eV to 350 eV (future) (112 nm to 5 nm)</td>
</tr>
<tr>
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<td>From $10^{12}$ to $10^{14}$ photons/s depending upon resolution</td>
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### High Flux

- Photon Flux (photons/s)
  - 380 l/mm
  - 925 l/mm
  - 2100 l/mm

### High Resolution

- Photon Bandpass (meV)
  - Resolution with 10μm slits
  - 380
  - 925
  - 2100

---

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Three Branch Lines (2 for AMO)

Solid State PES (HERS)  Ion Photon Beamline (IPB)

Gas Phase PES (HiRAMES)

8.50 m
Some of the AMO endstations

High Resolution e- Spectrometer

Angle-resolved photoelectron spectroscopy

Velocity Map Imaging

Ion-Photon Merged Beams Apparatus
Take home message and questions

• ALS is a mature 3rd generation light source that stays competitive by constantly having important upgrades.
• Plans to “split” the undulator or beamline 10.
Take home message and questions

• ALS is a mature 3rd generation light source that stays competitive by constantly having important up-grades.
• Plans to “split” the undulator or beamline 10.

• Building and operating a beamline in an existing ring for few years?
• Heavy ion storage ring? (non in the US or the Americas)
Gracias por su atención
Status of New IDs

- **5 cm EPU (PEEM3)**
  - Similar to 3 others that had been installed in the ring already
  - First shimmed for dynamic multipoles

- **In-Vacuum ID (Femtoslicing)**
  - First in-vacuum device
  - Smallest gap (5mm vacuum)
    - Next smallest gap is 9mm
  - New Lattice for Femtoslicing
    - 12 skew quadrupoles added

- **9 cm QEPU (MERLIN)**
  *Most challenging device to be installed*
  - First quasiperiodic EPU
  - First large period EPU
  - Compensation for...
## Status of New IDs

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  - Compensation for

---

**EPU shimming**

![EPU shimming graph](image)

**New Femtoslicing Lattice**

![New Femtoslicing Lattice](image)

C. Steier et al., 2007 Particle Accelerator Conference, Albuquerque, New Mexico, June 2007