ALS-U Project Beamlines

Introduction

The ALS-U Project is an ongoing upgrade of the Advanced Light Source (ALS) at Berkeley Lab that will endow the ALS with revolutionary x-ray capabilities. Although most existing ALS beamlines will remain as part of the upgraded facility, the ALS-U Project will include a small number of new and rebuilt beamlines designed to exploit the new high-brightness source.

The selection process to determine those beamlines formally began in October 2017 and concluded in January 2019. Community input on potential new and upgraded beamlines was solicited through User Meeting workshops, crosscutting reviews, online user forums and feedback forms, ALS staff discussions, and Users' Executive Committee (UEC) meetings. A working group consisting of ALS staff and UEC leadership synthesized the input into a series of possible scenarios that were evaluated by external advisory committees, which then made a recommendation to the ALS-U project director.

The selection criteria for determining the beamlines were:

- Scientific importance
- Relevance of ALS-U characteristics and potential world leadership
- Technical feasibility and fit to project resources
- Strength of the relevant user community and expected productivity

This document outlines the selected beamlines, which will be built inside the scope of the ALS-U Project. These beamlines will enable the ALS-U Project to meet the U.S. Department of Energy Office of Basic Energy Sciences mission need by providing the advanced capabilities necessary to observe and understand materials and material phenomena in real time as they emerge and evolve.

Throughout the ALS-U Project and beyond, the ALS will continue to innovate with new and upgraded experimental systems, many of which will benefit from ALS-U characteristics. The input and advice from the ALS-U beamline selection process will inform ALS strategic planning and future projects.

Beamline Overview

The ALS-U Project will build two new beamlines—a soft x-ray beamline in Sector 10 dubbed "FLEXON" and a tender x-ray beamline in Sector 8. It will also upgrade two existing soft x-ray beamlines in Sector 7, COSMIC and MAESTRO. The specifications of these beamlines are listed in Table 1, and their layout in the ALS facility is shown in Figure 1.

New Soft X-Ray Beamline

Sector 10 will house the FLEXON beamline (FLuctuation and EXcitation of Orders in the Nanoscale), a high-brightness coherent soft x-ray beamline for probing the roles of multiscale heterogeneity in quantum materials. FLEXON will integrate multiple complementary techniques to provide the powerful multimodal probes required for revolutionary progress in understanding the complex physics of quantum materials.

The beamline will be illuminated by a full-length insertion device that will serve two branchlines. One branch will be optimized for high efficiency and medium energy resolution for x-ray photon correlation spectroscopy (XPCS) and nano-focused resonant soft x-ray scattering (nRSoXS). The second branch will provide x-rays with high energy resolution in a nano-focused spot and will be optimized for nano-focused resonant inelastic x-ray scattering (nRIXS). The energy range of operation will be 400–1400 eV with full polarization control.

Table 1: Specifications of the new and upgraded beamlines for the ALS-U Project.

Beamline	Techniques	Monochromator, energy resolution, spot size	Insertion device	Core energy range (extended range)	Polarization
FLEXON (new beamline)	XPCS, nRSoXS, nRIXS 3 endstation ports	Branch 1: E/ΔE = 5000, focus: 1 µm (XPCS) and ≤50 nm (nRSoXS) Branch 2: E/ΔE ≥20,000, focus: ≤100 nm (nRIXS)	Full-length Delta or EPU	400–1400 eV (400–1800 eV)	Variable linear, Circular
TENDER (new beamline)	STXM, coherent scattering 2 endstation ports	Branch 1: Grating mono, focus: 10 µm Branch 2: Crystal mono, focus: 100 nm	Full-length in vacuum	1–5 keV (up to 8 keV at 2^{nd} branch)	Linear
COSMIC (beamline upgrade)	STXM, Ptychography	Unchanged after the upgrade	Existing EPU	250–2500 eV	Variable linear, Circular
MAESTRO (beamline upgrade)	nARPES, micro-ARPES, PEEM	Layout unchanged after the upgrade	Existing EPU	20–1000 eV	Variable linear, Circular

Each technique leverages the enormous gains in coherent brightness provided by the upgraded source, enabling wholly new measurement regimes. XPCS experiments will achieve three to four orders of magnitude improved time resolution over the current ALS, while the nRIXS and nRSoXS capabilities will enable measurements with 100-fold improved spatial resolution.

The ARPES program currently housed in Sector 10 will merge with existing ARPES programs at Beamlines 4.0.3 and 7.0.2. The strengths of these two beamlines are evolving, with 4.0.3 excelling at high resolution with some materials growth and 7.0.2 focusing more on materials discovery with high throughput. Increasingly, ARPES users are using other ALS tools, notably capabilities that will be available at the FLEXON beamline.

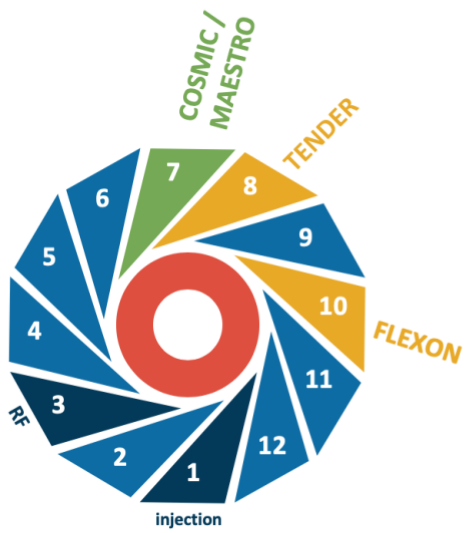

Figure 1: Future ALS facility layout, showing location of upgraded (green) and new (yellow) beamlines. Sector numbers are shown and refer to the first numeral in a beamline's number.

New Tender X-Ray Beamline

Sector 8 will house a new tender x-ray beamline designed to address challenges at the frontiers of diverse scientific areas, ranging from soft condensed matter and biomaterials to energy science and Earth and environmental sciences.

The beamline will be served by a single, full-length in vacuum undulator and will comprise two branchlines. One branch will use a grating monochromator and will have a target energy range of 1–5 keV. It will feature coherent scattering capabilities enabling operando and in situ studies of materials in the tender energy range. The second branch will use a crystal monochromator to examine an extended energy range from 2–8 keV. This higher-energy branch will be optimized for scanning transmission x-ray microscopy (STXM).

The brightness of the upgraded ALS in this energy range, when coupled with advanced detectors and experimental systems, will allow for coherent x-ray scattering with micro-second time resolution and scanning spectromicroscopy with few-nanometer spatial resolution. Importantly, the proposed core energy range uniquely allows simultaneous coverage of absorption K-edges of elements (Na through Ca) most important to a host of research topics in Earth, environmental, energy, and soft condensed matter sciences. The combination of large penetration depth and optics with long working distance will uniquely enable operando sample environments for complex materials characterization with chemical sensitivity.

The chemical RIXS/XAS programs currently housed in Sector 8 will migrate to the new AMBER beamline over the next year. AMBER deploys a modern-design plane grating monochromator on a half-length undulator, while Sector 8 uses an older spherical grating monochromator on a full-length undulator. AMBER will provide better energy resolution and comparable throughput.

Upgraded COSMIC Beamline

The ALS-U Project upgrade of COSMIC will consolidate the ALS's insertion-device STXM instruments (currently occupying 7.0.1.2 and 11.0.2.2) on a single straight section. Following the upgrade of the beamline optics, the full brightness of the upgraded ALS will be available for zone-plate-based microscopy, ptychography, and 3D tomography, all of which require coherent illumination of the zone plate and the sample. The upgrade will lead to an up to hundred-fold increase in measurement speed and an improvement in spatial resolution down to 1 nm.

The current COSMIC beamline has already demonstrated an imaging capability that extends our achievable spatial resolution not only beyond current conventional soft x-ray STXM but also beyond scanning x-ray microscopy at any x-ray energy. The upgraded COSMIC imaging beamline will have a suite of instruments available to meet the demands of a diverse user community. Coupled to this instrument will be unparalleled combined expertise in nanofocusing, nano-positioning, x-ray sample environments, x-ray detectors, x-ray spectromicroscopy, and high-performance computing for x-ray data analysis.

Upgraded MAESTRO Beamline

The MAESTRO beamline is one of the newest operating ALS beamlines, and makes use of zone-plate and reflective focusing optics to investigate the electronic, chemical, and morphological structure of in situ deposited materials using scanning probe and full-field angle-resolved photoemission spectroscopy (ARPES) instrumentation. The high-throughput, high-resolution bandmapping instruments are microARPES (µARPES) and low-energy/photoemission electron microscopy (LEEM/PEEM), which each employ microfocus beams. The beamline's most novel feature is the new nanoARPES (nARPES) chamber with world-record ARPES spatial resolution of around 110 nm currently. In addition to spectroscopic capabilities, MAESTRO features a unique and comprehensive suite of interconnected sample preparation tools, enabling deposition by diverse methods of molecular beam epitaxy, pulsed laser deposition, mechanical exfoliation, or arbitrary combinations of the three. These tools, together with the small probe beams, enable the creation and study of high-throughput library samples, with the potential to apply ARPES as a high-throughput materials discovery tool for the first time.

The ALS-U Project will carry out an upgrade to the MAESTRO beamline's optics, enabling it to take full advantage of the improved coherence of the upgraded ALS, and thereby improving the ARPES collection efficiency by more than an order of magnitude. This will enable much better spatial resolution, faster measurements, and more comprehensive data sets. In turn, these improvements will allow much faster materials discovery, as well as better spatial and momentum resolution for mesoscopic materials.