Stanford Synchrotron Radiation Lightsource (SSRL)

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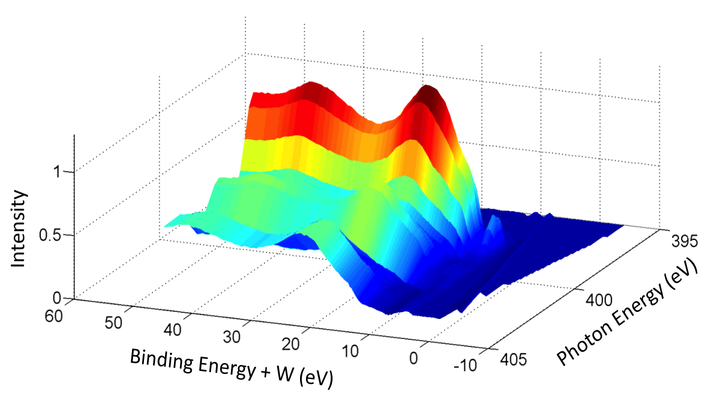
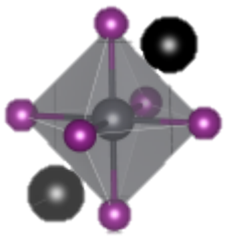
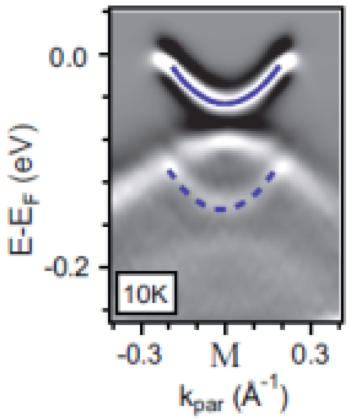
http://www-ssrl.slac.stanford.edu/toneygroup

Outline

1. SSRL & Synchrotron Radiation
   - What is SSRL?
   - What is Synchrotron Radiation?
2. Research Focus
   - How do we use X-rays?
   - Quantum materials (strongly correlated electron systems)
   - Energy materials research
3. Opportunities for grad students

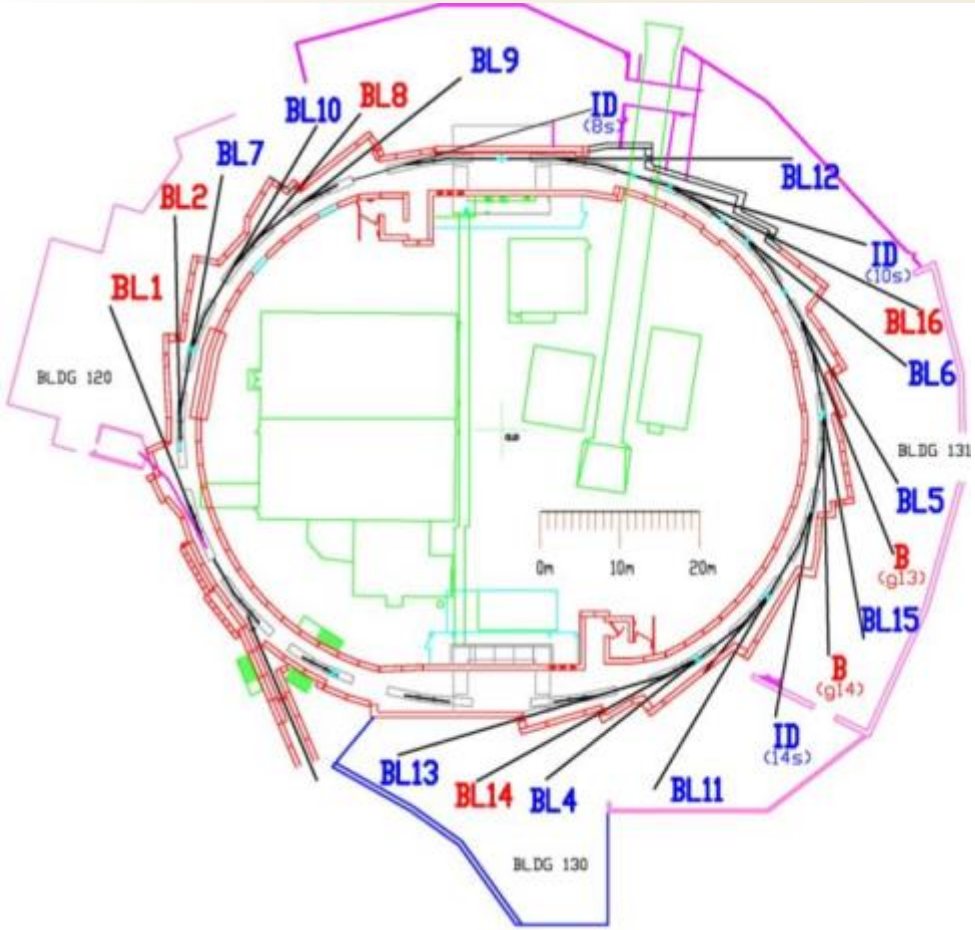


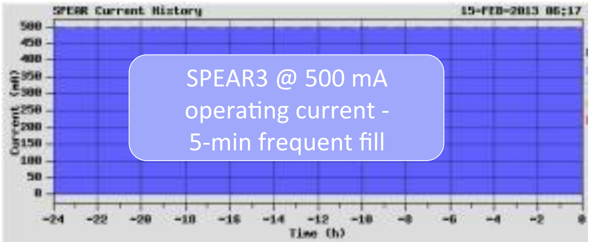




SSRL Overview

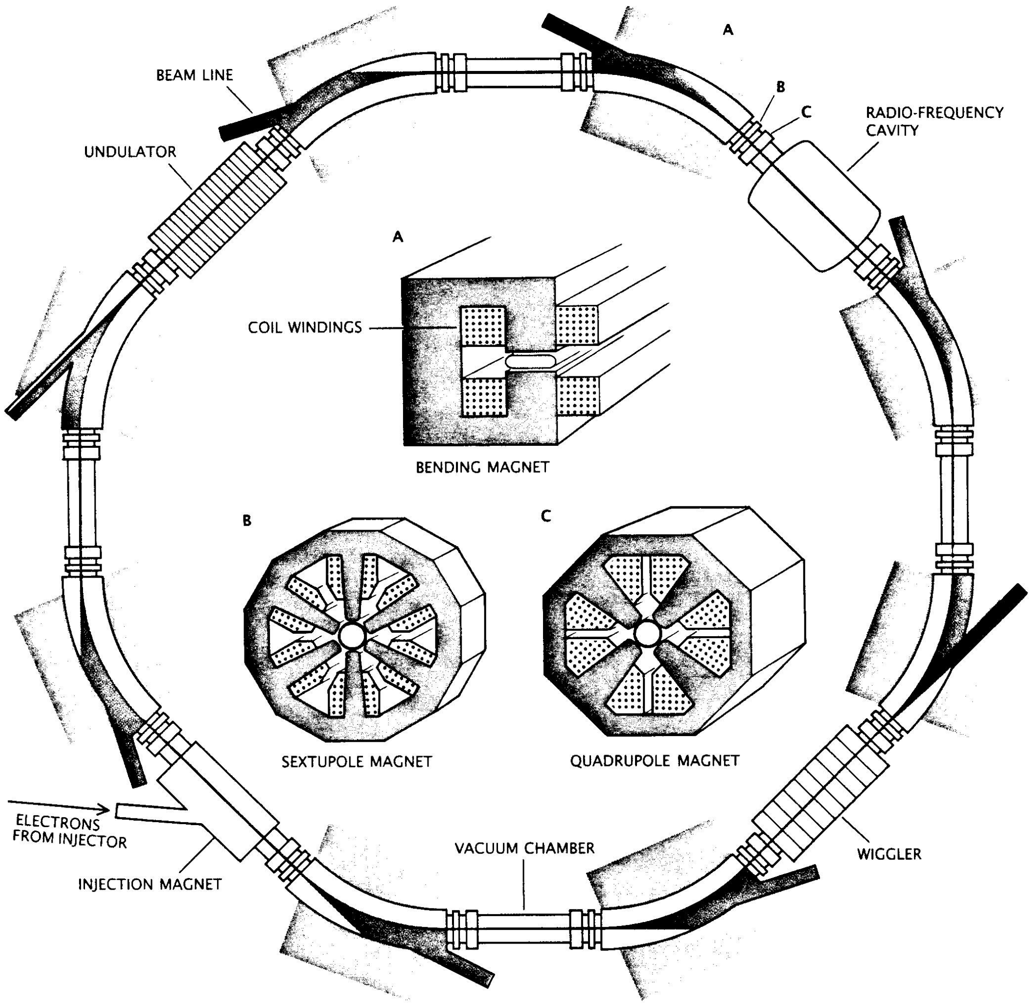
SSRL Overview



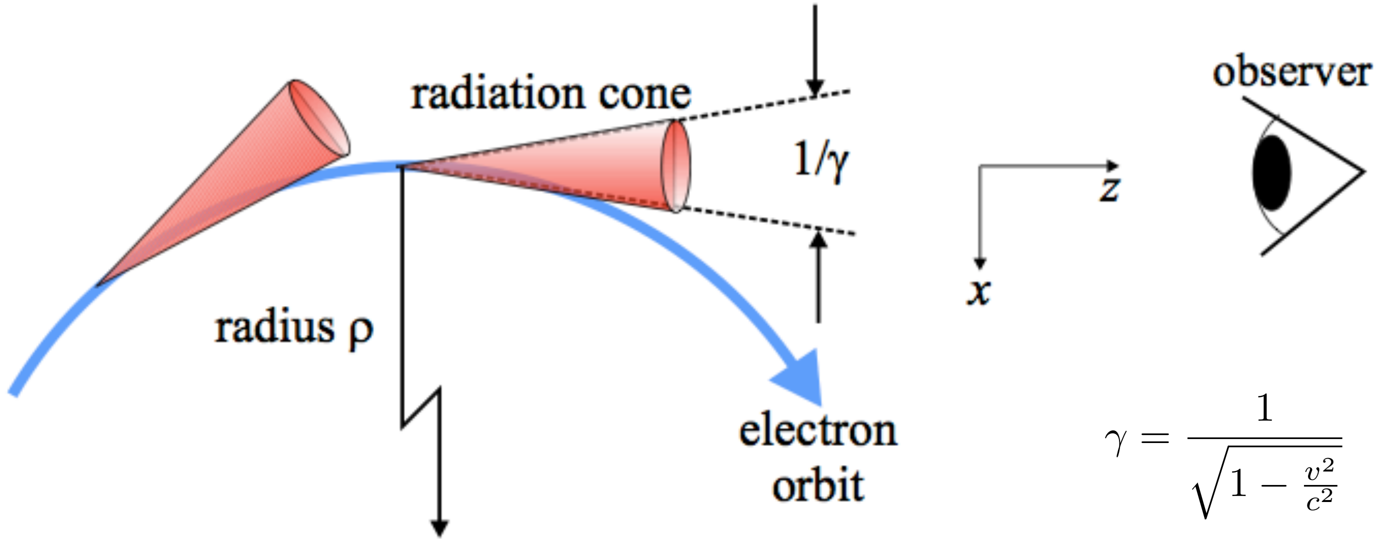


- SPEAR3
  - New ring - 2004
  - 3 GeV, <u>500 mA</u>
  - Top-off injection every 5 minutes
  - Reliability >97%; > 5,100 hrs/yr
  - 6 nm-rad emittance
- operates 33 stations
- supports ~1,600 user annually
  - Annual growth >5%
- >400 journal pubs/yr, 1/3 hi-impact
- **~50 thesis per year**
  - Strong educational focus
- Strong programs in quantum materials, energy materials

SSRL Overview



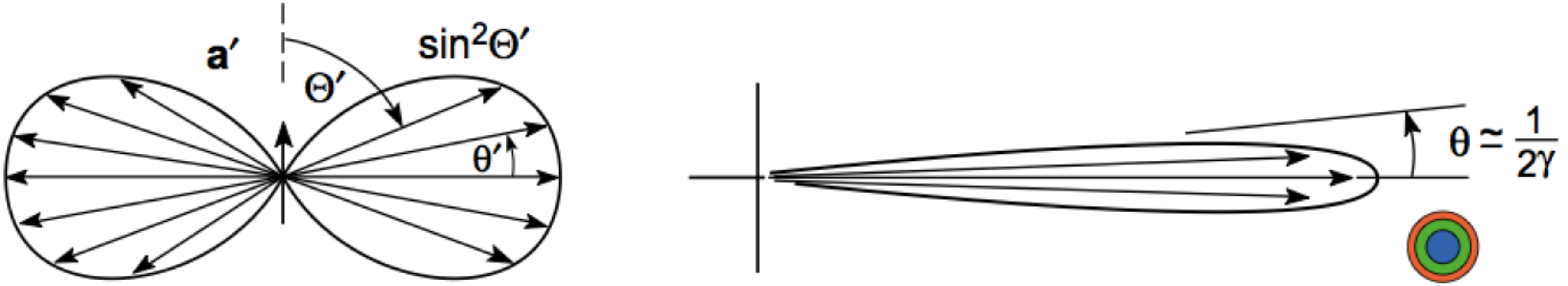
c/o Aaron Lindenberg



$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}$$

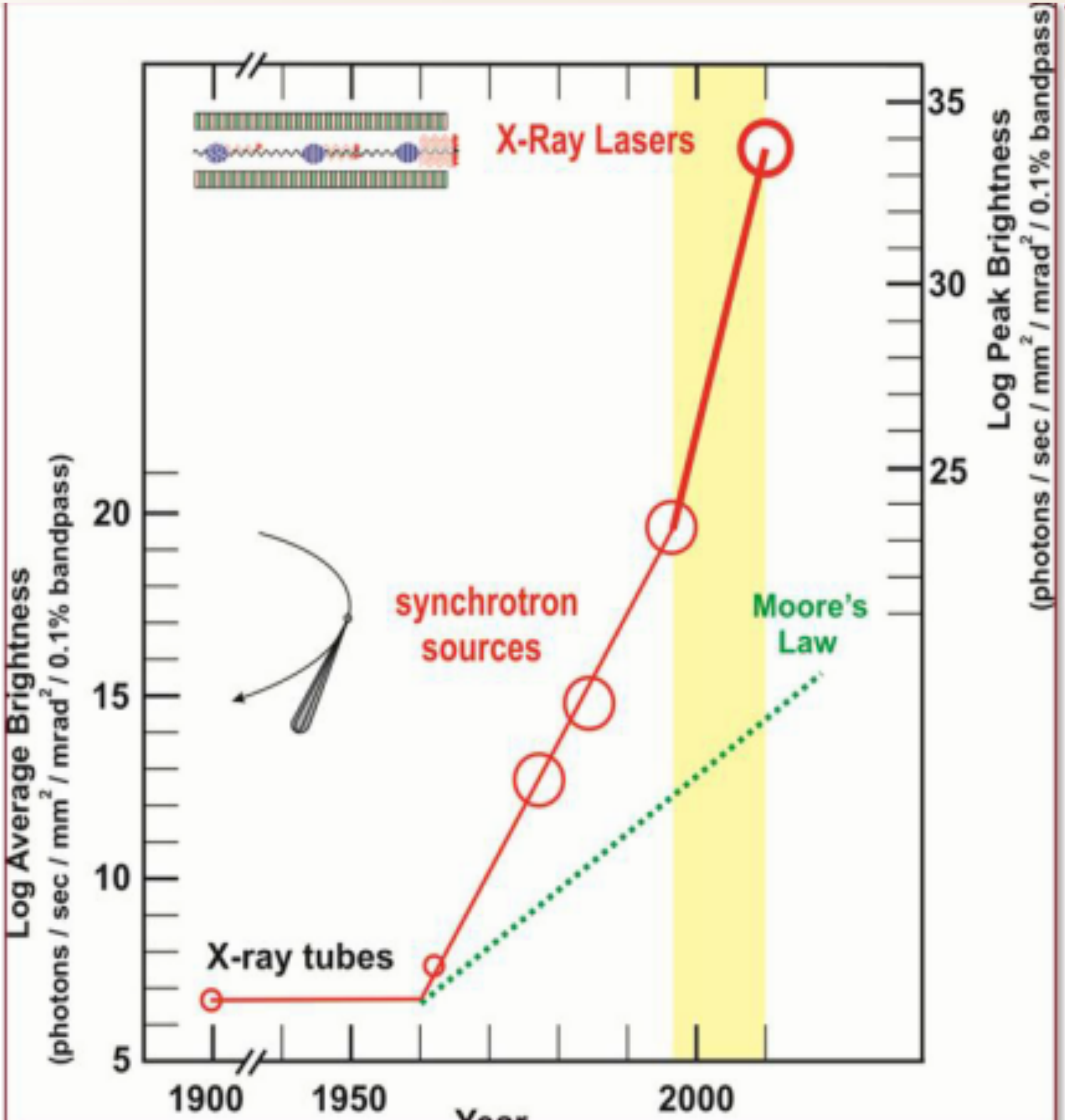
Frame moving with electron

Laboratory frame of reference



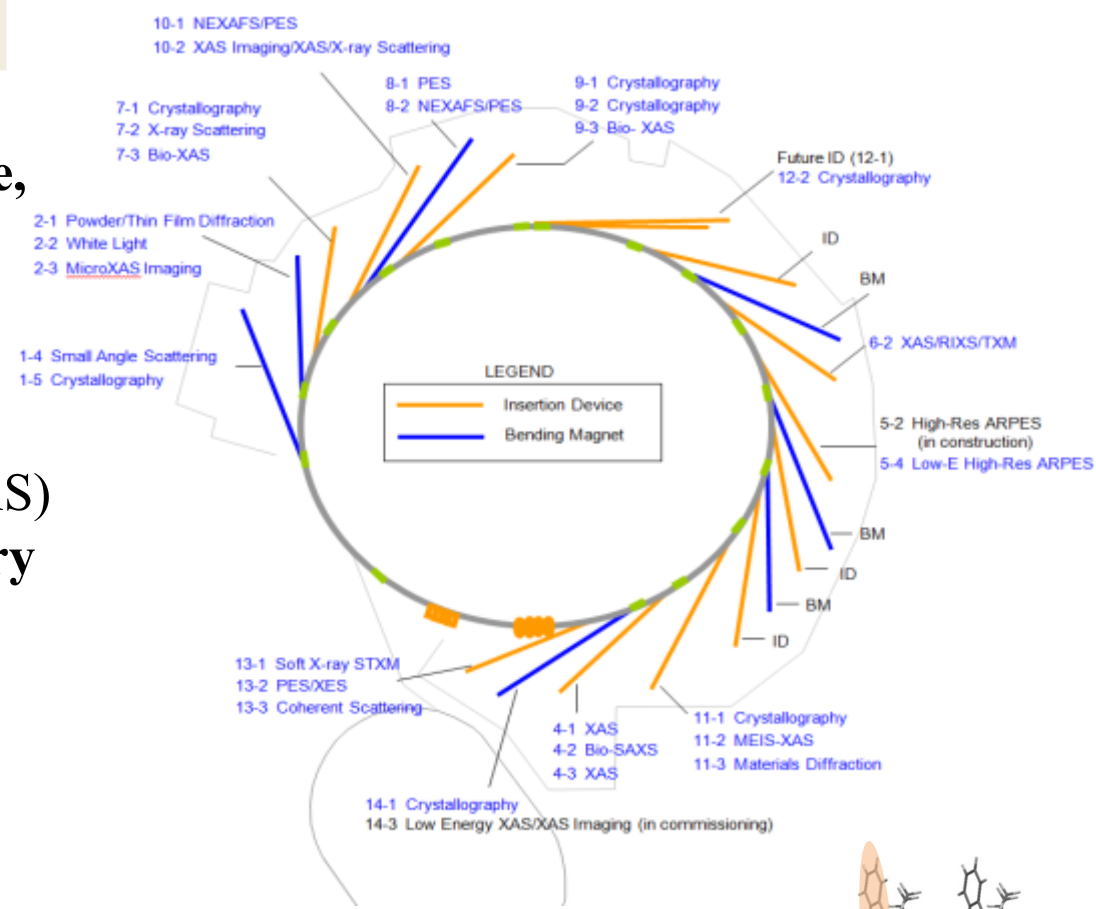
c/o Aaron Lindenberg

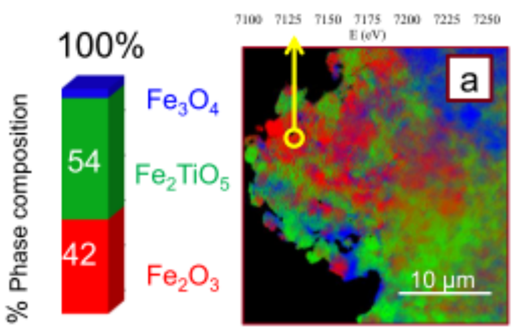
SLAC: Synchrotron Radiation

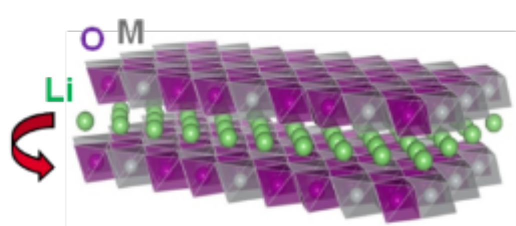


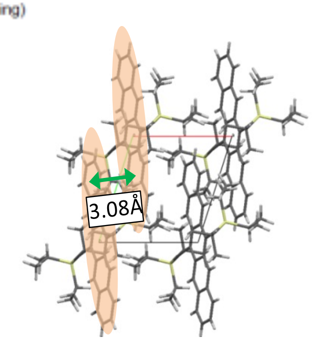
X-ray Beamlines / Techniques

- X-ray Scattering/Diffraction
  - ➢ **Crystallite Properties, Phase, Defects**
- X-ray Microscopy (XM)
  - ➢ **10s nms morphology & topography**
- X-ray Absorption Spectroscopy (XAS)
  - ➢ **Local Structure & Chemistry**
- Photoemission Spectroscopy
  - ➢ **Electronic structure**







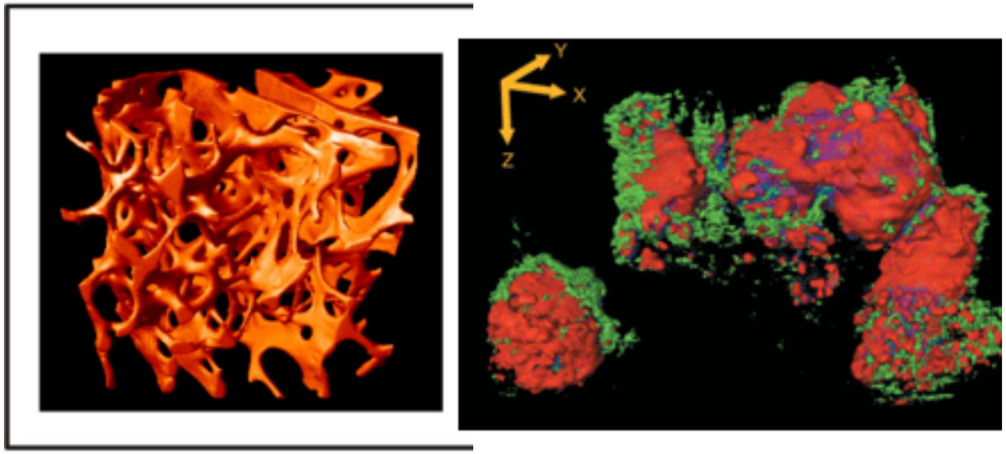


Printed film, strained
Fast charge transport

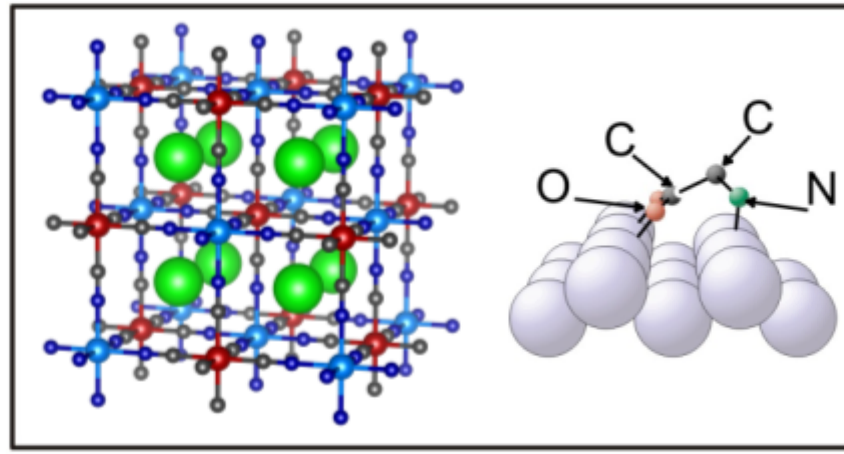
X-Rays - Seeing the Invisible

SLAC

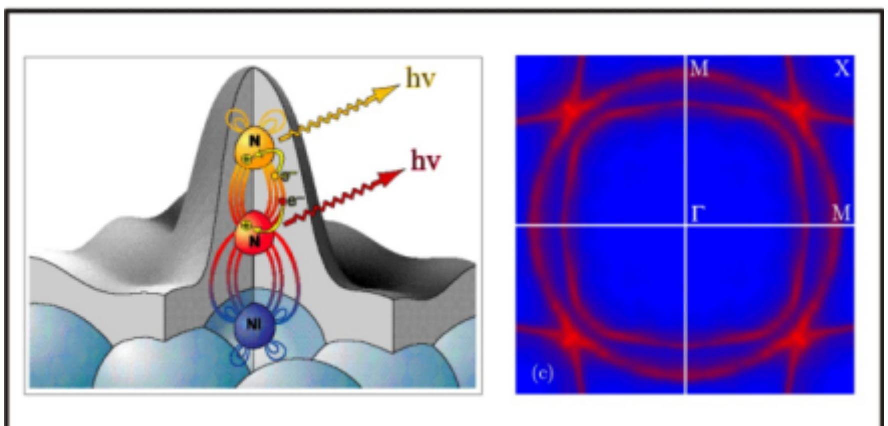
Nanostructures



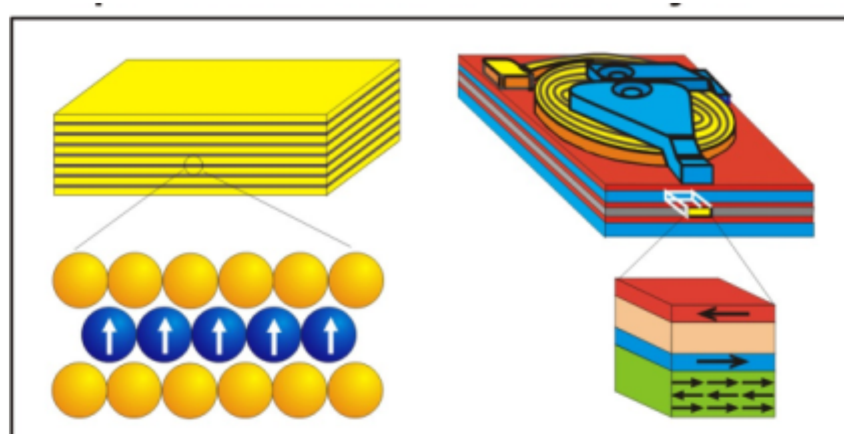
Positions of Atoms & Molecules



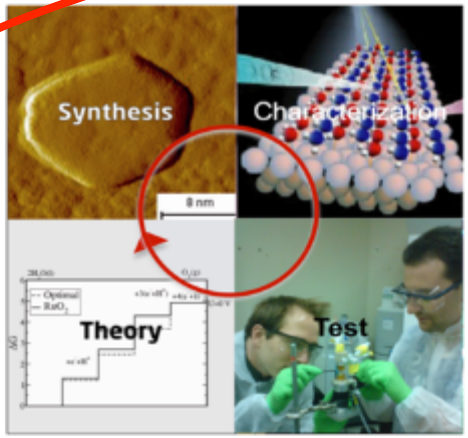
Electron Distributions &Dynamics



Spin Distributions & Dynamics

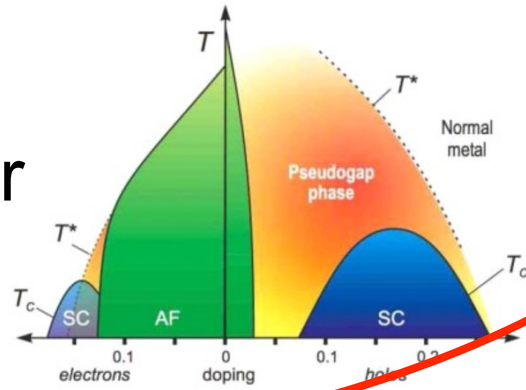


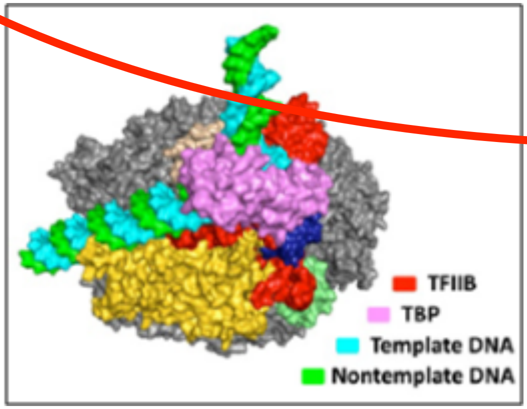
SSRL Enables & Supports World-class Science in Targeted Areas



Materials by Design

Emergent Behavior





Complex Bio-processes

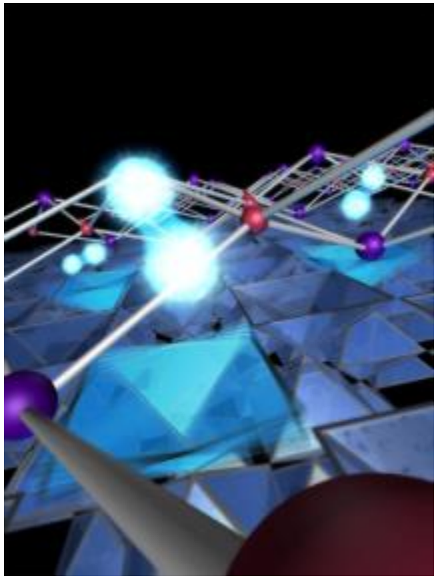
Substrate phonons enhance superconductivity at the interface

Scientific Achievement

SIMES researchers have discovered a mode coupling between electrons in iron selenide (FeSe) and phonons in strontium titanate (STO) which enhances the superconducting transition temperature in the interfacial layer of FeSe.

Significance and Impact

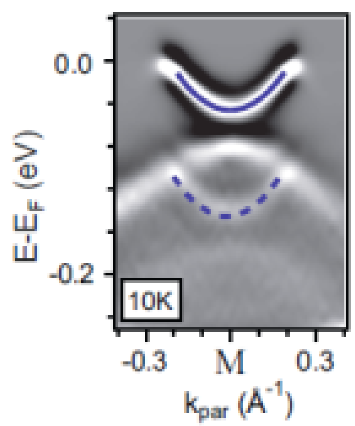
This coupling points to ways of possibly engineering materials with higher T_c and also gives insight into the general mechanism behind high-T_c superconductivity.



Research Details

- Used molecular beam epitaxy (MBE) to grow single-unit-cell-thick films of FeSe on STO, which were studied *in-situ* with angle-resolved photoemission spectroscopy (ARPES).
- Observed “shakeoff” bands in the ARPES spectra, indicating electron-phonon coupling of a very specific nature.
- Extracted the electron phonon coupling magnitude and calculated the enhancement of T_c, which agrees with other experiments.

Right: Image representing interfacial electron-phonon coupling. Bottom: Band structure showing the shakeoff bands.



J.J. Lee, F.T. Schmitt, R.G. Moore et. al., *Nature* 515, 245 (2014).

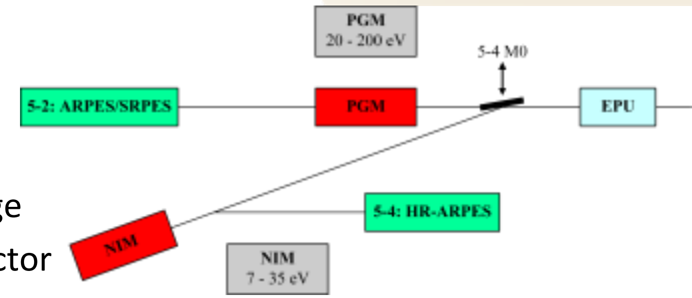
Work was performed at Stanford University and SSRL, SLAC

BL5: A state-of-the-art ARPES facility

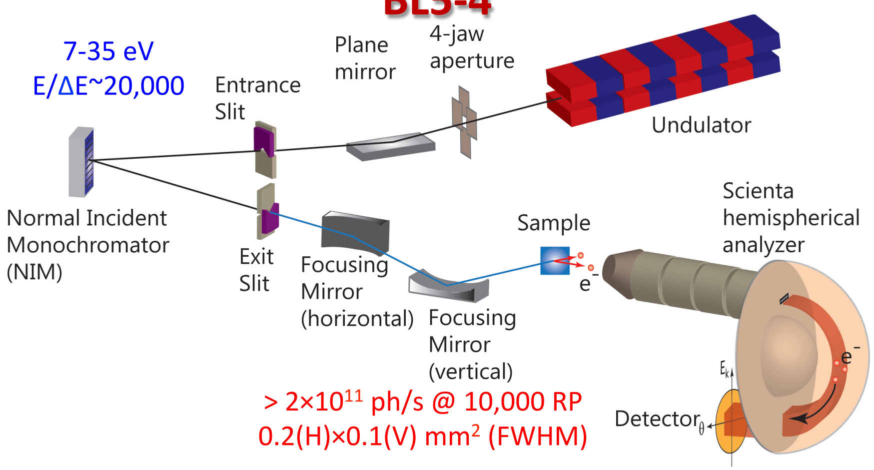
- Excellent control of the photon polarization (7-200 eV)
  - EPU: 2.33 m, 31 pole, LH, LV, CL, CR
- Two complementary branch lines/end stations
  - NIM branch line: high resolution, high stability, low photon energy range
  - PGM branch line: high flux, wider photon energy, small spot, spin-detector
- Sophisticated material synthesis chamber

⇒ *Enable rich science with both depth and diversity*

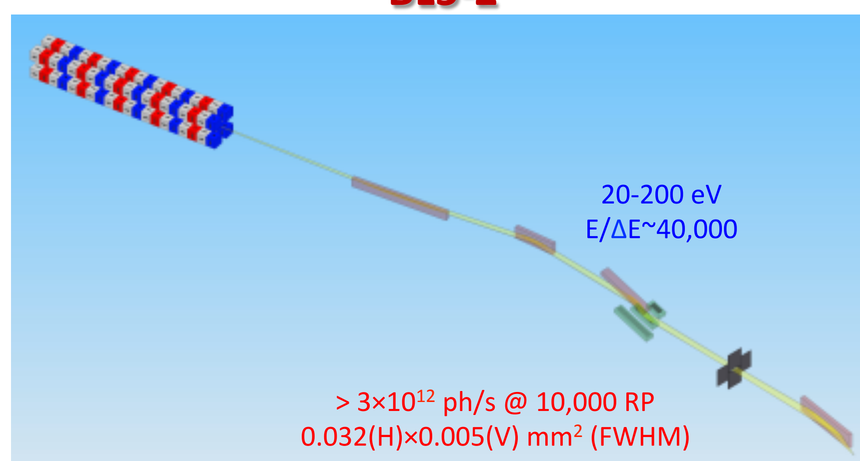
- **High Tc superconductors;**
- **Materials with novel spin-orbit physics;**
- **Novel low dimensional materials;**
- **Surface and interface…**



BL5-4



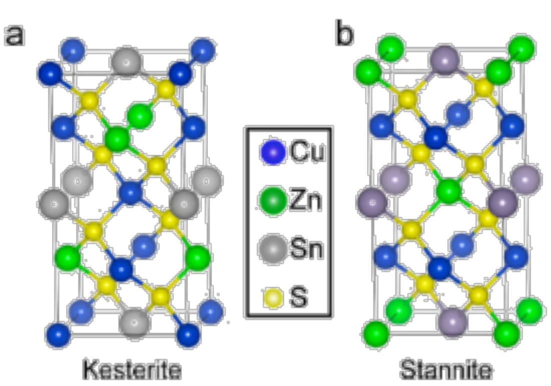
BL5-2

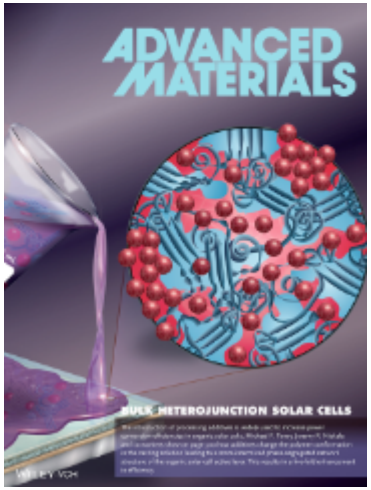


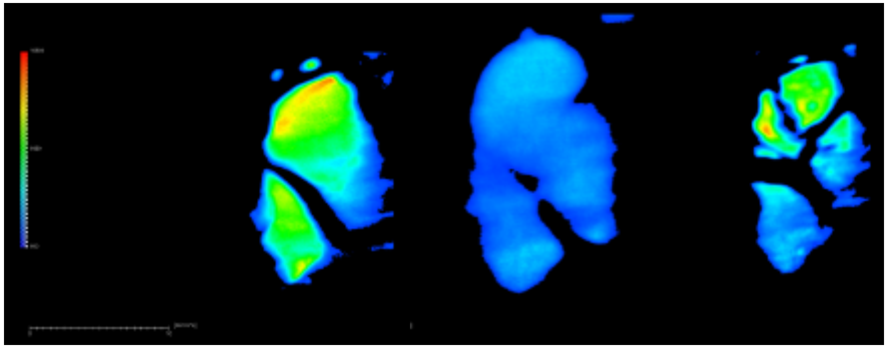
Sustainable Energy Materials Research

Sustainable (Renewable) Energy - Materials and Processes – *In-Situ*

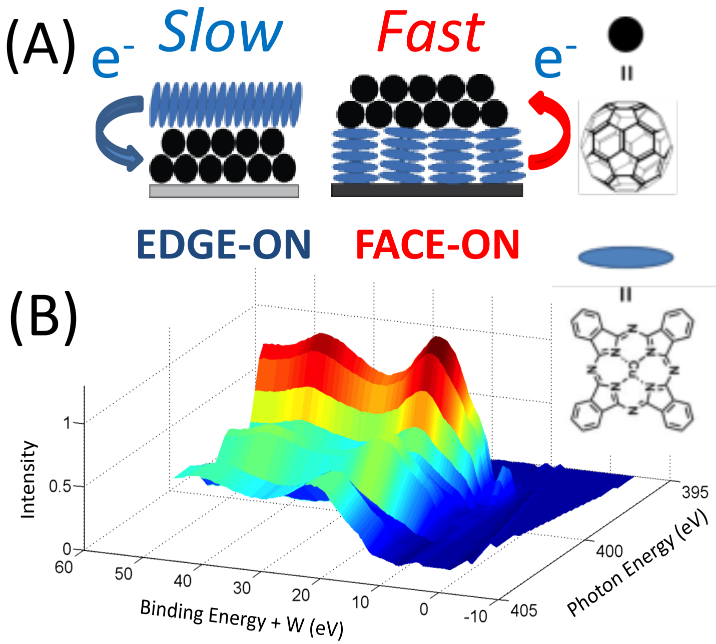
- Photovoltaics (PV)
  - Si contacts, CIGS, CZTS, OPV, RTP, printing, …
- energy storage
  - anodes: Si, Ge, Sn, alloys, Mn hexacyanomanganate, …
  - cathodes: $LiMnNiCoO_x$, $LiFePO_4$, sulfur, Cu hexacyanoferrate, …







Effect of Molecular Orientation on Ultrafast Electron Transfer



Resonant Electron Spectroscopy shows that donor/acceptor electron transfer is faster at face-on vs. edge-on orientations. (A) Cartoon illustrating the relative orientations between the Cu phthalocyanine donor (blue) and C_{60} acceptor (black). (B) Resonant Auger electron spectra, which were used to measure the branching ratio of Auger electron decay processes. This branching ratio is related to the average time it takes an electron to hop from the excited donor to a nearby acceptor.

Scientific Achievement

Measured dependence of photoexcited electron transfer rate on relative molecular orientation an organic heterojunction interface.

Significance and Impact

Showed that face-on interfaces (larger intermolecular π-electron overlap) have significantly faster electron transfer rates at donor/acceptor interfaces and that control of relative molecular orientation is important to maximize charge generation in organic solar cells.

Research Details

- The core-hole clock implementation of resonant Auger electron spectroscopy was used to measure electron transfer rates on ultrafast sub-50 fs time scales.
- Face-on interfaces show electron transfer (ET) times below 35 fs, whereas edge-on interfaces lead to ET times of > 50 fs.

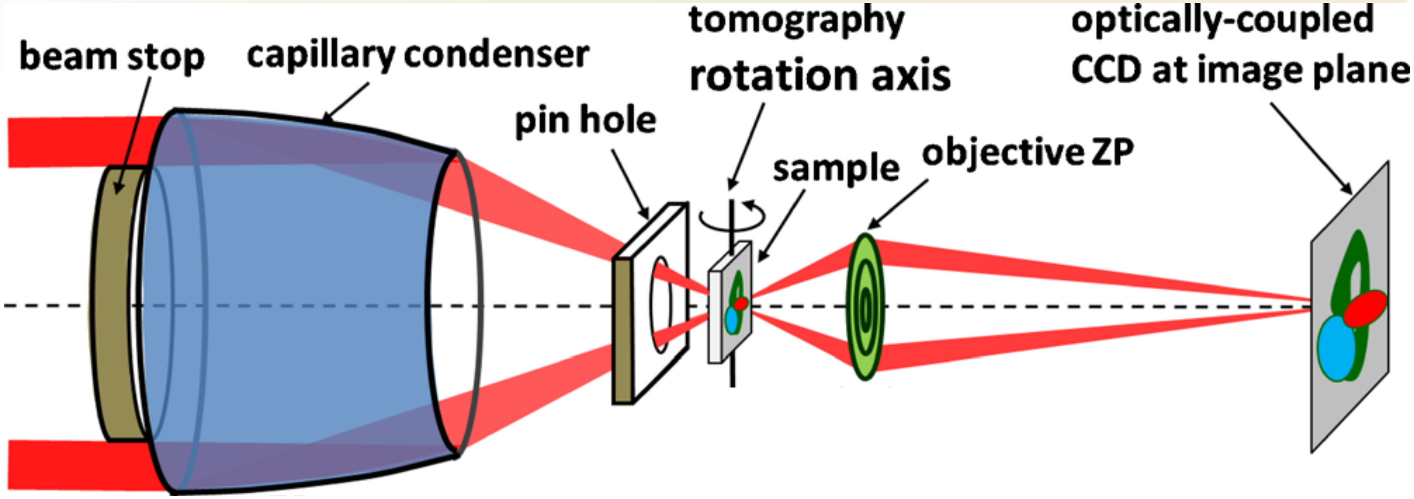
A.L. Ayzner, D. Nordlund, D.H. Kim, Z. Bao, M.F. Toney *J. Phys. Chem. C* **6**, 6-12 (2015)

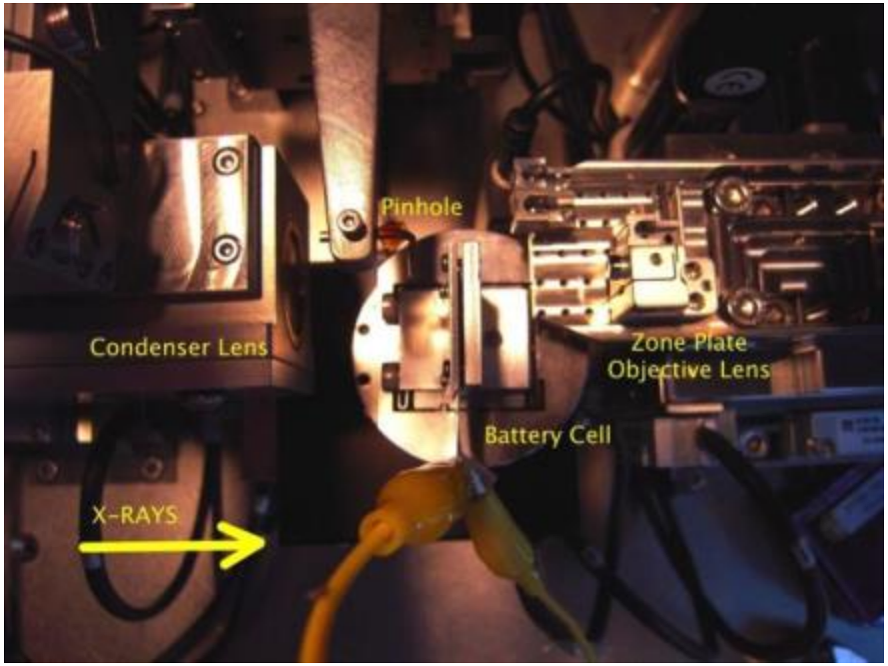
Work performed at Stanford University and Stanford Synchrotron Radiation Lightsource

U.S. DEPARTMENT OF ENERGY | Office of Science

KAUST SSRL SLAC

Transmission X-ray Microscopy



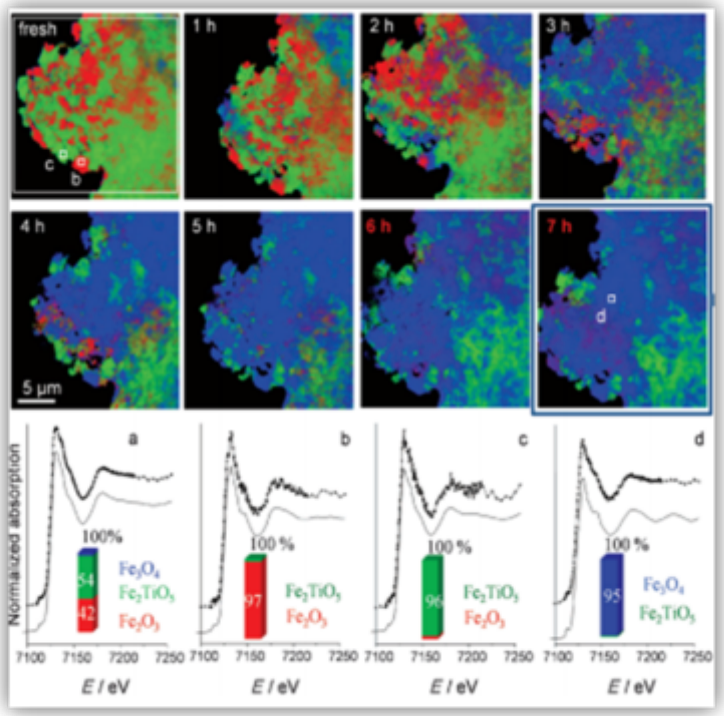


Capabilities:

- Morphology – 30 nm resolution.
  30 µm field of view
- 2D & 3D imaging (density, porosity)
- Elemental/chemical maps

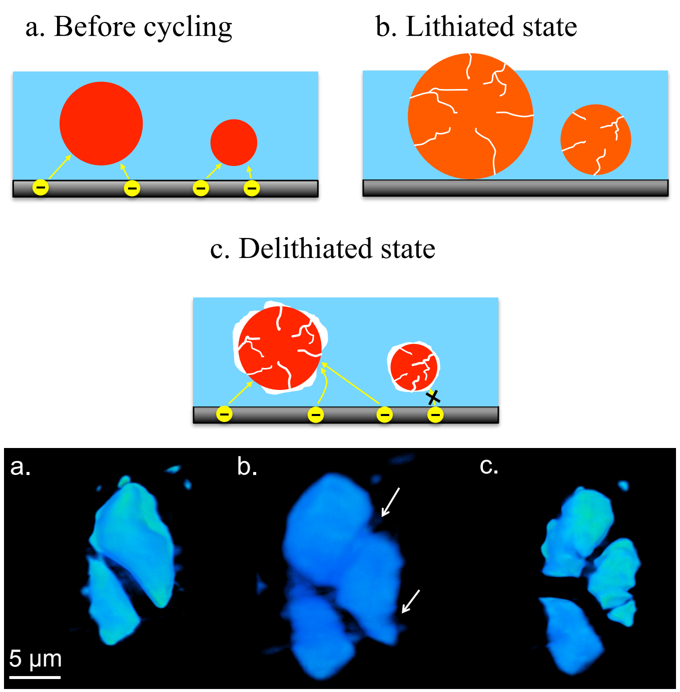
Transmission X-ray Microscopy

Imaging 1895



Imaging now

2D and 3D *in Situ* Imaging of Battery Anodes



Upper: Schematic showing irreversible deformation of the conductive carbon matrix (blue) electronically isolates the small particles, making them inactive in the second cycle.
Lower: Volume rendering of Ge particles (a) before cycling, (b) after lithiation, and (c) after delithiation

J. Nelson Weker, N. Liu, S. Misra, J. C. Andrews, Y. Cui, M. F. Toney, *Energy Environ. Sci.* **7,** 2771 (2014).

Work was performed at Stanford Synchrotron Radiation Lightsource

Scientific Achievement

Operando **imaging shows size dependent cycling characteristics of Ge particles.** ***In situ*** **3D imaging demonstrates fracturing of anode material into completely unconnected pieces.**

Significance and Impact

This work demonstrates the value in linking electrochemical performance with morphological evolution to better understand battery failure and further the search for high capacity electrode materials.

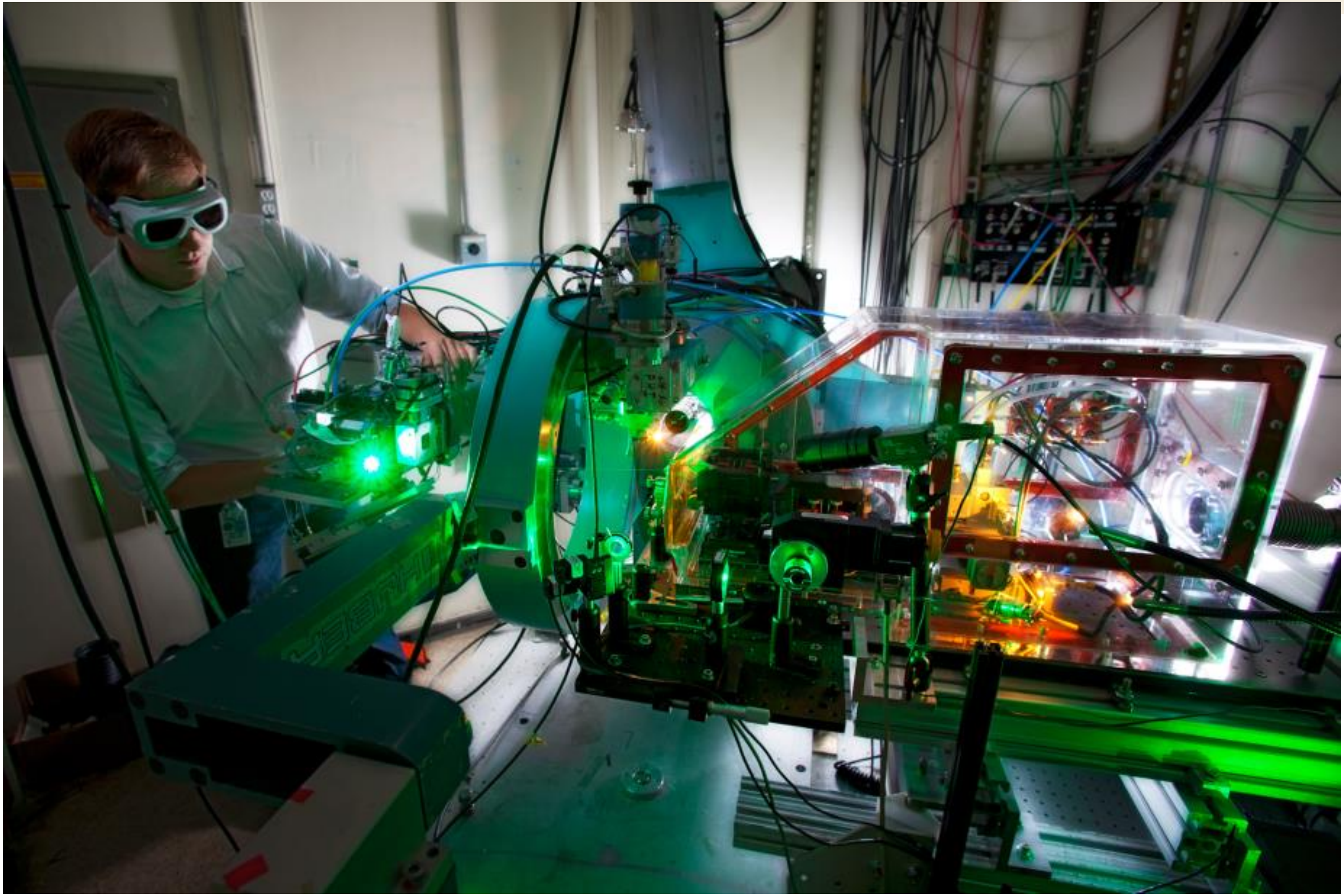
Research Details

– Only Ge particles with diameters larger than a few microns crack during cycling.

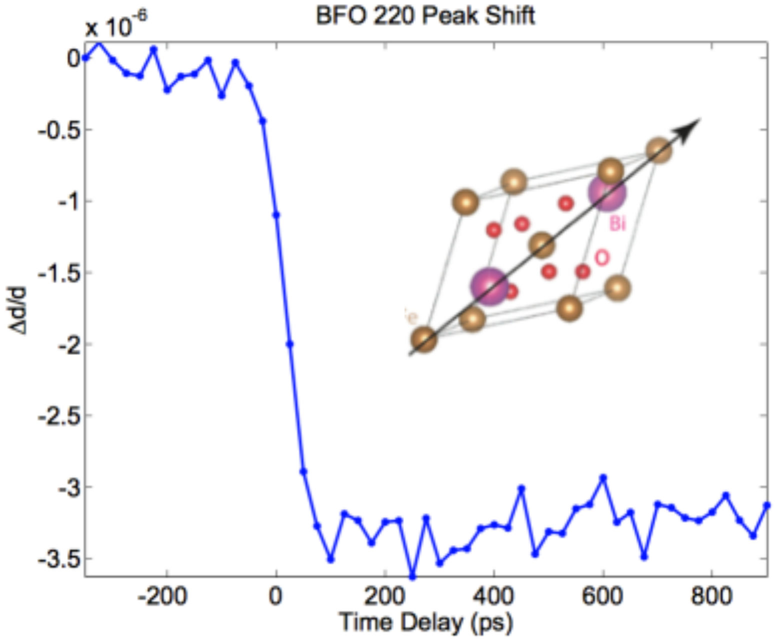
– Small particles lose electrical contact by the second cycle.

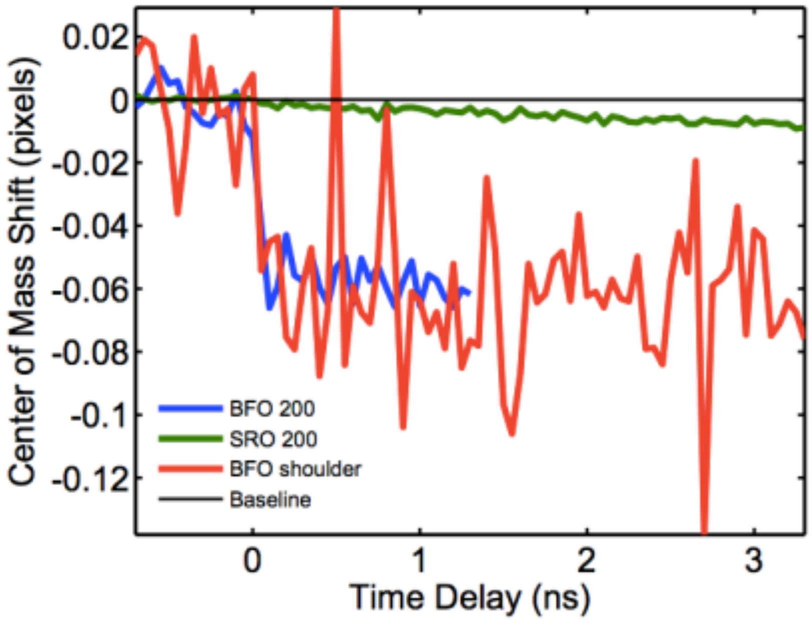
– The density changes due to lithiation are consistent with partial transformation into a $Li_{15}Ge_4$-like phase.

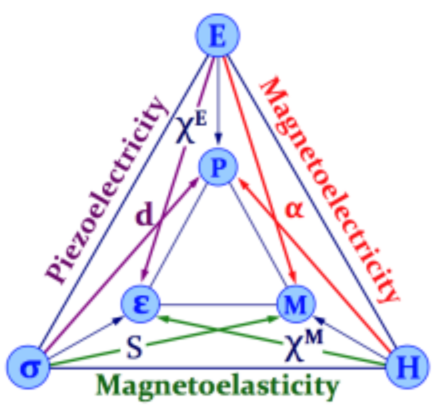
Time resolved X-ray Science



Multiferroic thin films; Ultrafast thermal transport





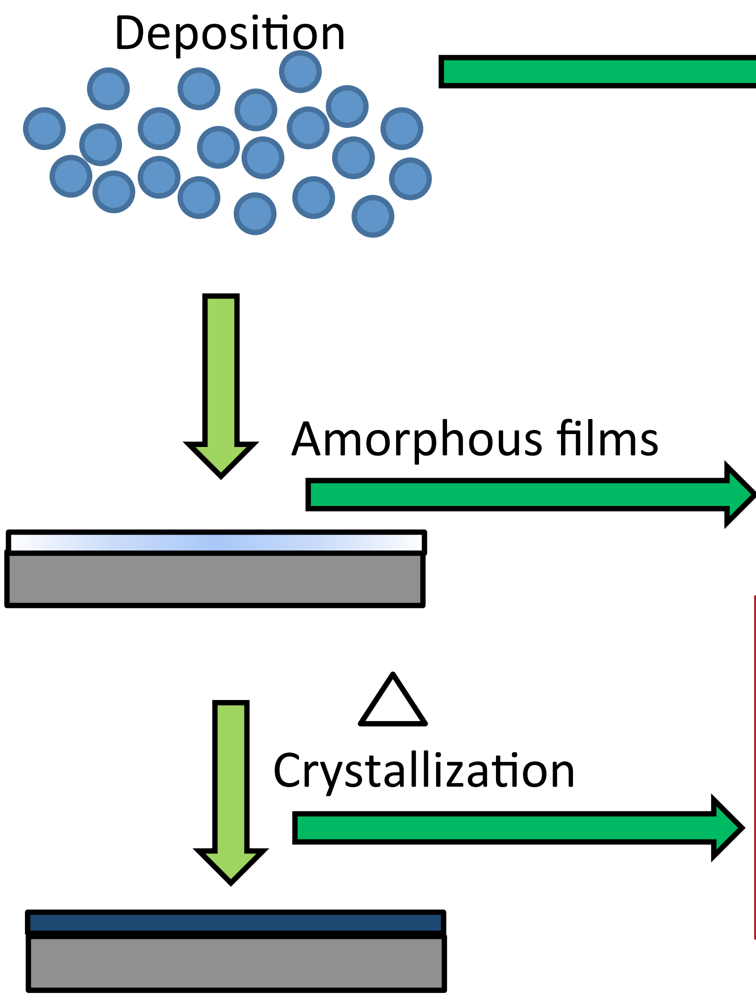


M. Kozina et al., *Struct. Dyn.* (2014)

Influence of Amorphous Structure on Crystallization of Different Polymorphs

CNGMD Incorporating Metastability

Outline:



Pulsed Laser Deposition (PLD)

NREL

Electrochemical Deposition

HARVARD

Characterization of the amorphous structure:
- Grazing Incidence Pair Distribution Function (GIPDF)
- X-ray Absorption Spectroscopy (XAS)

Modelling of GIPDF data (LBNL)

BERKELEY LAB

Structure of crystallized thin films (Identification of polymorphs):
- GIXRD, Powder XRD on scraped films, *in-situ* XRD
- Modeling of structural relationships (LBNL)

SLAC NATIONAL ACCELERATOR LABORATORY

Summary – Opportunities

- Research opportunities at SSRL
  - PV, energy storage, catalysis
  - Strongly correlated electrons