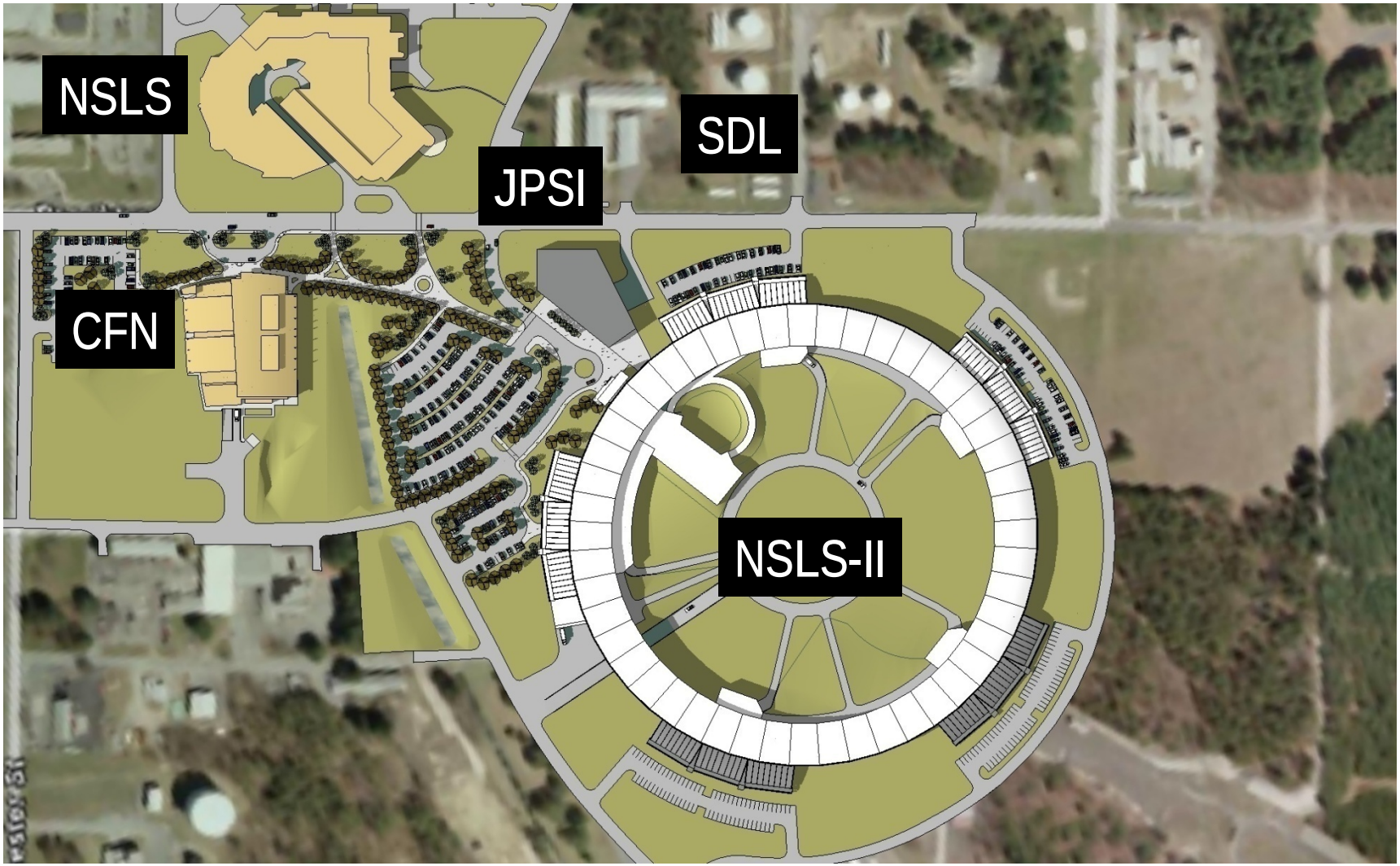
Brookhaven National Laboratory :NSLS and CFN



Chi-Chang Kao
National Synchrotron Light Source
Brookhaven National Laboratory

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NSLS Today

VUV Storage Ring:

51 m circumference

E = 0.808 GeV

I= 1.0 A

7 bunches

Orbital Period = 170 ns

Pulse Width = 320 ps

X-Ray Storage Ring:

170 m circumference

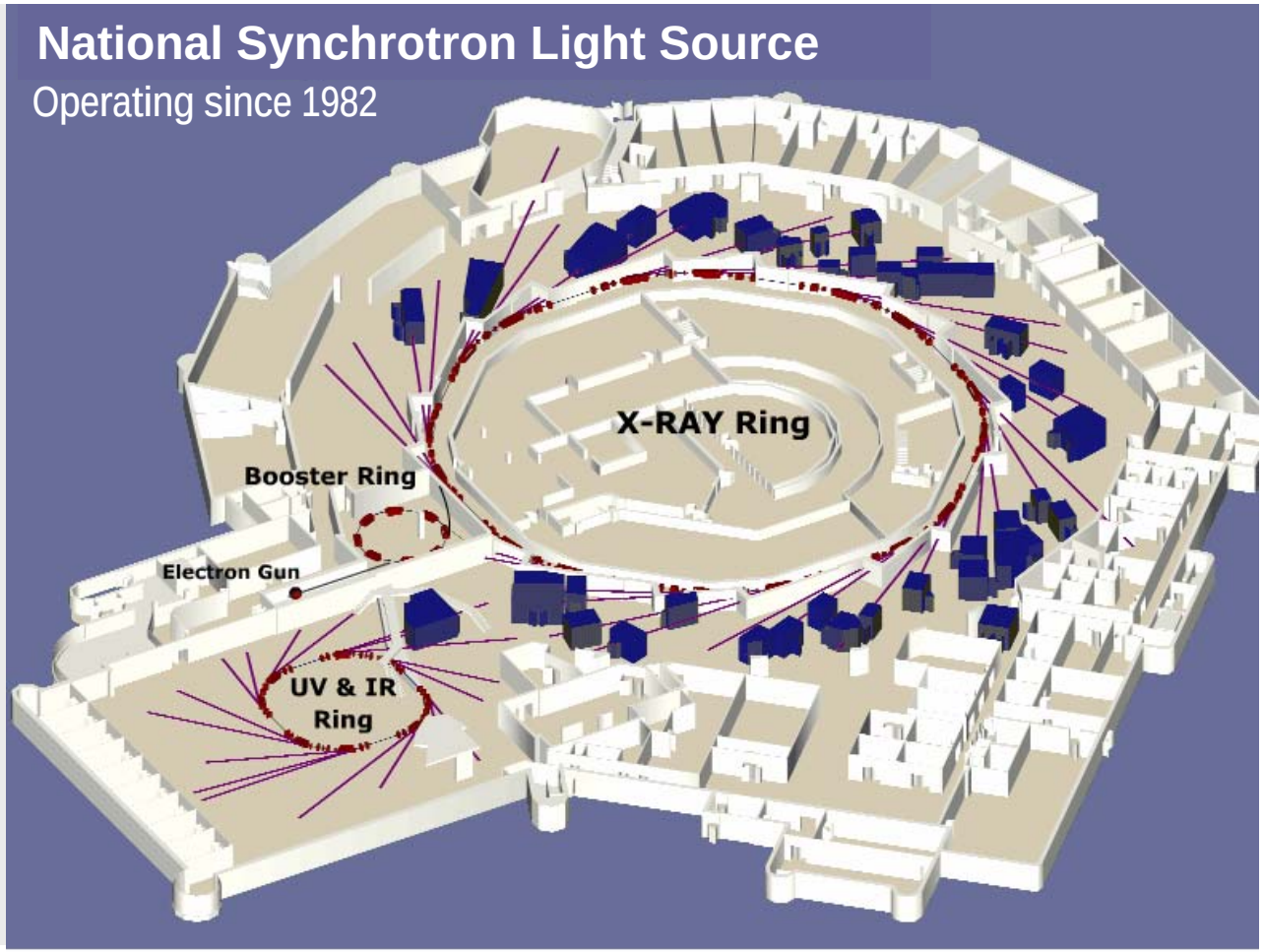
E = 2.8 GeV

I = 280 mA

25 bunches

Orbital Period = 567 ns

Pulse Width = 290 ps



- 65 operational beamlines which support ~2200 users annually

Distribution of Operating Instruments

- **Macromolecular Crystallography**
  X3A, X4A, X4C, **X6A**, X8C, X12B, X12C, **X25**, X26C, X29, X28C

- **Imaging and Microprobes**
  U2B, **U10B**, X1A1, X1A2, X2B, **X13B**, **X15A**, X26A, **X27A**

- **X-Ray Scattering & Diffraction**
  X1B**,** **X6B**, **X9**, X10A, X10B, **X13A**, X20A, X20C, **X21,** X22A, X22B, X22C, X27C

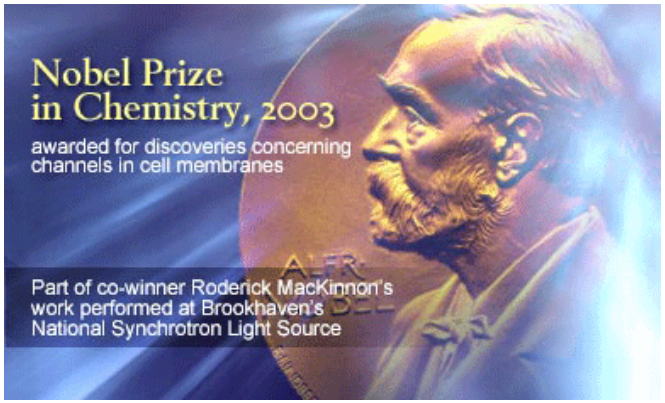
- **Powder/Single Crystal Diffraction & High Pressure**
  U2A, X7B, X14A, X16C, **X17B1**, **X17B2**, **X17B3**, **X17C**, X18A, X19C

- **X-ray Spectroscopy**
  X3B, X10C, X11A, X11B, X15B, **X18B**, **X19A**, X23A2, X23B, X24A, X27B

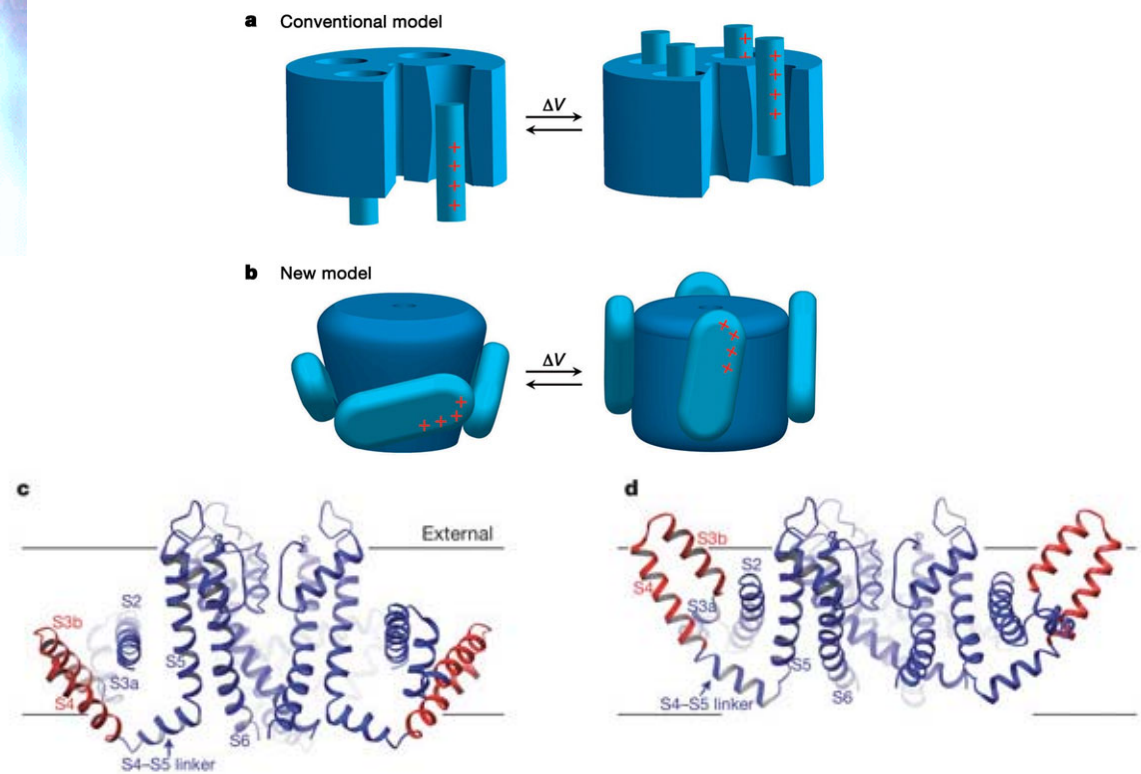
- **IR, VUV and Soft X-ray Spectroscopy**
  U1A, U3C, U4A, **U4B**, **U5UA**, U7A, U9B, U11, U12A, **U12IR**, U13UB, X8A, X24C

Major Scientific Programs

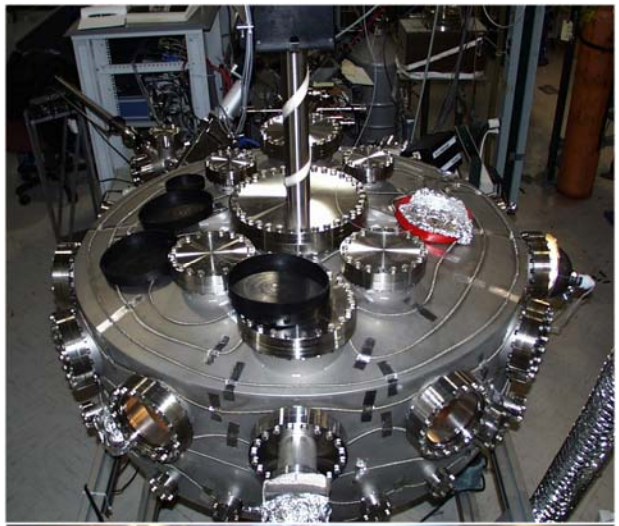
Structural Biology – Macromolecular Crystallography

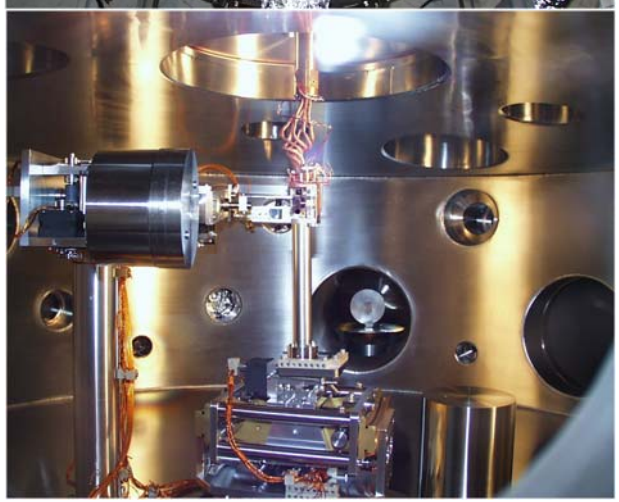


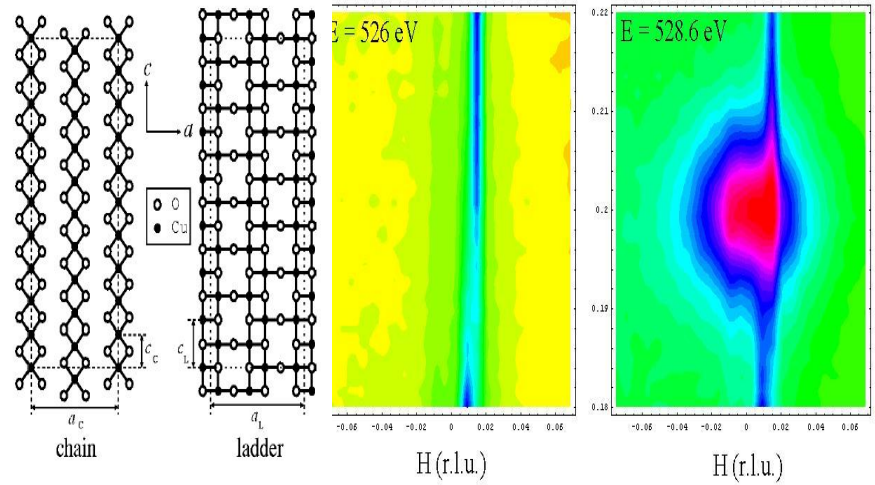
MacKinnon



Condensed Matter Physics: Resonant X-ray Scattering



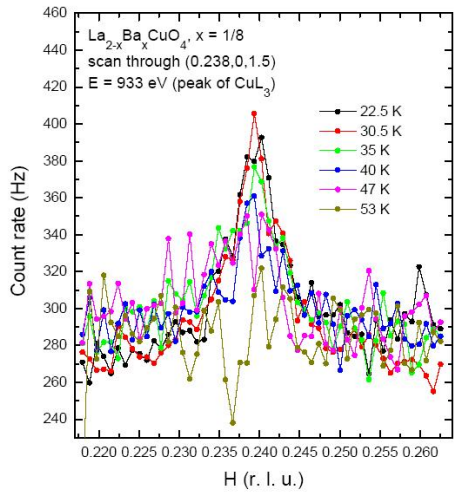




$Sr_{14-x}Ca_xCu_{24}O_{41}$ Abbamonte et al, Nature (2004)

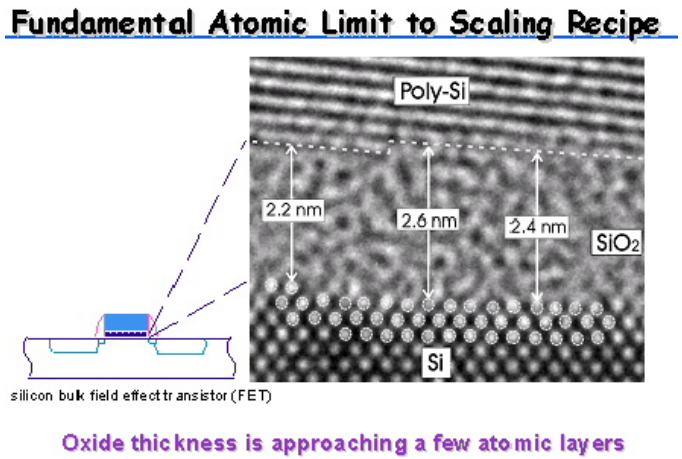
Direct observation of charge stripes

Nature-Material(2006)

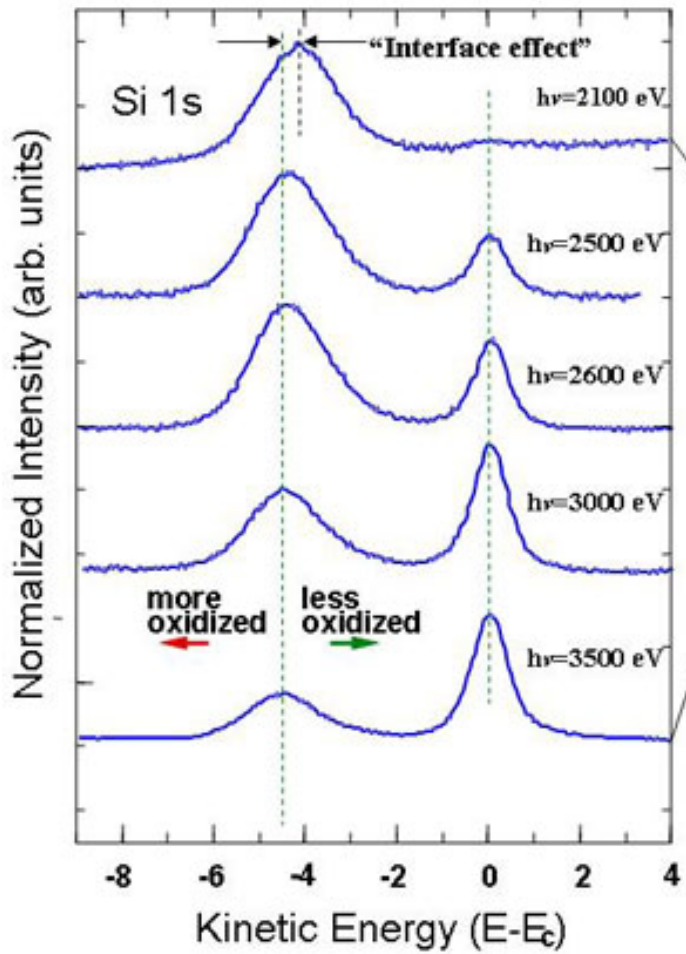


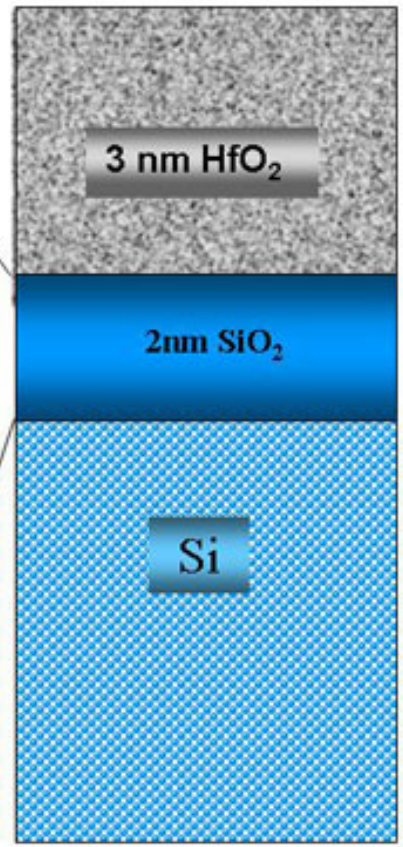
Materials Sciences: X-ray Photon Electron Spectroscopy

Variable High Energy Photoemission: Probing buried interfaces



- High leakage current for <2nm SiO2
- Hf based oxides are promising, but not good enough
- Modifying of Hf oxides thin film to optimize their properties





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Patrick S. Lysaght SEMATECH
Joseph C. Woicik and Daniel A. Fischer NIST (JAP)

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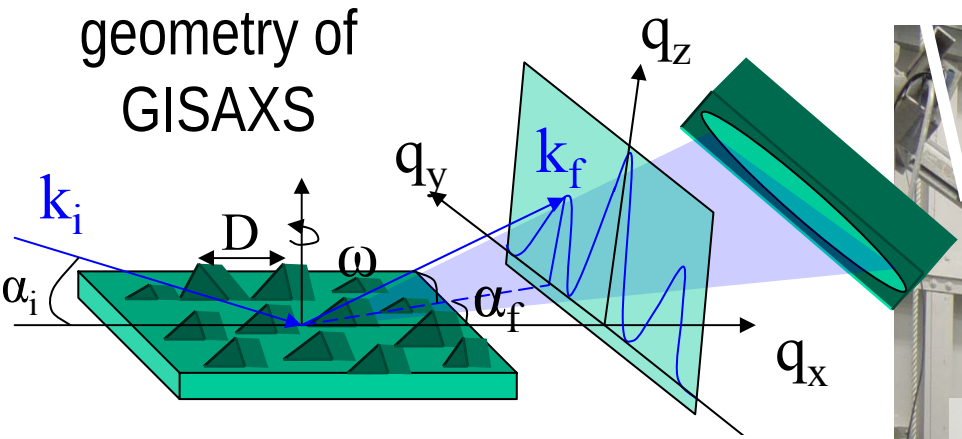
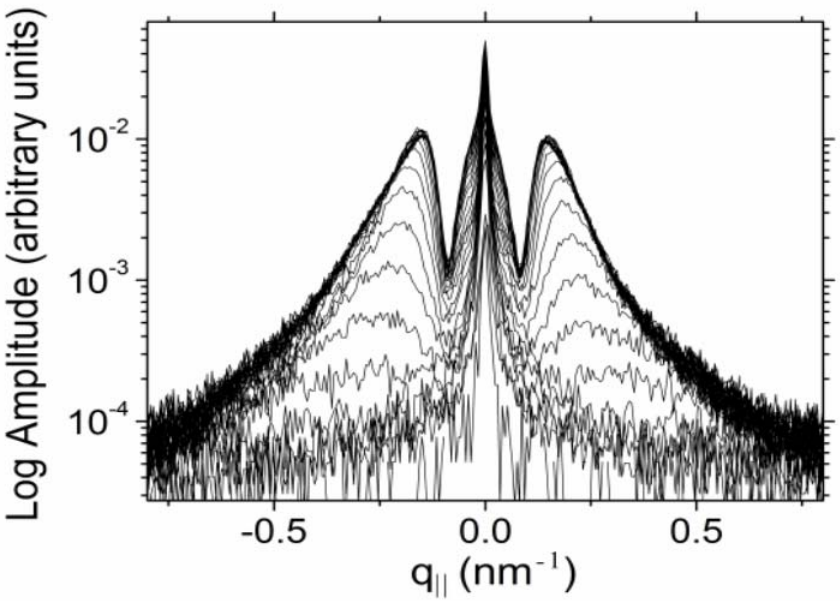
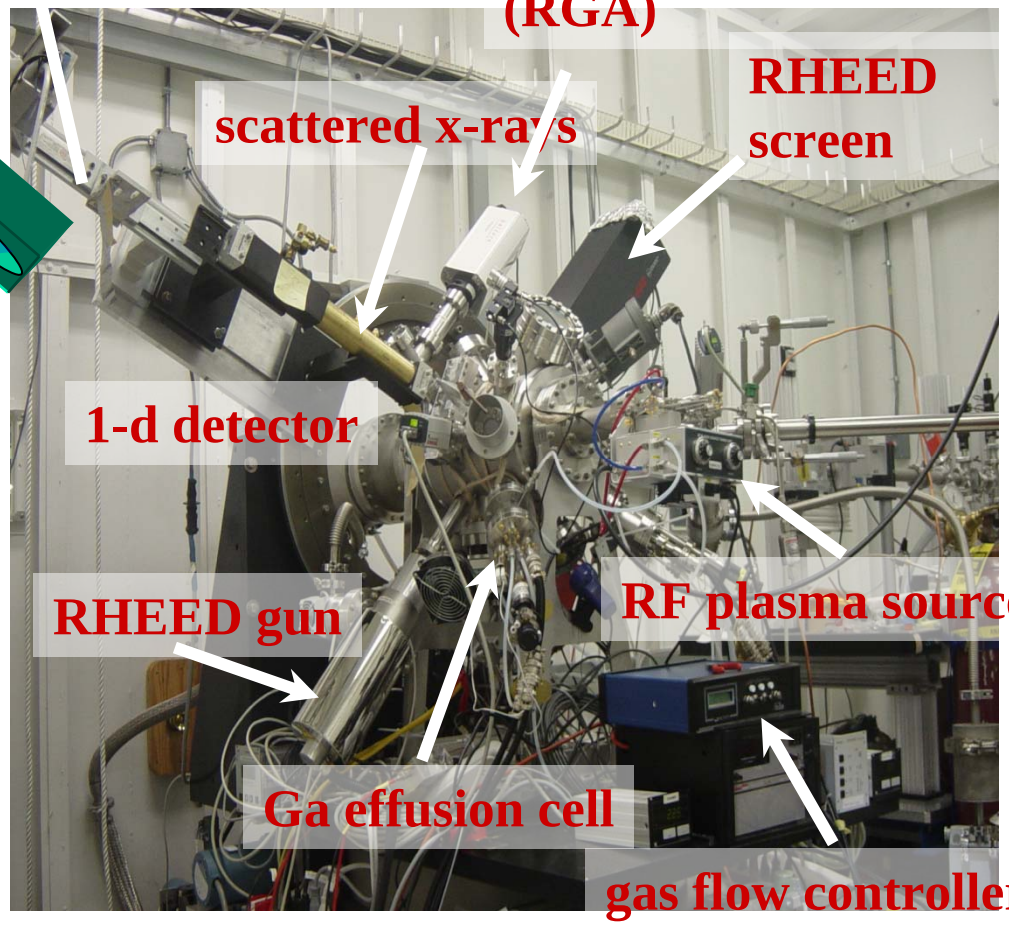
Materials Sciences: Real-time X-ray Scattering

Scattering geometry of GISAXS

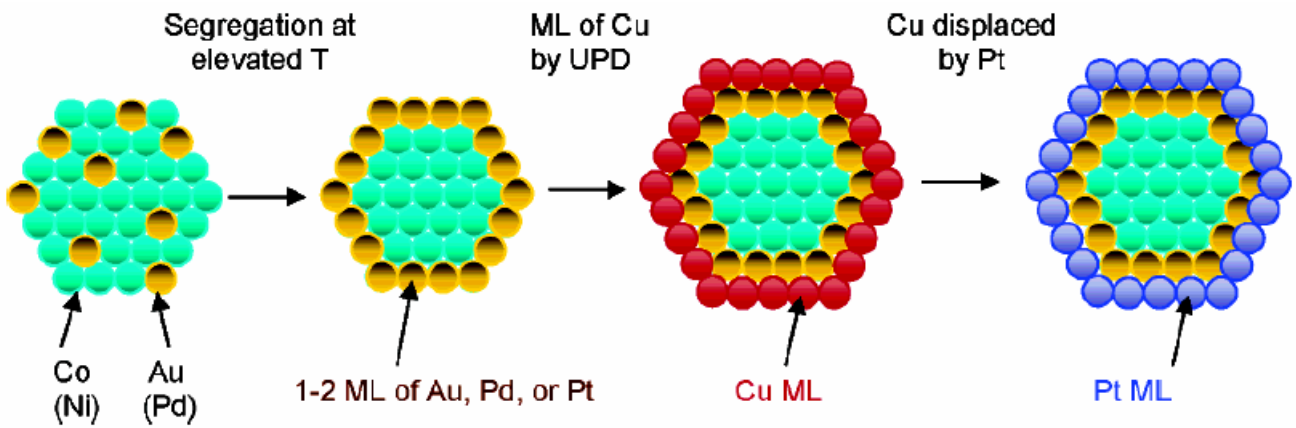


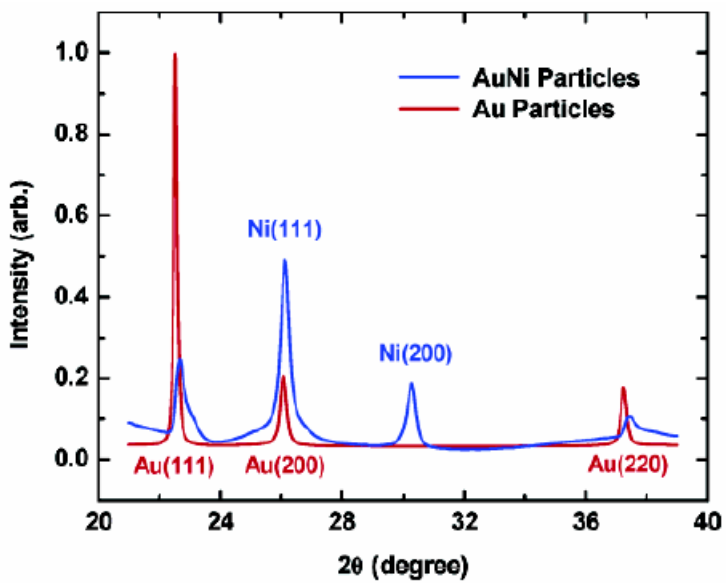


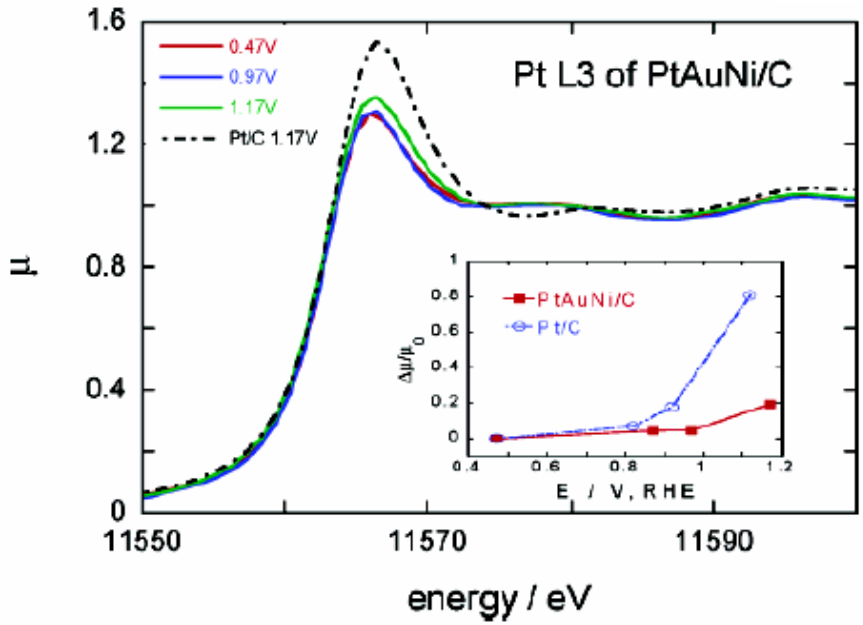


Ludwig(BU) and Headrick (Vermont), X21

Chemical Sciences : X-ray diffraction and Spectroscopy







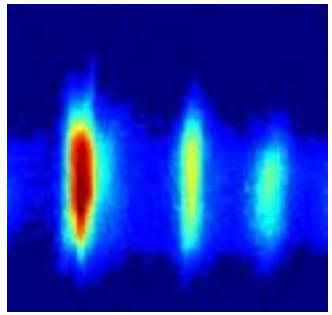
Adzic/Hanson, J. Phys. Chem.B (2005), X7B

Source Development Laboratory

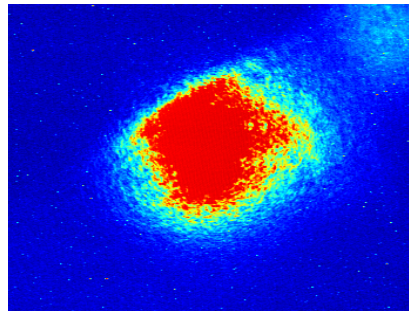
Operating IR & UV FEL Amplifier

300 MeV S-Band Linac

Bright Photo-Injector



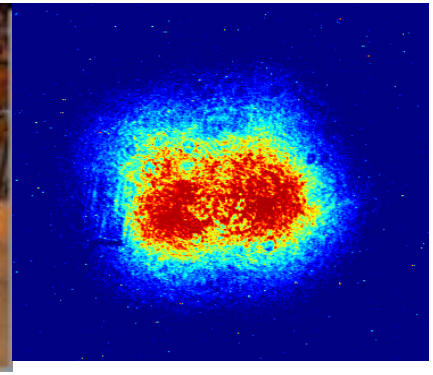
Beam Dynamics



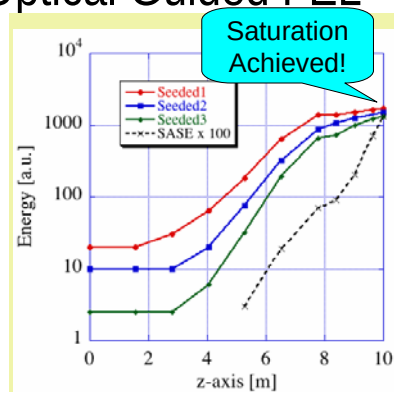
Optical Guided FEL

10 meter Undulator

Chicane Compressor



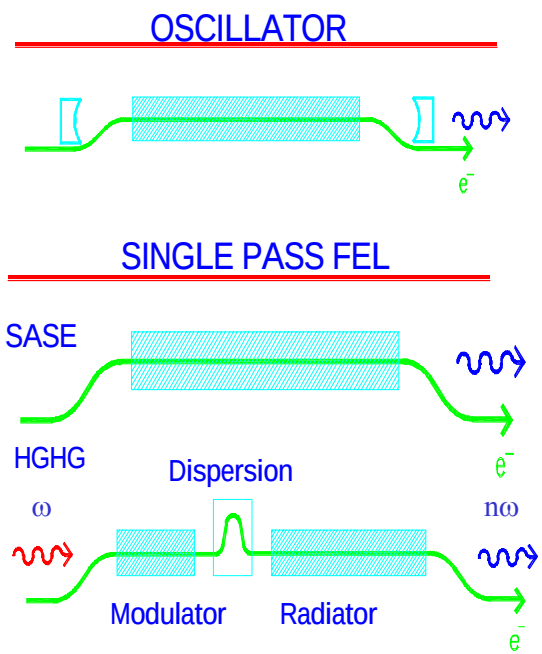
FEL Harmonics

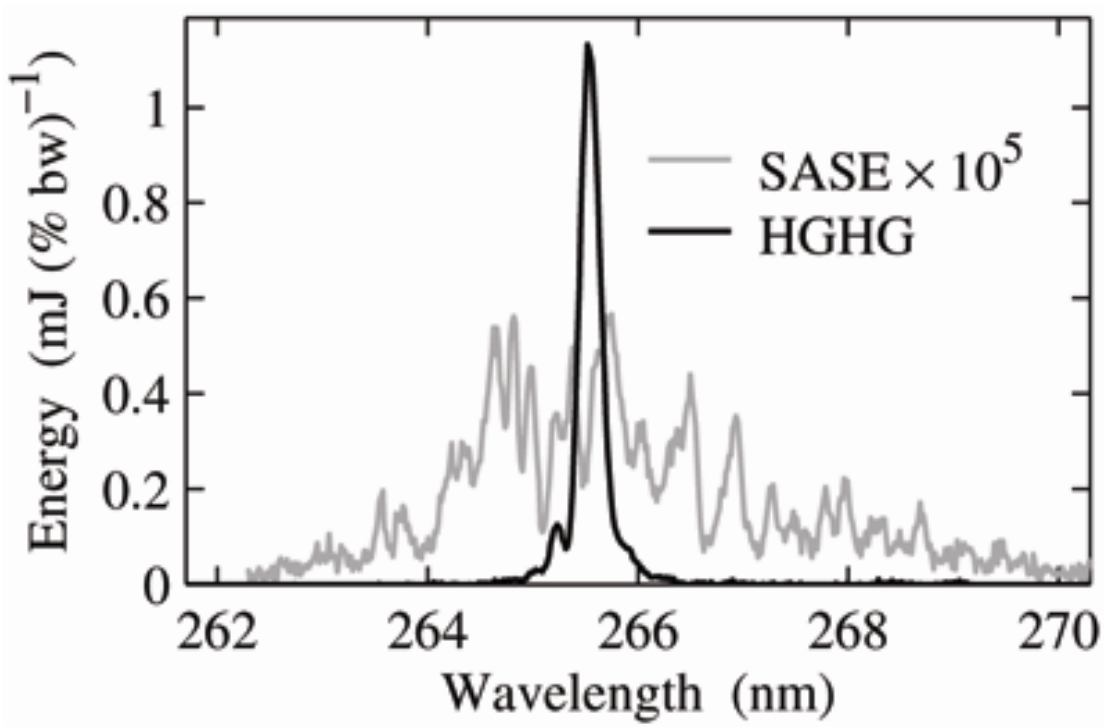


FEL Saturation

High Gain Harmonic Generation FEL

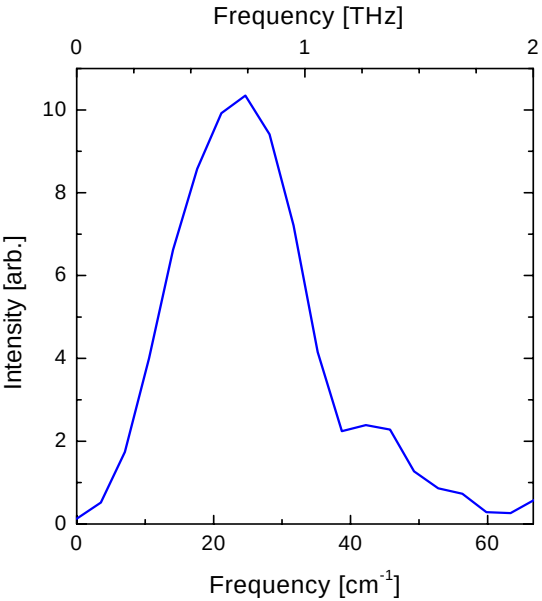
HGHG: 130 μJ / pulse

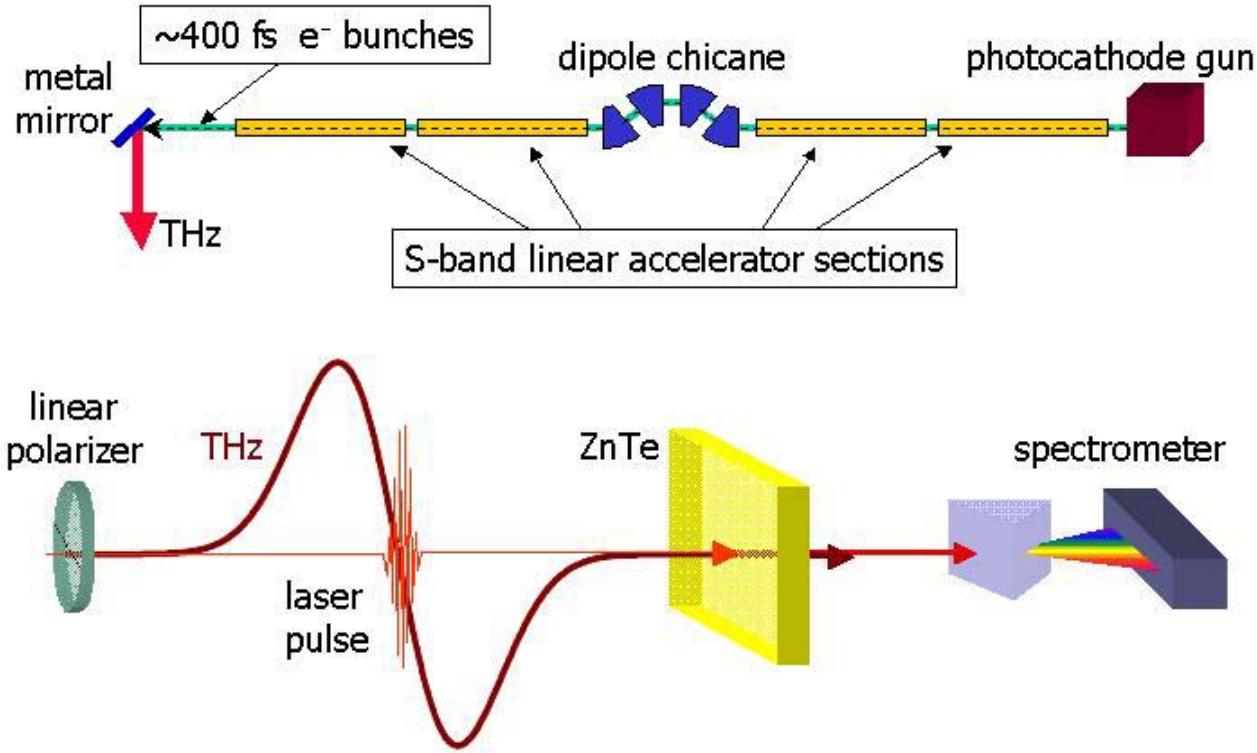




Yu, et. al., PRL 91, 74801 (2003)

Coherent Tera-Hz Transition Radiation





100 μJ in a single sub-psec pulse

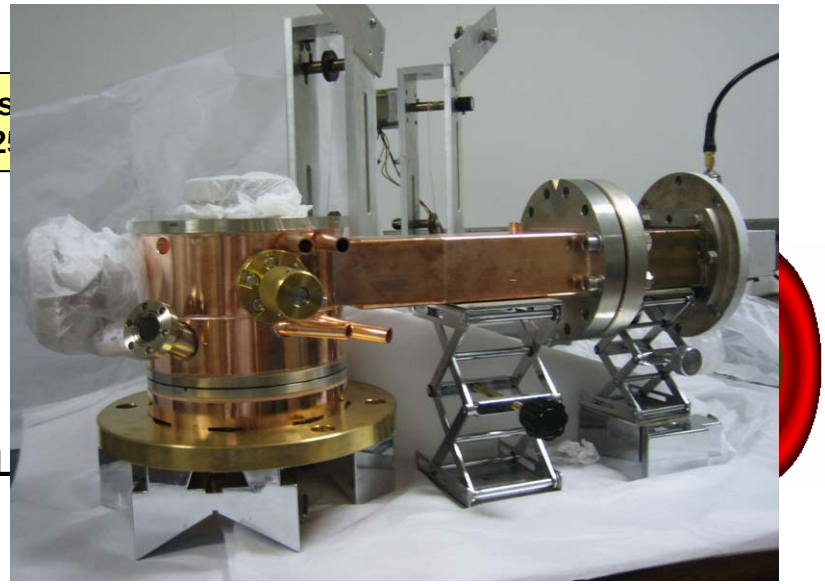
E: 100kV – 1MV/ cm

H: > 0.1T

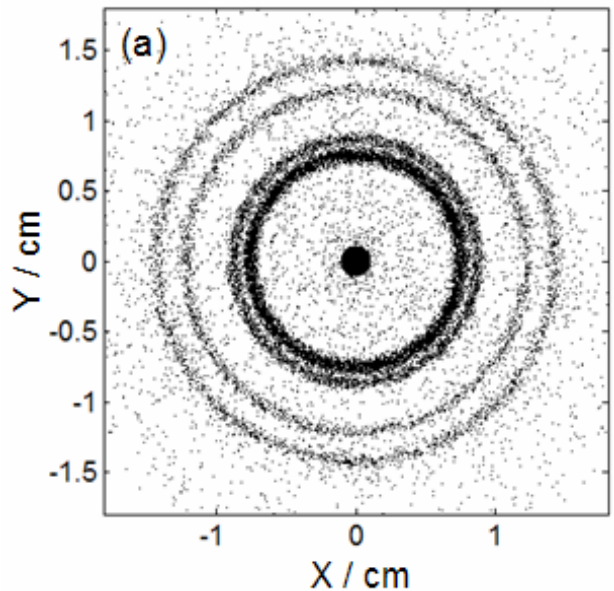
Ultrafast Electron Diffraction

Las
100-2

BNL



E-Beam: 1-4 MeV, 10^5-10^6 electrons



Latest BNL Optimization:
2.7 MeV diffraction pattern
R. Li & X.J. Wang

Center for Functional Nanomaterials
at Brookhaven National Laboratory

A User-Oriented Research Center

Focus on Functional Nanomaterials for Energy-relevant Applications

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CFN Scientific Themes

CFN-Based Research:

- **Nanocatalysis** (Peter Sutter, psutter@bnl.gov)
- **Electronic Nanomaterials** (Charles Black, ctblack@bnl.gov)
- **Soft- & Biological Nanomaterials** (Oleg Gang, ogang@bnl.gov)
- **Electron Microscopy** (Yimei Zhu, zhu@bnl.gov)
- **Theory & Computation** (Mark Hybertsen, mhyberts@bnl.gov)

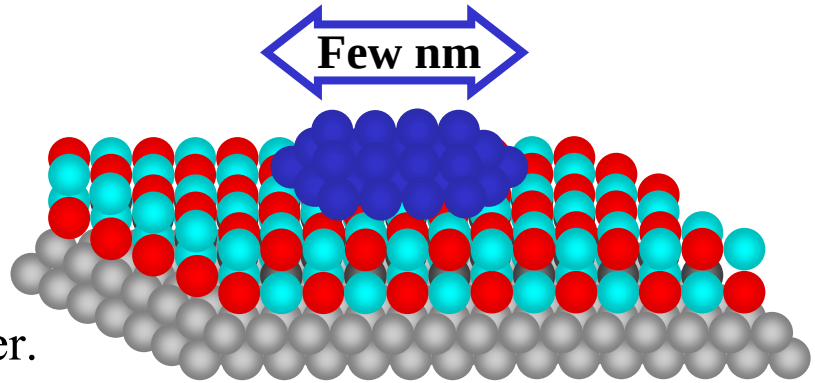
Focus - **Energy Applications**: Functional nanomaterials for exploiting renewable energy sources, energy storage, utilization.

Nanocatalysis

Leader: Peter Sutter (psutter@bnl.gov)

Nano-Catalysis - utilize phenomena at the nanoscale to achieve improved activity, selectivity, resistance to poisoning.

- Increased surface/volume ratio.
- **Electronic** structure**, charging**.
- Availability of specific **active sites**.
- **Dynamically changing** active sites.
- Alloying, tuning of composition, strain.
- Cooperative/proximity effects, spill-over.



Focus - In-Situ Microscopes & Probes

Interrogate individual nanostructures …

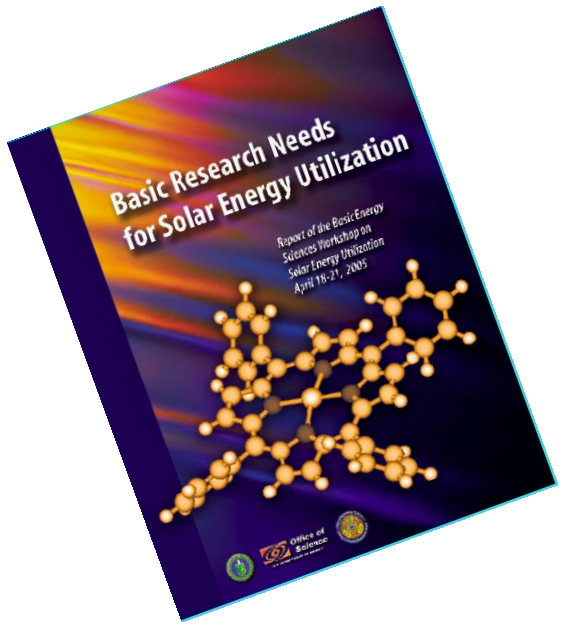
- In relevant environments: realistic pressures & temperatures.
- With combined spatial, temporal, and spectral resolution.

Electronic Nanomaterials

Leader: Charles Black (ctblack@bnl.gov)

Explore nanostructured materials for enhanced or novel optical/electronic properties (esp. *energy conversion*)

- **Science program:**
  - Photovoltaics
  - Photochemistry
  - Nanoplasmonic structures



"The Sun is a singular solution to our future energy needs"

- **But:** Enormous gap between potential and current use of solar energy
- ⇒ Need conceptual breakthroughs through high risk/high payoff research

Soft- & Biological Nanomaterials

Leader: Oleg Gang (ogang@bnl.gov)

Challenges:

- Control of nano-object , **positioning and orientation.**
- Assembly of **large scale systems/devices** w. designed architectures.
- Building **hierarchical structures.**
- Dynamic (re-configurable, responsive, self-repaired…)

Soft/Biomimetic Approach for Building Nanoscale Systems:

- Utilize/adopt biological structures with recognition interactions and regulated behavior for the control of non-biological nano-objects
- Use a rich phase behavior of soft systems for assembling functional nano-components
- Apply assembly approaches to build functional nano-systems for applications in energy transfer, catalysis and sensing.

Electron Microscopy

Leader: Yimei Zhu (zhu@bnl.gov)

- **Hitachi HD2700C Dedicated scanning TEM**

  Analytical STEM (EELS)

- **FEI Titan 80-300 Environmental TEM**

  In-situ experiments at elevated pressure & temperature

- **JEOL 2100F High resolution analytical TEM**

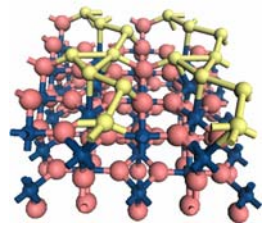
  Analytical TEM (imaging, EDS)

Theory & Computation

Leader: Mark Hybertsen (mhyberts@bnl.gov)

Expertise in theory & computation:

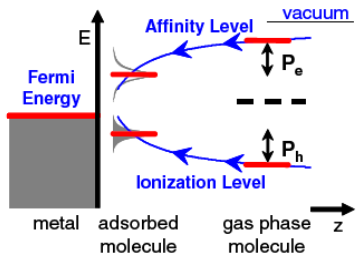
- Bonding, structure & reactivity
- Electronic states, transport & optical properties
- Assembly & emergent pattern formation



Liu, Muckerman & Adzic, J Chem Phys, 2006

Current research projects:

- Mechanism & design: Oxygen reduction reaction on nanocatalysts (Ping Liu)
- Catalyzed water oxidation by solar irradiation of band-gap-narrowed semiconductors (Jim Muckerman)
- Bonding, electronic states and electron transport at metal-organic interfaces (Mark Hybertsen)



Neaton, Hybertsen & Louie, PRL, 2006

Venkataraman, et al, Nano Lett, 2006