How Will NSLS-II Serve Infrared Science?

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*NSLS Infrared*

and the NSLS-II design team
Synchrotron Infrared Source Qualities

- High brightness
  - ~ 3 orders of magnitude higher than conventional “white” IR spectroscopy sources.
  - Needed for throughput limited spectroscopy (microspectroscopy)

- Broad spectral coverage
  - everything from visible down to microwaves, though weaker at long wavelengths.
  - Compatible with high-performance FTIR spectrometry.

- Pulsed output
  - 10s of picoseconds out to nanoseconds
  - Time-resolved spectroscopy / dynamics
High Brightness Enables Throughput Limited Techniques

Microscopy at diffraction-limit

Spectroscopy of materials under extreme conditions:
- diamond anvil cells
- complex cryostats & magnets

Restrictive angle of incidence
- Grazing incidence
- Attenuated total refl. (ATR)
- Ellipsometry

Very high (spectral) resolution (requires small collimating aperture)
\[ r = f \left(2\frac{\Delta \nu}{\nu}\right)^{1/2} = 2 \text{ mm} \]
for \( f = 20 \text{ cm}, \Delta \nu = 0.001 \) and \( \nu = 20 \text{ cm}^{-1} \)
If electron energy is sufficiently high (> 100 MeV) then IR brightness depends only on:

- beam current
- source size/emittance
- extraction aperture
Recently Upgraded VUV/IR Beamlines

**NSLS VUV**

**800 MeV**

**1000 mA at injection**

**U4A**
- SGM: 15-1200eV (1996)

**U4B**
- SGM: 8-250eV (1996)

**U2A/B**
- A: 2.5meV-2eV (1999)
- B: 2.5meV-2eV (1998)

**U12A**

**U12IR**
- A: 2.5meV-3.1eV (1999)
- B: 48-840meV (1998)

**U10A/B**
- 125µeV-600meV (1997)

**U7A**

**U13UB**
- NIM: 3-30eV (1998)

**U13UA**
- White

**U13UC**
- White

**U4IR**
- 1.2-480meV (1987)
IR Performance of VUV Ring: 90x90mr Extraction

![Graph showing brightness vs. frequency with ideal and VUV-IR 700mA lines]

Brightness [W/cm²/(cm⁻²·rad²)]

Frequency [cm⁻¹]
Infrared Performance: NSLS VUV Ring

**Relative Signal**
- U10A Synch/Globar
- 1 mm diam. aperture, f/4

**Signal Intensity**
- Synchrotron
- HiP Hg Arc

**Ratio (100% line comparison)**
- BB (1200K globar)
- Synchrotron U10A
Pulses for Time-Resolved Spectroscopy

- Synchronized M-L laser (<10 ps pulses) & VUV ring pulses (down to 300 ps).

- Need shorter synchrotron pulses (down to 100 fs, but any gain is useful)
Existing IR Programs/Activities

- **Biological and Life Sciences**
  - vibrational microscopy/imaging of proteins and cell structures
  - bone mineralization osteoporosis/osteoarthritis
  - chemistry of diseased tissues at the cellular level

- **Environmental and Space Sciences**
  - vibrational microspectroscopy of soils and interplanetary particles

- **Corrosion and Catalysis**
  - grazing incidence spectroscopy of molecular layers on metal surfaces

- **Geosciences**
  - spectroscopy and microscopy of molecular solids and minerals at extreme pressures and temperatures.

- **Materials**
  - infrared conductivity of complex metal oxides.
  - dynamics (time-resolved) in superconductors and nanomaterials.
  - spectroscopy of spins and magnetic resonances in ordered solids.
Infrared Considerations for NSLS-II

- **Existing NSLS & VUV/IR Ring**
  - high current (high brightness), ~ 1 ns duration pulses
  - ~ 25 years old (increasing maintenance for linac, booster, RF systems)
  - ring chamber and magnets remain reliable

- **NSLS-II: New Ultra-Bright Storage Ring for X-rays**
  - 500 ma (top-off)
  - new injector
  - 500 MHz
    - at least 10X shorter bunches
  - *but* large aperture ports could be problematic
    - estimate 20 mrad from geometric considerations.
Infrared on the NSLS-II Main Ring?

Graph showing the relative brightness of different synchrotron radiation sources as a function of frequency. The graph compares Ideal, VUV-IR (700mA), and NSLS-II (500mA) sources.

- **Ideal**: 700mA
- **VUV-IR**: 700mA
- **NSLS-II**: 500mA

**Axes:**
- Y-axis: Brightness [W/cm^2/(rad^2)]
- X-axis: Frequency [cm^-1]

**Inset:**
- NSLS-II / VUV-IR relative brightness comparison.
Plan: Relocate VUV/IR to NSLS-II: Infrared Ring

- Maintain investment in ring chamber, magnets and beamline front-ends

- NSLS-II -> new injector (Linac)
  - Top-off injection for IR too
    - can tolerate modes with shorter lifetimes
      - brighter mid-IR beam
      - higher average current (1 A)
      - short bunch lattice

- New RF
  - 500 MHz to match NSLS-II systems
    - intrinsically shorter bunches (10s of picoseconds)
    - possible coherent mode?
The NSLS-II Project
Option 1:
200 MeV linac + Booster
Inject IR ring at 200 MeV

Option 2:
3 GeV linac
Inject IR Ring at up to 800 MeV
Infrared Brightness Comparison

![Graph showing infrared brightness comparison. The x-axis represents frequency [cm⁻¹], and the y-axis represents brightness [W/cm²/(cm²-rad²)]. Three lines are shown: VUV t/o 1000mA (green solid), VUV-IR 700mA (red dashed), and NSLS-II 500mA (blue dotted). The graph compares brightness at different wavelengths and frequencies.]
Possible Infrared Beam Ports

1.2-480meV (1987)
A: 2.5meV-2eV (1999)
B: 2.5meV-2eV (1998)

Chamber modification for a U16IR Far-IR port (magnetospectroscopy)

NIM: 3-30eV (1998)

NSLS VUV
800 MeV
1000 mA at injection

Chamber modification for a U7/8 extended source (imaging array microscopy)

125µeV-600meV (1997)
A: 2.5meV-3.1eV (1999)
B: 48-840meV (1998)
Extended Source for Small Array FTIR Microspectrometer

- Rapid scan FTIR with 16 element array detector
- Full spectral range MCT

Detector schematic

Two 25 mrad by 100 mrad ports 25\(\mu\)m

Perkin-Elmer “Spotlight” IR microscope with linear detector array
Rough / Strawman Elevation Drawings

Main NSLS-II Ring
(cross section)

Infrared Ring

Linac below grade to use earth shielding
• Infrared beamlines extract light from ring (below grade)
• Endstations on upper level (stable concrete support)
• Most of ring covered (additional useful floor space, walkways)
Other Possibilities: Coherent Emission

- Abo-Bakr et al demonstrate stable coherent emission from BESSY II (PRL March 2003)
- Berkeley Lab proposal for CIRCE (storage ring primarily for coherent far-IR)
Current plans call for relocating NSLS VUV/IR Ring to NSLS-II

- **Space for additional ports and beamline endstations**
  - Let’s make sure it’s all stable!
    - beamline hutches for environment stability?
  - extended source based on 200 mrad horizontal (two U10 or U2 ports)?
    - New Imaging Capability

- **Top-off mode for higher current and higher brightness**
  - how often?, how stable?

- **500 MHz RF**
  - shorter bunches … modes for very short?
  - coherent emission?

- **At least 200 MeV**
  - adequate for IR and Visible, but may need more to avoid excessive topping-off
  - higher energy -> undulators could serve as tunable pump for time-resolved