Surface and Interface Science with

Low Energy Electron Microscopy & Nano-Optics

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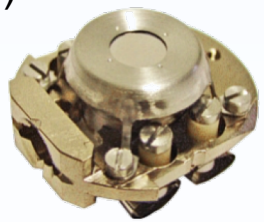
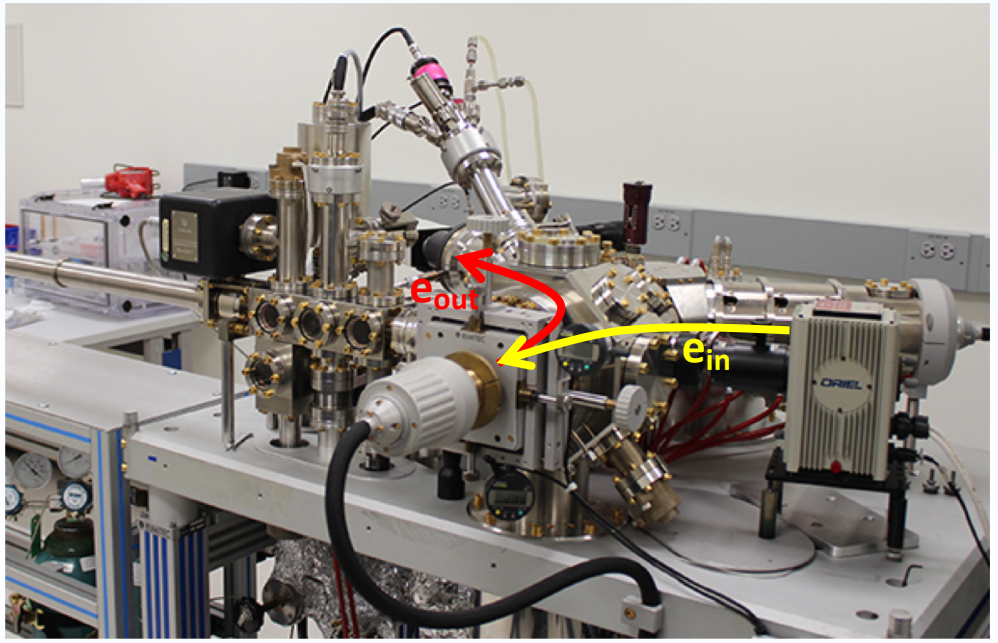
(https://nanoscaleimaging.yale.edu)

Low Energy Electron Microscopy (LEEM)

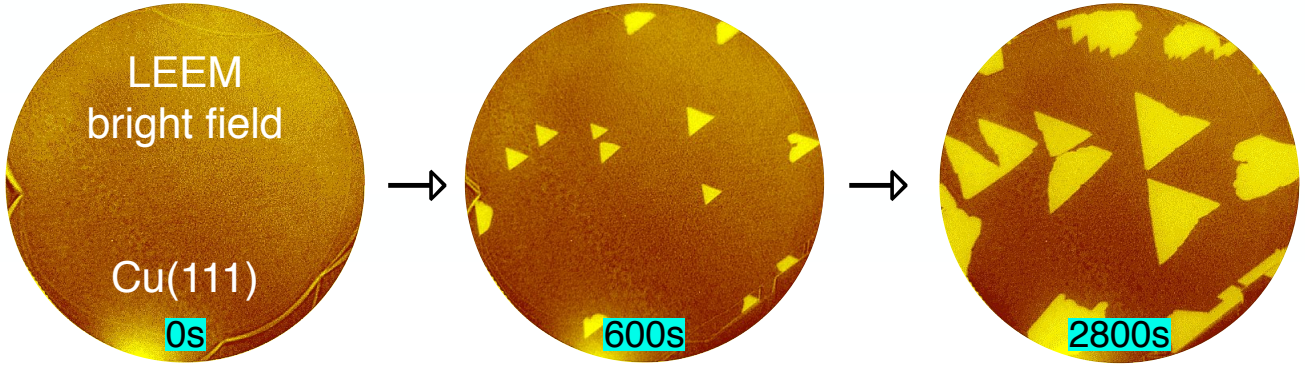
- LEEM uses low energy (0 – 100 eV) elastically scattered electrons for microscopy & diffraction
  - Lateral resolution → 10 nm
  - Field of View → 1.5 to 150 µm (µ-LEED)
  - Sample size → ϕ = 7 – 12 mm
  - E-beam source up to 3500 °C
  - Sample temperature up to 1600 °C
  - Gas dosing and prep chamber with sputtering/annealing capabilities

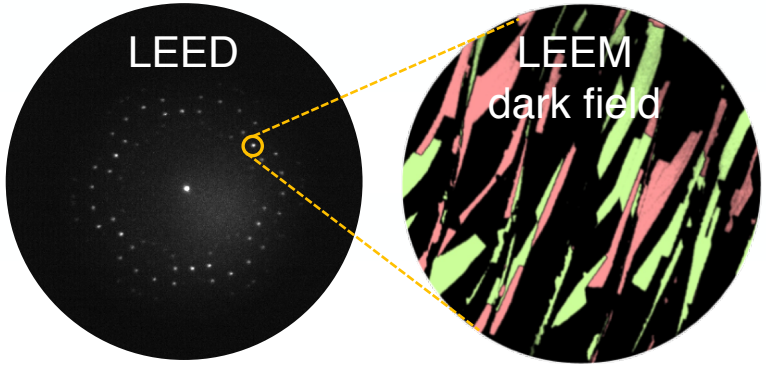


sample holder



- Real-time monitoring of surface dynamics or film growth (watch our movies online !)
  - Example: synthesis and characterization of large-area single crystals of borophene on Cu(111) surfaces (FOV = 10 µm)

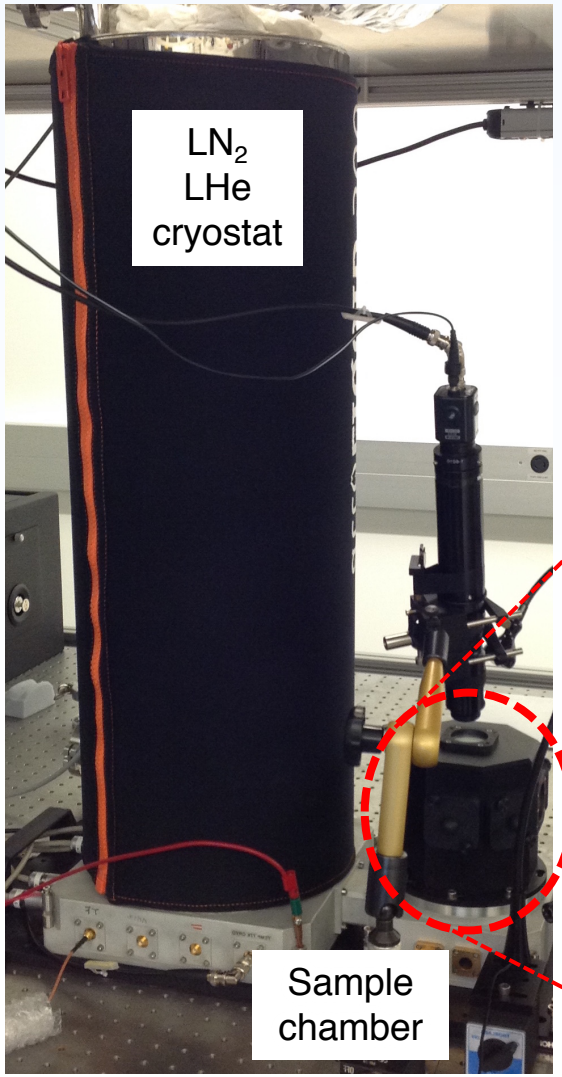




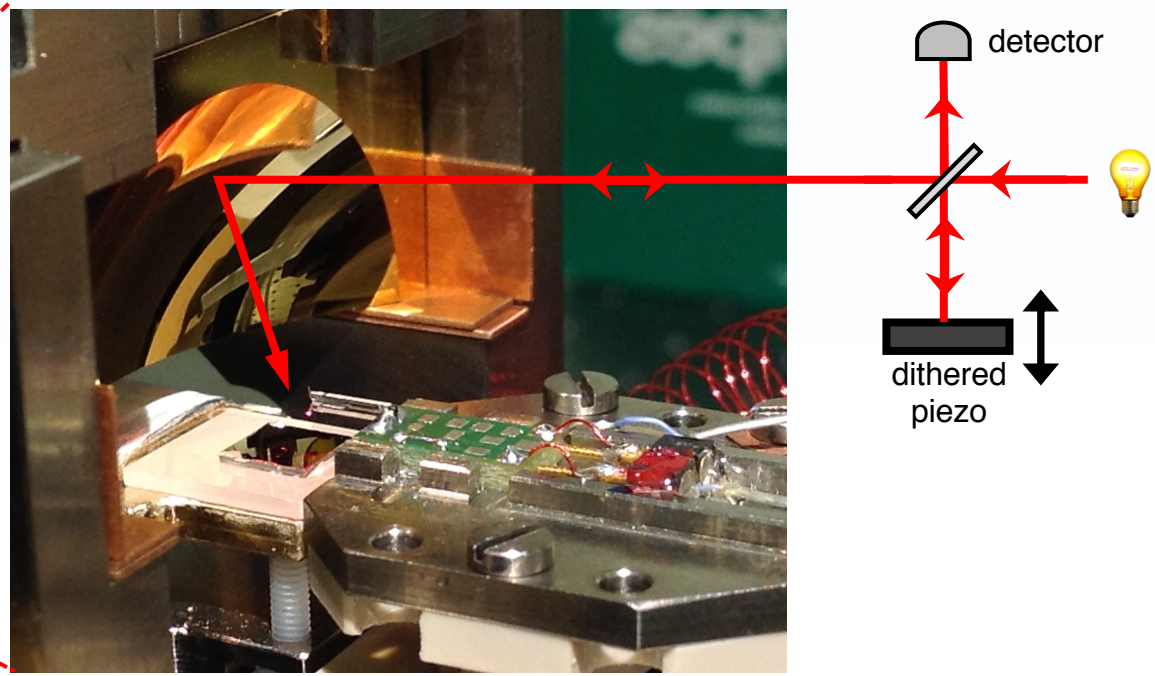
Wu et al., *Nature Nanotechnology* (2018), in press

Nano-Optics: Beyond Diffraction with Near-Fields

- Our AFM-based Cryogenic Scanning Near-Field Optical Microscope (SNOM) for determination of the complex conductivity at the nano-scale



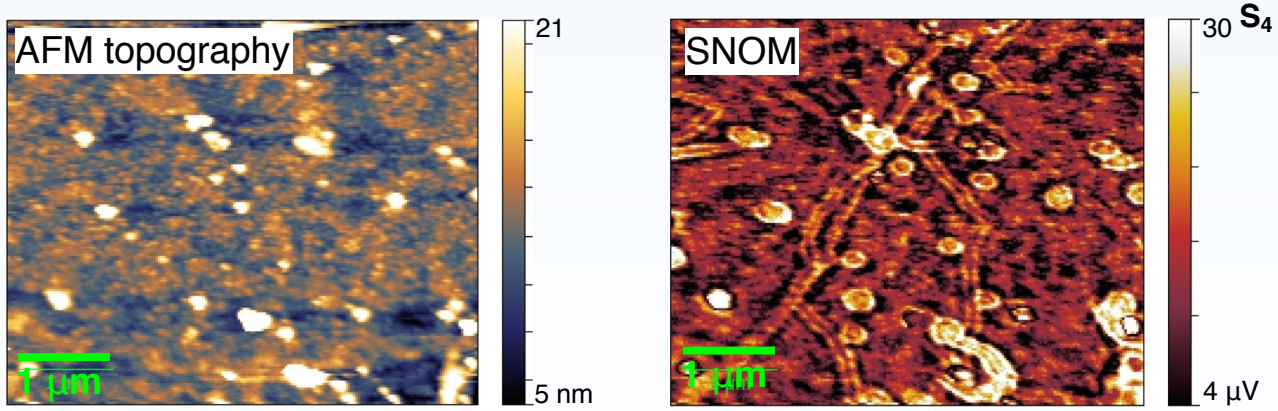
- Spatial resolution → ~ 20 nm (given by the size of the AFM tip)
- Temperature range → 22 K – 300 K
- Optical sources → mid-IR (λ = 9 – 11 μm; 110 – 140 meV)
  THz (λ = 0.5 – 0.3 mm; 600 – 850 GHz)
- Depth probing range → 10's of nm (material dependent) for sub-surface sensitivity



Near-Field Studies of Surfaces and Interfaces

➢ Studies of 2D materials

- Surface plasmon interferometry in graphene: plasmon scattering at grain boundaries (optics with finite momentum transfer)



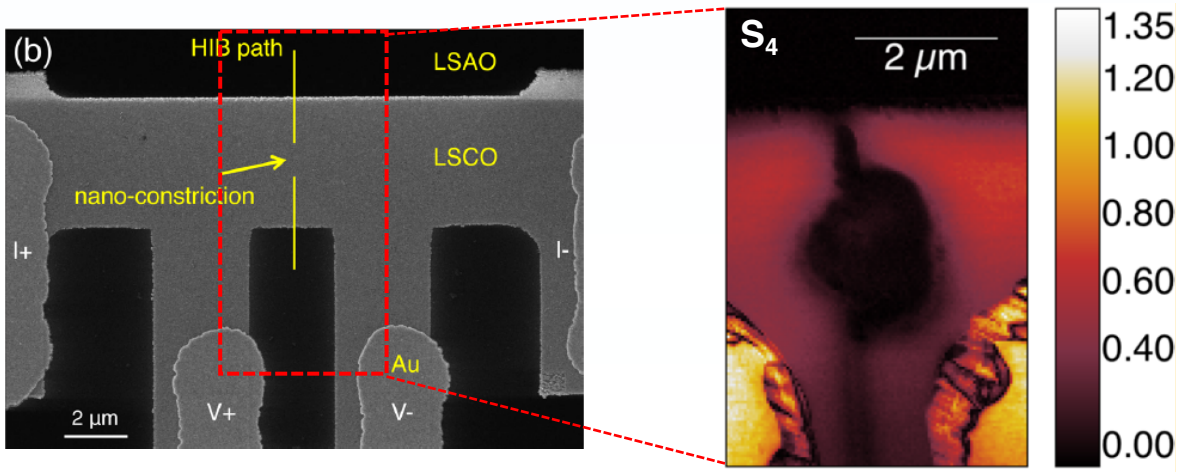
Sample: Graphene Supermarket (SLG / 90 nm SiO_2 / Si)

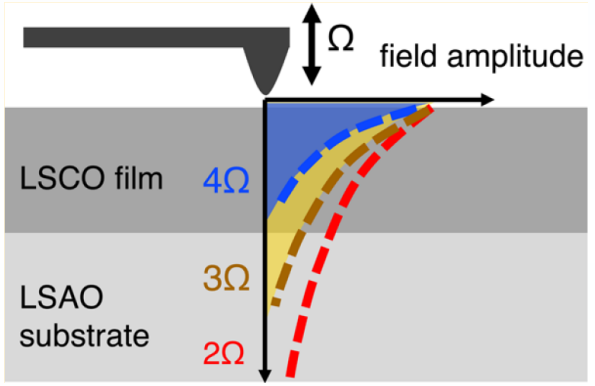
$\lambda \rightarrow 10\ \mu m$

$S_4 \rightarrow$ SNOM signal at $4\times\Omega$ of the AFM tapping frequency

➢ Device characterization

- Optical nanoscopy of a high-T_c cuprate nano-constriction device patterned by He ion beams



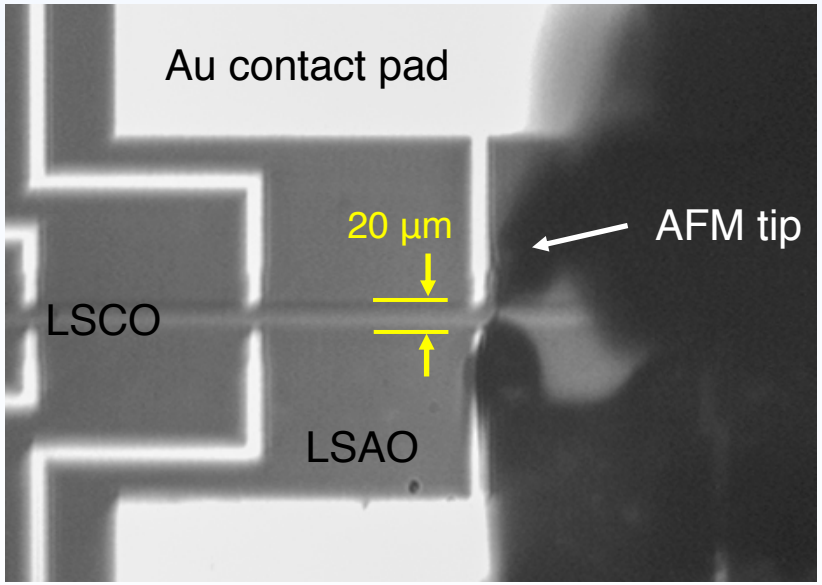


AFM-SNOM can provide dielectric depth (tomographic) information

Gozar et al., *Nano Letters* (2017)

SNOM studies of Surfaces and Interfaces

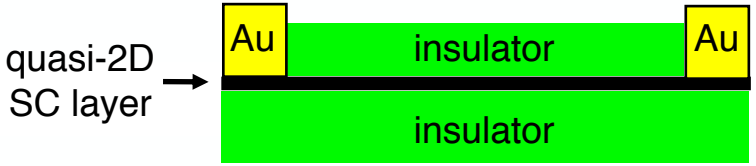
- Superconductivity in the $La_{2-x}Sr_xCuO_4$ (LSCO) high-T_c cuprate material



- We can perform infrared and THz optical nanoscopy of superconucting devices
- Low temperature data in the THz range enables detection of superconducting fluctuations in a cuprate wire (13 nm thick and 20 µm wide)

Sample: Hall bar pattern of LSCO grown on $LaSrAlO_4$ (LSAO) substrate – A. Bollinger & I. Bozovic, Brookhaven

- Needed: devices with high-T_c superconductors (SC)
  - Encapsulated $Bi_2Sr_2CaCu_2O_{8+\delta}$ (BSCCO) $T_c \sim 90$ K
  - It cleaves easily but the surface is sensitive to ambient conditions



- Why do we want such devices?
  - detection of superfluid polaritons
  - superconductivity in ultra-thin films and nano-wires
  - inhomogeneous superconductors