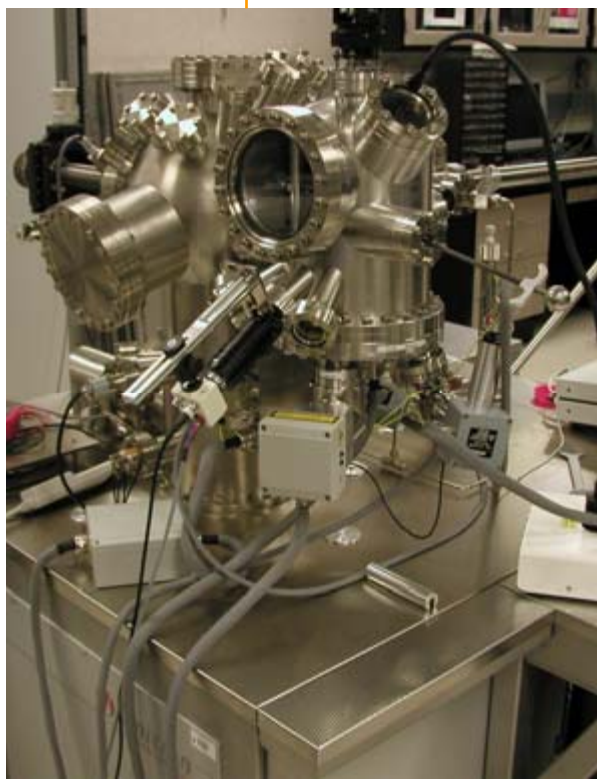
Microscopy Team

Measurements and Characterization Division, National Center for Photovoltaics, National Renewable Energy Laboratory

http://www.nrel.gov/measurements

1 mm | 100 μm | 10 μm | 1 μm | 100 nm | 10 nm | 1 nm | 1 Å

Scanning electron microscopy (SEM)
Field-emission (FE) scanning electron microscopy

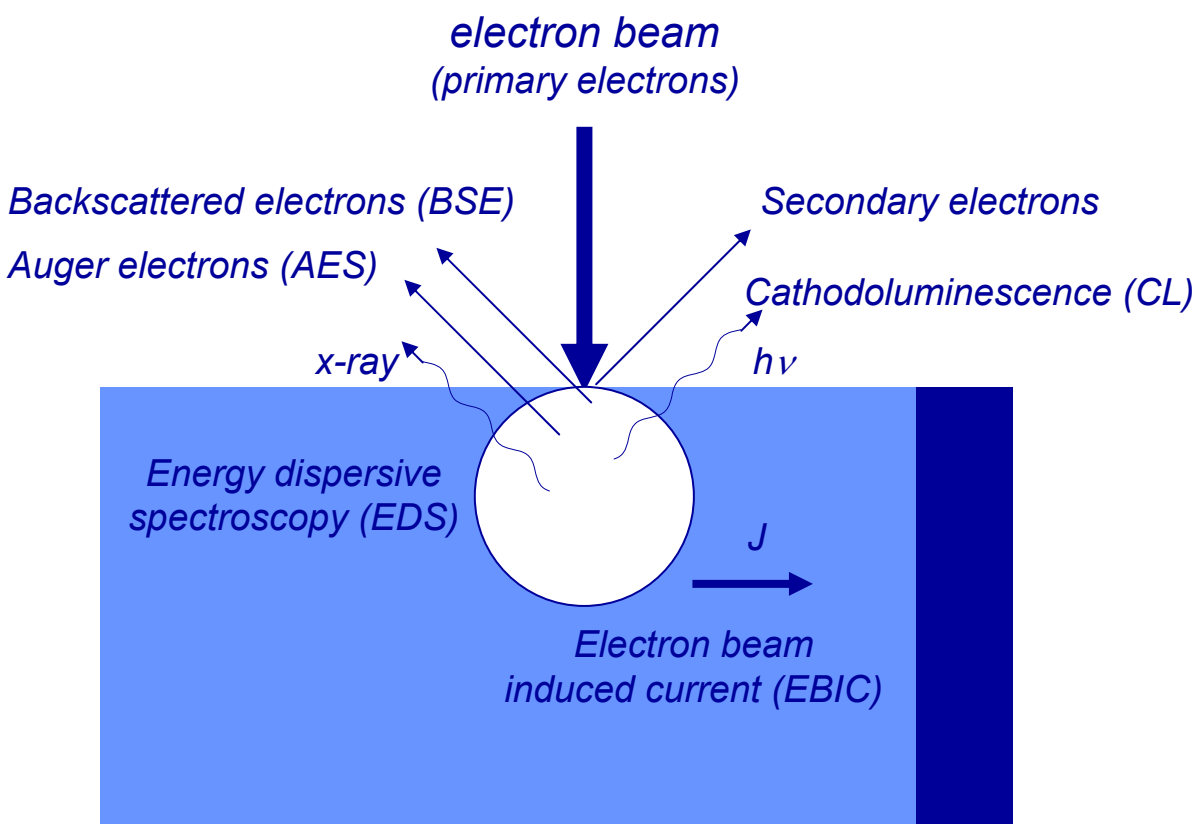


Scanning probe microscopy (SPM)
UHV-SPM

Transmission electron microscopy (TEM)
High resolution electron microscopy (HREM)

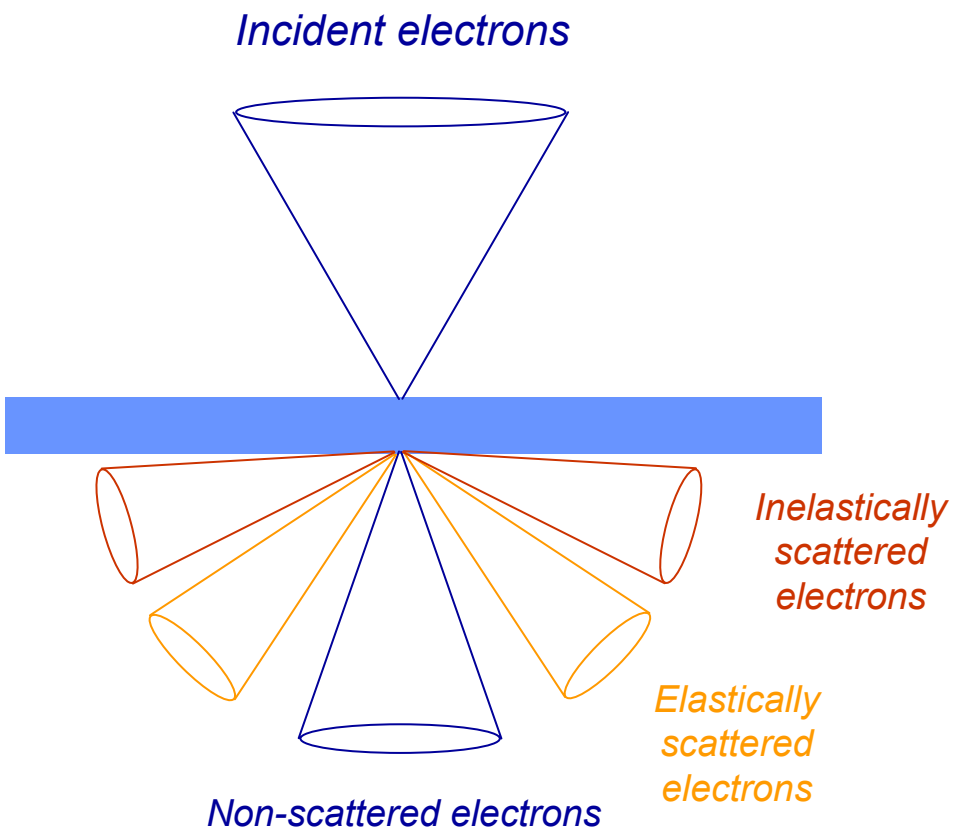
Electron microscopy

Scanning Probe Microscopy



Electron microscopy

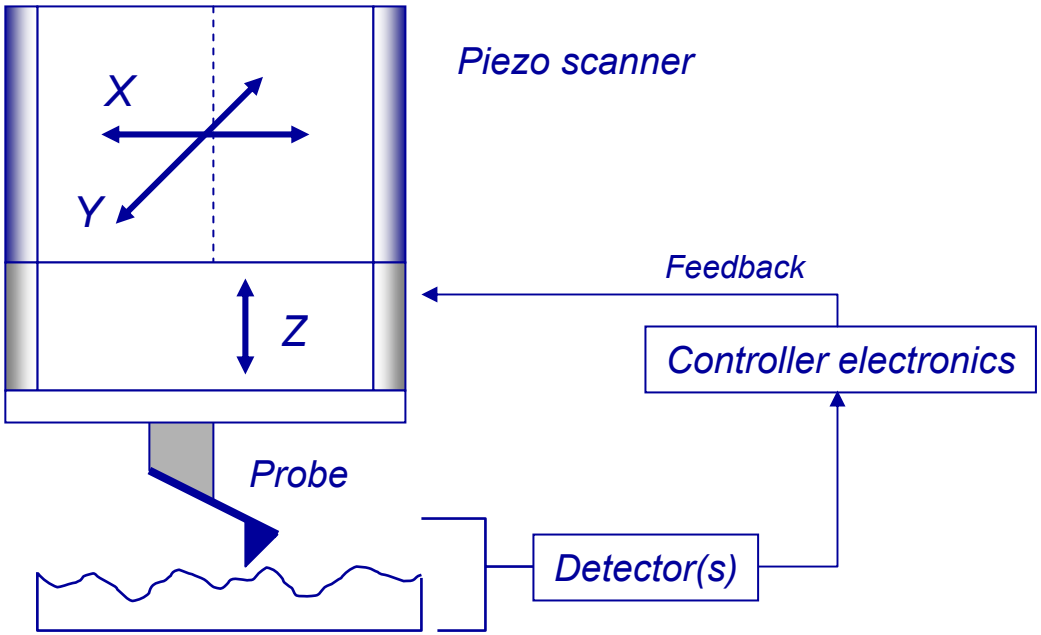
Scanning Probe Microscopy



- Transmission Electron Microscopy (TEM)
  - Bright Field TEM (BF)
  - Dark Field TEM (DF)
  - Weak-Beam Dark-Field TEM (WBDF)
- High Resolution Electron Microscopy (HREM)
- Scanning Transmission Electron Microscopy (STEM)
- Electron Diffraction (ED)
- Convergent Beam Electron Diffraction (CBED)
- X-ray Spectroscopy
- Electron Energy Loss Spectroscopy (EELS)

Electron microscopy

Scanning Probe Microscopy

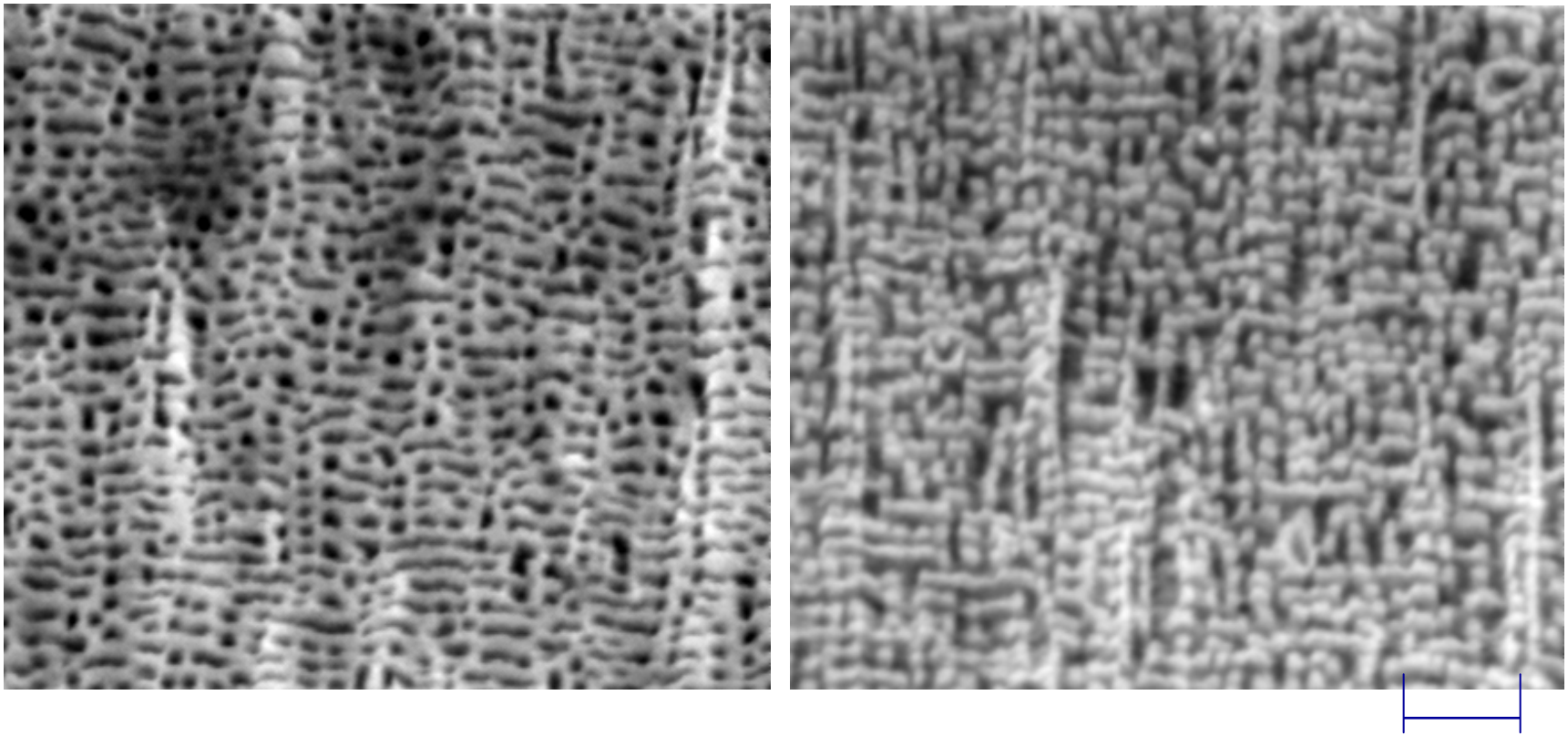


- Scanning Tunneling Microscopy (STM)
- Atomic Force Microscopy (AFM)

- Lateral Force Microscopy (LFM)
- Magnetic Force Microscopy (MFM)
- Scanning Kelvin Probe Microscopy (SKPM)
- Scanning Capacitance Microscopy (SCM)
- Scanning Tunneling Luminescence (STL)
- Near-field Scanning Optical Microscopy (NSOM)
- Piezoelectric Force Microscopy (PFM)

- *E004 Scanning Electron Microscopy*
  - **JEOL-5800** *(SE, EDS, Cathodoluminescence, EBIC, Scanning Tunneling Microscopy (STM)) Cryostage*
- *E005 Field Emission Scanning Electron Microscopy*
  - **JEOL-6320F** *(SE, BSE, EBIC)*
- *E009 Electron Probe Microanalysis*

Field Emission Scanning Electron Microscopy

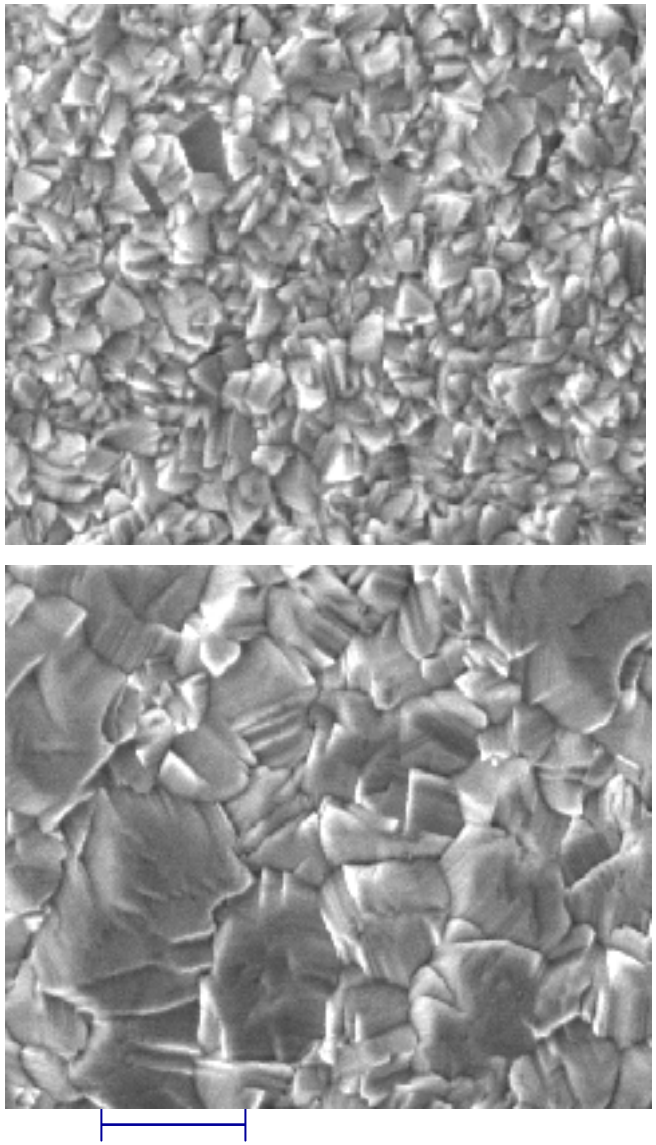


FE-SEM images of GaInP:Ge nanostructures. E_b = 1 keV, I_b = 50 pA.

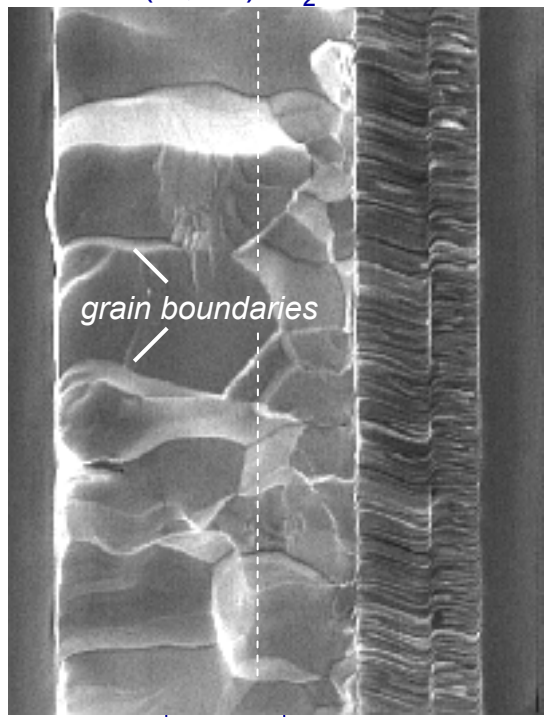
Field Emission Scanning Electron Microscopy

$Cu_{/Ga}$ = 0.92

$Cu_{/Ga}$ = 0.99



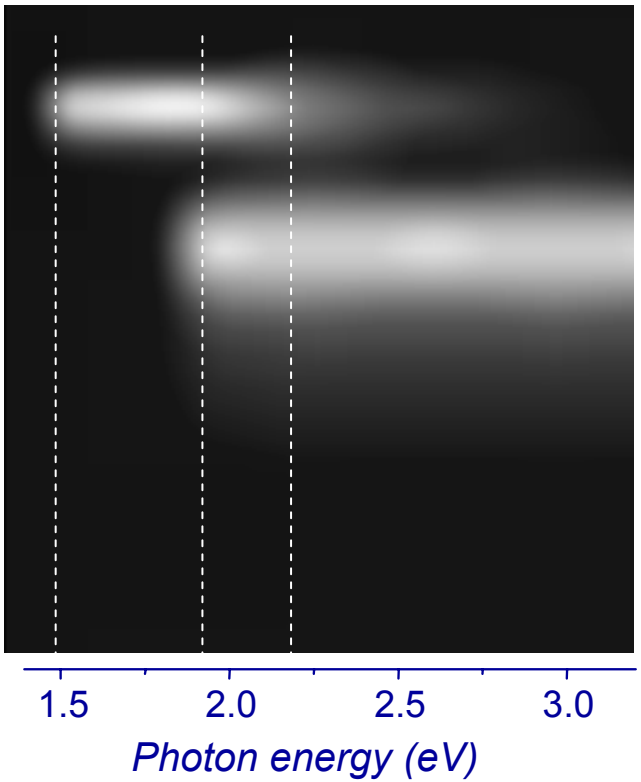
1 μm

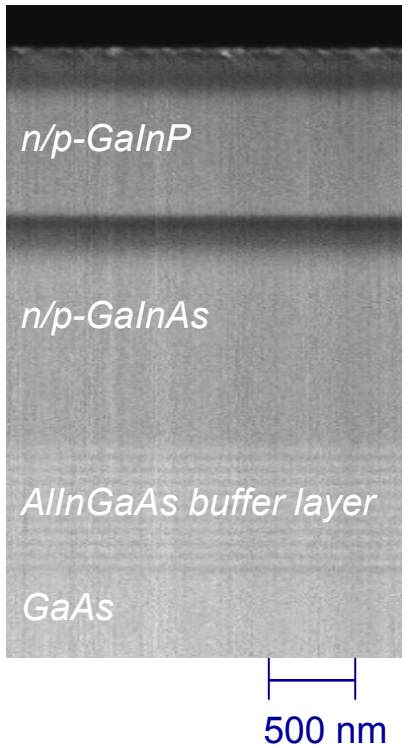


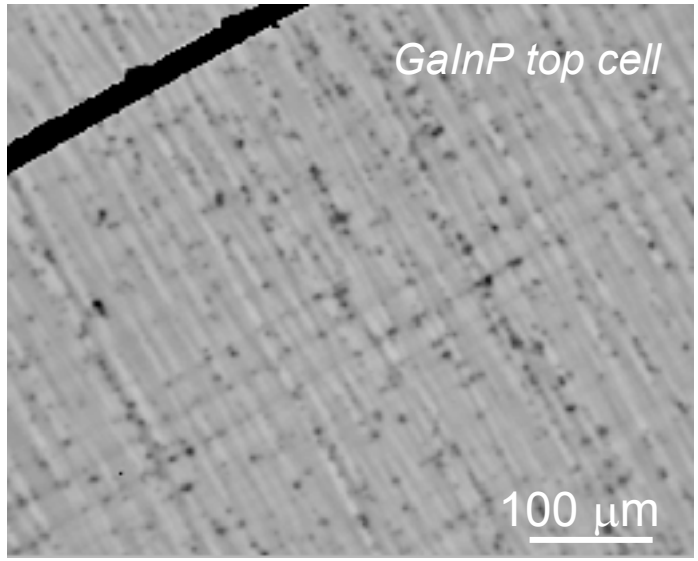
1 μm

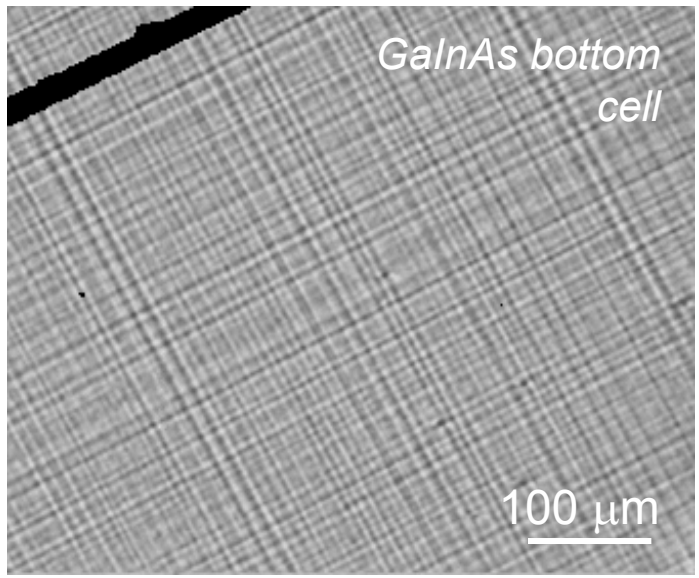
FE-SEM images of $Cu(In,Ga)Se_2$ and $CuGaSe_2$ thin films. E_b = 2 keV.

Electron beam induced current (EBIC)



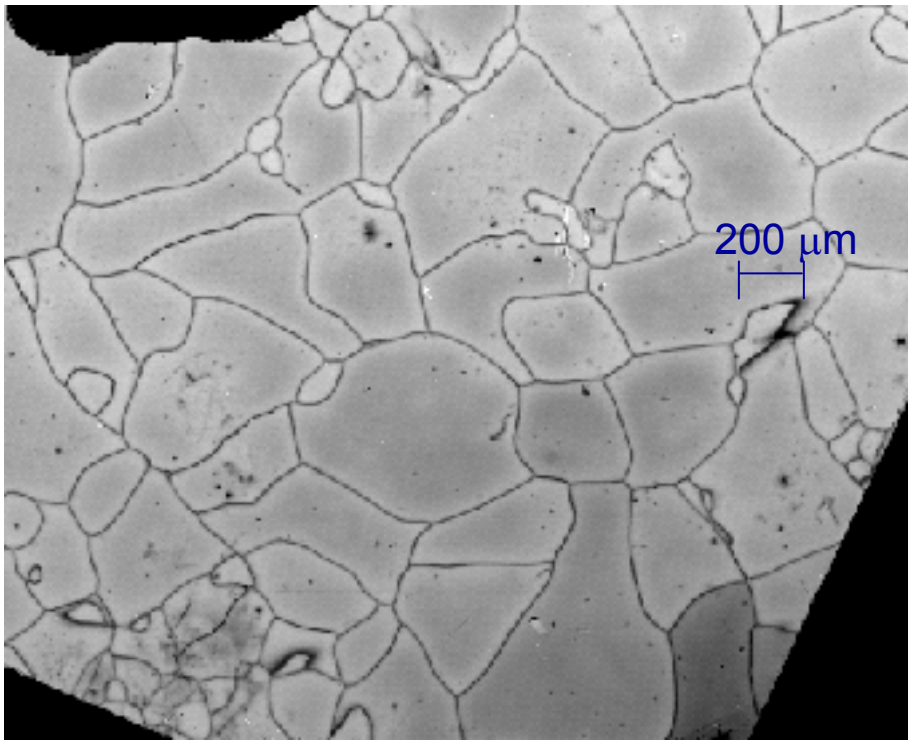




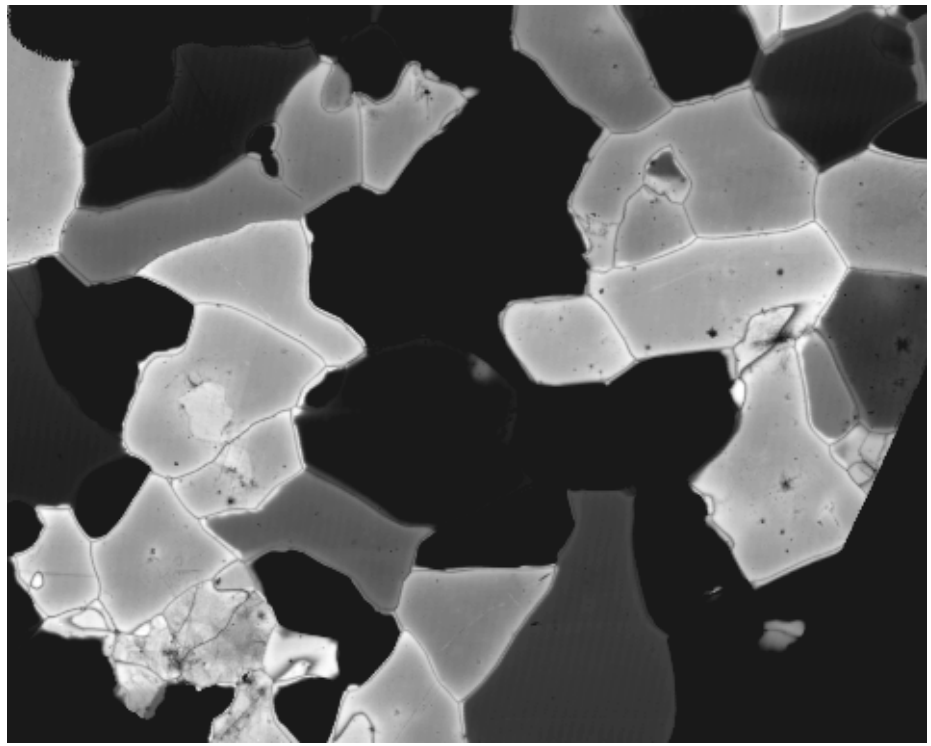


Electron beam induced current (EBIC)

T= 300 K

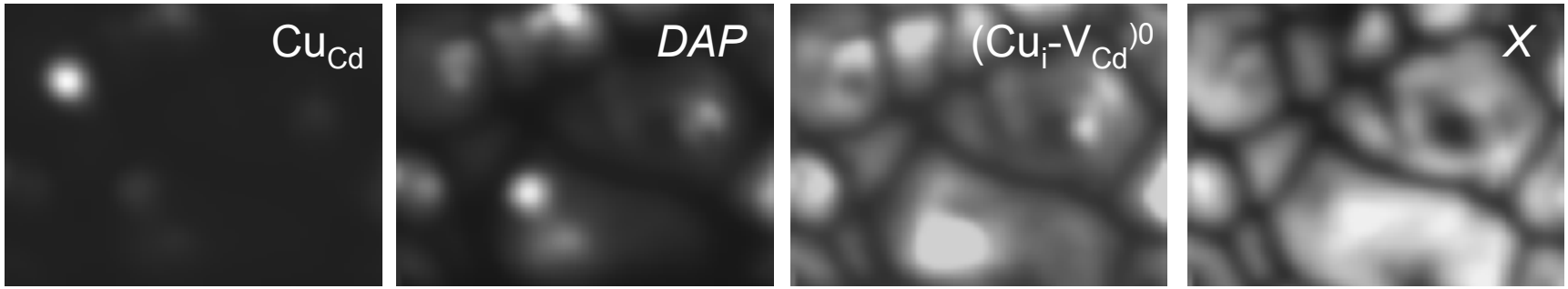


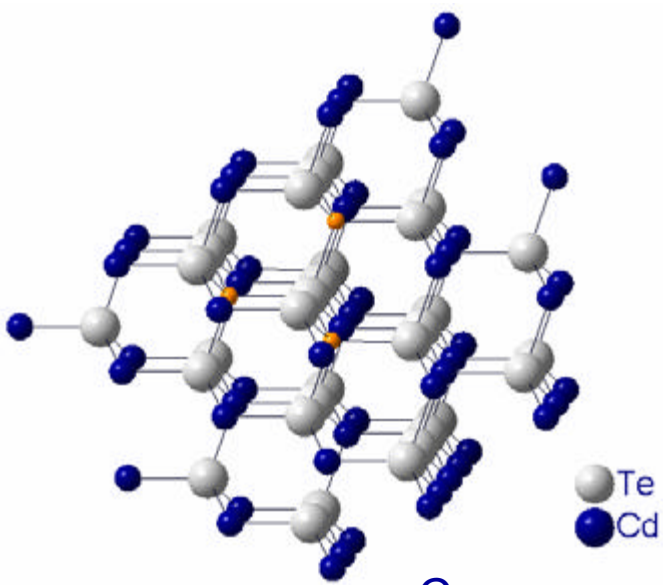
T= 80 K

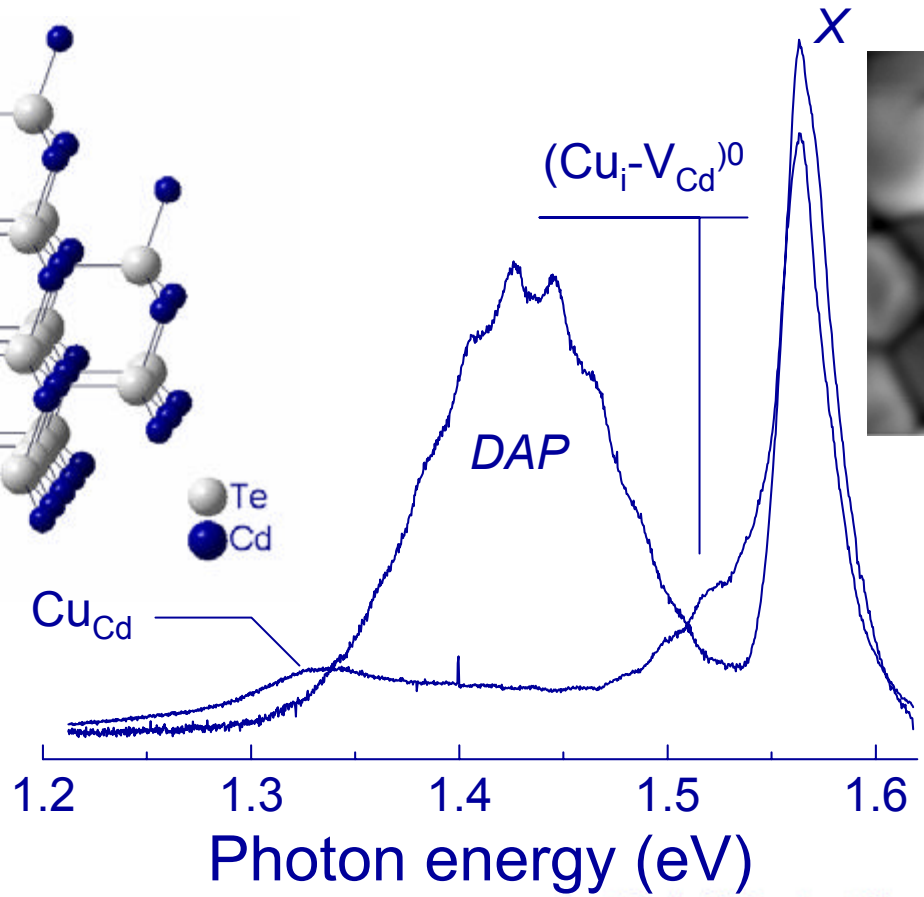


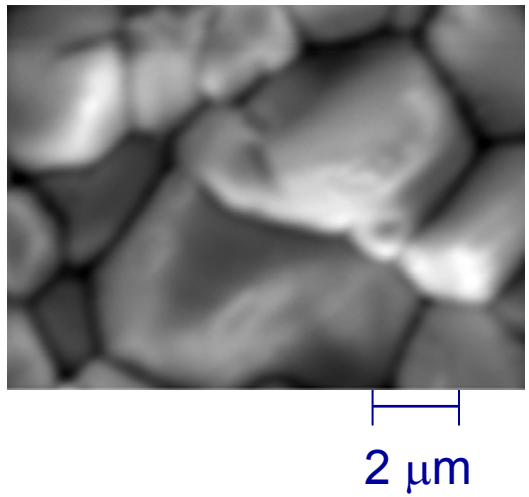
Temperature dependent EBIC in mc-Si solar cells. E_b = 30 keV, I_b = 900 pA.

Cathodoluminescence (CL)





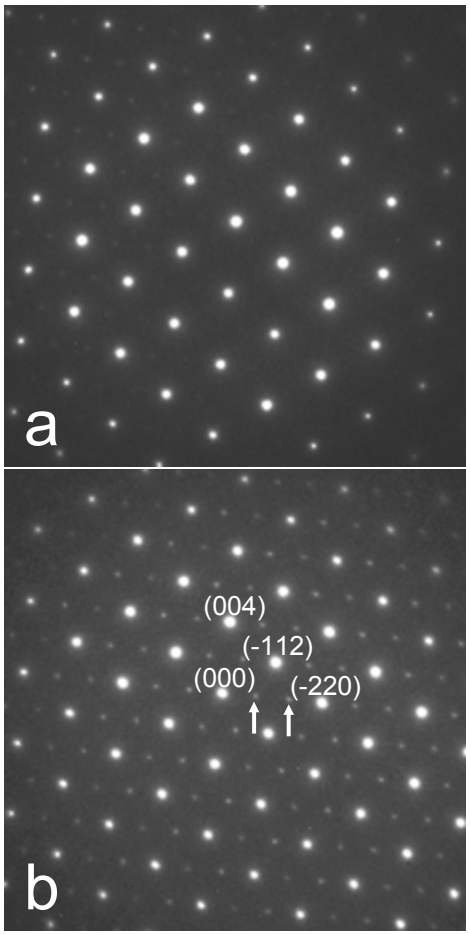


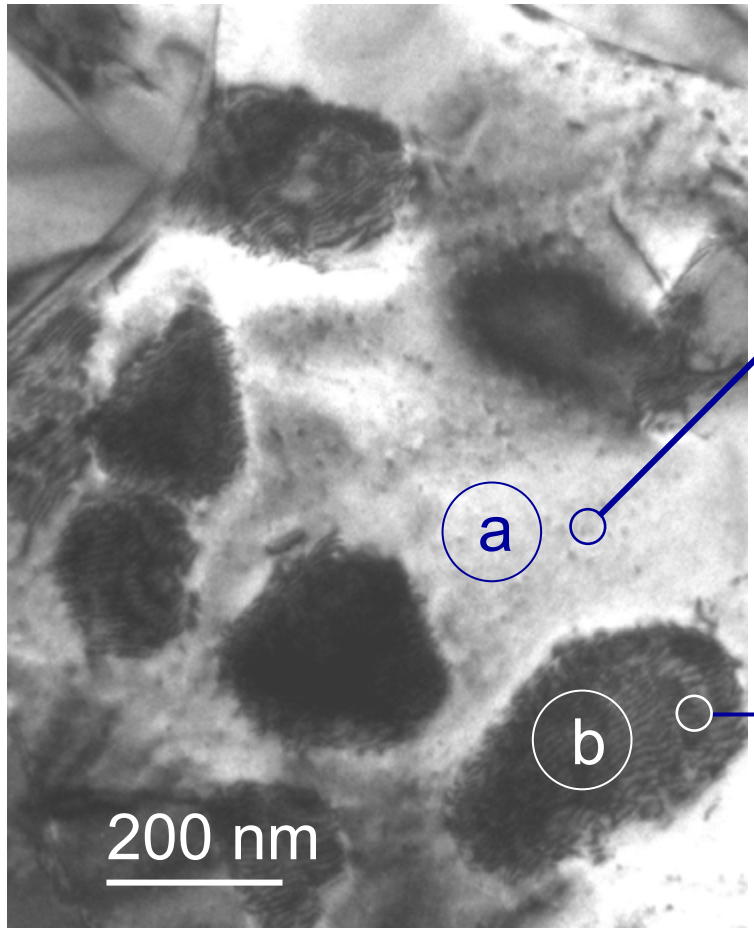


- *E010 Field Emission Transmission Electron Microscopy*
  - **FEI Tecnai F20-UT** *(nanodiffraction, CBED, diffraction contrast, HREM, atomic-resolution STEM, EDS, EELS)*
- *E014 Transmission Electron Microscopy*
  - **Philips CM-30**

Cu_xSe in $Cu(In,Ga)Se_2$ thin films

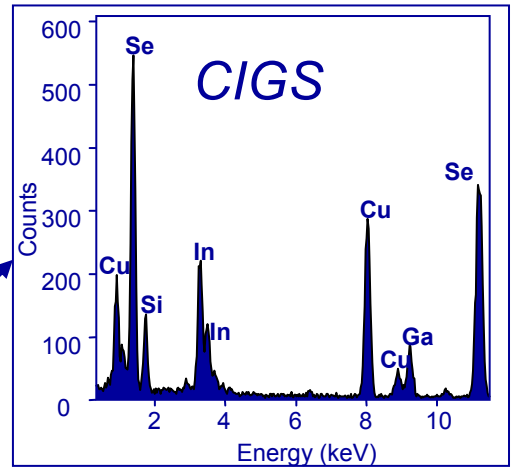
EDP

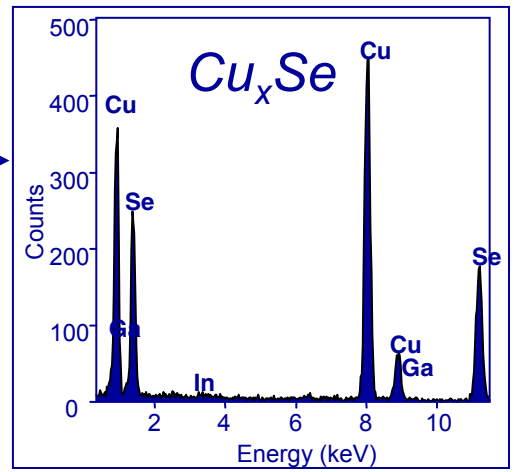




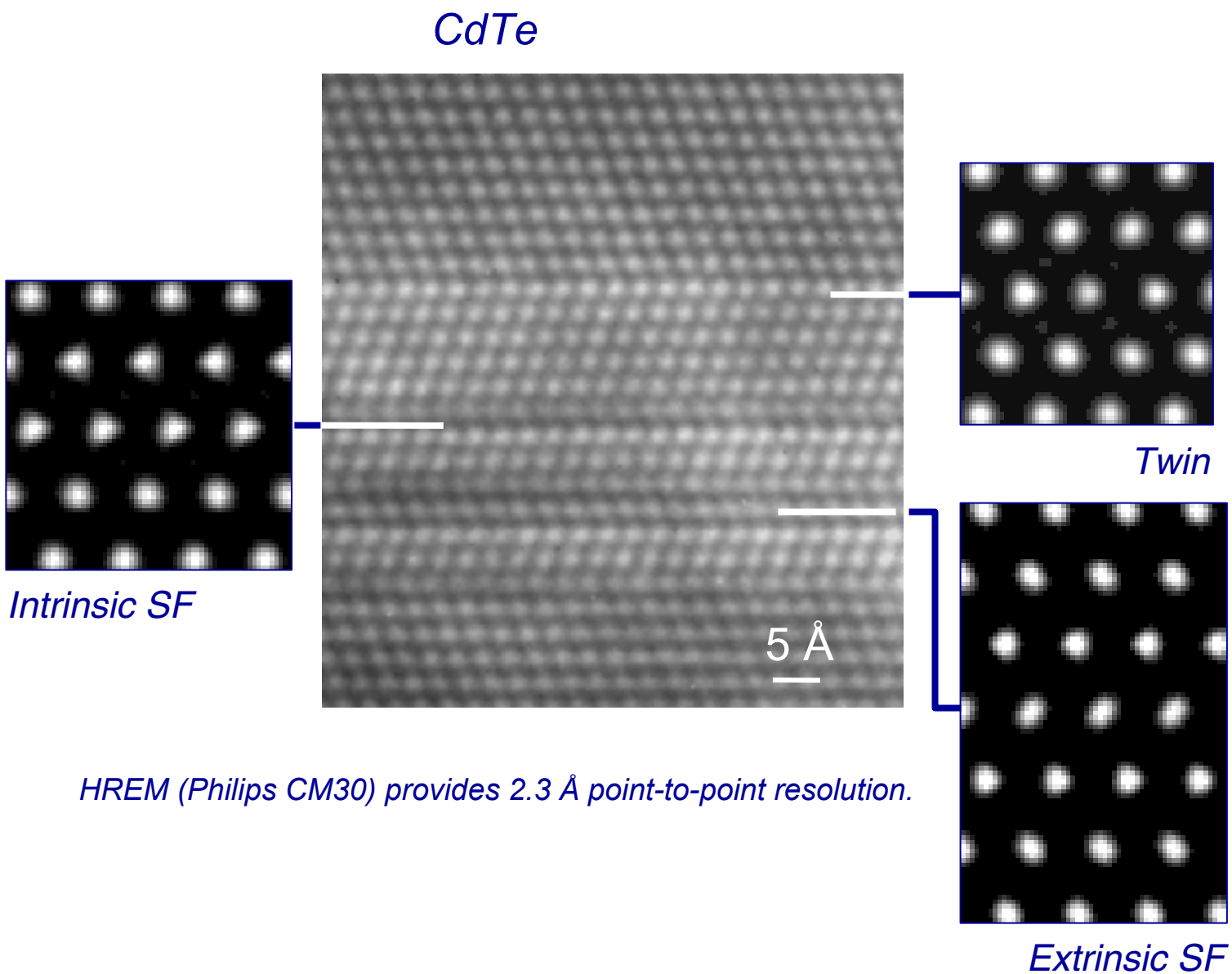
BF TEM Image

EDS





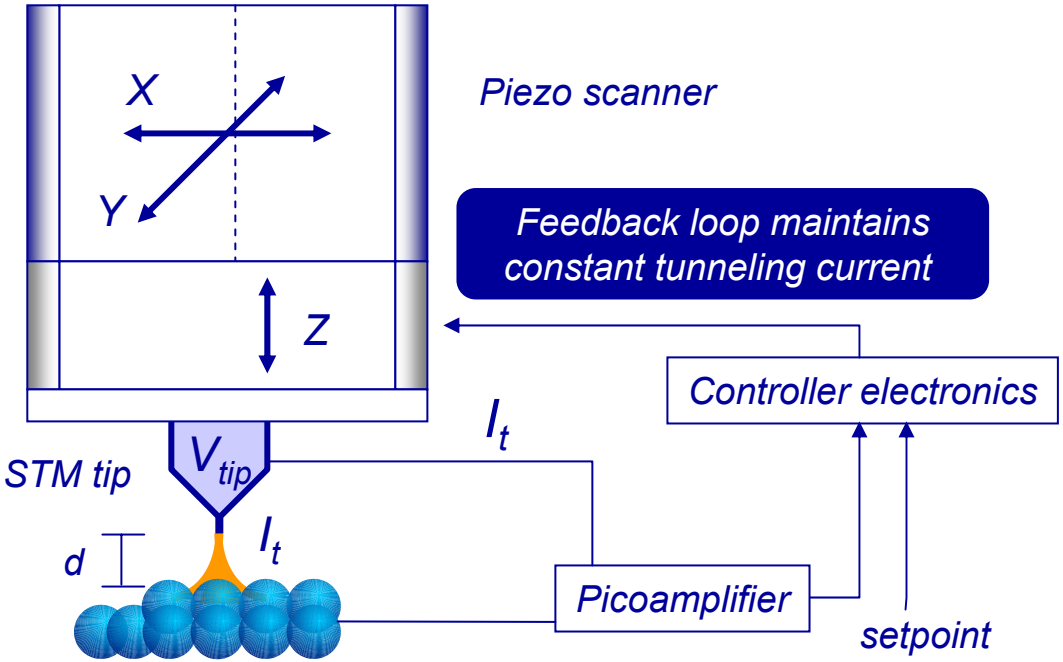
High resolution electron microscopy (HREM)



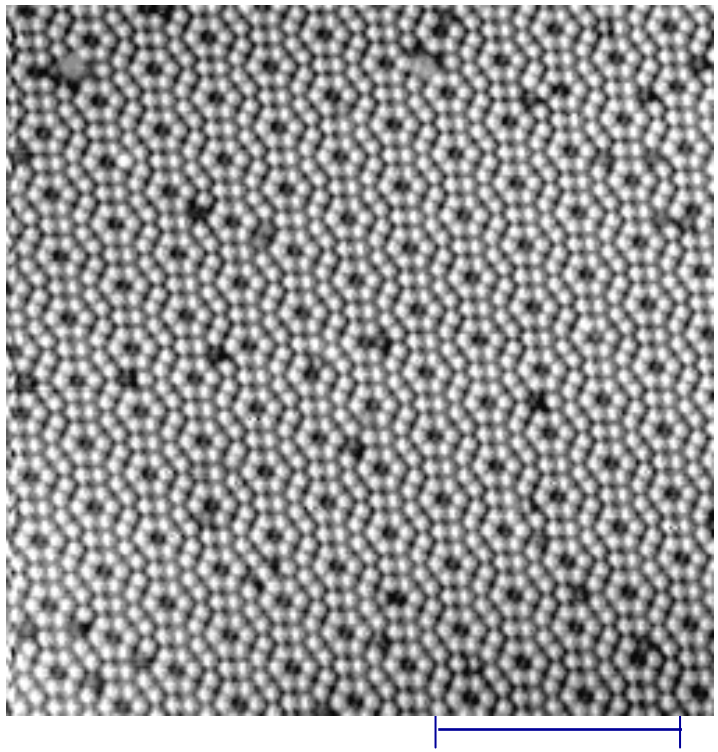
HREM (Philips CM30) provides 2.3 Å point-to-point resolution.

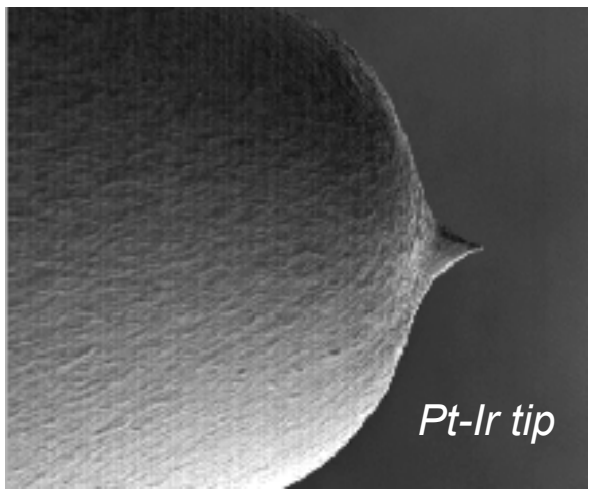
- *E007 Nanoscience and Technology Laboratory*
  - **TM Microscopes Autoprobe** *STM, AFM (CT, NC, TP, LF), EFM, SCM*
  - **DI Dimension 3100 Nanoscopes IIIa** *(+C-AFM)* **and IV** *(ultrafast scan mode)*
  - **Omicron Multiprobe S** *UHV, variable temperature (25-1500 K)*

Scanning tunneling microscopy (STM)



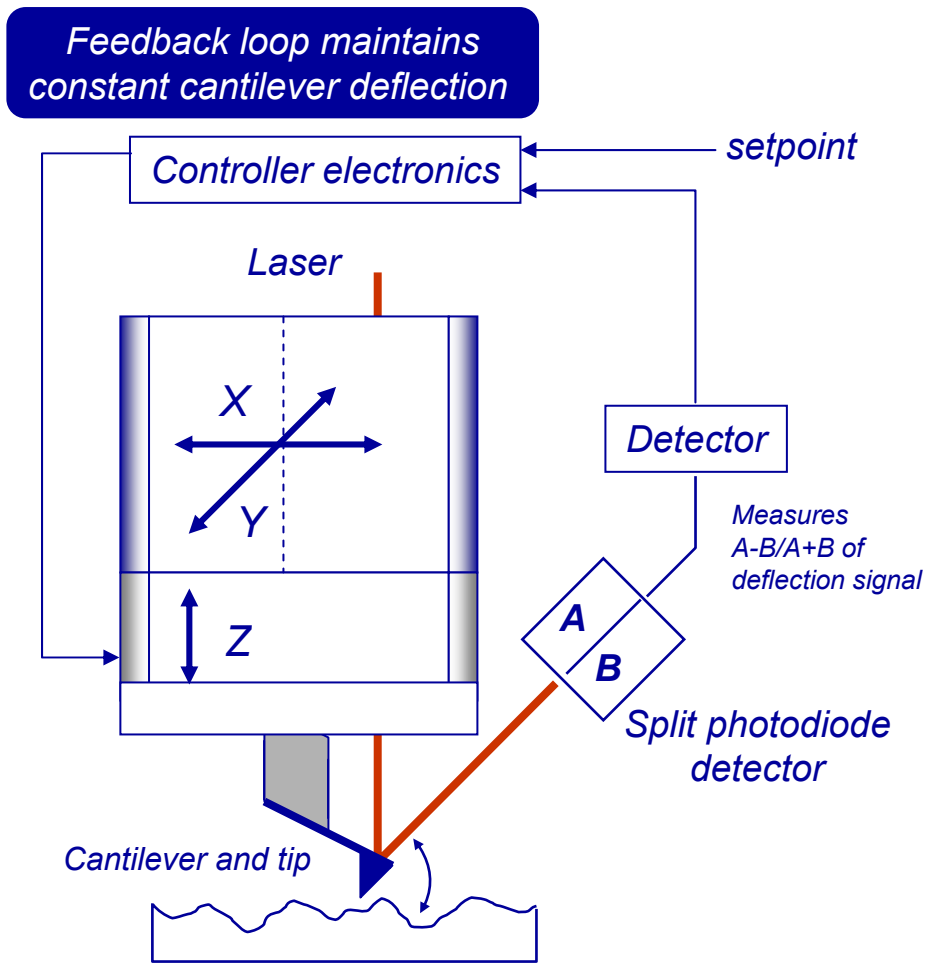
Si (111) 7×7 Reconstruction

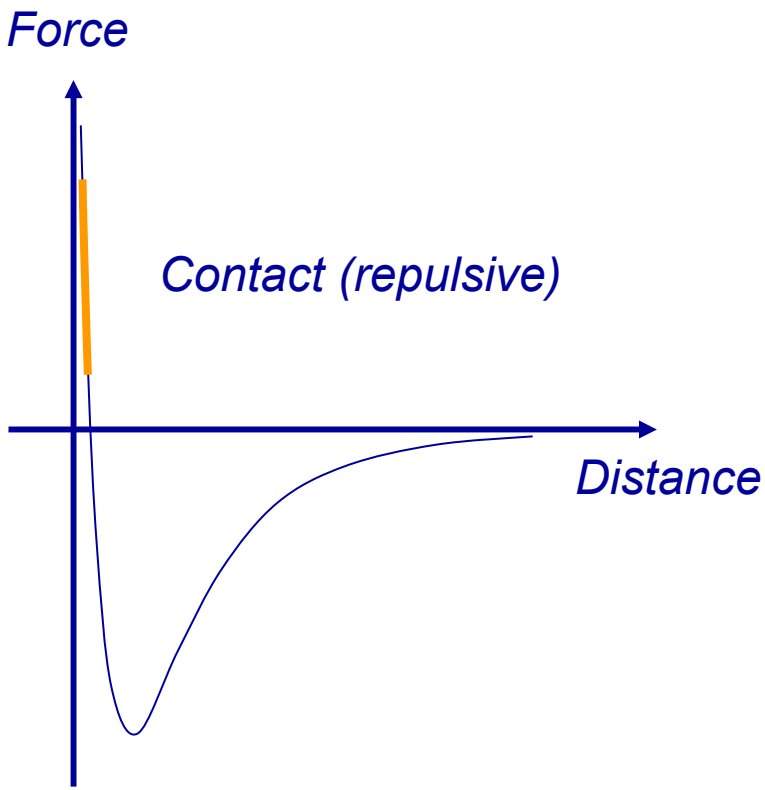




Atomic force microscopy (AFM)

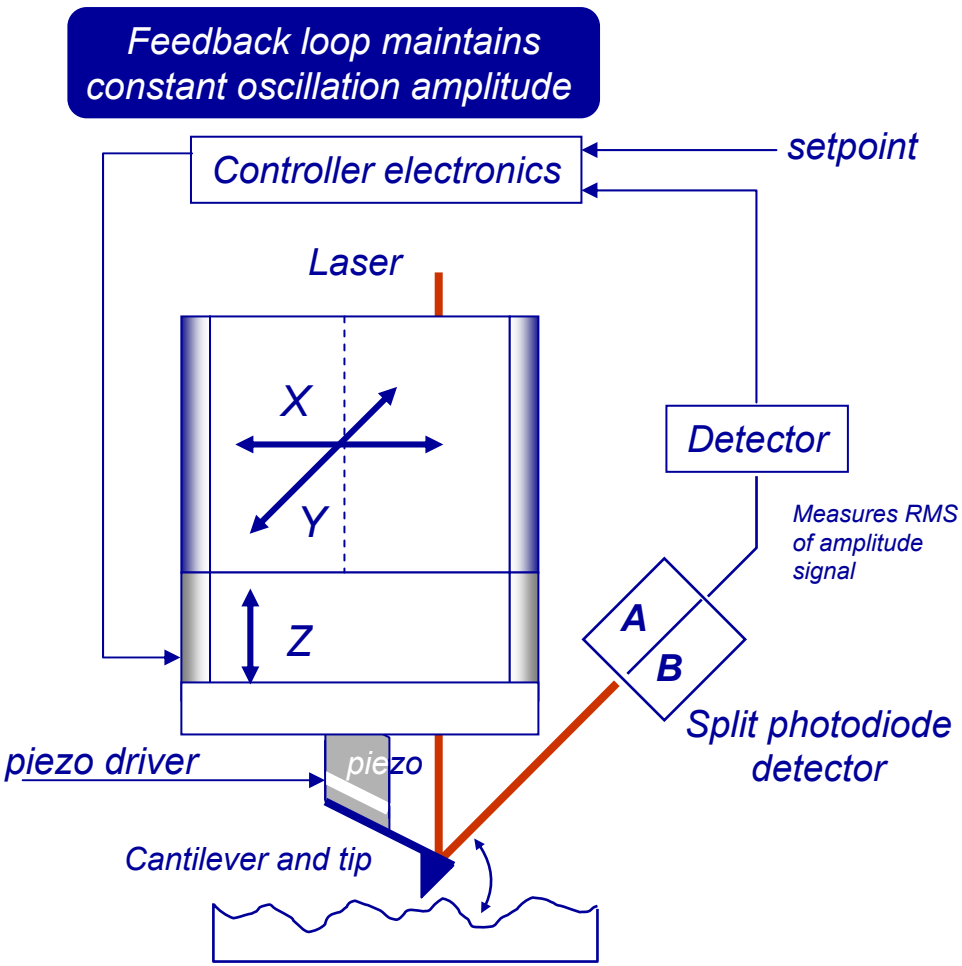
- Contac Mode(CM) AFM
- Lateral Force Microscopy (LFM)

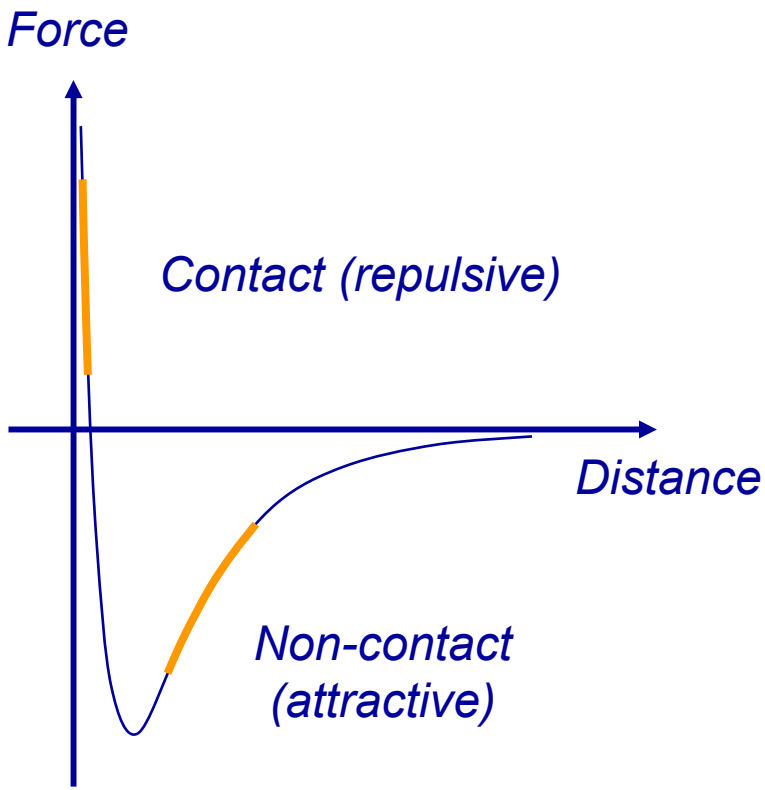




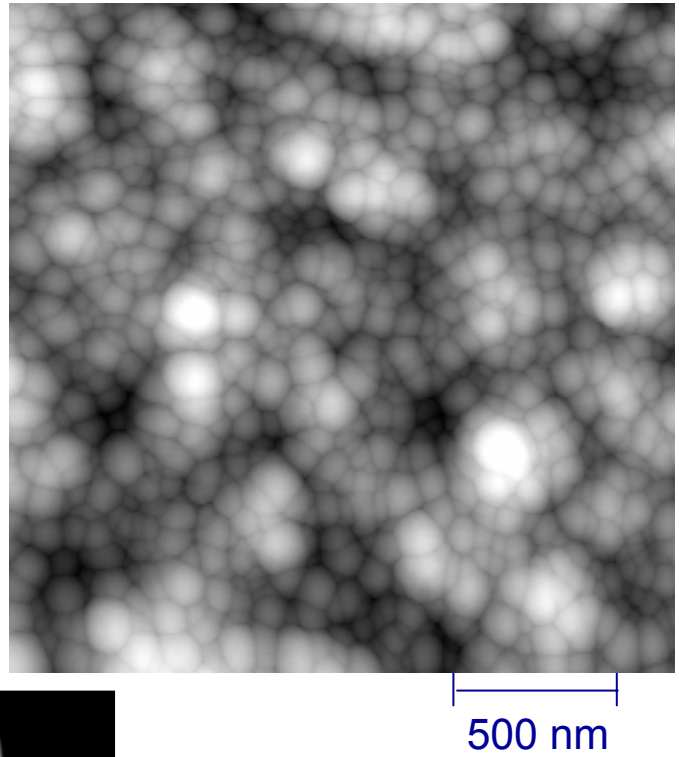
Atomic force microscopy (AFM)

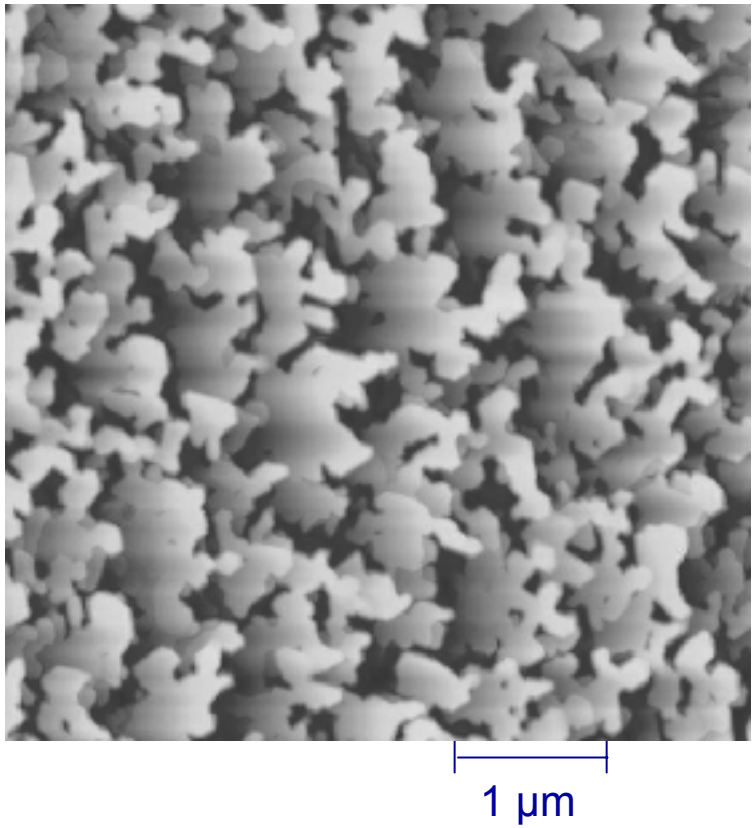
- Contac Mode(CM) AFM
- Lateral Force Microscopy (LFM)
- Non-contact Mode (NC) AFM
- Tapping Mode (TP) AFM

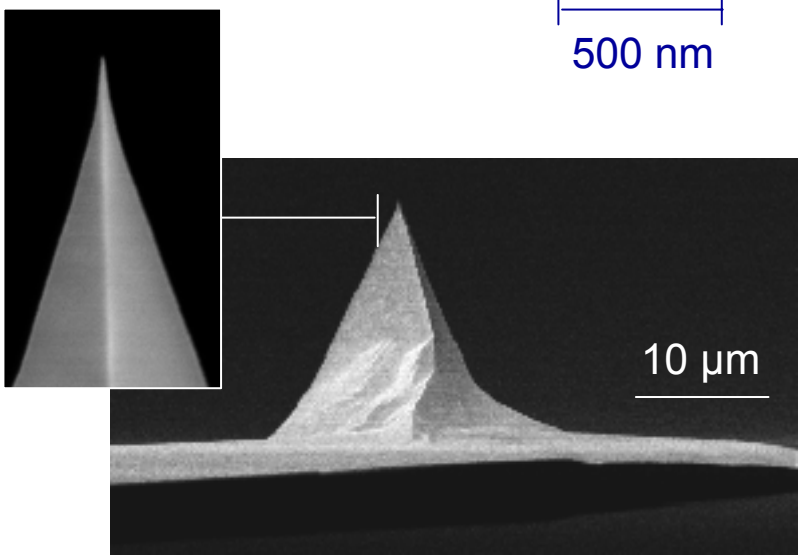




Atomic force microscopy (AFM)



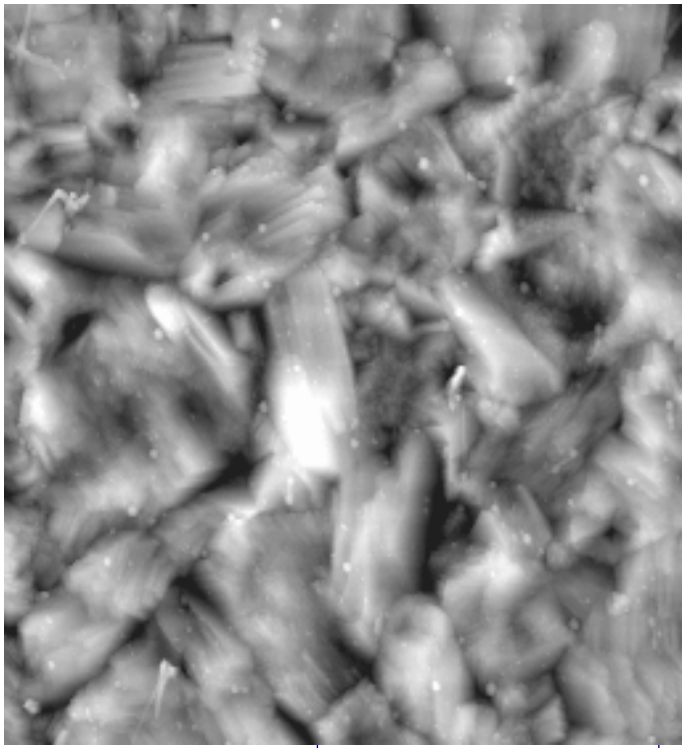




Tapping Mode AFM. Above- Left. CdS deposited on SnO_2 by CBD. Z range = 60 nm. Above-Right. Epitaxial GaP on Si. Z range= 20 nm

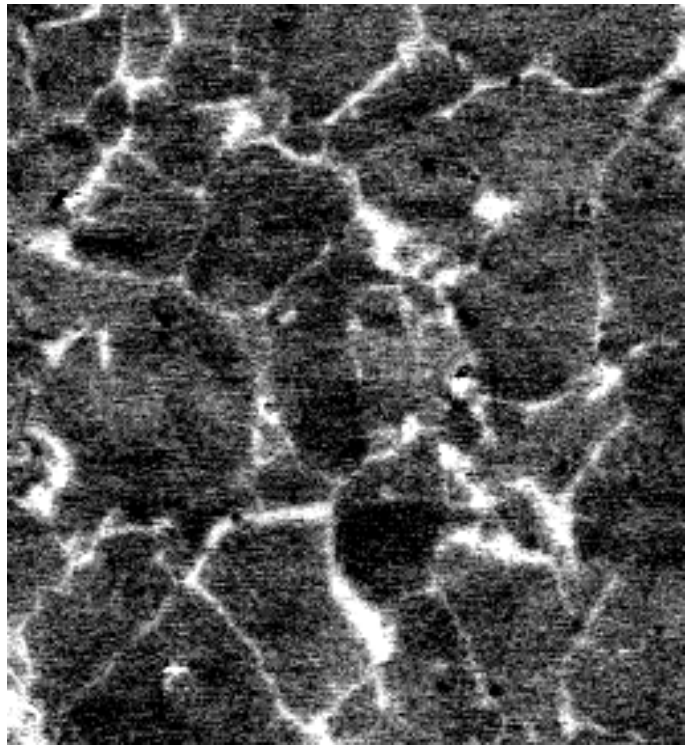
Scanning Kelvin probe microscopy (SKPM)

AFM



5 μm

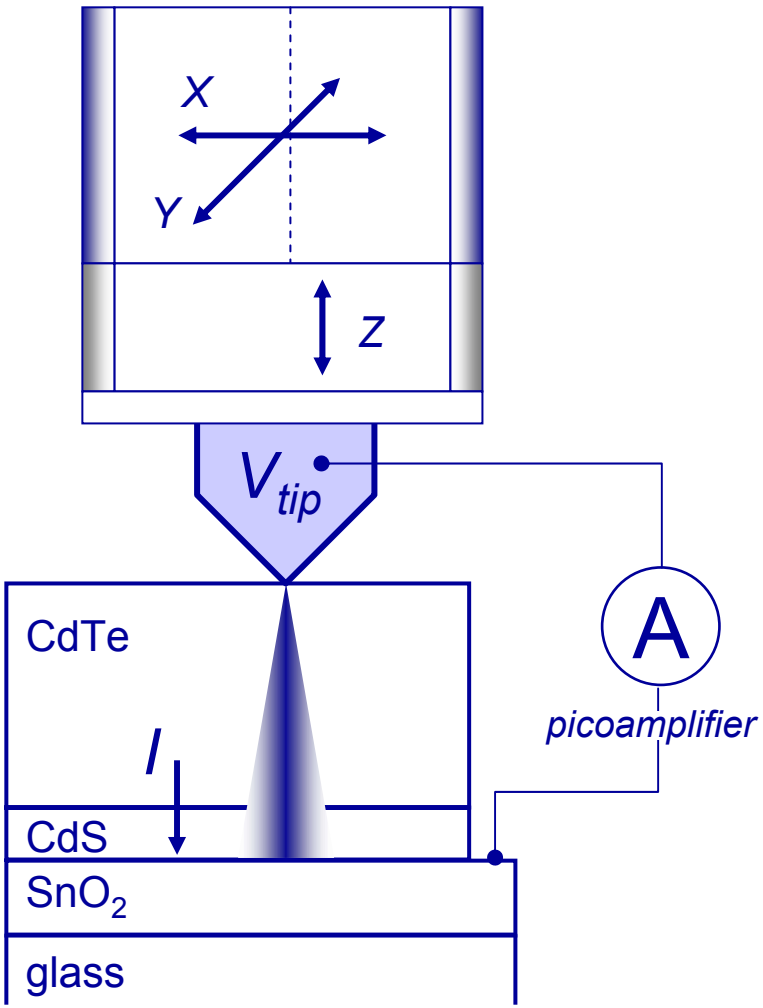
SKPM



AFM and SKPM images of a $Cu(In,Ga)Se_2$ thin film. A higher surface potential (about 150 mV) is observed at grain boundaries.

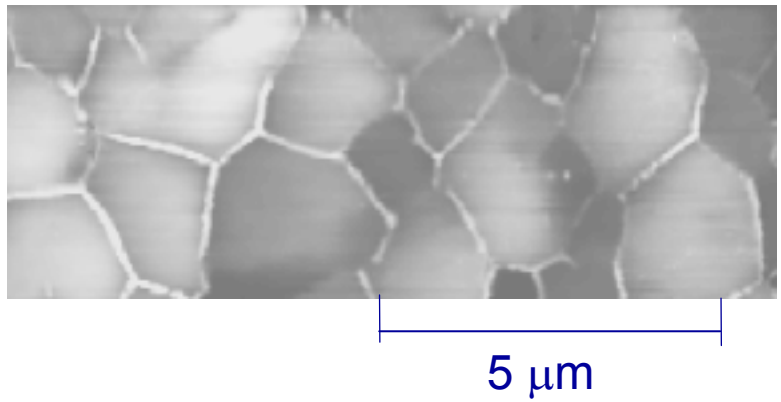
Conductive atomic force microscopy (C-AFM)

The AFM operates en contact mode



Contact mode AFM

C-AFM



C-AFM of a CdTe/CdS/SnO_2 structure after $CdCl_2$ + Br:MeOH treatments.