

**Laboratory Skills / Scientific Instrumentation**

1. **Clean Room**: Clean-Room user (EE, Penn State), Photolithography, Reactive Ion Etching (RIE), Device Fabrication

![Clean Room](image1)

- Standard Photo-Lithography
  - (a) Flip-Flop
  - (b) Discrete MOSFETs
  - (c) Ring Oscillators
  - (d) Single MOSFET made by standard Photolithography

2. **Chemical Vapor Deposition (CVD)**: Growth of nanostructures (SWNTs, MWNTs, Nanowires etc.), Annealing of material in controlled environment. Involves: Chemicals (gas, liquids), Furnace, Vacuum Pumps, Mass Flow Controllers etc.

![Chemical Vapor Deposition](image2)

- 1-Zone Furnace
- 3-Zone Furnace
- High Temperature Furnace
  - $T \sim 1600 \, ^\circ C$

- Exfoliation of intercalated graphite
- Growth of isolated SWNTs
- Growth of ZnO nanostructures
3. **Deposition Techniques**: E-beam evaporation, Thermal evaporation, sputtering, Electroplating

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![PVD 75 (Kurt J. Lesker): E-beam, Thermal Evaporator](image1)

4. **Scanning Probe Microscopy**: Atomic Force Microscopy[AFM] (Non-Contact mode, Contact mode), MFM (Magnetic), EFM (Electric), Scanning Tunneling Microscopy (STM), Force-Distance microscopy.

![PSIA-XE100](image2)

![Asylum Research](image3)
5. **Raman Spectroscopy and Photoluminescence**:

Renishaw: Single Grating micro Raman, Air Cooled CCD, Laser: 514, 647, 785 nm, Temperature attachment

T-64000: Single/Triple Grating (additive & subtractive), L-N2 Cooled CCD, PMT, Laser: Any wavelength, Micro/Macro, Temperature attachments (micro and macro), Gas-cell, high pressure attachment

Microscope Attachements:

(Pressure, Temperature, Gas, Macro)

Temperature (micro)

Temperature (macro)
6. **Optical absorption/transmission:**

![Lambda 950 (US-vis)](image)

7. **FTIR (Fourier Transformed Infrared spectroscopy)**
8. **TGA**

![TA Instrument's: TGA5000](image)

9. **Electrical Measurements:**

   - **Low T, Vacuum**
   - **Low T, High T, Vacuum, Gas, TEP**
   - **High T, Vacuum, Controlled Environment**
10. Scanning Electron Microscopy:

Jeol FESEM, Focused Ion Beam, Environmental Scanning Electron Microscopy (ESEM), SEM (Hitachi 3000)

Dual beam (electron, ion) FIB