Optical Interconnect Science and Technology at ORNL

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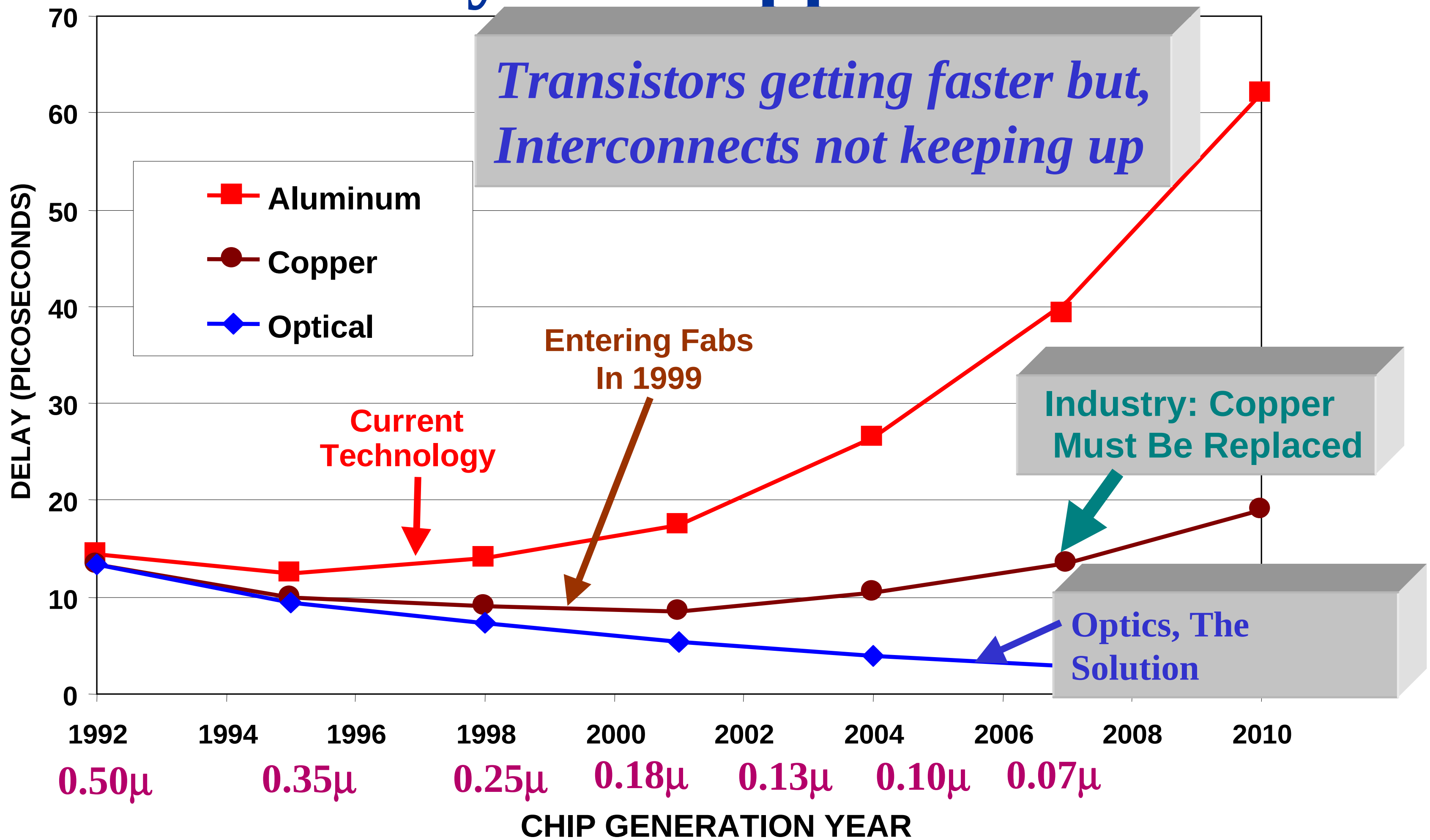
11/8/99

Optical Interconnect Is A Viable Solution Beyond Copper

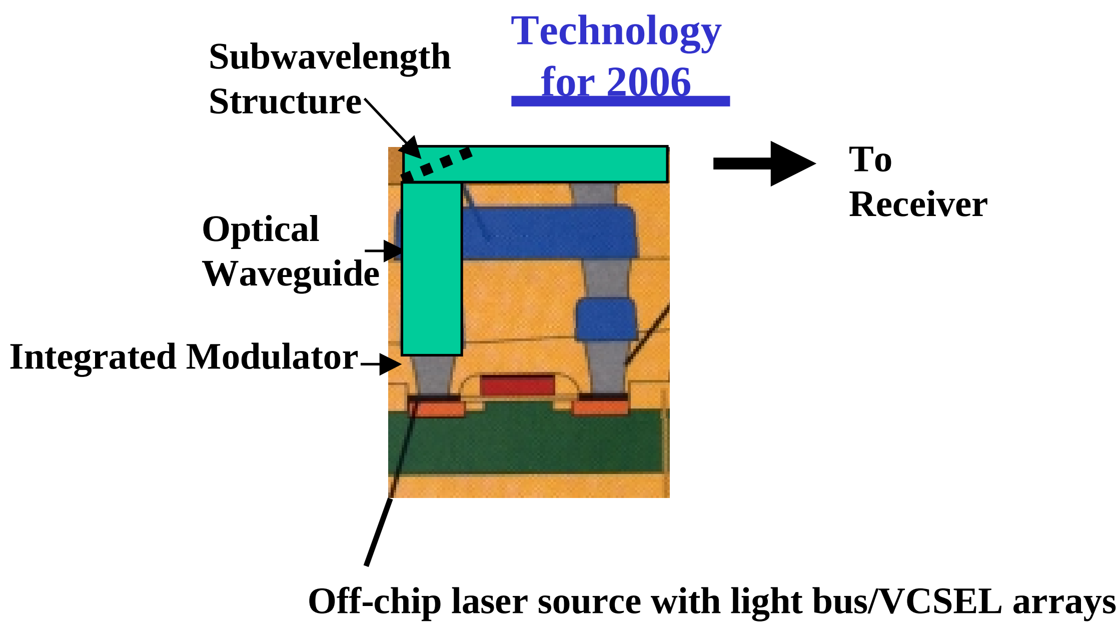


Emphasis of OI Research at ORNL is CMOS-compatible Intra-chip

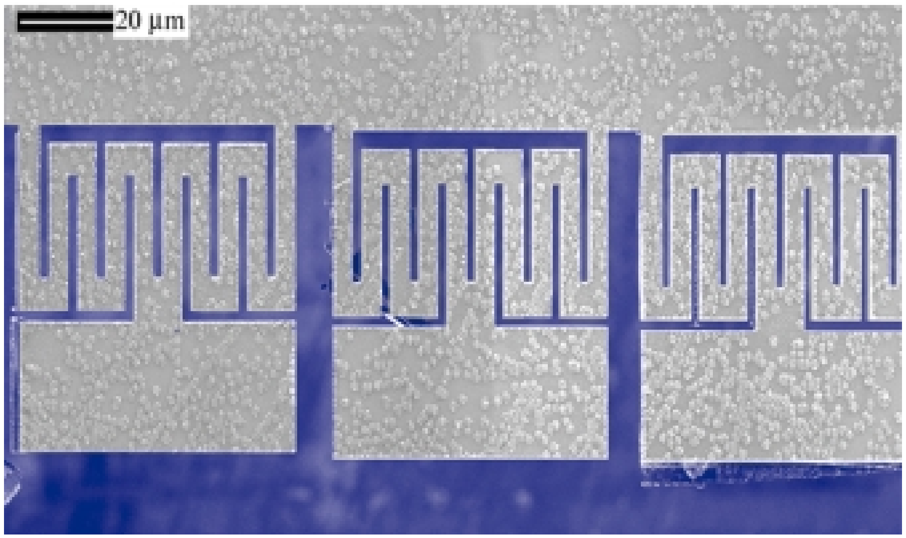
- Addressing Detector Bandwidth/Power Issue
  - MEMS Devices
  - Nanotechnology
- Addressing the High Density Requirements
  - Optical materials for nano-structures and devices

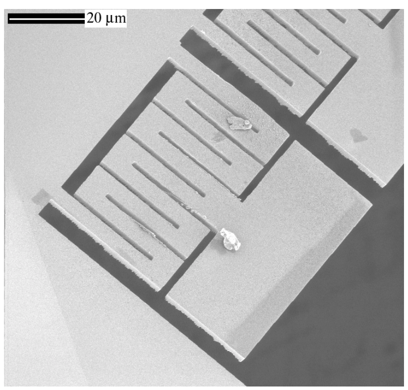
Intra-chip Optical Interconnect R&D

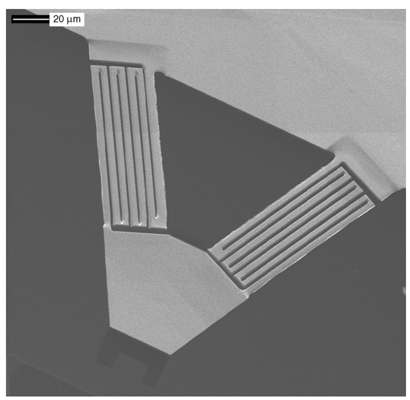
- Requires research in variety of optical/electronic materials and structures
- Hybrid implementations show much promise in the near horizon (sources, waveguides, splitters, modulators, detectors)



1999 R&D 100 Award Winning Micromechanical Photon Detectors

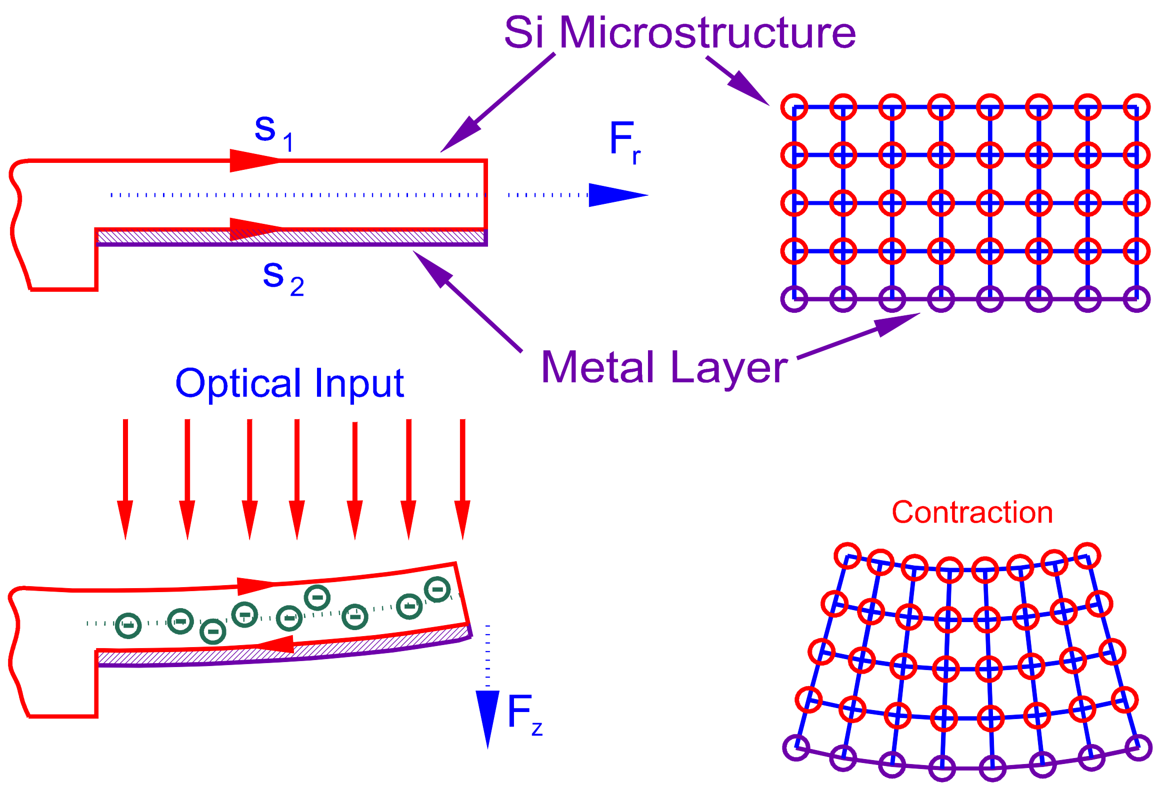




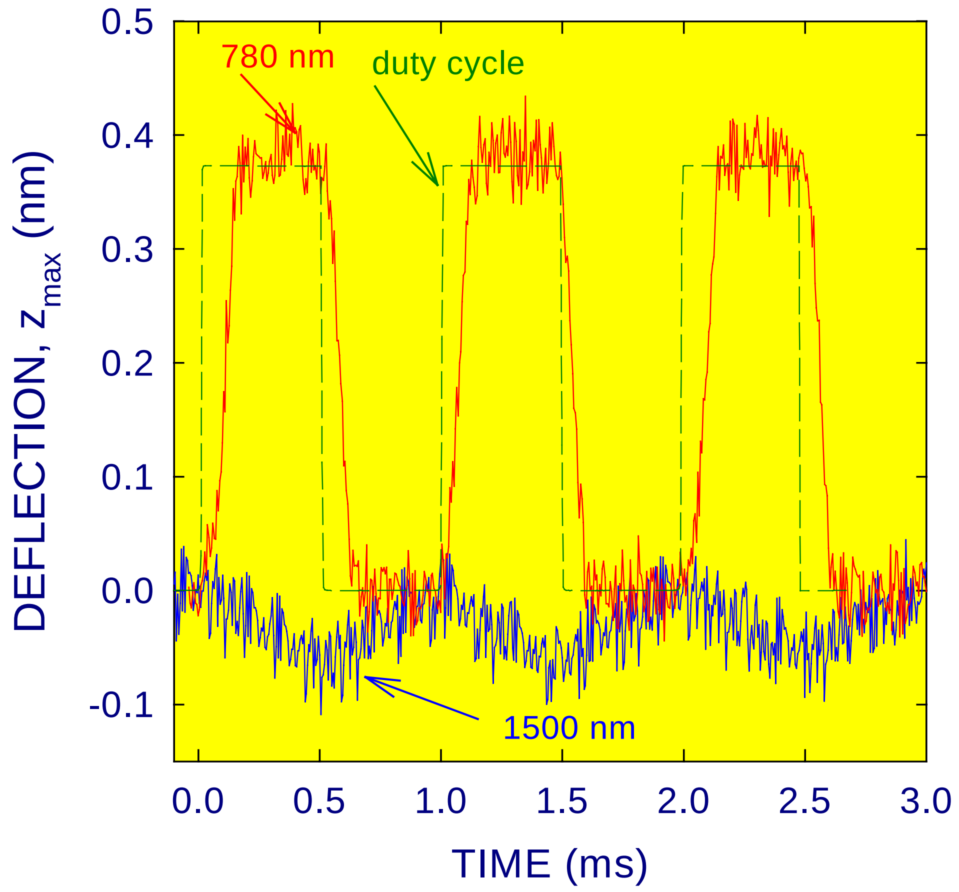


- ORNL fabricated small linear arrays of microstructures using rapid prototyping methods (made from InSb, GaAs, and Si/Pt).
- Such devices can be used as micromechanical (photon or thermal) detectors for uv to infrared radiation.
- These devices have been produced using new microfabrication approaches.

Photo-Induced Stress or Internal Photo-Emission



Quantum Detector Response



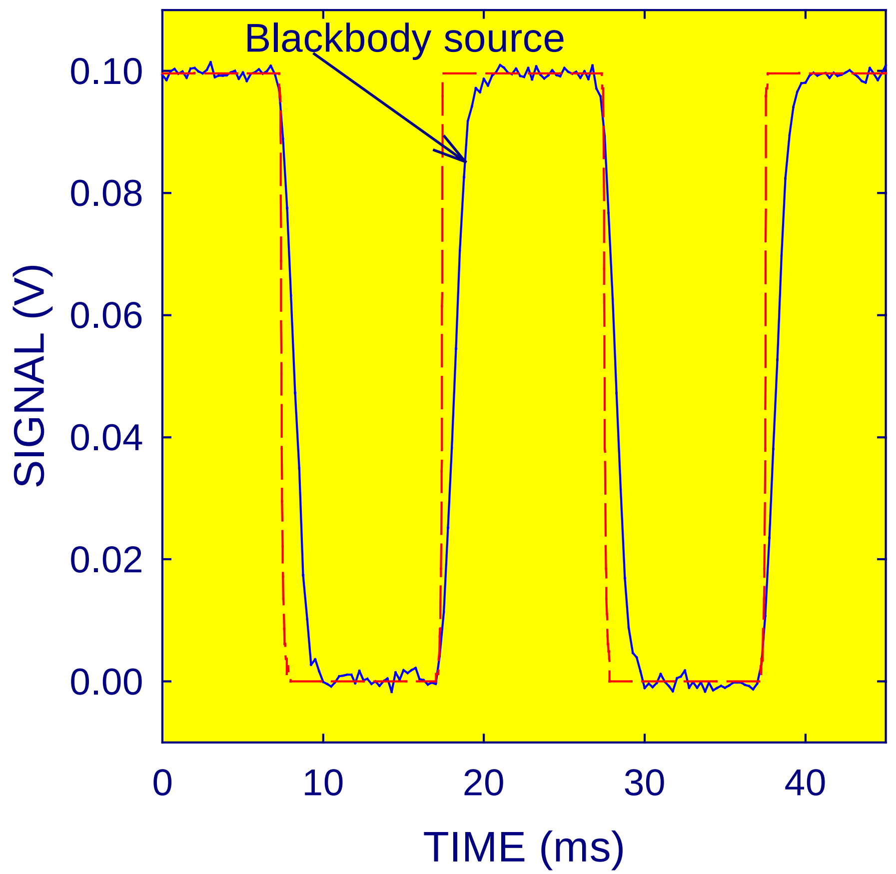
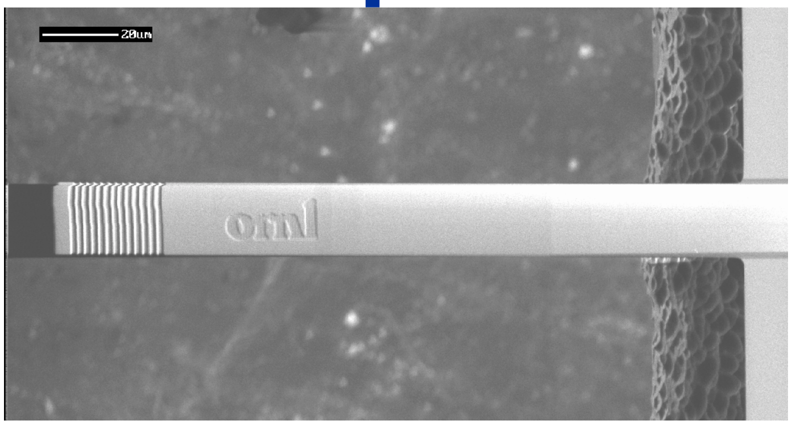
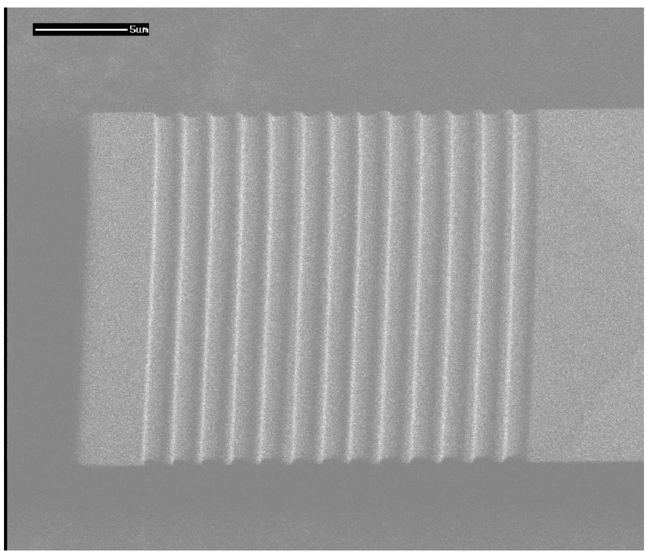


Photo-induced deflection of Si quantum detector to 780 nm photons

Photo-Induced Deflection of InSb Quantum Detector Exposed to Blackbody Source with $\lambda > 1.1$ μm

Integrated Microdevice/Grating for Optical Coupling/Steering





- SiNx microcantilever with an integrated grating that has a period of 1µm and a blaze angle of 45 degrees.
- Fabricated rapidly using direct write techniques.
- Grating can be used to couple or decouple laser light or provide collimation and focusing.
- The SiN_x microdevice shown below demonstrated the feasibility of the micromechanical waveguide concept.

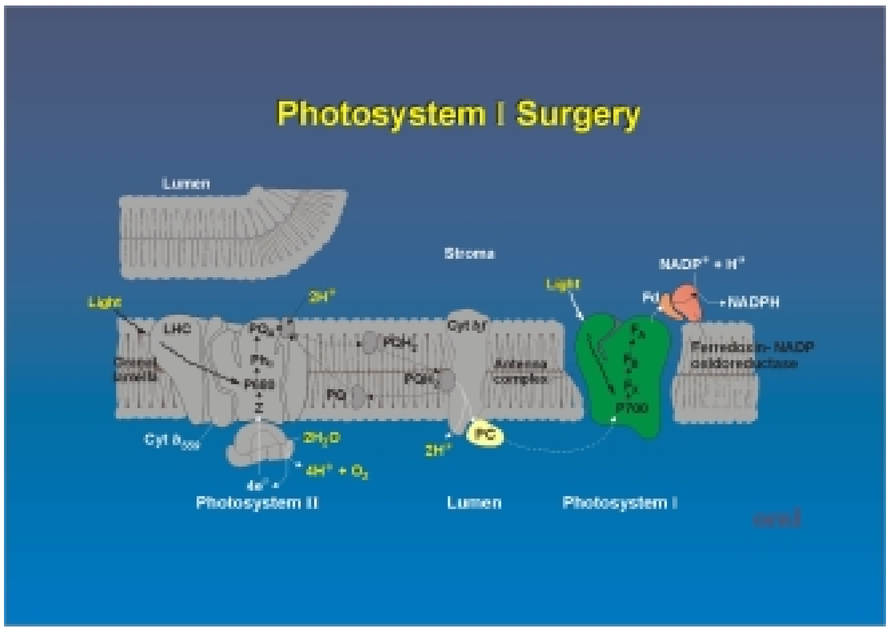
Nanotechnology: what it is

A bottom-up approach to design and fabrication where the dimensions on the lowest level are smaller than ~100 nm (usually much smaller). Assembly may take place atom by atom or molecule by molecule. However, self-assembly/organization is required for practical technology. ***Phenomenon that arise on the nanoscale are essential to the operation of the device/system.***

Manipulation and Coupling of Properties at the Nanoscale

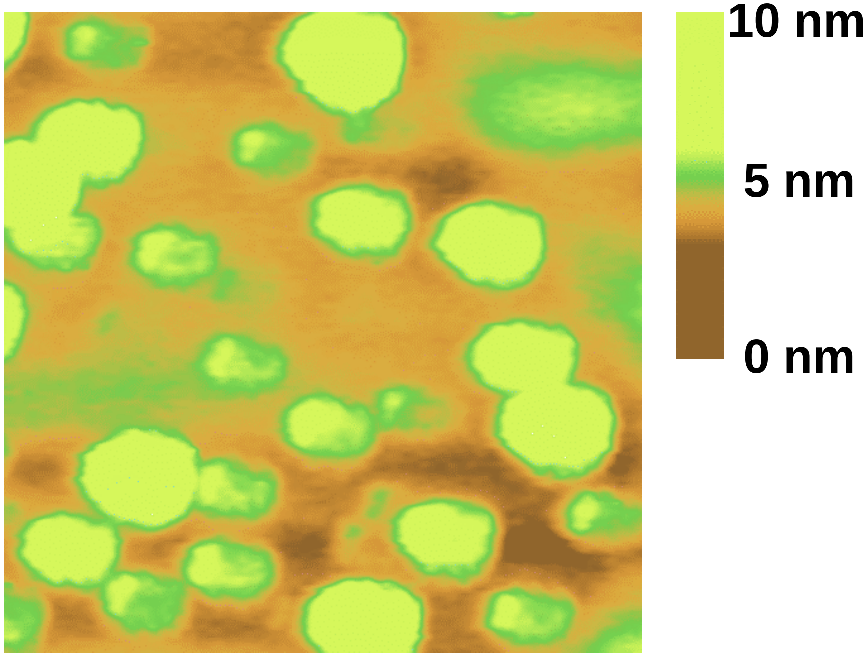
- *Electronic, optical, mechanical properties*
- *Couple to structure and couple to each other*
- *Manipulate statically and dynamically*

Understanding and Mimicking Biological Functions

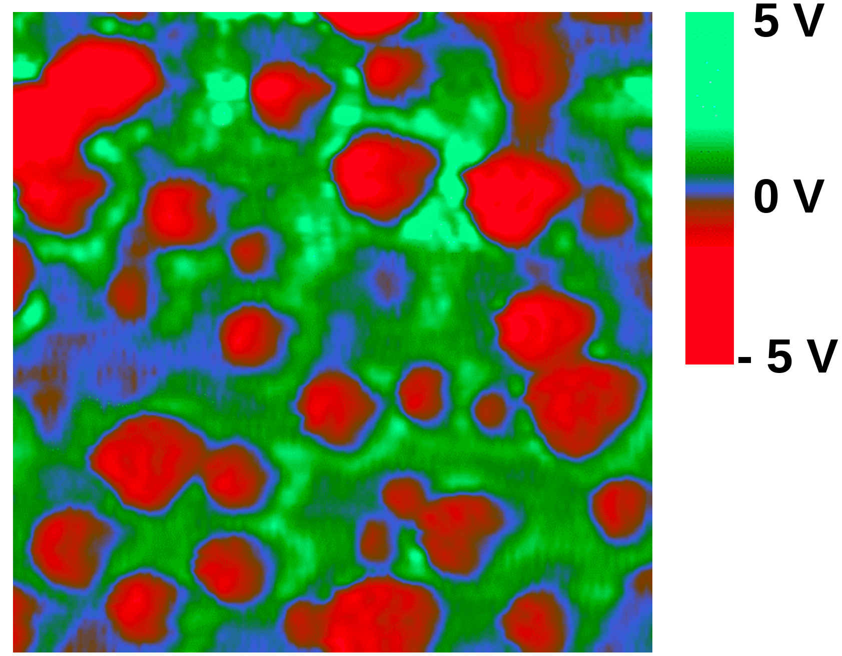


Use or imitate nature's engineering

PSI Image vs. Potential

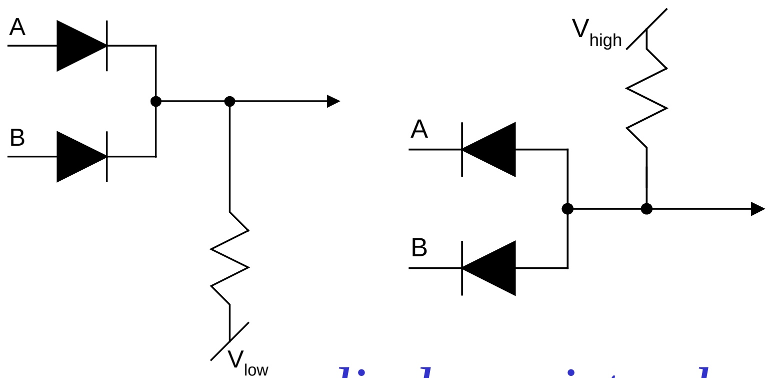


250 nm x 250 nm

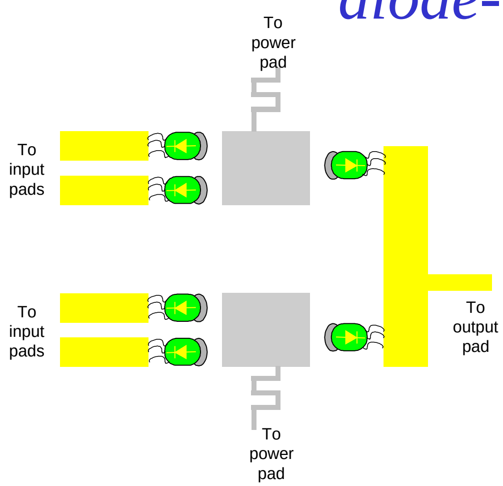


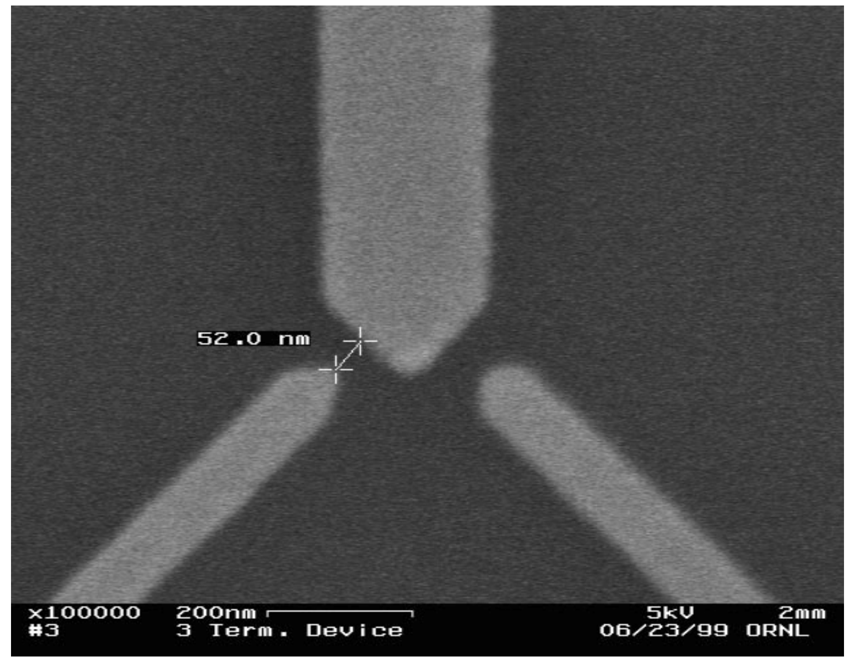
250 nm x 250 nm

PSI Molecular Electronic Circuits

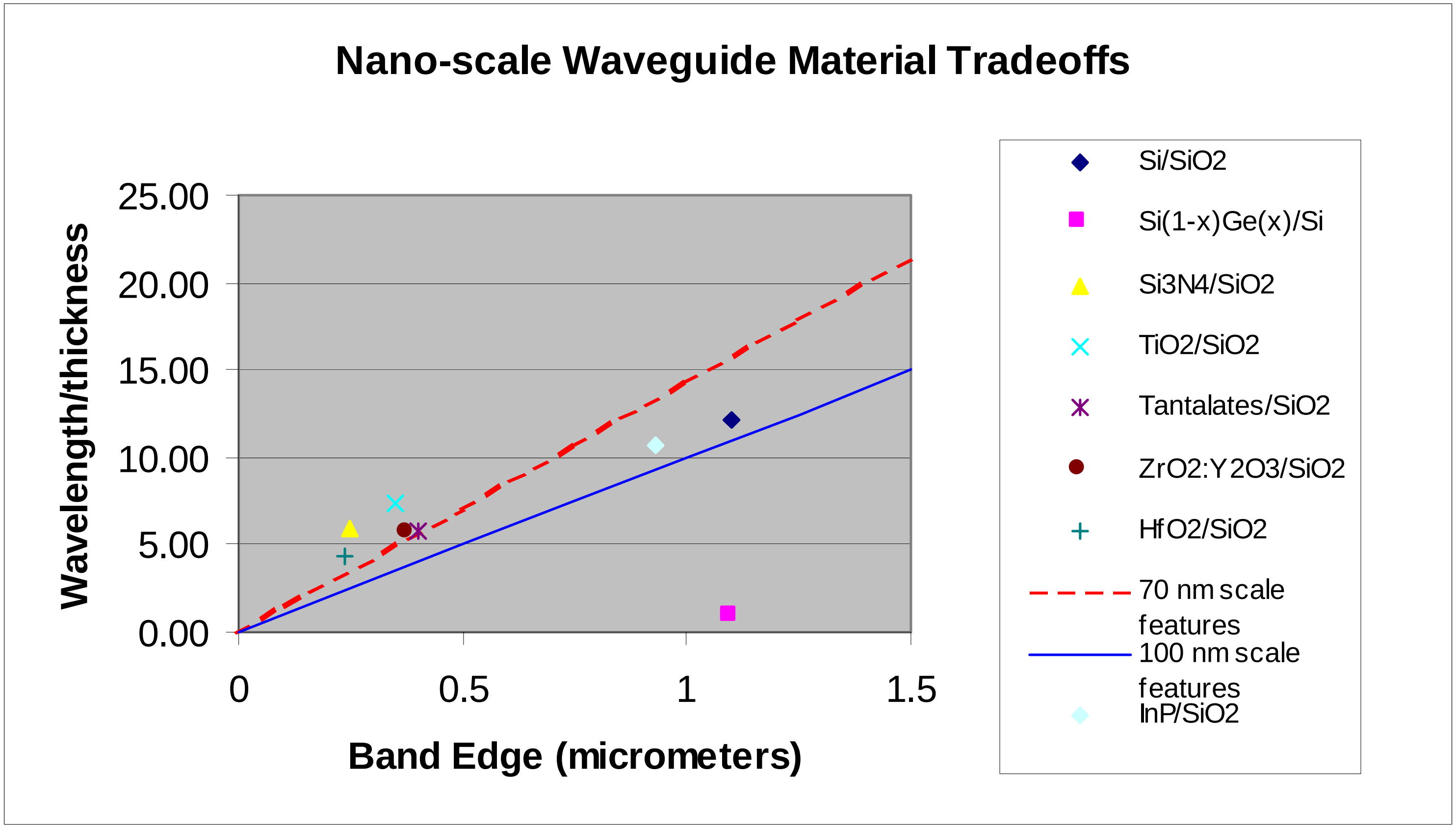


diode-resistor logic



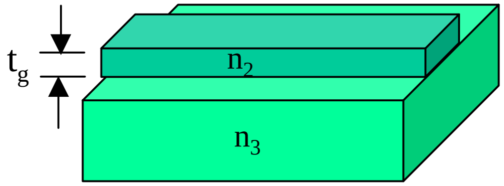


narrow the gaps with electroplating and attempt to place single PSIs in gap

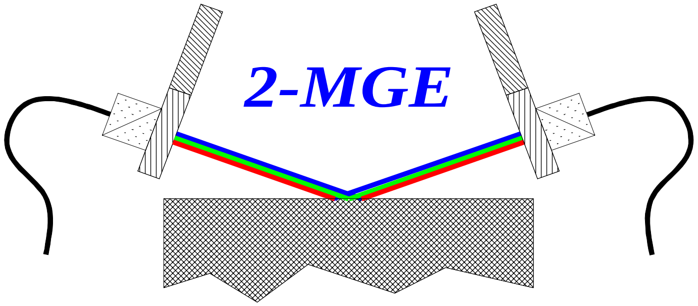


Governing equation for assymetric waveguide

$$\Delta n = n_2 - n_3 > \frac{(2m+1)^2 \lambda_0^2}{16(n_2+n_3)t_g^2} \quad m = 0,1,2,3,\ldots$$

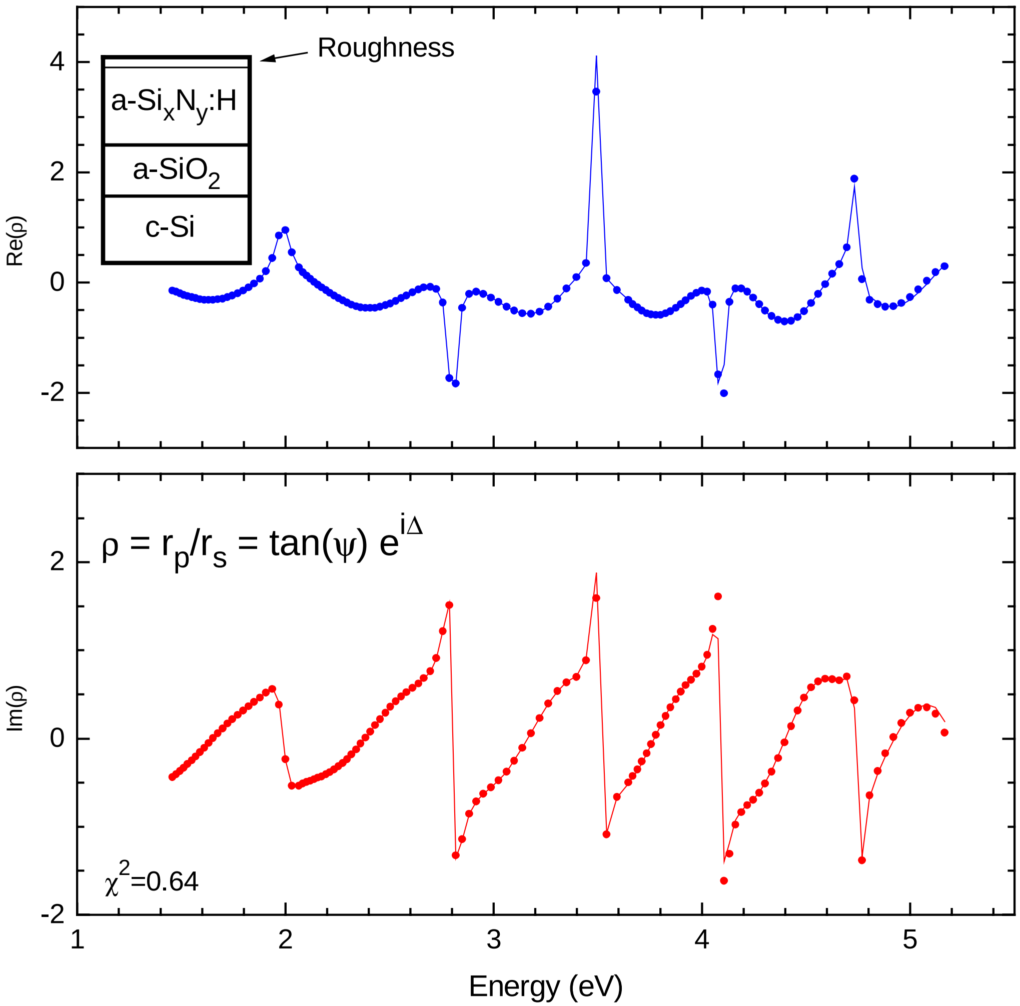


• 2-Modulator Generalized Ellipsometry (2-MGE)



- **2 polarizer-photoelastic modulator (PEM's) pairs (50.2 kHz and 60.3 kHz).**
- **Wavelength range: 230 to 850 nm.**
- **Measures 8 parameters which can be used to characterize most anisotropic systems.**

Spectroscopic Ellipsometry Measurements of Waveguide Thickness and Absorption



Thicknesses (nm):

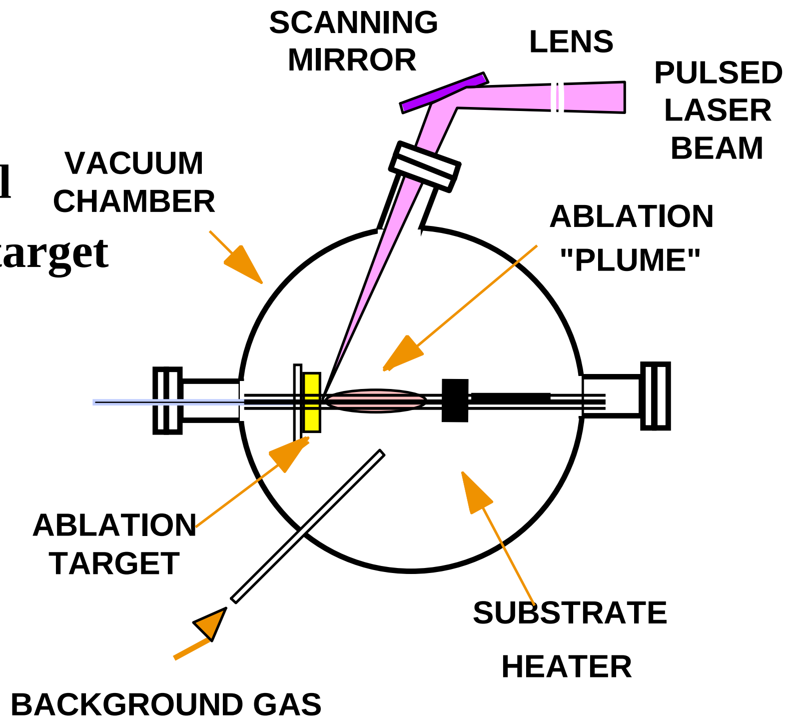
roughness	2.8 ± 0.5
a-Si$_x$N$_y$:H	232.5 ± 0.8
a-SiO$_2$	295.7 ± 1.9

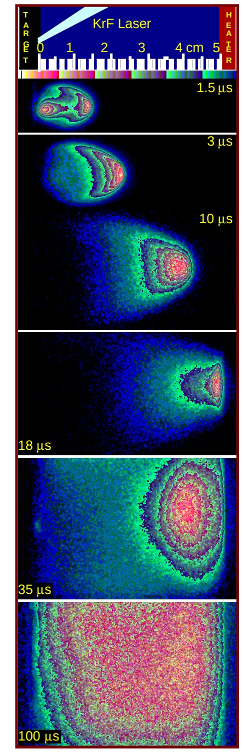
E_g (a-Si$_x$N$_y$:H) = 3.76 ± 0.05

λ(nm)	n(SiN)	n(SiO$_2$)
350	2.137	1.478
400	2.099	1.472
600	2.040	1.460
800	2.021	1.456

Pulsed-Laser Deposition at ORNL

- **Thin-film growth technique**
- **Congruent transport of material**
- **Energetic species ablated from target**
- **Background pressures range from UHV to few Torr**





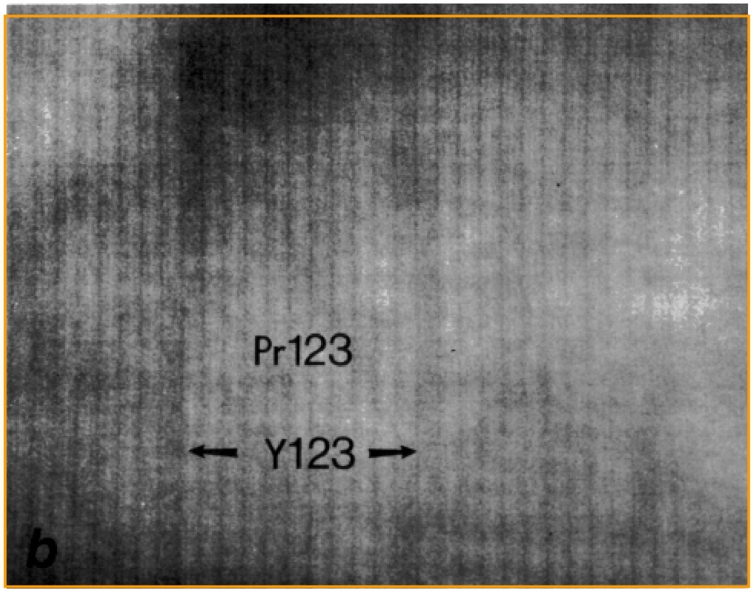
Complex oxide research at ORNL

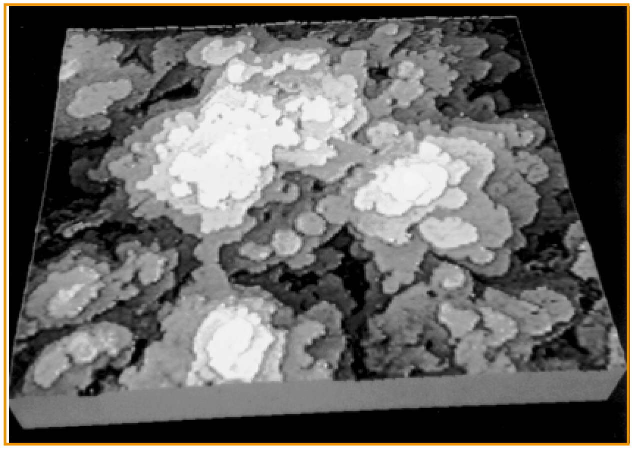
Superconductors
  $YBa_2Cu_3O_7$, Bi-2201, Bi-2212
Binary oxides
  Y_2O_3, CeO_2, ZrO_2, MgO
Dielectrics
  $SrTiO_3$
Ferroelectrics
  $K(Ta,Nb)O_3$, ZnO

Semiconducting oxides
  ZnO, Cu_2O
Conducting oxides
  $SrRuO_3$, $(La,Sr)CoO_3$
Phosphors
  $Eu{:}Y_2O_3$, $Mn{:}ZnGa_2O_4$

Pulsed-Laser Deposition

- **"Digital" growth process with atomic-level control**
  - **growth rate varies from sub-angstrom to several angstroms per laser shot**
  - **film thickness determined by number of laser shots**

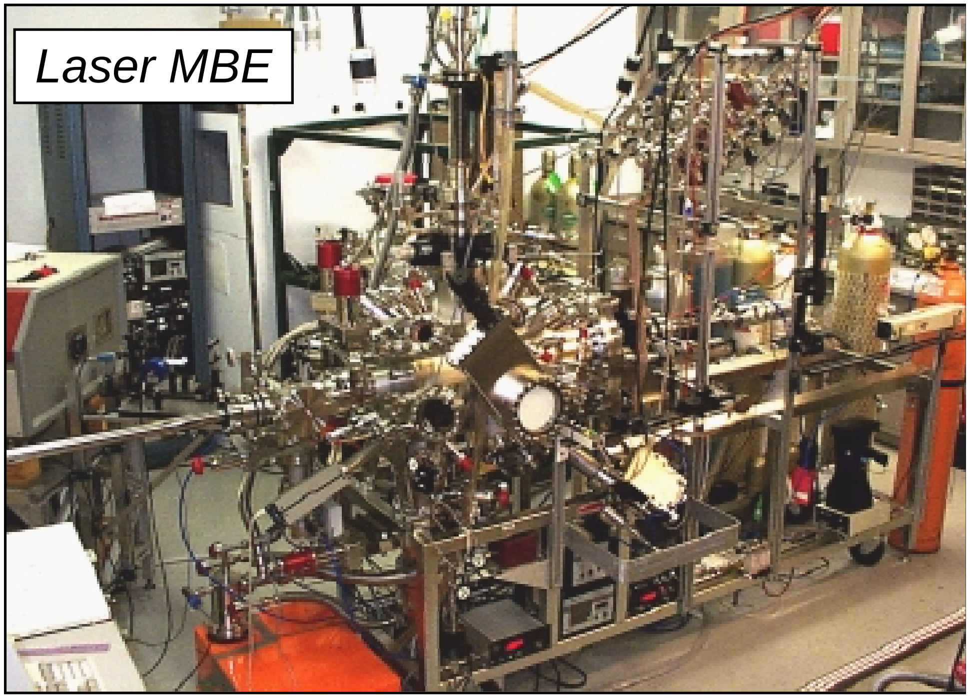


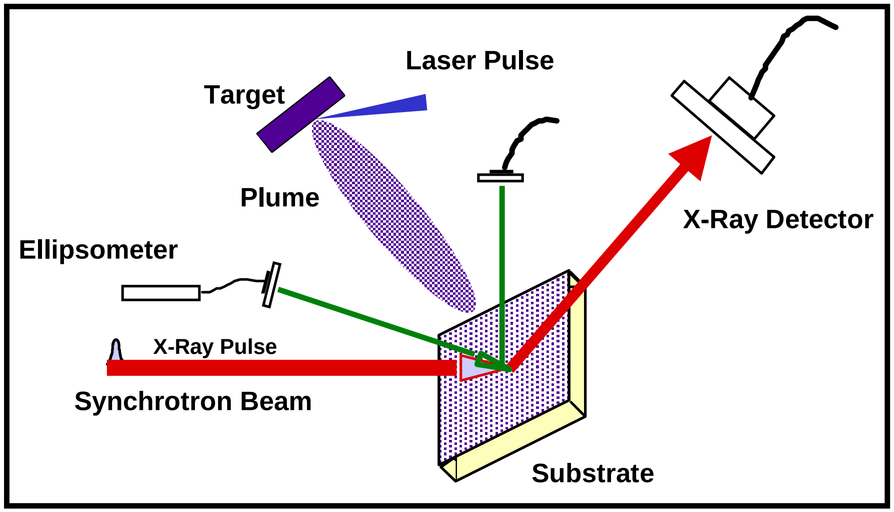


- **Pulsed-laser deposition has been used to grow wide range of thin film materials**
  - **Particularly with multicomponent oxides**

Unique Film Growth Facilities

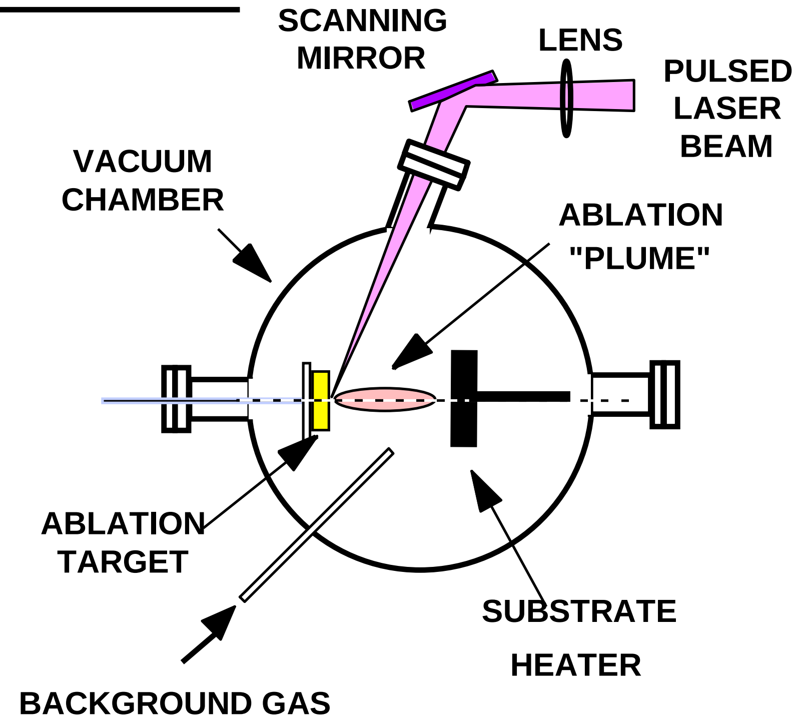
- Laser-MBE
  - PLD in UHV system
  - First Laser-MBE in U.S.A.
  - In Situ Film Growth Monitoring



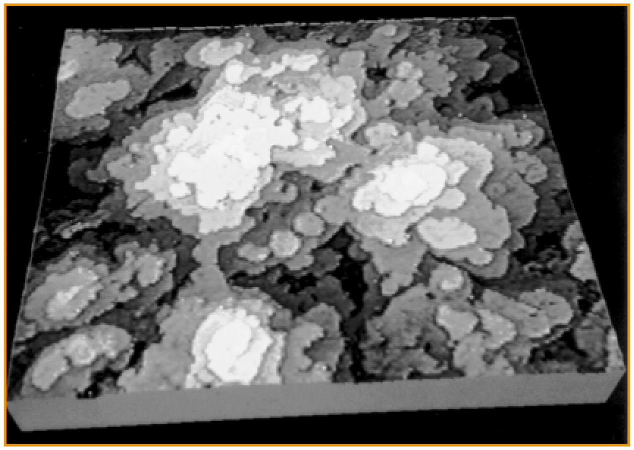


- In Situ Synchrotron X-Ray Diffraction (ORNL's UNI-CAT Synchrotron Beamline)
  - Unique In-Situ XRD Monitoring for PLD

Thin Film Synthesis

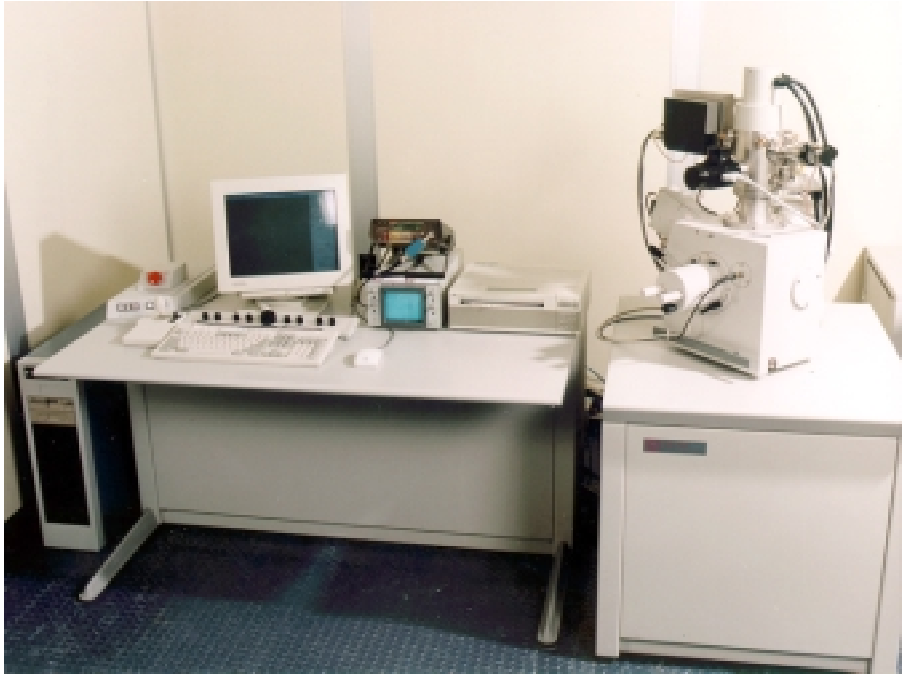


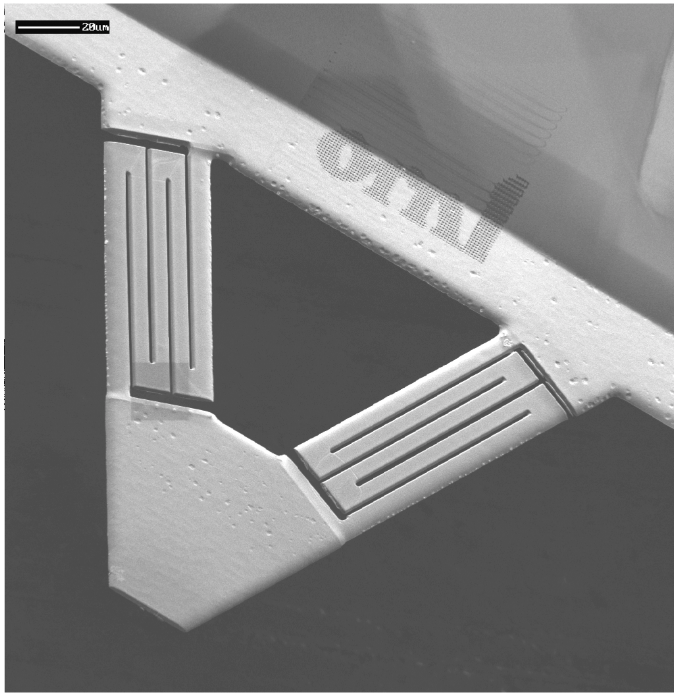
- Research Activites
  - Single Crystal Films with Varying Dislocation Densities
  - Bicrystals with Selected Angles
  - Polycrystalline Films (Random and Textured)



- Pulsed-Laser Deposition (PLD)
  - multiple systems
  - in situ monitoring of Film Growth
  - ex situ characterization AFM, STM, and SEM

ORNL Micro-Fabrication of Photonic Switch





Focused ion beam milling

ORNL is Exploring New Materials and Devices for Intra-chip OI

- New detector concepts for wide bandwidth/low power
- Nano-scalable materials and devices for high density
- Challenges: viable system concepts and technology integration