Scale Up of Quantum Well/Superlattice Thermoelectric Devices

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Objectives

- Develop methods to scale up deposition of quantum well thermoelectric devices
  - Scale up $Si/Si_{0.2}Ge_{0.8}$ structures
  - Scale up B_4C/B_9C structures
  - High volume
  - Low cost
  - Heavy truck applications
- Transfer deposition technology to High-Z

Coating Applications at PNNL

- **Modification of optical, mechanical, thermal, and electrical properties of surfaces**
  - Windows (transmission, reflection, heat flow, abrasion resistance)
  - Structures (thermal control, emittance, abrasion resistance)
  - Semiconductors (passivation, microcircuitry)
- **Energy related applications**
  - Solar reflectors
  - Thermal control
    - Low-e coatings
    - Emissivity control
    - Electrochromic (switchable) coatings
    - Photovoltaics
    - Thermophotovoltaics

Coating Applications at PNNL

- **Flat panel displays**
  - Plastic substrates
  - Barrier coatings
  - Light emitting organic materials and devices
- **Thin film polymer batteries**
- **Laser reflectors**
  - Space based and ground based
- Environmental protection
- Transparent conductive coatings (n and p-type)
- Abrasion resistance
- Micro-mechanical and thermal systems (Micro-CATS)
- Nanotechnology

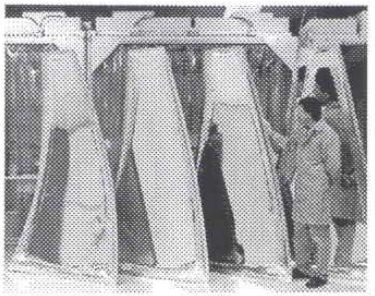
Thin film deposition facilities

- Fourteen coating chambers
  - Precision multilayer coatings
  - Magnetron sputtering (RF, DC reactive)
  - Electron beam evaporation
  - Triode sputtering
  - Vacuum deposited polymer
  - Web coating (hybrid)
- Heat treating facilities
- Barrier coatings
- OLED deposition
- CVD, MOCVD
- Molecular Beam Epitaxy

Coatings by the Vapor Deposition Methods Group

Large Optics Chamber

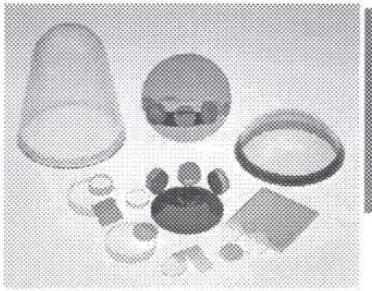
Al Solar Concentrator Panels with $Ag/AlN/Al_2O_3$ Reflector Coating



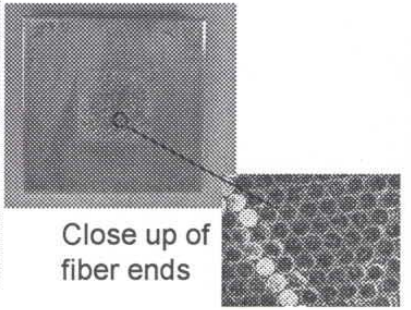
Excellent coating uniformity demonstrated on 2-meter optic

Small Box Chambers

Optical interference coatings produce an array of colors

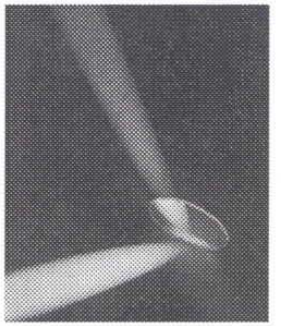


Coated Fiber Optic Scene Projector Array

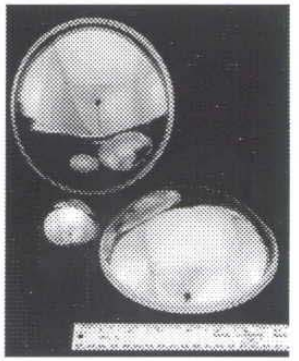


Close up of fiber ends

21-Layer Laser Mirror (reflects orange/transmits blue)

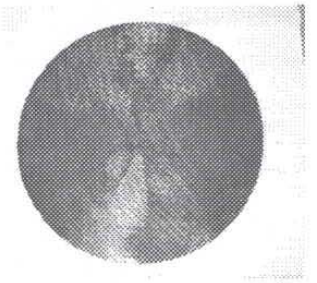


14-Layer 2-Band Laser Rejection Filter Coating



650 nm Trilayer Heater Coating

Si Coating on a SiC Woven 14"-dia. Substrate

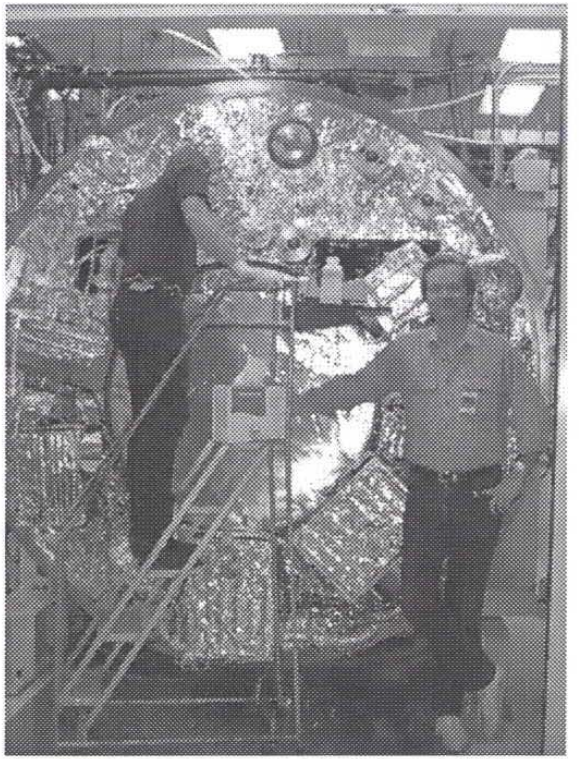


LARGE AREA COATINGS

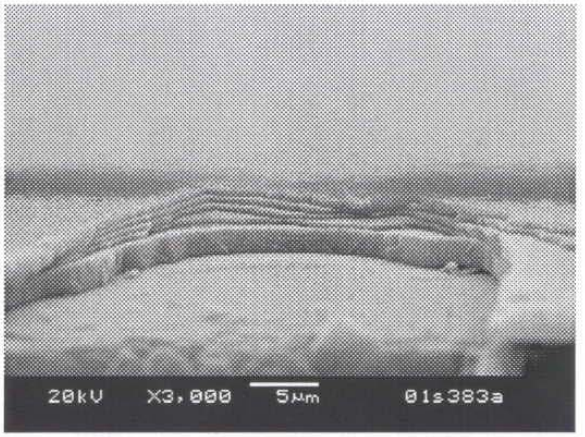
- SPACE OPTICS
- AIRCRAFT OPTICS
- WINDOWS
- PLASTICS
- LASER OPTICS
- TCO's

"Putting nanotechnology to work"

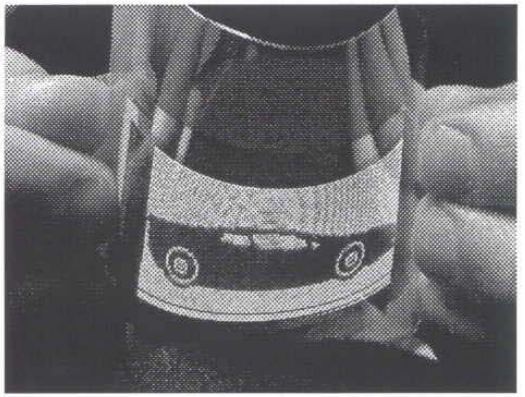
- Multiple laminated organic-inorganic barrier layers yield long-lived OLEDs on flexible plastic substrates!
- From concept to commercialization

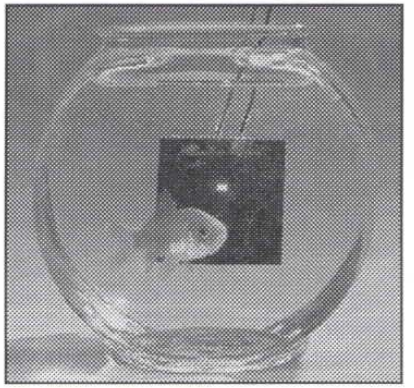


Flexible Substrate
Moisture Barrier



Flexible Display





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VITEX SYSTEMS

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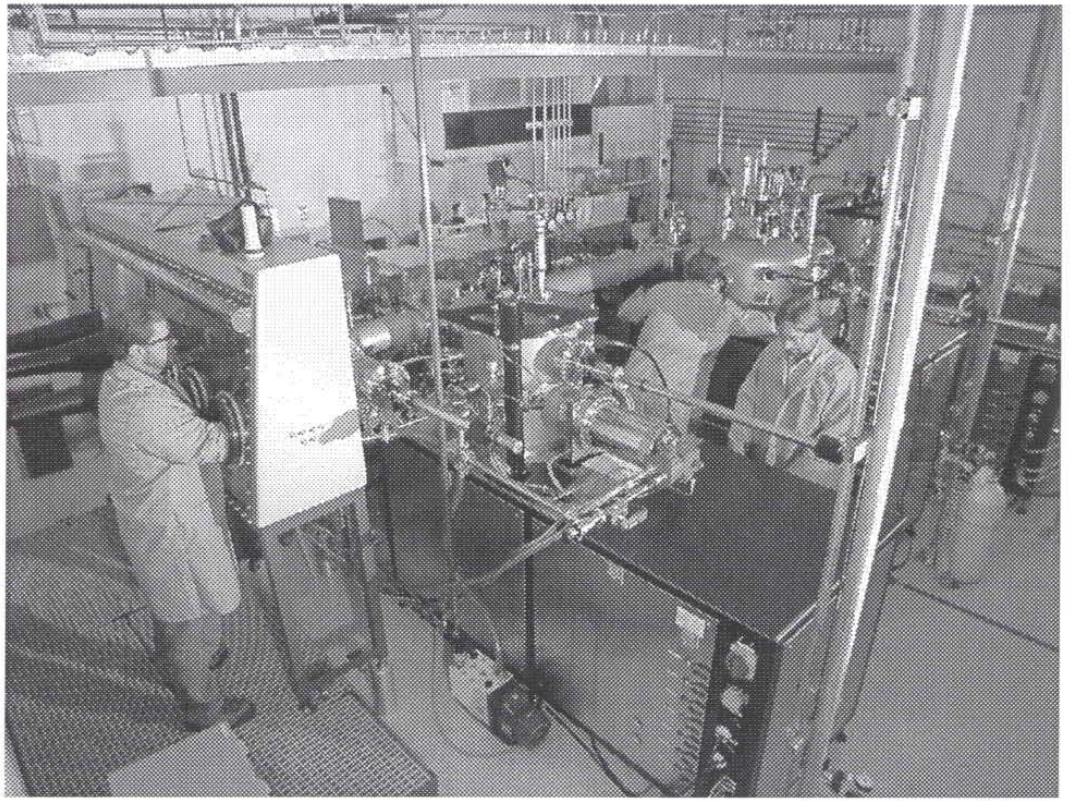
The Organic Thin Film Deposition Lab at PNNL



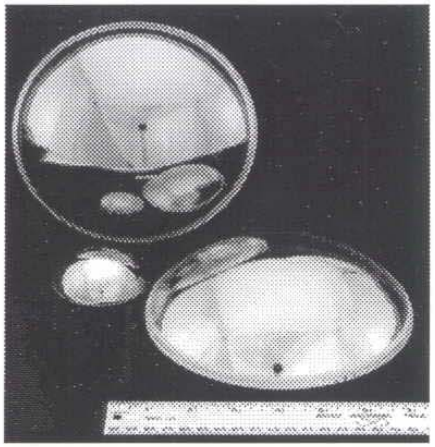
Arranging molecules for displays, solar cells, electronics…

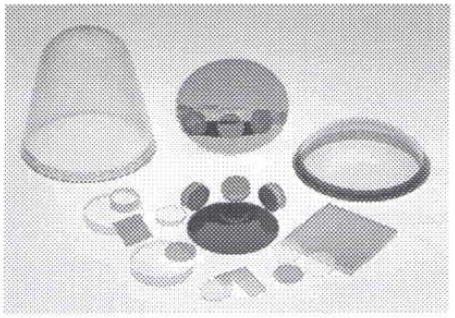
FLAT PANEL DISPLAYS

- ORGANIC LIGHT EMITTING DEVICES
- FLEXIBLE PLASTIC SUBSTRATES
- BARRIER COATING TECHNOLOGY TO PROTECT DISPLAY
- FABRICATION FACILITIES AT PNNL

ADVANCED OPTICAL COATINGS

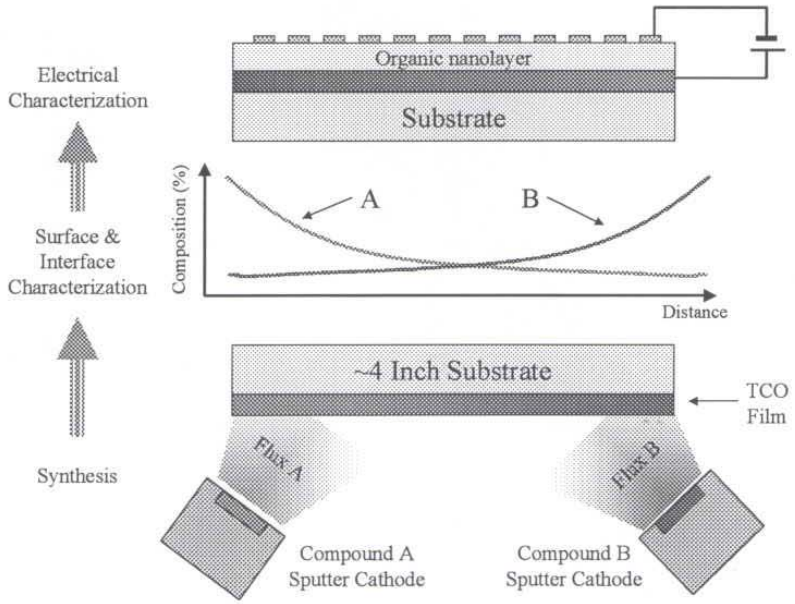
- LASER MIRRORS
- EMI SHIELDING FOR OPTICS
- THIN FILM PHOTOVOLTAICS
- THIN FILM FILTERS
- EMI ABSORBING COATINGS
- MAGNETIC MATERIALS
- WINDOWS, DOMES, SPACE OPTICS, Be OPTICS
- PATTERNED COATINGS
- ELECTROCHROMIC COATINGS
- N and p-type transparent conductive coatings

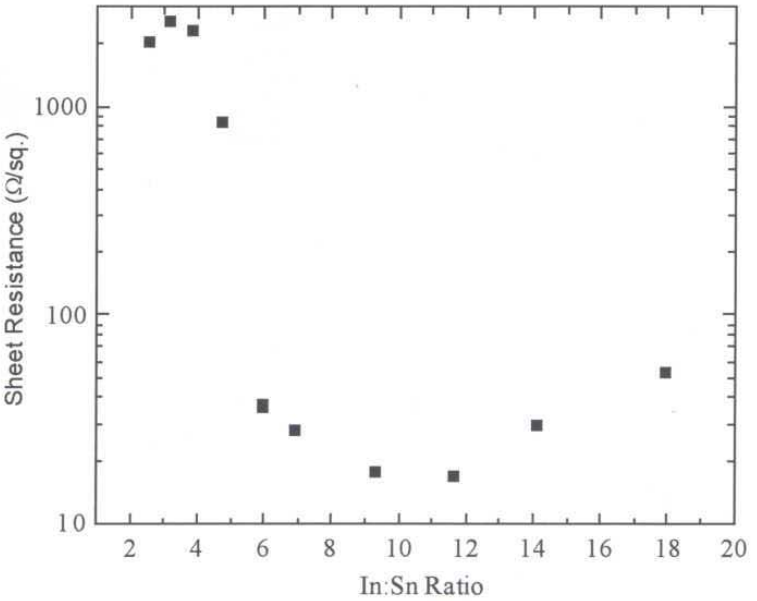




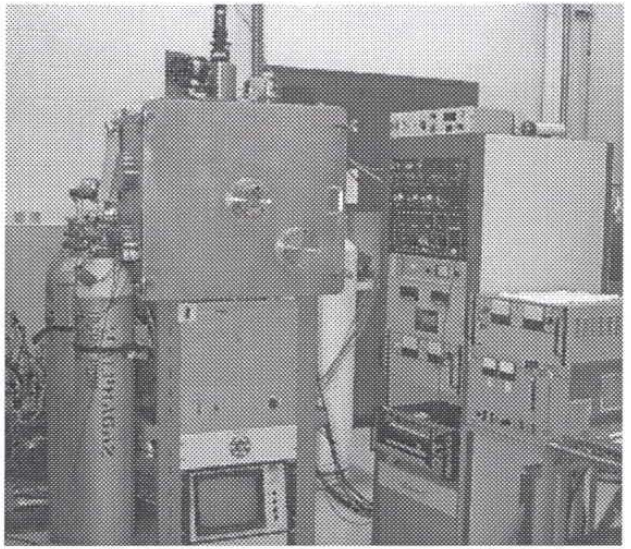
Novel Combinatorial Conducting Oxides

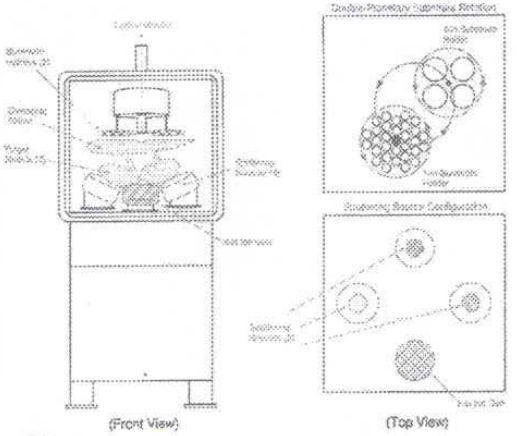
- New deposition techniques
- Novel p-type materials for OLED and IR applications
- Novel Thermoelectric Materials and Geometries





Midsize Coating Chambers





Small Box Chamber

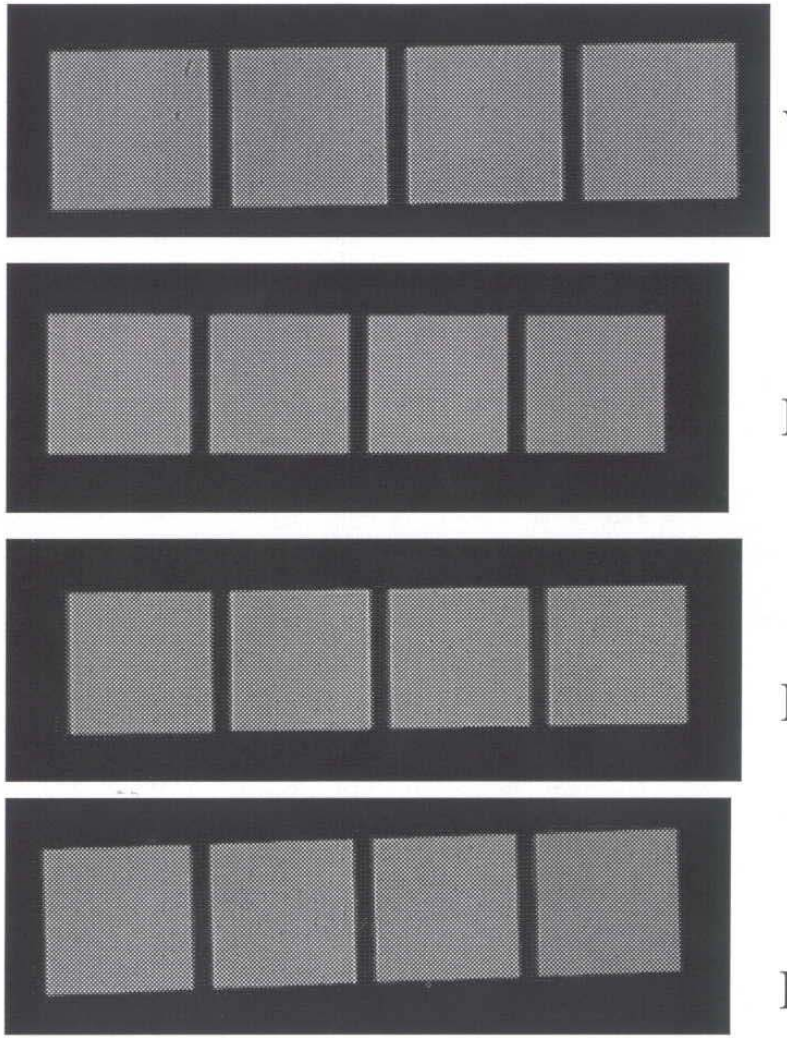
- Coatings and ion milling
- 28" Box chamber
- 2 available
- RF diode and DC magnetron
- Max 14"-diameter substrate

Commercialization/Tech Transfer

- Barrier coatings for flat panel displays (Vitex)
- Large area solar reflectors (United Solar and Edtek)
- Large area laser mirrors (Deposition Sciences, Inc.)
- Scale up of thin film lithium polymer batteries (Mine Safety Appliances)

OLED Encapsulation

- 2mm OLED pixels
- Fabricated at UDC
- Shipped to PNNL
- Encapsulated on rollcoater
- Air exposures
- Returned to NJ for testing



Witness

Polymer only

Barrier only

Barix

Solar Concentrator Panels

Planned TE Program

- Replicate High-Z quantum well structures in mid-size chambers
  - $Si/Si_{0.8}Ge_{0.2}$ quantum well
  - B_4C/B_9C quantum well
- Scale up process to
  - Multiple 15 cm (or larger) substrates
  - Web substrates, plastics (roll coater)
  - Magnetron sputtering

Progress to date

- Funding received in February, 2002
- $Si/Si_{0.8}Ge_{0.2}$ sputtering target ordered
- Fixturing for deposition on multiple substrates in place
- Initial depositions for crystalline Si layers in progress
  - Low cost characterization
  - Relate crystallinity to optical properties for rapid evaluation

Scale Up Issues

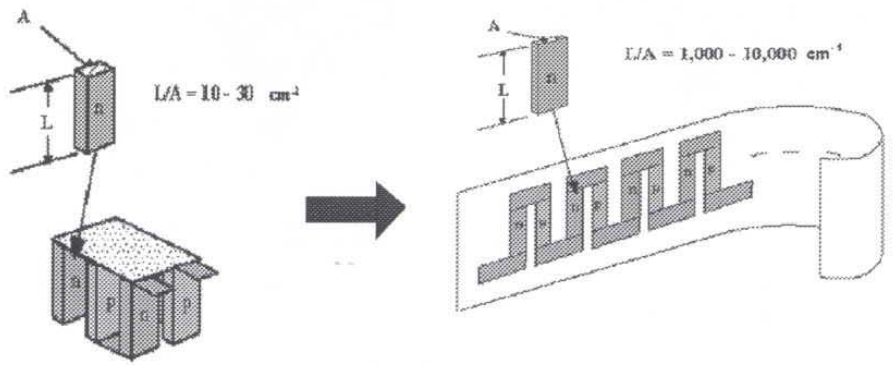
- ZT increase looks promising for small scale TE devices
- Scale up for TE power generation for heavy duty trucks is challenging
  - Substrate size/surface
  - Low cost substrates/process
  - Coating thickness uniformity
  - Crystallinity
  - Same properties as small scale devices
  - Substrate heating

PNNL Scale Up Solutions

- Large coating chamber
  - Coating thickness uniformity of ±1% over 2.5 m
  - Precision multilayer coatings
  - Precision thickness control
  - Semiconductors
  - Substrate heating
- Web (roll) coating

Battelle IR&D TE Project

- This program will develop an approach to sputter deposit thin films of bismuth telluride (Bi-Te) for thermoelectric energy conversion. Thin-film TE arrays will be formed on flexible substrates so that TE power sources can be fabricated in relatively small volumes.



TE Module With Discreet Elements

Thin-Film TE Array

Future Work

- Scale of up quantum well TE devices to ultra thin Si substrates
- Optimization of quantum well structure
- Deposition of 25 μm thick quantum well TE devices
- Process transfer to High-Z
- Build on Bi-Te IR&D work