Nanotechnology at IIT Bombay

Kartic C. Khilar

Nanotechnology

- Nanotechnology is the design, characterization, production, and applications of structures, devices, and systems by engineering the morphological and other aspects (size, shape, surface roughness etc.) at the nanometer level (up to 100 nm).
- An exciting, multi-disciplinary research area.
- Bottom –up approach in general. Very little difference between science and engineering. Most efficient use of mass and energy.
- Technology development and business in tandem.
- Environmental issues.

Background on Nanotechnology @ IITB

- Small groups of faculty and students in various departments (40 faculty members and over 200 students and project staff members).
- Electrical Engineering, Mechanical Engineering , Metallurgical Engineering and Materials Science, Chemical Engineering, Physics, Chemistry and Bioscience and Bioengineering, Environmental Science and Engineering.
- Institute wide initiative: Two in-house symposia on Nanotechnology @ IIT Bombay: Sept. 13, 03 and March 31, 04.
- A Major Thrust Area of Research of IIT Bombay
- Currently a annual research budget of appox. Rs. 150 M.

Generic Nanotechnology Research Areas at IIT Bombay

- Nanoelectronics
- Nanobiotechnology
- Nanomaterials
- Nano-Electro-Mechano-Chemical Systems

National Initiatives on Nanotechnology

- Initiative taken by His Excellency President Kalam
- Meeting with Nano Science and Technology Rsearchers, Specialists and the Policy Makers (April 29, 2004)
- Central focus for many technologies to converge and open up a large number of applications
- 300 novel materials and 50 devices with unique characteristics worldwide
- Global business may grow to one trillion dollars in next ten years
- A modest beginning has been made in India
- Focus Areas of Nanotechnology Applications: Health Care, Nanoelectronics and Computing, and Materials and Structures
- Action plans and budget estimates have been announced

Nanoelectronics and Sensors at IIT Bombay

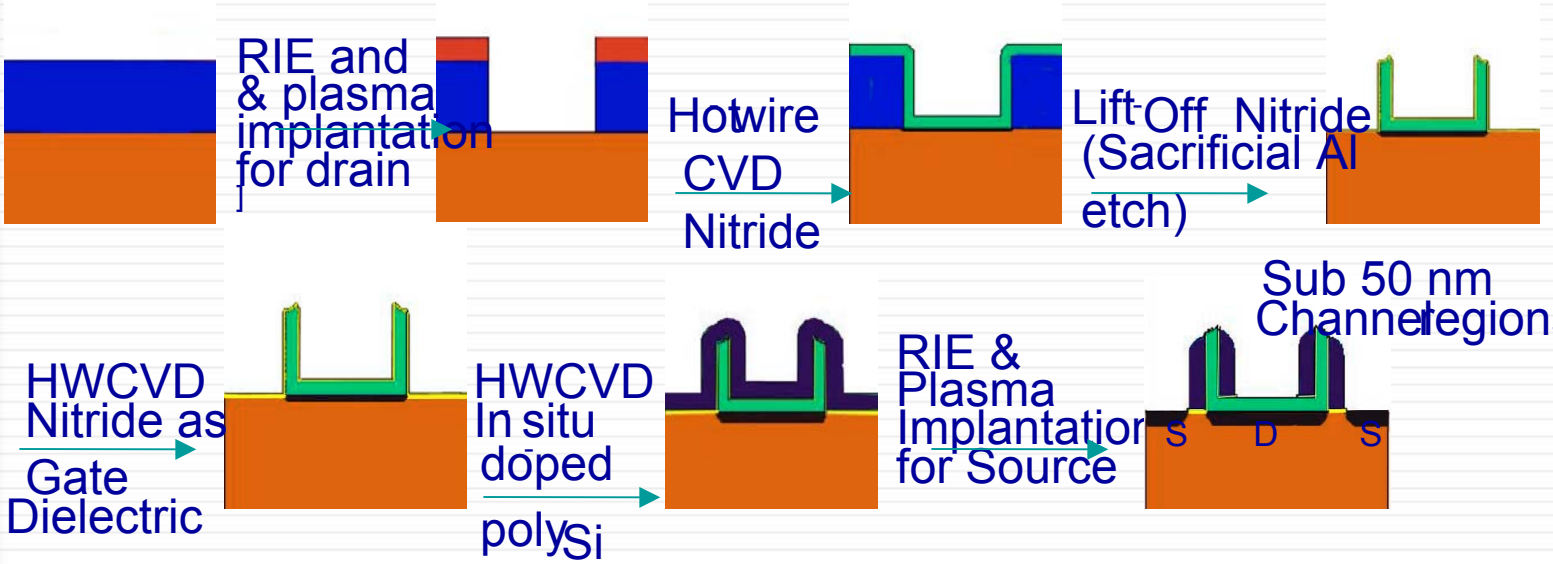
- IIT Bombay has traditionally been very strong in microelectronics. The current emphasis is on various aspects of nanoelectronics, sensors, especially biosensors, & MEMS.
- IITB has worked on several aspects, including the “shrink-down” approach and the “atmos-up” approach.
- In the “shrink-down” approach, IITB has been working on a non-conventional 50 nm CMOS devices using novel processes like plasma implantation and hot-wire CVD.
- Nanocyrstalline Si for making various nanodevices.
- In the “atoms-up” approach, IITB has been working on several approaches, including molecular electronics using porphyrin molecules and carbon nanotubes.

Nanoelectronics and Sensors at IIT Bombay

- In the areas of sensors and MEMS, IITB has a strong activity in bio-MEMS. Projects from NPSM (National Program for Smart Materials) and TCS (Tata Consultancy Services) are under way in this area.
- These activities are collaborative activities between the Departments of Electrical Engineering , Materials Science, Chemistry, Physics and Bioengineering.
- IITB has been awarded a grant to carry out education and research in the area Nanoelectronics jointly with IISc., Bangalore (total outlay Rs. 1000 M) by DIT (MCIT), under the guidance of PSA to the Govt. of India.

Sub 50 nm CMOS Technology Development

- Primary Collaborator - R.O.Dusane (Metallurgical Engg & Materials Science)



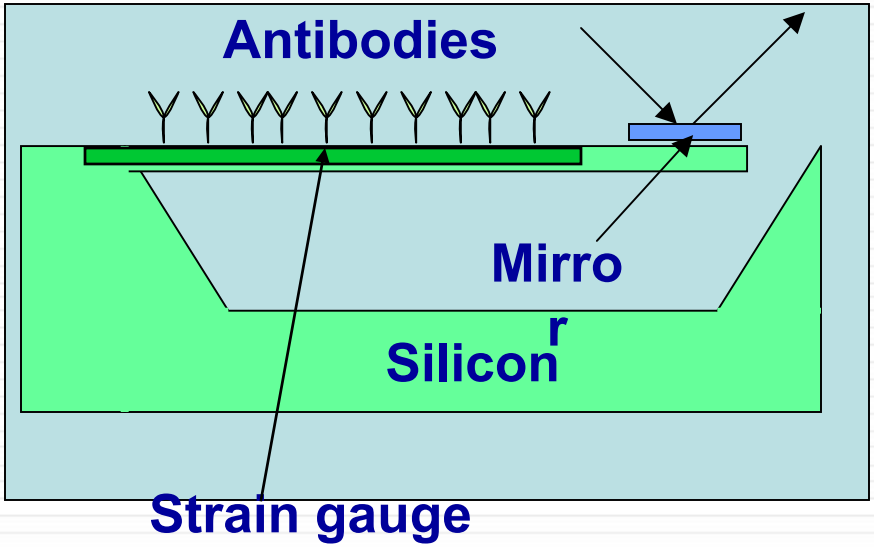
"IIT Bombay engineers demonstrate novel sub-50 nm CMOS technology", The Telegraph,
A leading Calcutta Daily Newspaper, 2002

Si
Al
PolySi
Nitride
Gate Dielectric (SiN)

Flavour of Biosensor Array: Affinity Cantilevers

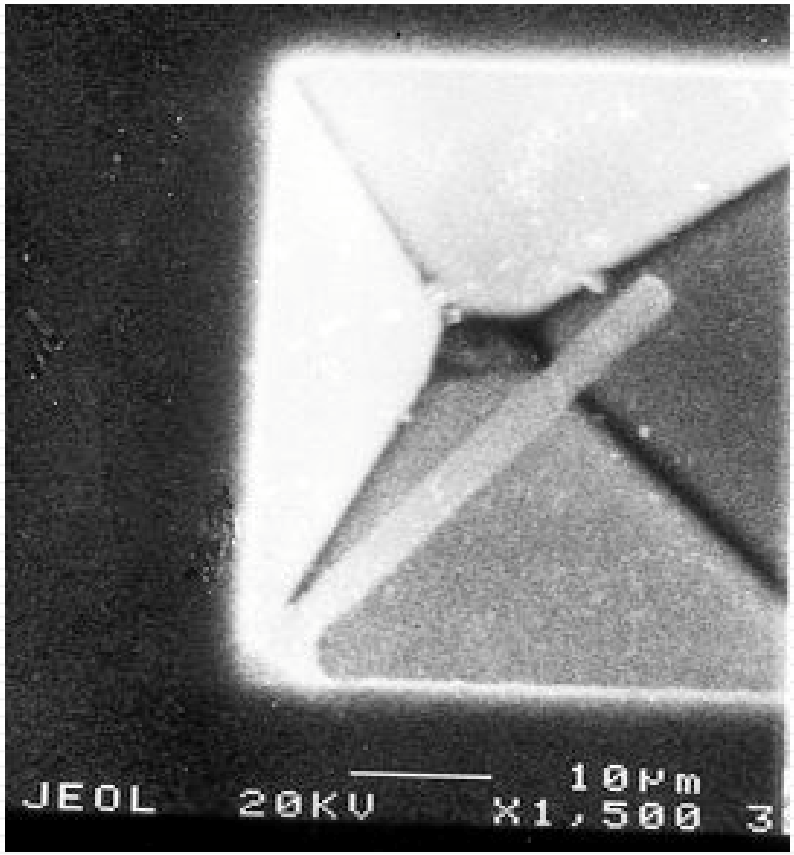
Based on resonating structure 0r deflection:

- Attachment changes mass or stiffness of resonating structure and thence resonant frequency
- Attachment changes bending of the cantilever



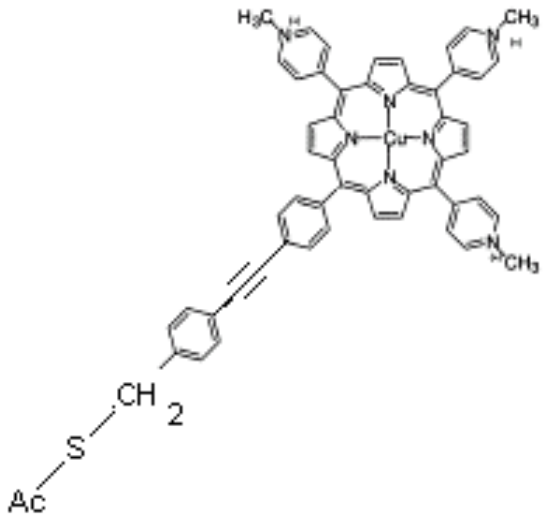
Status

- Have got started & working to have the devices ready
- This is how a microcantilever looks (not the latest, now have more interesting cantilevers!)



Porphyrin Molecules

- Porphyrin Molecule attatched with a thiol group protected by an acetate group
- Formation of SAM: in-situ cleavage of the S-Ac bond
- Metallo-porphyrin selected due to its intercalating properties with DNA
- The methyl groups attached make the porphyrin water soluble



Tetra Methyl Pyridyl Zinc Porphyrin Thiol Acetate

Facilities for Nanoelectronics Fabrication

- Class 1000 clean room (class 100 working area)
- Electron Beam Lithography*
- Reactive Ion Etch System*
- Multi-target Sputter System*
- Vacuum Evaporation Systems
- Optical Lithography (photolithography)
- Electron Beam Evaporation
- Spectroscopic Ellipsometer*
- Oxidation/Diffusion Furnaces
- RTP*
- AFM*

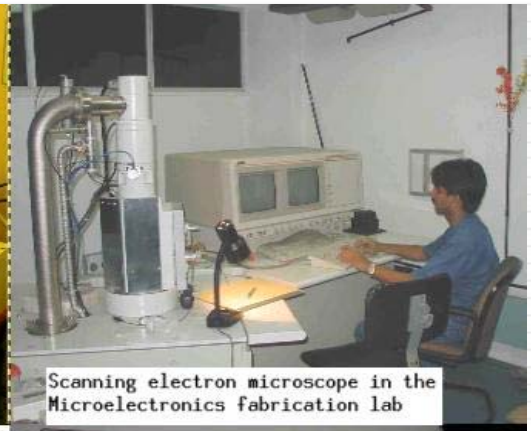
Recently upgraded. Can now make a full Nano-device!

Due to the generous support from the Institute and ADA

Fabrication Facilities – IIT Bombay

Clean room facility for semiconductor device fabrication

Inspection of a semiconductor device in the Microelectronics fabrication lab



Scanning electron microscope in the Microelectronics fabrication lab

Another view of the clean room facility for semiconductor device fabrication

The Intel Computer Lab for VLSI Design

Characterizing microfabricated capillary electrophoresis system for DNA and other biomolecules

Some Challenges for Chemical Engineers (Lab-on-a Chip)

- Micro-flows, Nano-flows and Microfluidics
- Electrically driven flows
- Minimizing viscous dissipation and Heat transfer
- Mass transfer and Reaction in Micro-and Nano-reactors

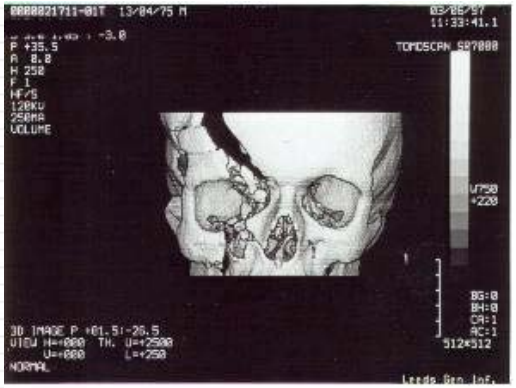
Some Broad Areas of Nanobiotechnology

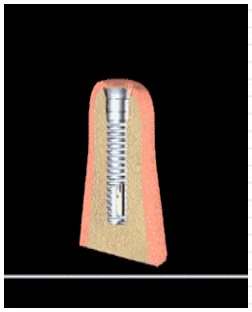
- Detection and imaging of molecules and assemblies of biological interest with high sensitivity.
- Nanoparticle applications to biological systems, bioactivity & biosynthesis, including therapeutics
- Biomaterials, nanoparticulates and nanocomposites for biological applications: synthesis, characterization and applications.
- Molecular, organelle and cellular engineering for nanotechnology, e.g., nanopore.
- Surface and interfacial modification for bioactivity.

Nanocomposites and Microdevices for Dental, Maxillofacial Use

Maxillofacial Injury

- The skeletal and soft tissue anatomy of the craniofacial region is complex and a specialist knowledge of the oral cavity, both anatomically and functionally, is essential for successful management of patients with facial injury.
- Customised Bone graft: with nanobiocomposites

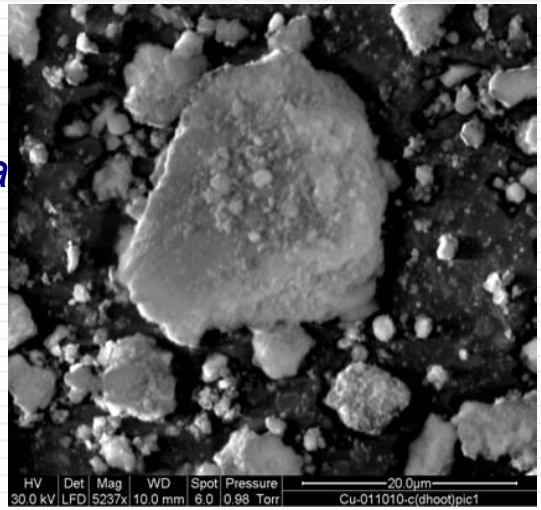




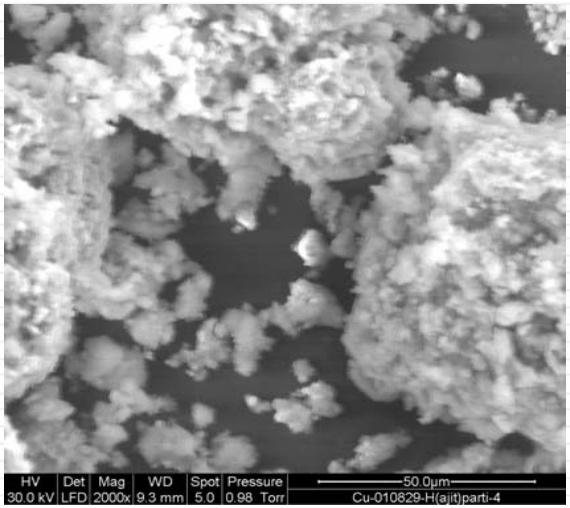
Nanoparticles in Medicine
Traditional medicinal systems: *Bhasma*

- *Bhasmas* are unique form of medicinal preparation used in *Ayurveda / Siddha* system.
- They are powders and made from a wide variety of base materials (e.g.- *Tamra Bhasma*- Cu, Mouktika Bhasma –Pearl, Suvarna Bhasma-Au)

Scanning Electron micrograph of *Tamra bhasma* made by
(A) Commercial
(B) Individual



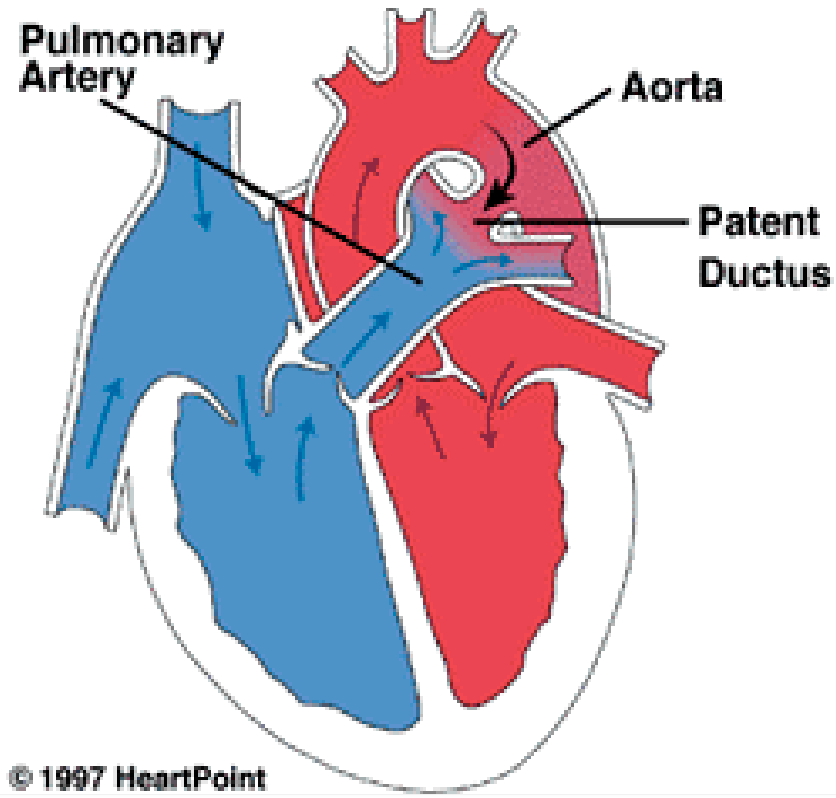
(A)



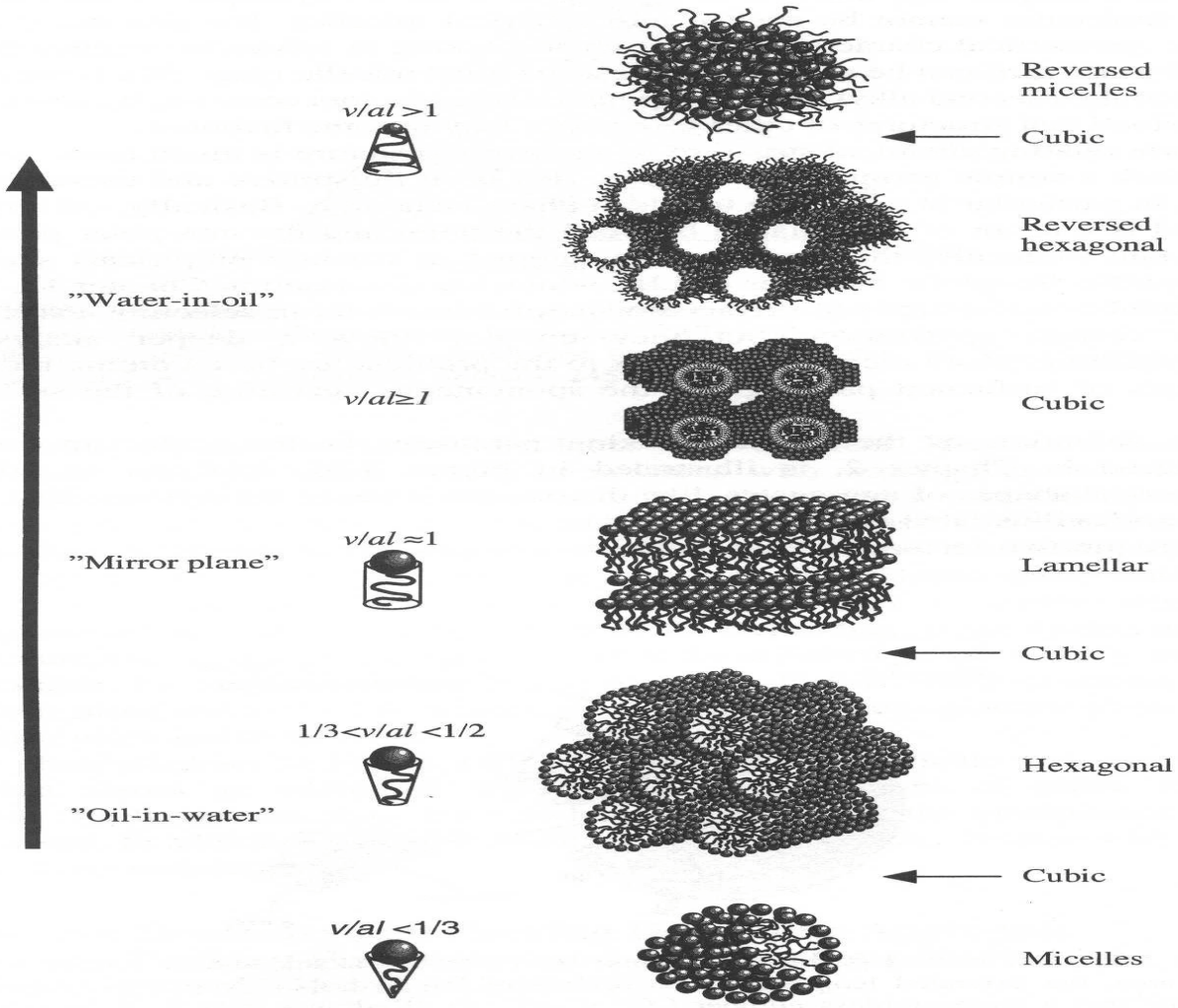
(B)

Nanotechnology in Minimally Invasive Surgery: Microengineered Devices: Patent Ductus Arteriosus.

- Abnormal connection between aorta and pulmonary artery.
- Blood flows from aorta to pulmonary artery.
- Leads to pulmonary hypertension, infective endocarditis and heart failure.
- Coatings of nanoparticles to promote thrombus (clot) formation



Nanoparticles Formation in Self - Aggregated Structures



Nanoparticles

- Metals: Silver, Gold, Platinum
- Metal salts: Silver Chloride, Cadmium Sulfide, Silver sulfide
- Nanocompsites of Silver sulfide and Cadmium sulfide
- Core-Shell nanoparticles of Cadmium Sulfide and Silver Sulfide
- Silica

Magnetic Nanoparticles work at IITB

Method of Synthesis ----- Wet Chemical technique

Materials – Ni, Fe, Fe-Ni, ……..

$NiCl_2.6H_2O$

$$\xrightarrow[\text{RT}]{NaBH_4} \text{Ni-Complex}$$

Ni-Complex

$$\xrightarrow[\text{High temperatures}]{\text{Reduction } H_2 \text{ gas}} \begin{cases} \text{Up to } 750^{o}\text{ C} \\ Ni + Ni_2O_3 \\ \\ 750^{o}\text{ C} \\ \text{Pure Ni} \end{cases}$$

Nano-Structured Magnetic Materials

- ferrites
- metal particles
- nano-composite & encapsulation

Possible Applications:

- Hyperthermia applications for Cancer treatment
- High Density Magnetic Recording
- Magnetic field Sensors (CMR/GMR)
- Permanent Magnet
- Ferrofluids

LANGMUIR BLODGETT Organic Multilayers & related Nanostructures

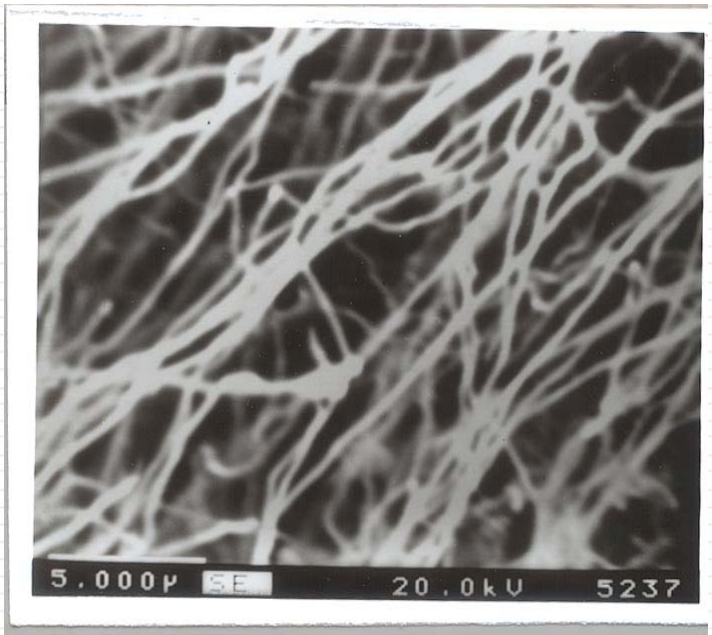
MATERIALS and ISSUES

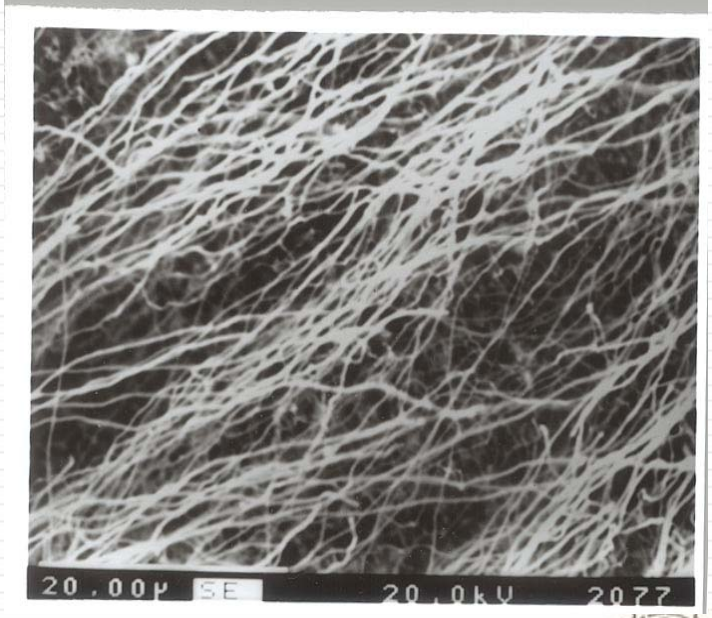
- Molecular organization and structure of prototypic long chain fatty acid salt LANGMUIR BLODGETT multilayers
- Semiconducting CdS, ZnS, Cu_2S and CdS-ZnS nanoclusters in organic/polymer multilayers : structure, size, shape and distribution
- Ultrathin and nanocrystalline oxides (ZnO,CuO) from LB precursor
- Conducting polymer-fatty acid salt composites (polythiophene / polyaniline / polydiacetylene) : structure, optical & electrical properties
- Optoelectronic and molecular / nano-electronic devices

TECHNIQUES

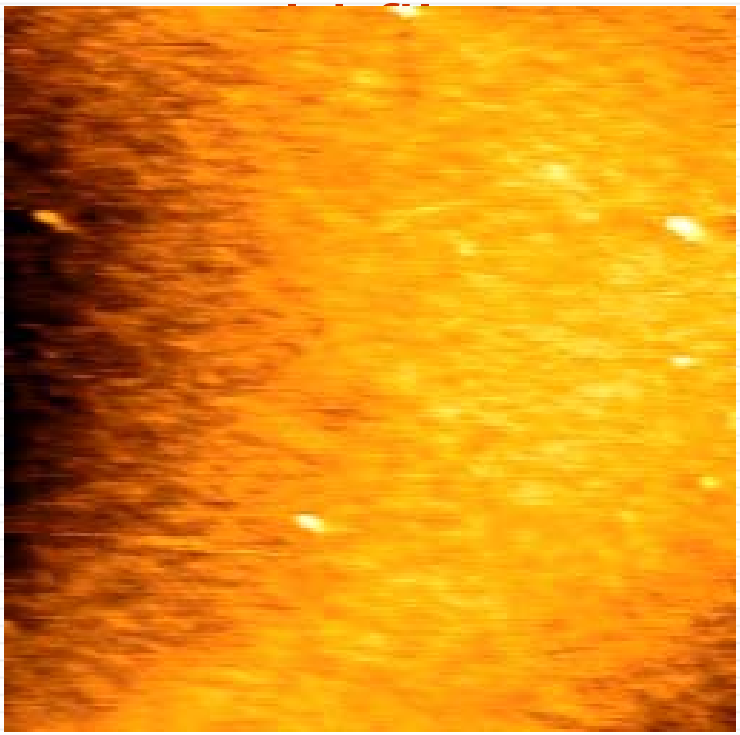
- GIXR, GIXD, AFM, TEM
- XPS and LEED-AUGER SPECTROSCOPY
- UV-VIS, FTIR, RAMAN, PL, EL
- Electrical Conductivity, low temperature measurements

SEM micrograph of Nickel filled carbon Nanotubes aligned parallel to substrate





Preparation and Characterization of the



1000nm x 1000nm scan Features height < 1nm

- Prepared using Physical Vapor deposition process
- Cleaned using the Piranha solution to remove organic impurities
- XRD spectrum taken to analyze the crystal structure
- STM/AFM pictures taken to gauge surface smoothness

Nanocrystalline silicon phase formation in thin films and its implications

Technological importance?

Few of the many applications that we are looking at are

- High efficiency thin film solar cells
- High luminosity thin film light emitting devices
- MEMS -?

Possibility of growing on any Substrate at low temperatures

Supercritical CO_2 Processes for Production of Nanoparticles

SC CO_2 as a Solvent

- *RESS (Rapid Expansion of Supercritical Solutions)*
- *PGSS (Precipitation From Gas Satd. Solution)*

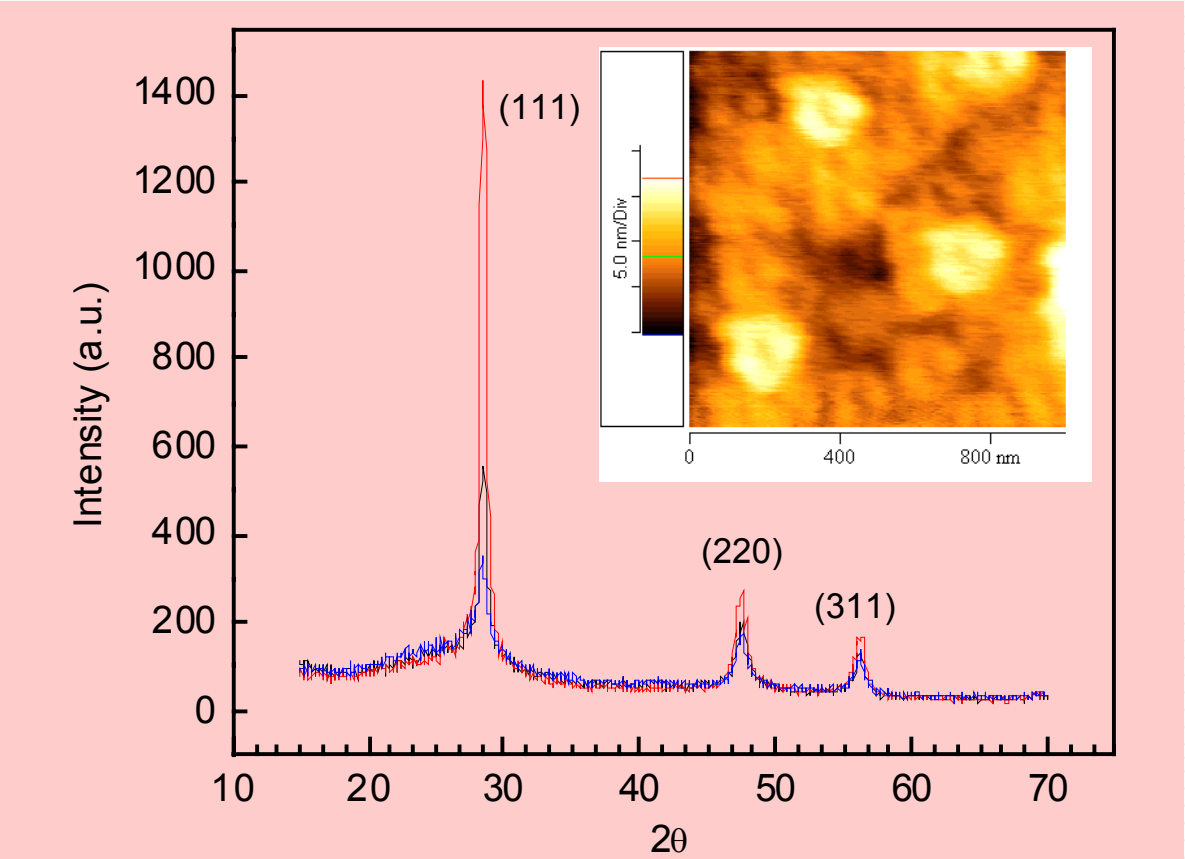
SC CO_2 as Anti-solvent

- *GAS (Gas Anti-solvent)*
- *SAS (Supercritical Anti-solvent)*
- *SEDS (Solution Enhanced Dispersion by Supercritical Fluids)*
- *DELOS (Depressurization of Expanded Liquid Org. Solutions)*

Some Challenges for Chemical Engineers (Nanoparticles, Nanofilms and CNT)

- New Scale-up Rules: Nano reactors
- Separation of nanoparticles
- Stability of nanofilms
- Manufacture of CNT

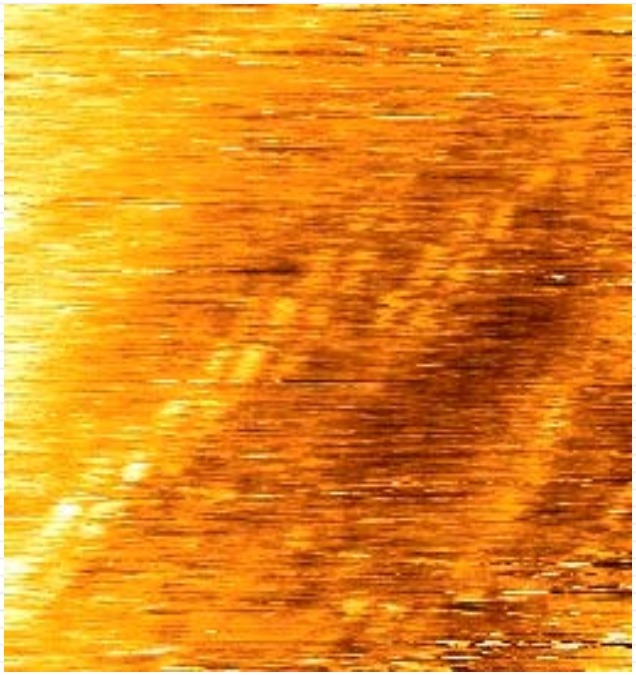
Results obtained so far :-

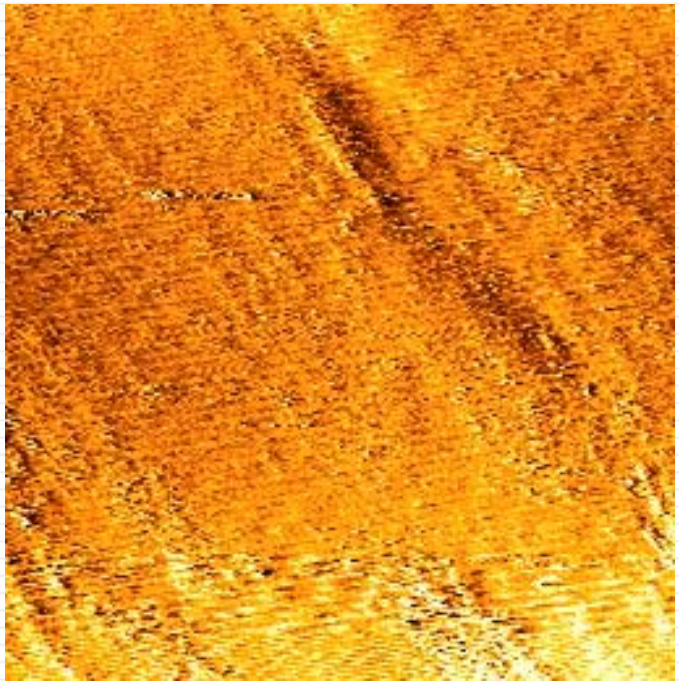


X-ray data of films made at different T_f The inset shows a typical AFM image

- Films with grain sizes ranging from 2-12 nm
- Oriented in <111>
- Grain size and crystalline fraction highly dependant on process conditions

STM Images

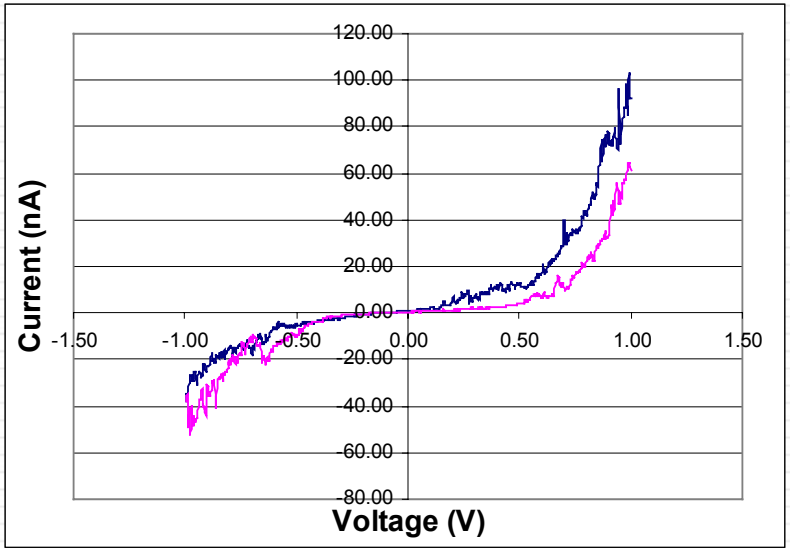


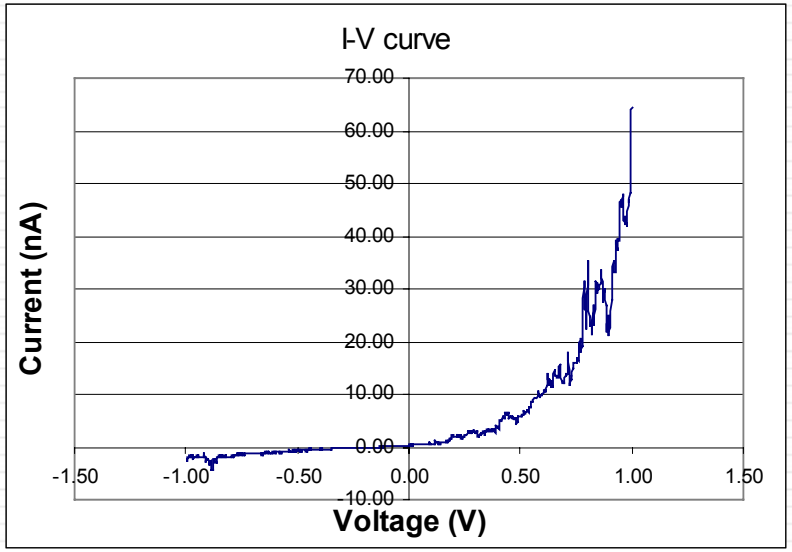


Ridges type structure obtained in the first figure (10nm x 10nm scan)

Valley of depth ~1nm observed in the second image (50nm x 50nm scan)

I-V curves obtained





Diode type characteristics with a barrier potential

Measurements taken on the hill shown before

Areas of application

- Nano and Pico satellites,
- NEMS,
- Aerospace, Automobiles, ……

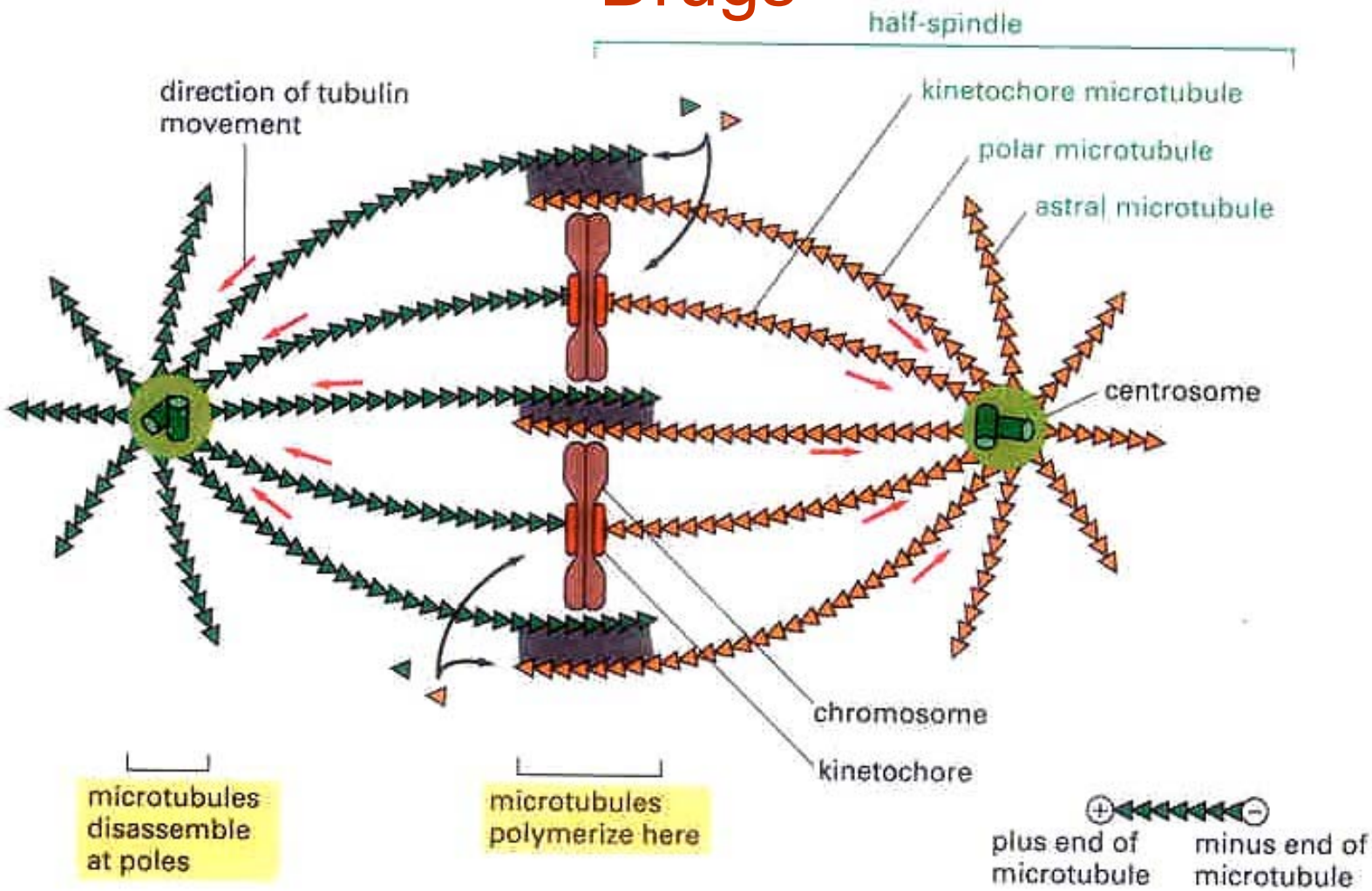
Developments required

- Glass composition with optimal photosensitivity
- Mechanics of vitrification & devitrification
- Nucleation & growth of crystals

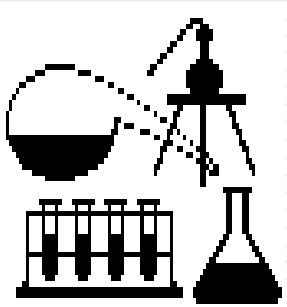
Work in progress

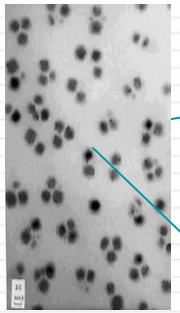
- Two aluminosilicate compositions formulated and made
- Detailed characterization is in progress !

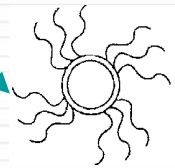
Mitotic Spindle: Target for Many Cancer Drugs

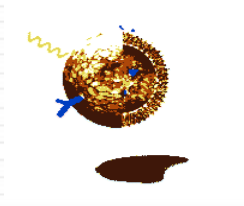


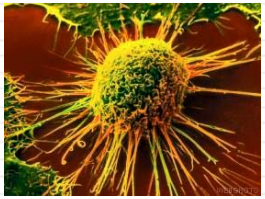
Over view of the work

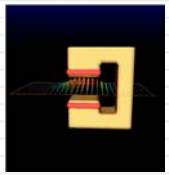






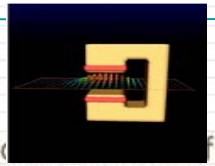


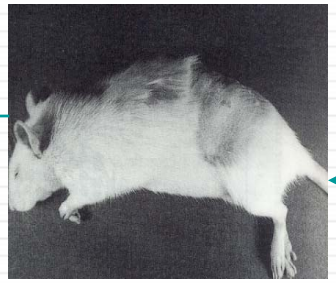




In-vitro assessment

In vivo assessment



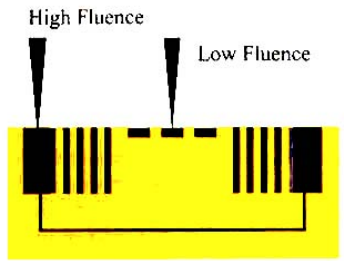


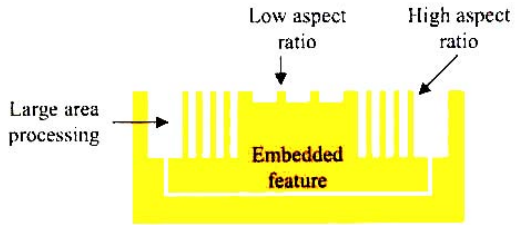
In-vivo assessment

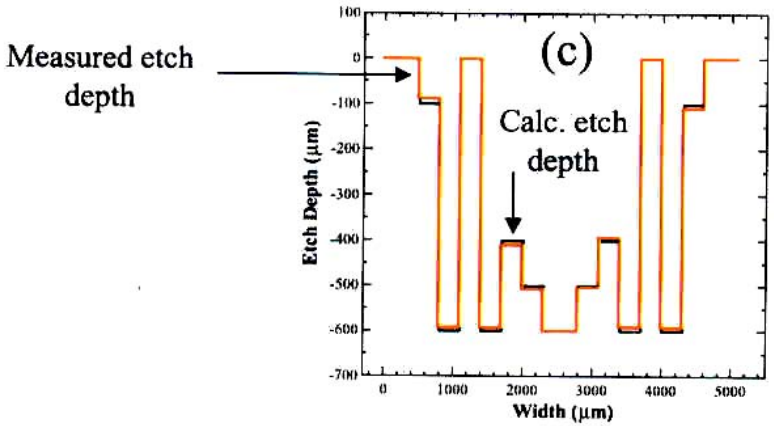
????

Inc f Technolo

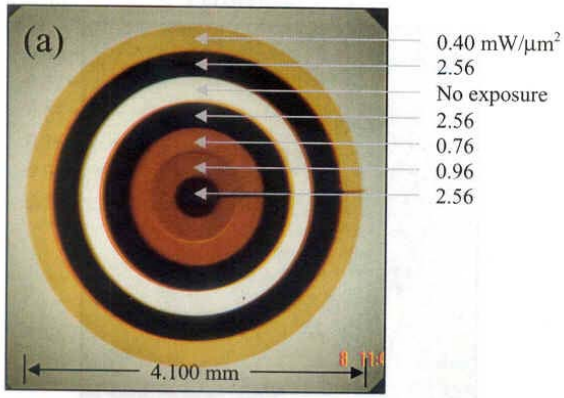
Nanostructure by Photostructuring



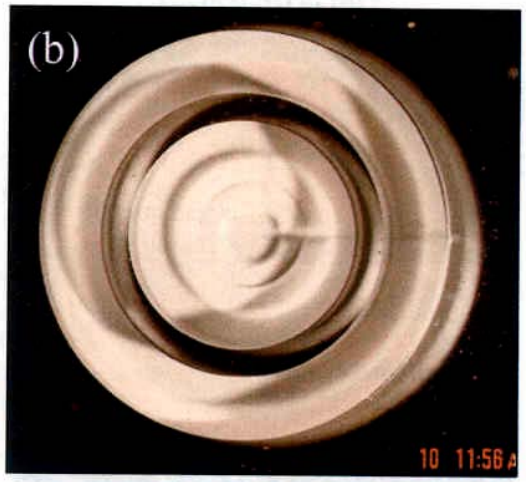




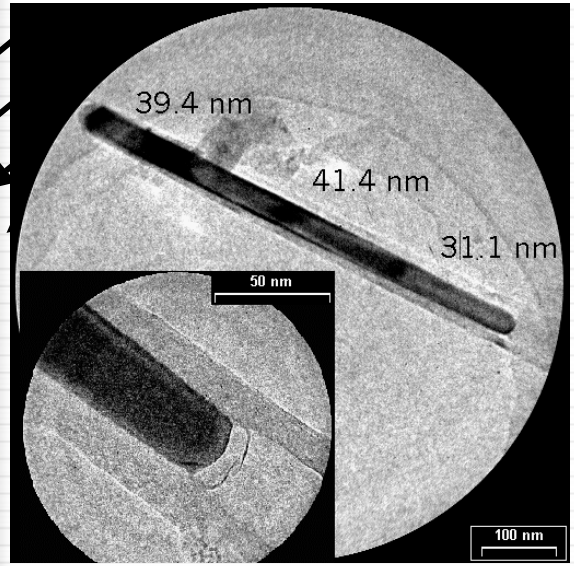
Permanent Image

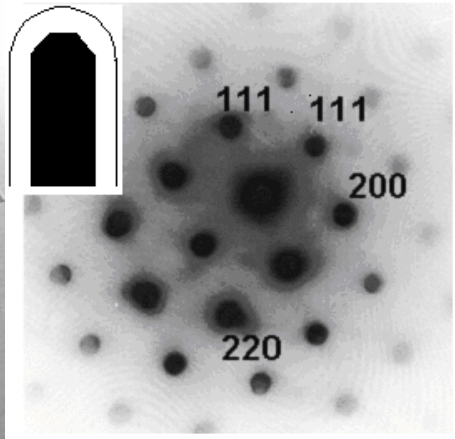


Etched Structure

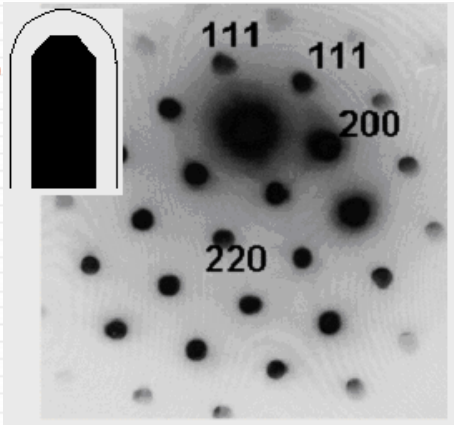


TEM image of nickel filled tube and nanodiffraction pattern at different locations





Ni phase



Ni phase

Catalysts, Coatings, Explosives, Specialty Chemicals, Polymers, Drugs

Interests in Nanoparticles at IITB

Pharmaceutical nanoparticles find uses in treating diseases ranging from diabetes to cancer in the form of:

Controlled Drug Delivery Systems:

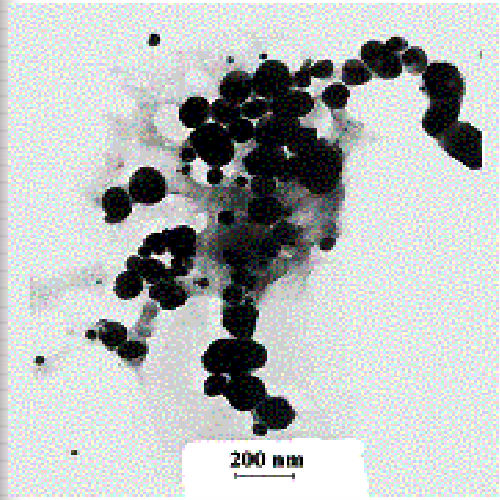
- **Dry Powder Inhalers**
- **Needle-Free Injections**
- **Controlled Release Devices**

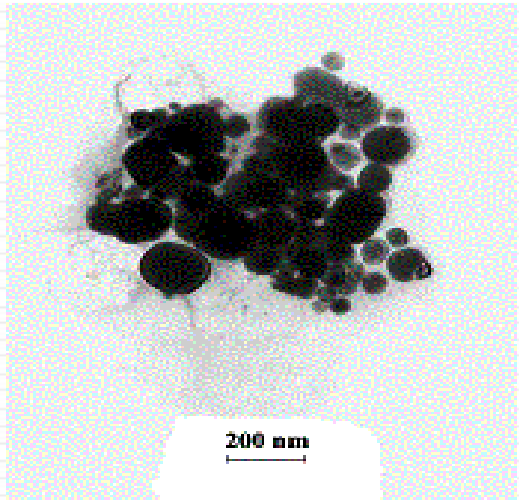
Processes:

- ⇒ **Micronisation**
- ⇒ **Microencapsulation**
- ⇒ **Microimpregnation**

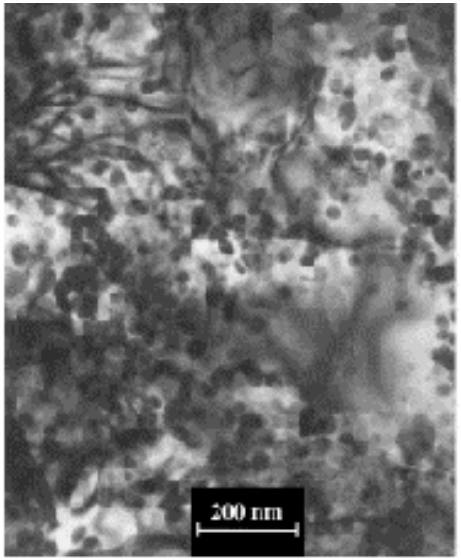
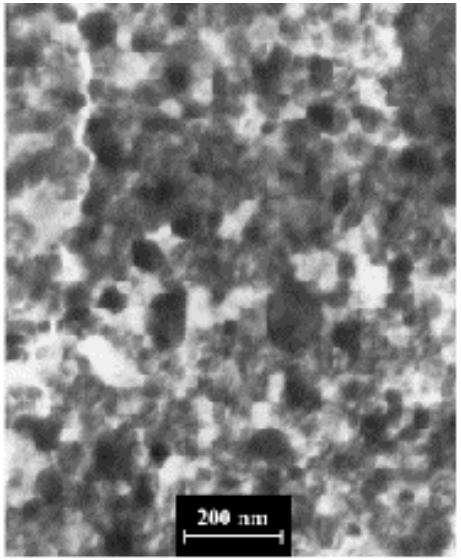
Nanocrystalline Material

- Interest in magnetism of small particles.
- High density recording media require particles with very small grain sizes.
- Working almost at the limit of superparamagnetic critical size.
- Critical sizes can be different in nanocrystalline thin films due to inter-granular interactions.
- When the grain size is in nanometre range, the crystalline habit may differ from bulk causing changes in magnetic properties.





Typical Grain sizes – 20 to 30 nm (Obtained from XRD and TEM)

Reduction at 550° C Reduction at 850° C

Nanocrystallites with grain size around 5 nm in the as-deposited film