Potential Research Vision

Nanotechnology Research Potentials in University of Bridgeport

Prof. Prabir Patra
Mechanical Engineering

Prof Xingguo Xiong
Electrical and Computer Engineering

Prof. Hassan Bajwa
Electrical Engineering

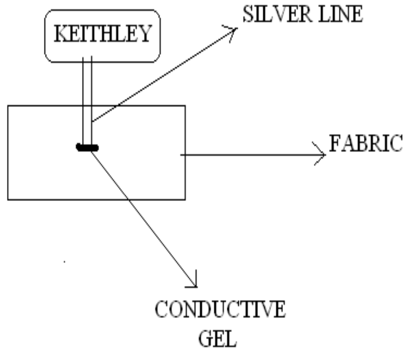
School of Engineering
University of Bridgeport

Wearable conductive hydrogel sensors and actuators (nano-bio)

- Conductive hydrogels as thin films, dots, patterns
- Stabilization of the gels in textile matrix

a. In-situ nanostructure synthesis by reactive inkjet printing

b. Direct writing of the nanocomposite gel on the substrates in definite patterns



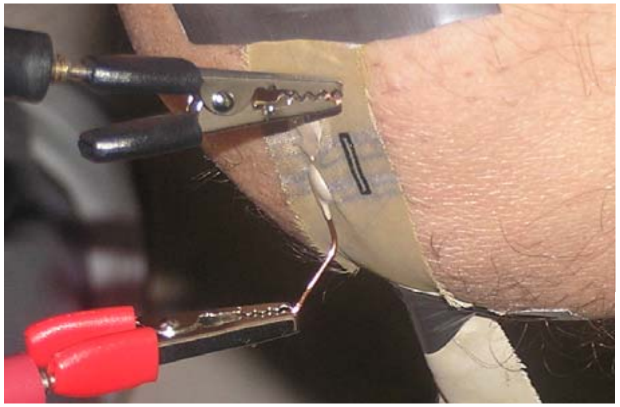
Wearable glucose sensor

Actuation response of a wearable textile gel

Nano-bio- gel continued….

- Swelling of gels by pH change via ionization of amine group in amine-epoxy gels

- Incorporation of the enzymes (such as glucose oxidase) will lead to pH change that in effect results in resistance change of the gel (sensor)
- Stress induced electrical signals (piezoelectric actuation)
- CNT filled polymer gels with low percolation threshold changes electrical resistance as a function water intake or water expulsion



Piezoelectric textile sensor from Polymer-CNT formulations

Calvert, Patra and others, AATCC Review, 7(6), 42-46, 2007

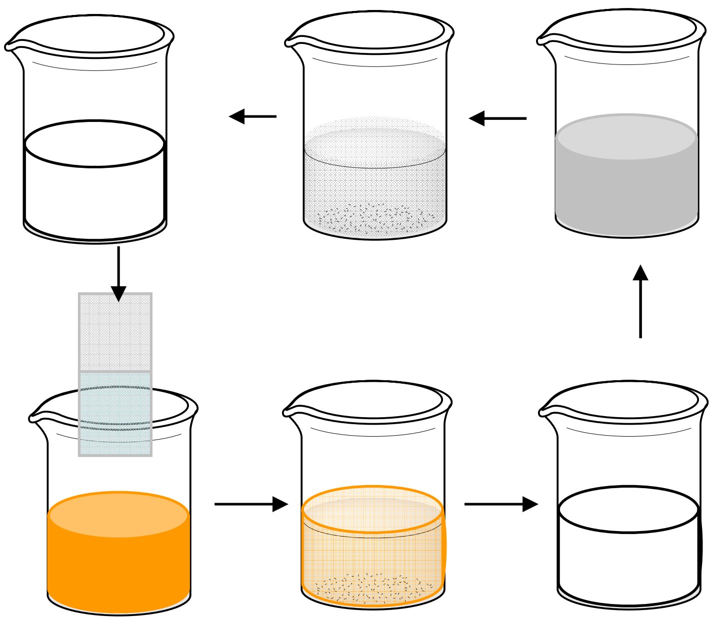
Multifunctional Nanocomposites

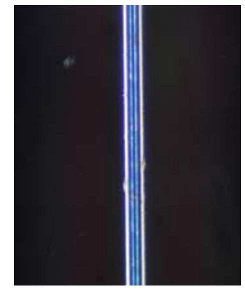
Layer-by-Layer Assembly of polymers and nanoparticle

a. Optically active films and fibers

b. CNT-polymer inks

c. CNT-textile flexible antenna

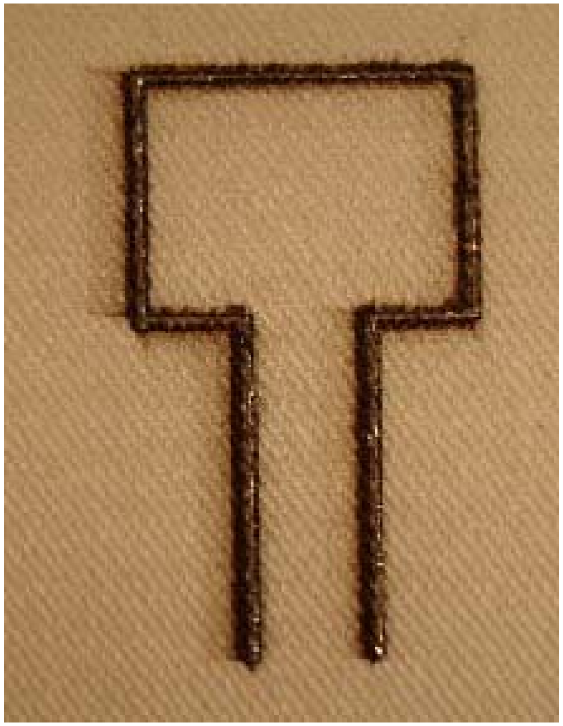




LBL assembly of PEI and SiO2/SnO2 nanoparticle stacks as fibers

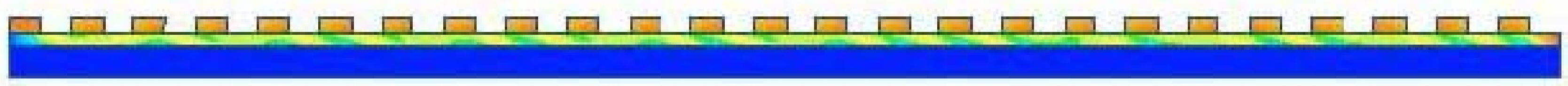
Color from LBL Stacking (PEI-SiO2-PEI-SnO2)(Patra et al, **PMSE preprints, 2007)**

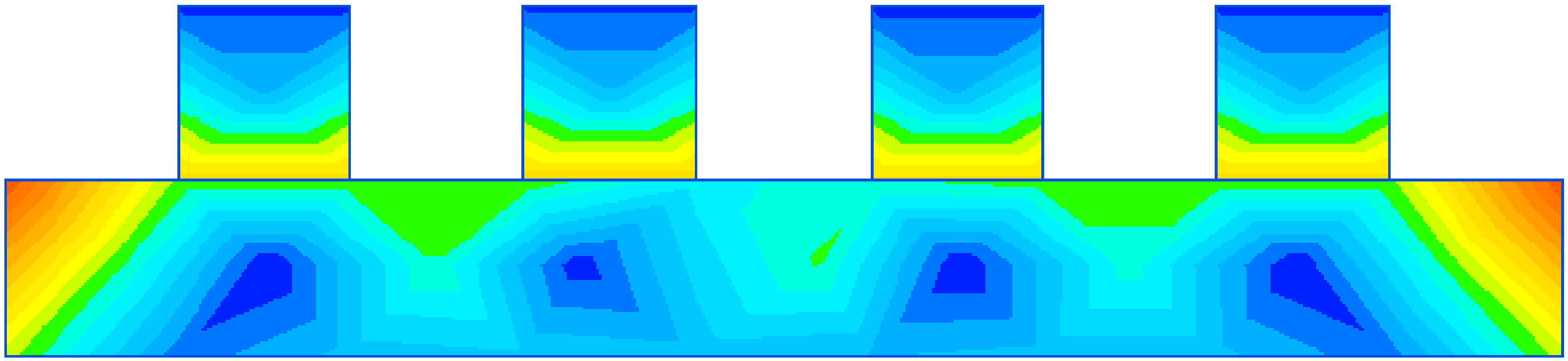
Inkjet Printed polymer-silver antenna



In-situ silver lines printed onto PEDOT-PSS polymer lines on a cotton substrate

Modeled structure continued….

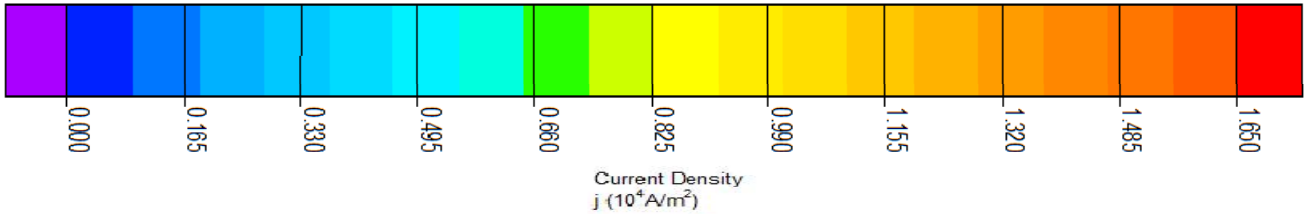




Modeled structure of discontinuous silver on continuous polymer lines

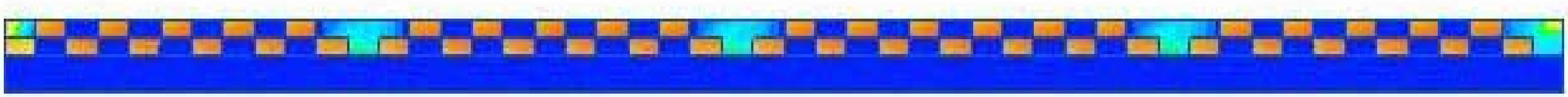
Modeled antenna structures by QuickField TM

Modeling of the structure where continuous silver line is printed over PEDOT-PSS line

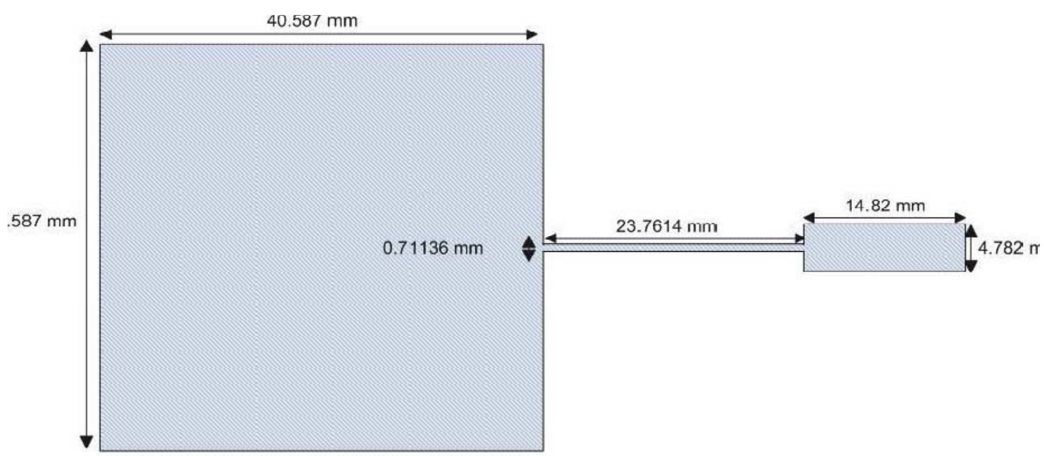


Current distribution on 10 mm composite structure

Modeled structures and real antenna made

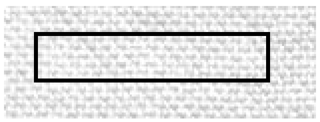


PEDOT-PSS bridge where silver particle are discontinuously connected

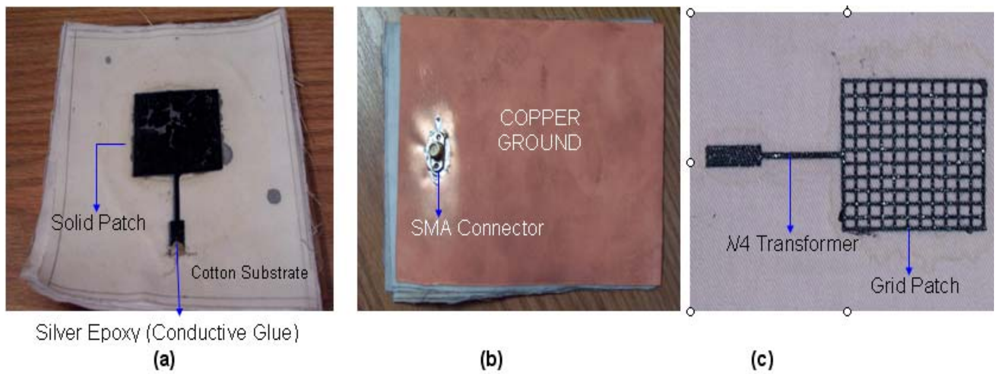


2.4 GHz micro strip patch antenna

CNT-PEDOT-PSS inkjet printed antenna (Printenna)



Patterned electronic inks on textiles and films, Ajayan and Patra

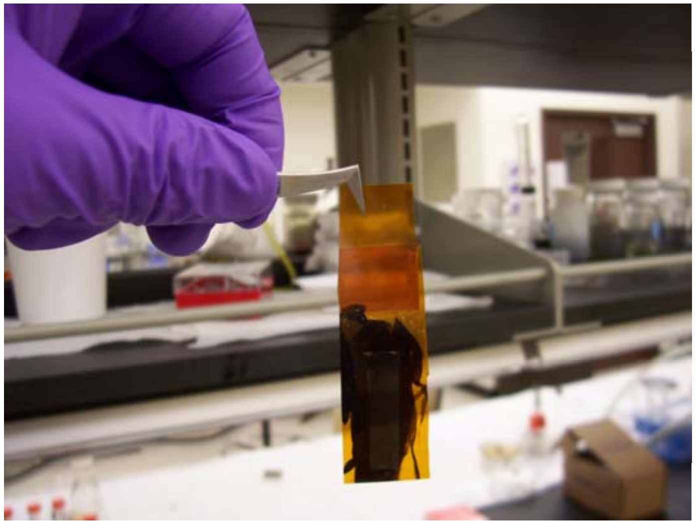


a) Top view b) Bottom view of the prototype c) Grid patch design

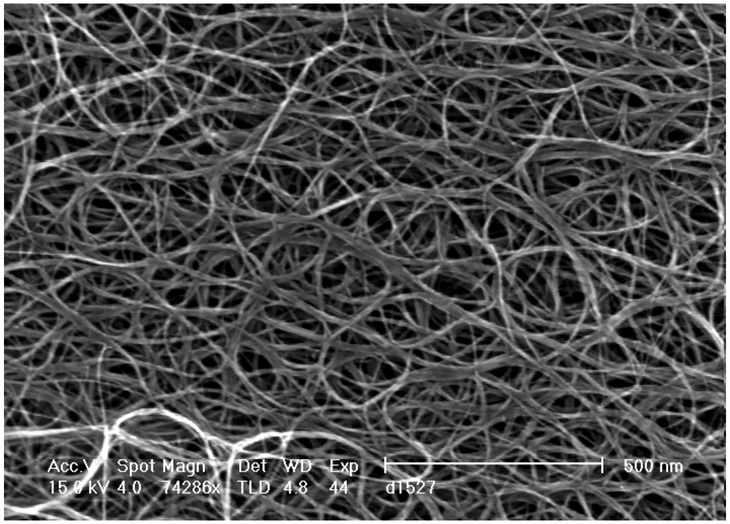
The antenna of solid patch is ready for measurements. Silver epoxy was used to connect the feeding node to the antenna.

Patra, Ajayan, Calvert and others unpublished work

Flexible and transparent electrodes as an alternative to ITO

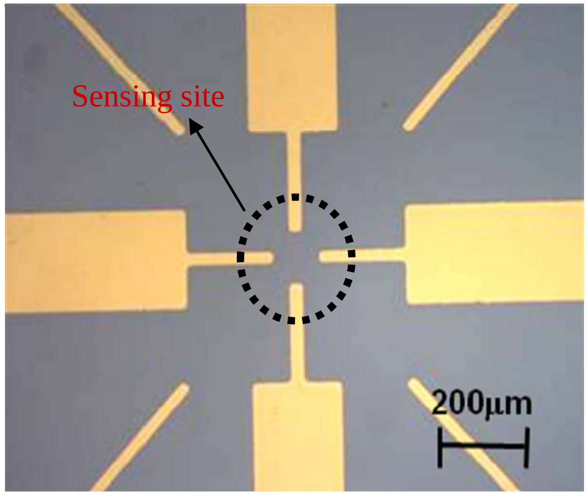


Transparent CNT-PEDOT-PSS polymer film by LBL

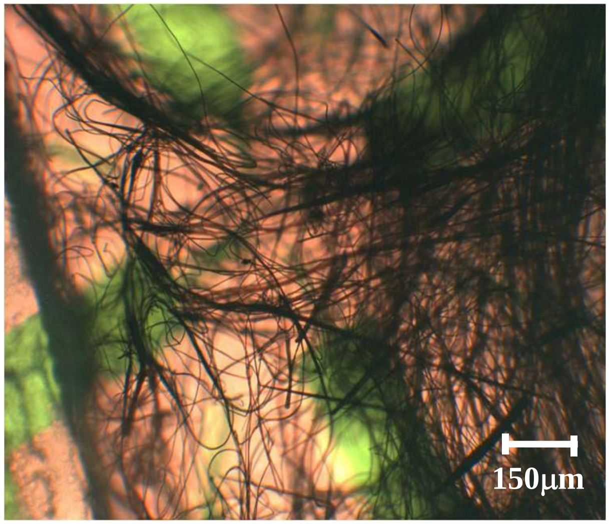


CNT mats (Li, Patra and Ajayan)

Lab on chip protein sensor

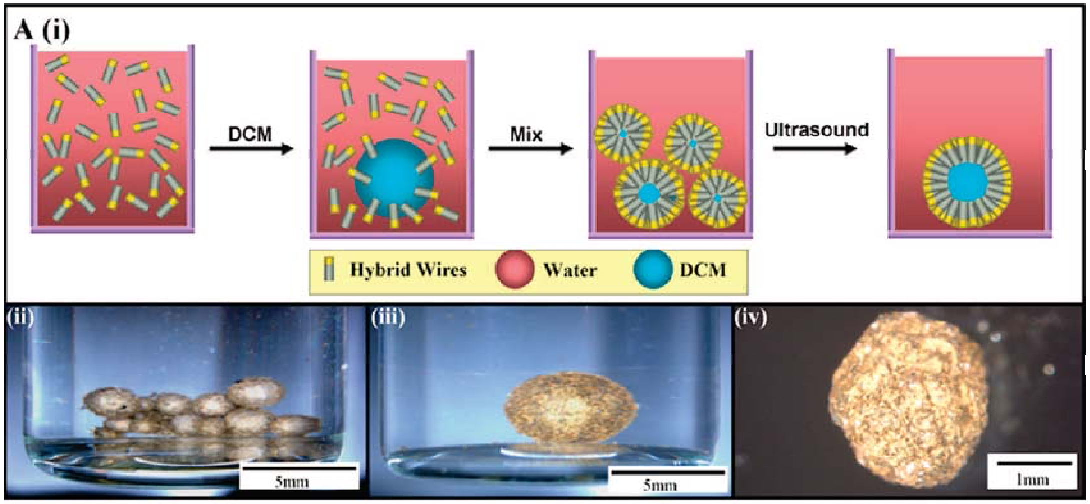


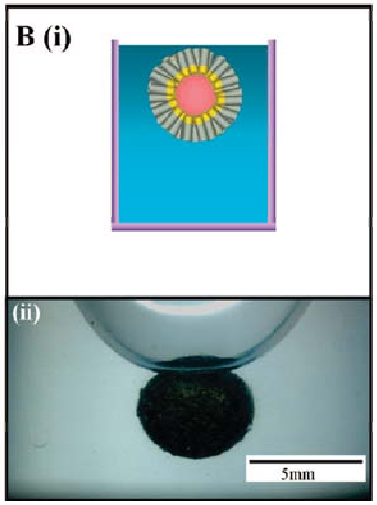
Planar microelectrode array (Kunduru, Patra, Prasad, ACS Nano submitted 2009



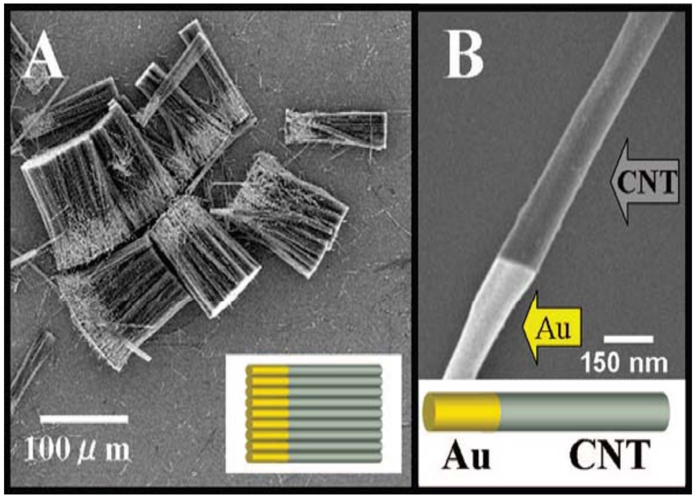
Optical micrograph of electrospun nanofibers layered on the electrical sensing platform of the protein sensor chip

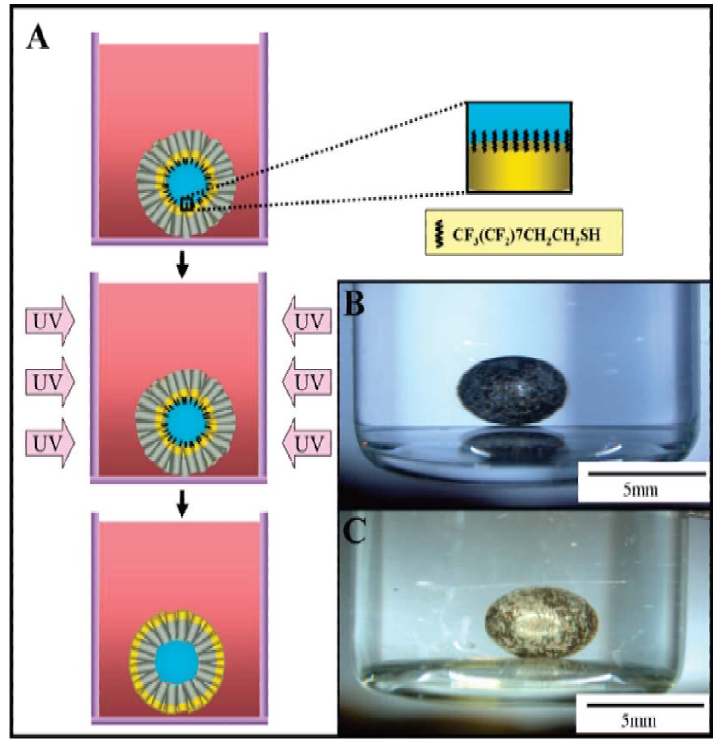
Hybrid nanostructures and assembly for microfluidics





Hybrid nanostructures and assembly…..



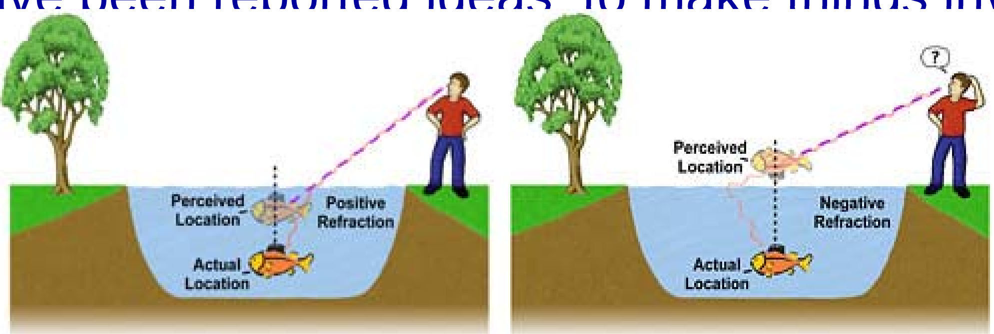


Hybrid CNT-Au assembly (Ajayan and group, Nanoletter 2008)

Metamaterials and invisibility cloak

- Inspiration from Nature (figure below)
- Borrow from “star trek” and Harry Porter novels.
- Theoretically explained for radar (John Pendry and others) optical wavelength (Valentine and Zhang)
- Experimental realization of darkest materials with almost zero absorption of light (Lijie and Ajayan, Nanoletters 2008)

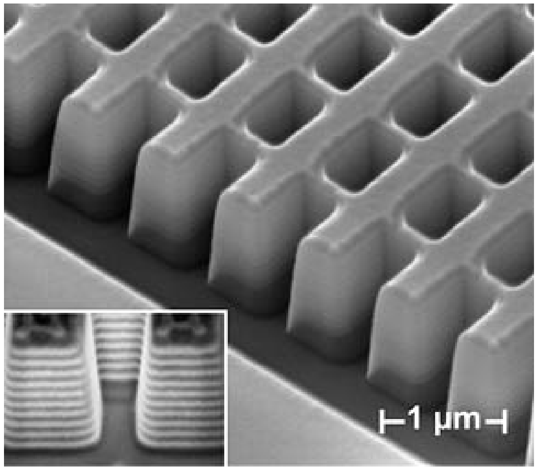
A. There have been reported ideas to make things invisible — using methods … the light from nearby o… an be projected as a mov… gies involve "metama… ly coils or wires that twist the paths of electromagnetic radiation.

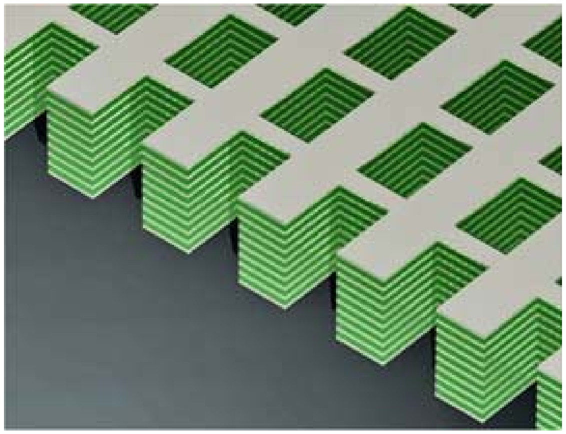


An illustration of how a fish in water is seen by an observer, with the red lines marking the refraction of light and the purple lines representing the path towards the perceived location of the fish, which appears above its actual location

Metamaterials…..

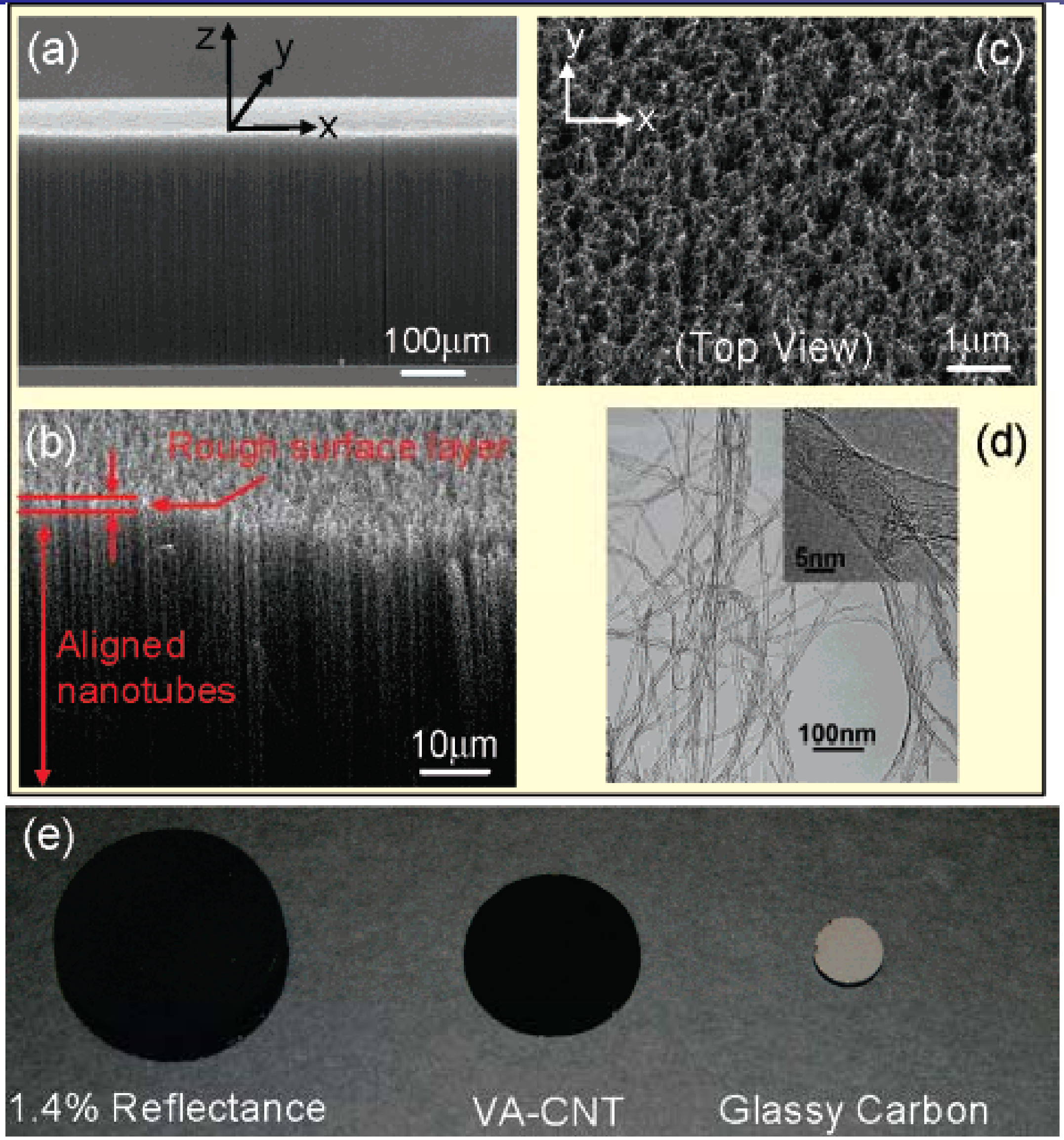
- In the Nature paper, the UC Berkeley researchers stacked together alternating layers of silver and non-conducting magnesium fluoride, and cut nanoscale-sized fishnet patterns into the layers to create a bulk optical metamaterial. At wavelengths as short as 1500 nanometers, the near-infrared light range, researchers measured a negative index of refraction (Valentine, Zhang, Nature 2008)
- Darkest materials on earth solely from carbon nanotube a potential stealth material (Ci , Ajayan, and others Nanoletters, 2008, awarded Guinness Book of World Record)



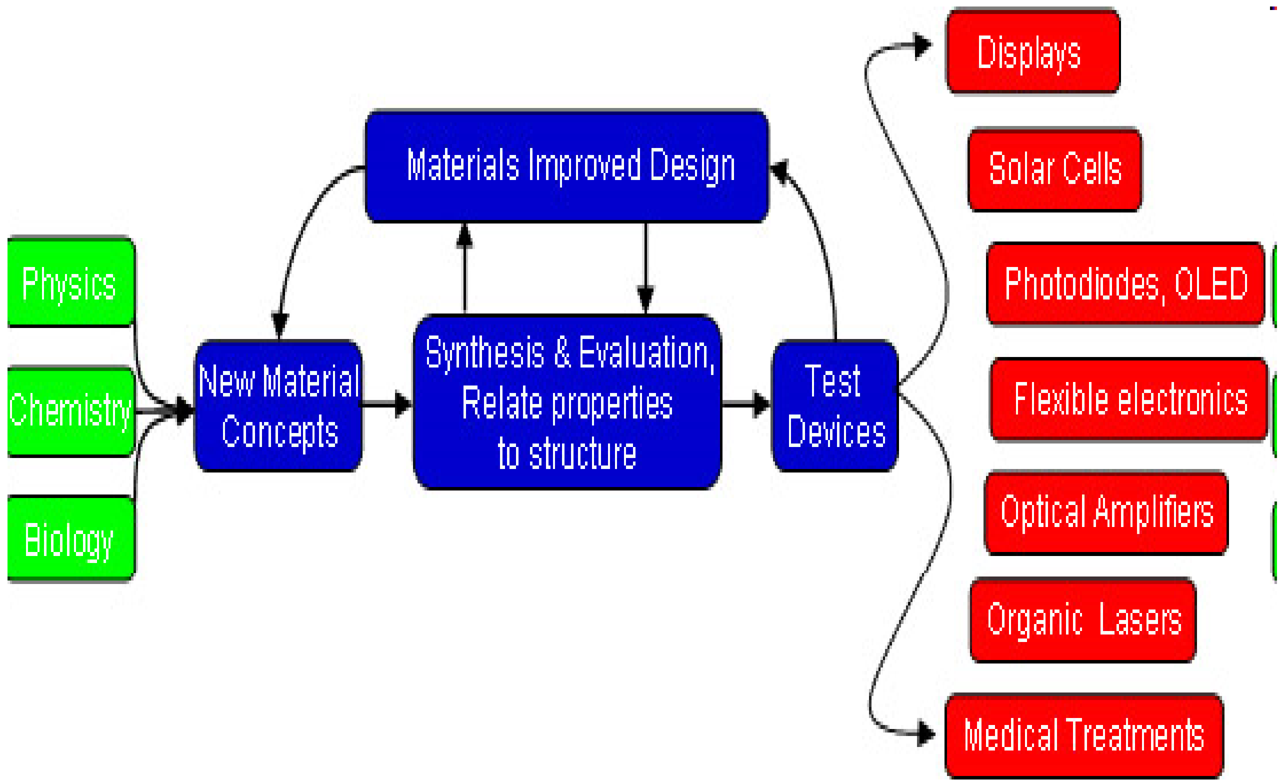


3D fish net negative refractive index (model right) and experimental metamaterials (left)
Valentine and Zhang , Nature, 2008

Metamaterials-darkest material

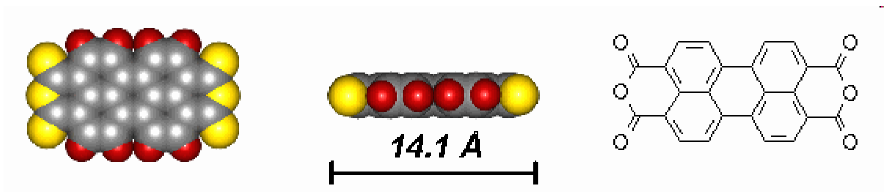


Interdisciplinary research-flow chart

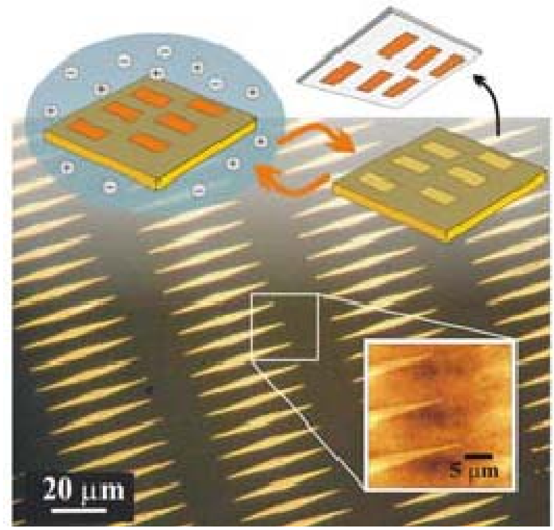


Flow chart-courtesy organic semiconductor center, UK

Assembly and patterning of organic semiconductor



Space filling model of PTCDA



Patterning of OSC on flexible substrate

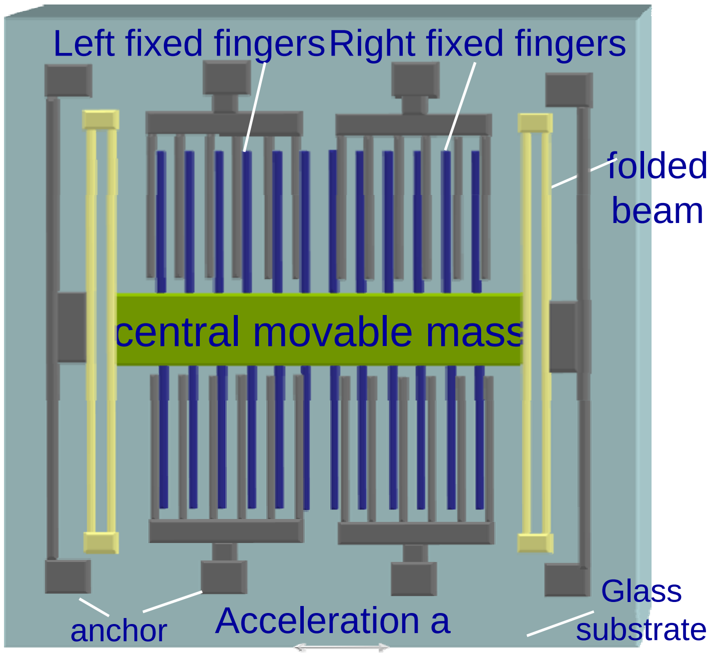
MEMS/NEMS Research: Bulk-micromachined Comb Accelerometer

- ❑ Previous work: Limitations of ADXL50 accelerometer by Analog Devices.

✓Device capacitance is small (C_0~0.1pF), difficult to detect
✓Parasitic capacitance
✓Poly-Si as structural material: stress
✓Surface-micromachining: "stiction"

- ❑ Contributions of our design:

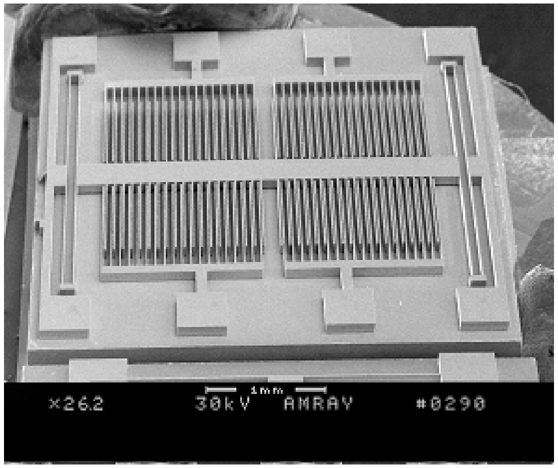
✓Device thickness>100μm, C_0~2 pF
✓Glass substrate: parasitic effect is avoided
✓Single-crystal silicon as structural material: residual stress is avoided
✓Pre-etched channel for releasing: no "stiction", no released holes required



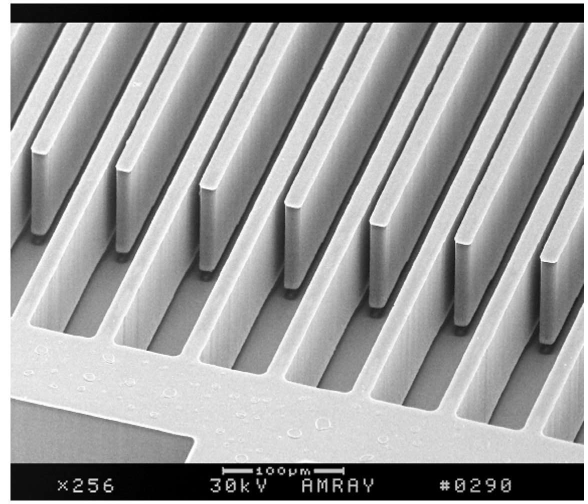
Device structure of bulk-micromachined accelerometer*

(* X. Xiong, D. Lu, W. Wang, *China Applied Novel Patent*, Application Number: ZL 00217895.8, Patent Number: 2424450.)

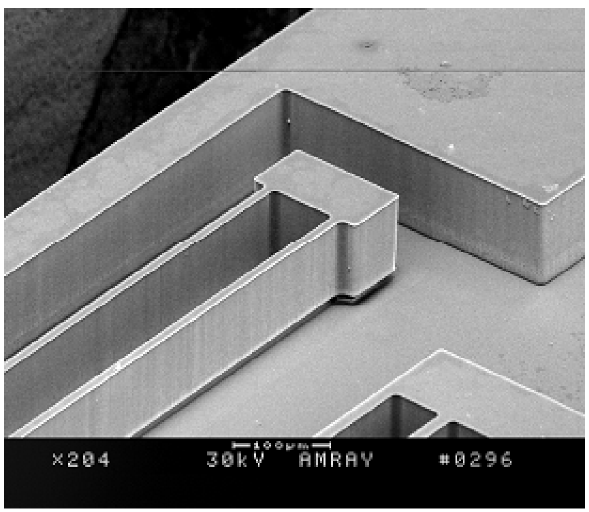
Fabricated MEMS Microaccelerometer



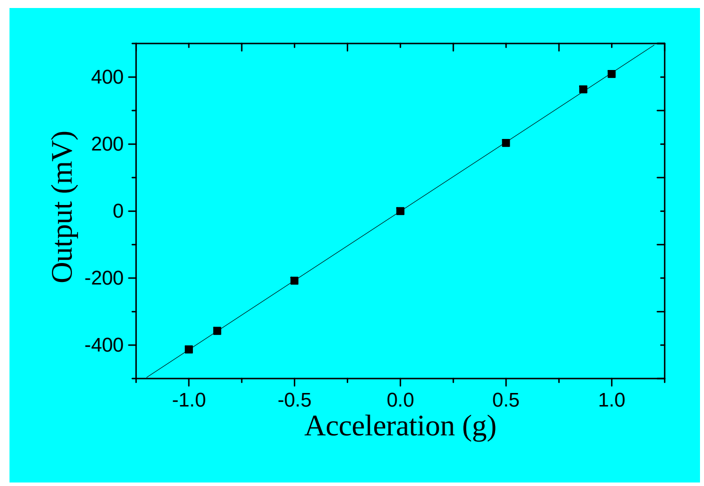
(a) Global view of the device



(b) Local view of fingers



(c) Local view of beams



(d) Measured result (S=412mV/g, NL<0.4%)

Experimental results of the fabricated accelerometer

MEMS/NEMS Research: Bulk-micromachined Microgyroscope

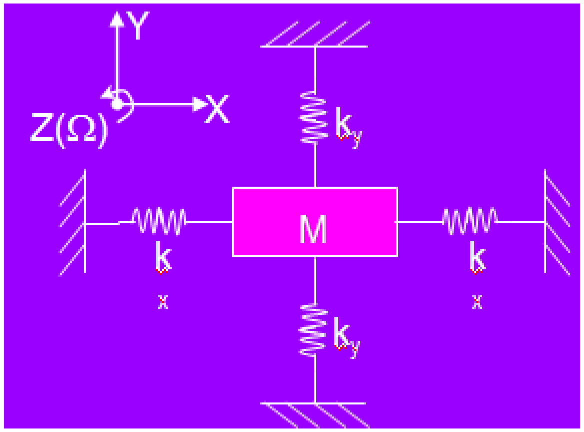


Fig. Microgyroscope working principle

- If M vibrates along x direction,

$$x(t) = A_x \sin \omega t$$

It experiences Coriolis' force along y direction:

$$F_C(t) = 2M\Omega\dot{x}(t) = 2MA_x\Omega\omega\cos\omega t$$

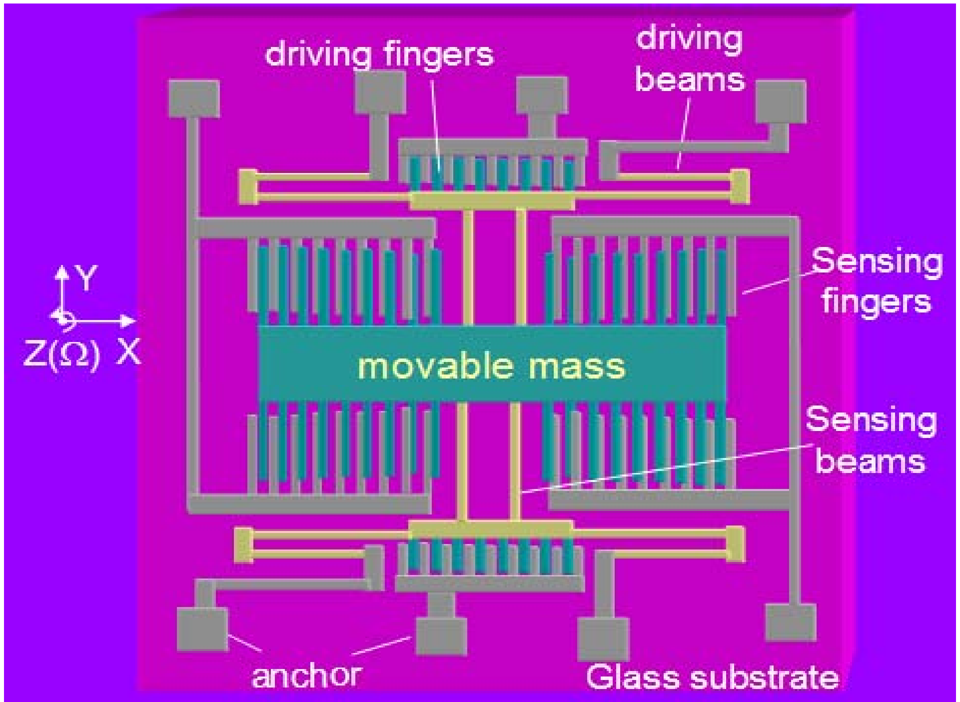
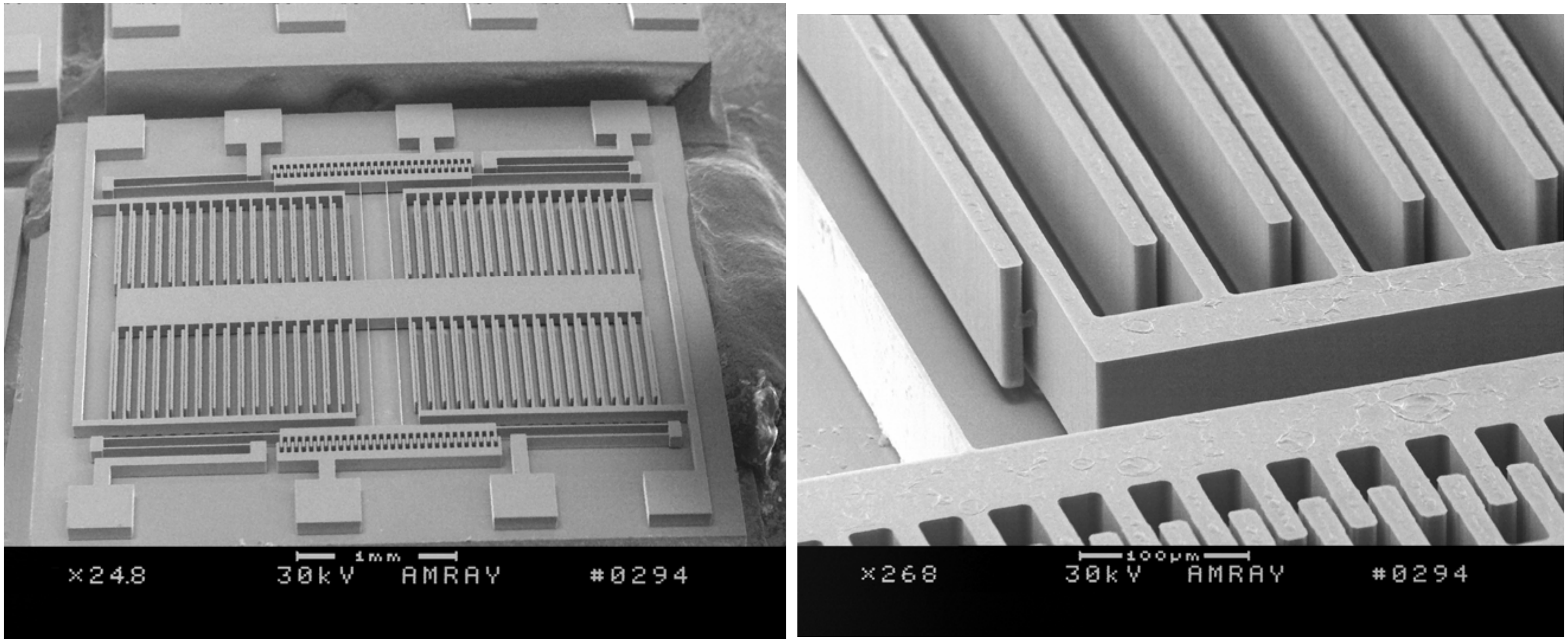


Fig. The schematic diagram of bulk-micromachined microgyroscope

- Contribution of our design:

  * increased device thickness led to larger device capacitance
  * better decoupling between driving vibration & sensing modes
  * glass is used as substrate: parasitic effects are minimized

Fabricated MEMS Microgyroscope

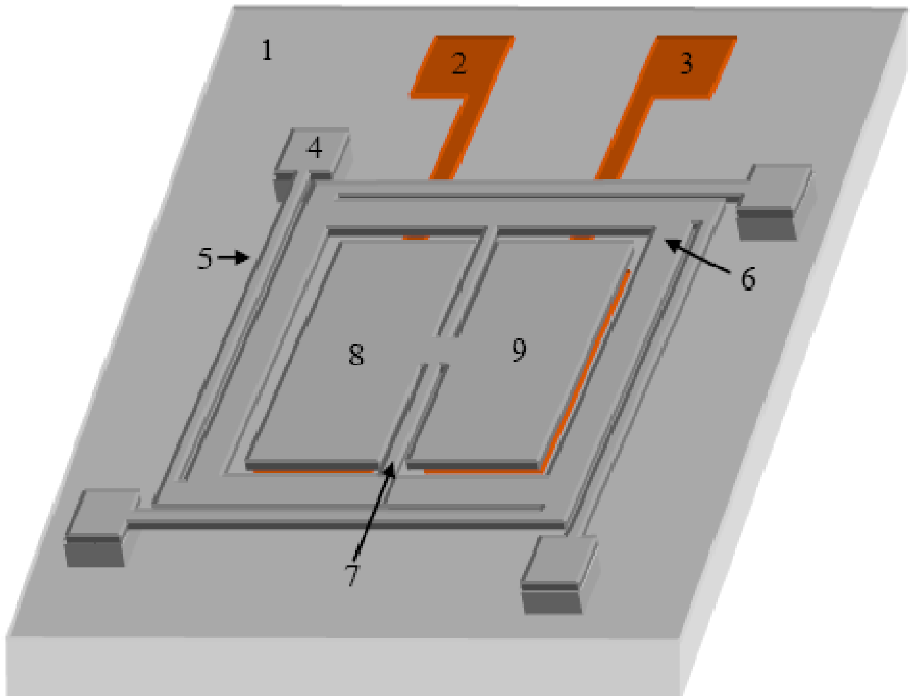


The SEM photos of the fabricated microgyroscope

MEMS/NEMS Research: Bi-functional Aluminum Spatial Light Modulator

- Previous work:
  - ✓ Piston micromirrors have been reported.
  - ✓ Torsional micromirrors have been developed (DMD)
  - ✓ Bi-functional micromirrors have been reported.
- Our work: a bi-functional Aluminum MEMS micromirror device. It can work in both piston and torsional modes.
  - ✓ Electrostatic driving is used for mirror operation.
  - ✓ It is fabricated with thick-photoresist sacrificial layer technique.
  - ✓ Nominal maximum displacement in piston mode: 4um.
  - ✓ Nominal maximum rotation angle in torsional mode: ±5.7°.
  - ✓ Easy for fabrication.
  - ✓ It can be used to modulate both the phase and the direction of the incident light.

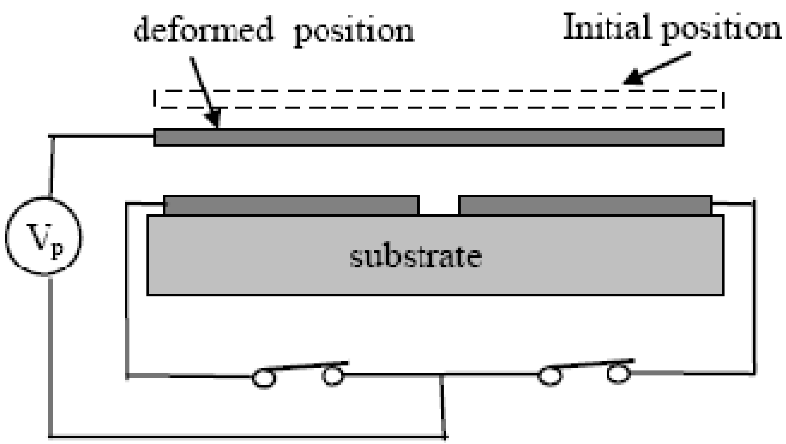
Aluminum Bi-functional Micromirror Design



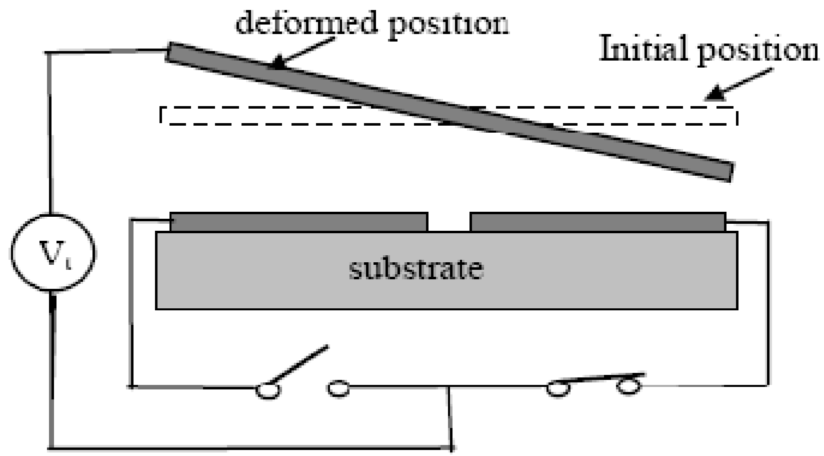
Structure diagram of bi-functional aluminum micromirror.

In it: 1.substrate. 2. left Al bottom electrode. 3. right Al bottom electrode. 4. anchor. 5. piston beams. 6. frame. 7. torsional beam. 8. left mirror surface. 9. right mirror surface.

Piston and Torsional Modes of Micromirror



Piston mode of micromirror

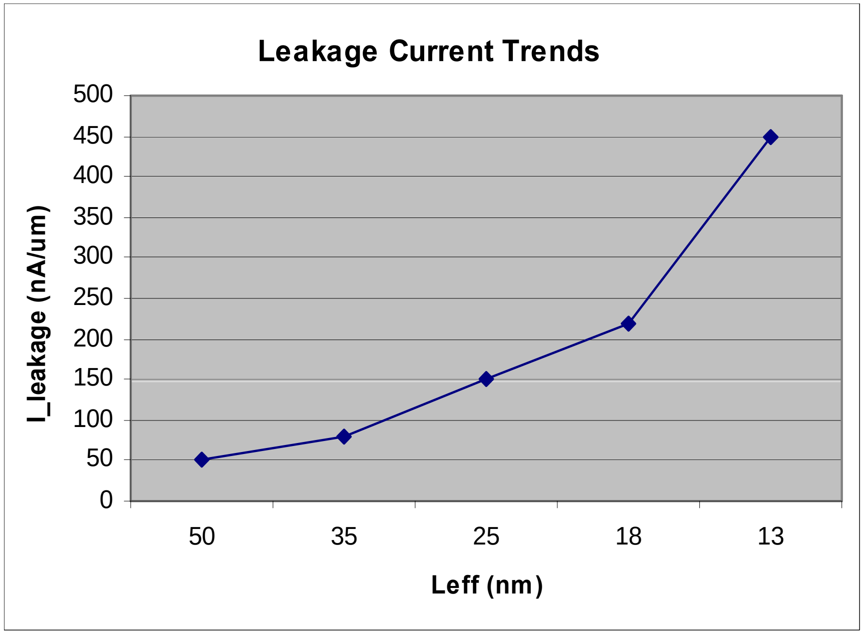


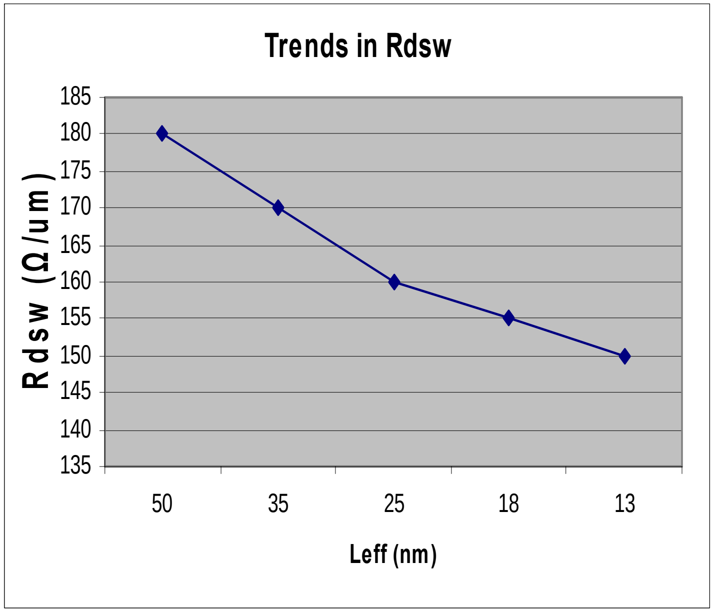
Torsional mode of micromirror

- Piston mode: The piston driving voltage Vp is applied between the mirror surface and both bottom driving electrodes.
- Torsional mode: The torsional voltage Vt is applied to only left or right bottom fixed driving electrode (instead of both).

Nanoelectronics Research: VLSI Technology Trends

Leakage current and R_{dsw} as technology scales from 180nm to 32nm.



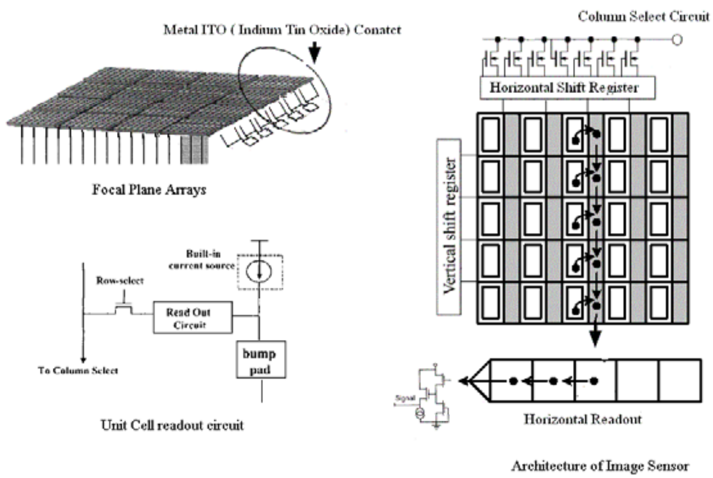


Leakage current increases and R_{dsw} (Source/Drain) resistance decreases as technology scales from 180nm to 32nm.

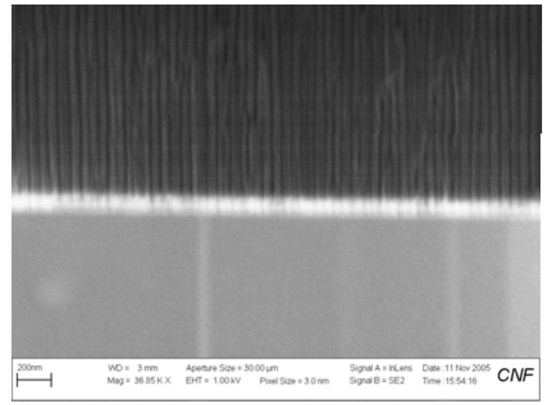
VLSI nano integration

Scanning Electron Microscope (SEM) image of nanowires array grown at CUNY.

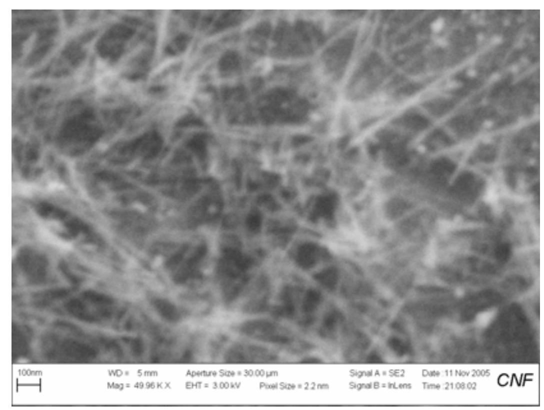
Image of nano-wires after dissolving the template



CMOS to provide signal gain and latching capabilities.



Cross-sectional SEM view of CdTe nanowires



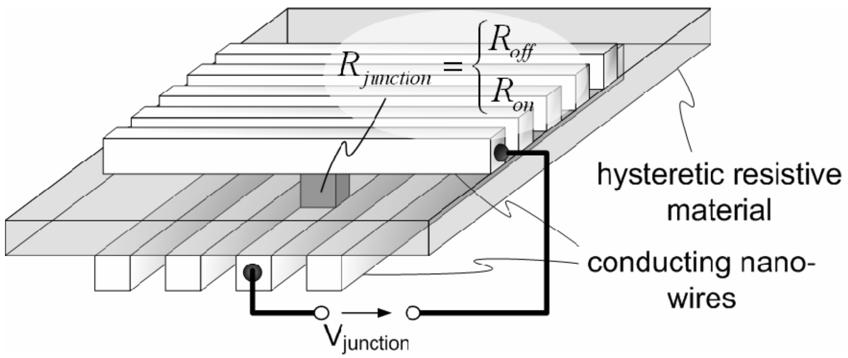
SEM Top view of CdTe Nanowires

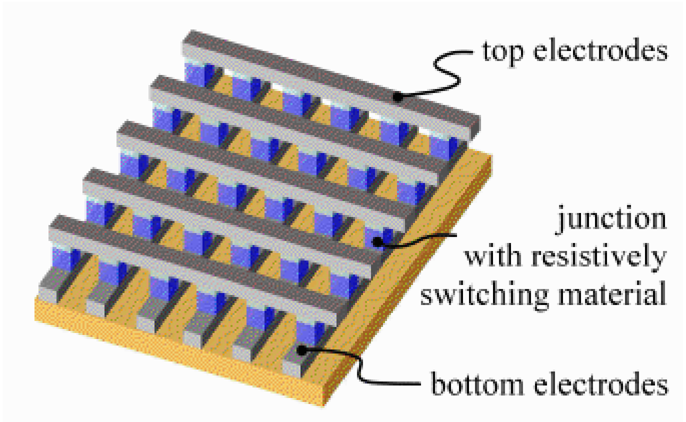
Nanoscale specific integrated circuits

- Top-Down Fabrication versus Bottom-Up Assembly
  - physical dimensions of these devices is limited by the resolution of the top-down process, e.g., lithography.
  - Size limits of bottom-up self-assembly could be much smaller, since assembly can be self-controlled on the atomic or molecular scale.
  - bottom-up assembly approaches will be cheaper
- Nanoelectronics
  - *Nanotube field effect transistor (NFETS) ,* molecular wires, diodes, and single-electron transistors (SETs) have been proposed and differential and logical function have been implemented using nanotube electronics.
- Challenges
  - integration of technology with existing chip-making techniques.

Crossbar Circuits

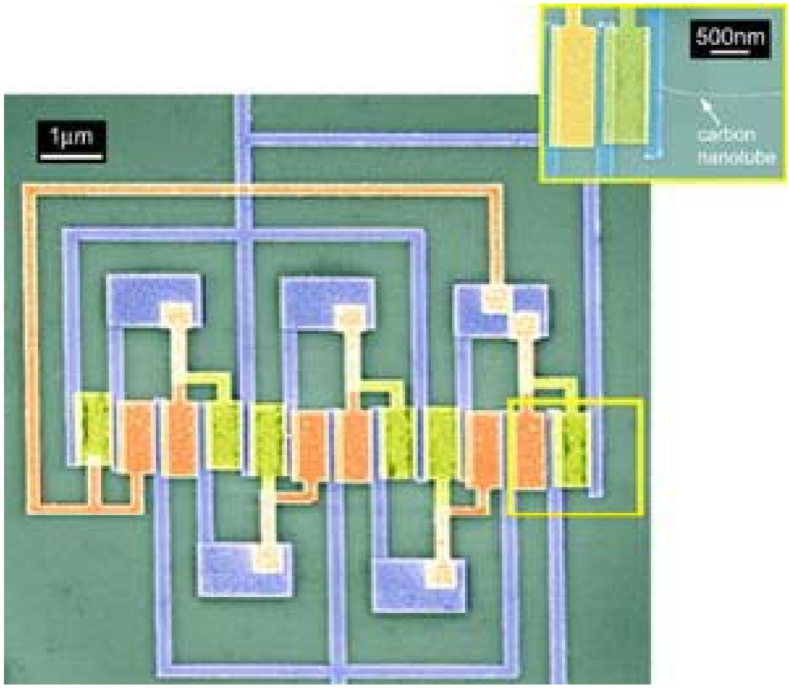
- Nanoscale crossbar structure consists of two planes of nanowires crossed perpendicularly and connected by bi stable junctions.

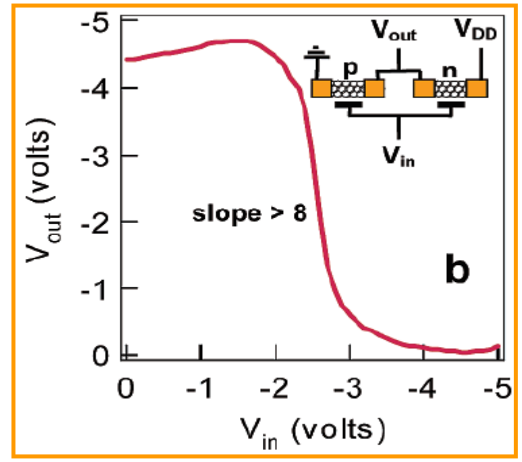


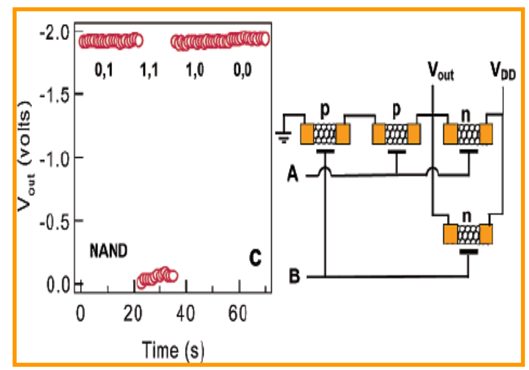


- Crossbar can be programmed by applying voltage causes the resistance of the junction to change.

Integrated Logic Circuit with NANOtube







Chen group IBM

5-stage CMOS type nanotube ring oscillator.

Electric properties of interfaces, engineer a molecular device to give a specific IV cartelistic , Integration with existing chip making techniques are challenges faced by research community.

Research Expertise and interest

- Multifunctional nanomaterials, Carbon nanotube architecture, polymer nanocomposites, biomedical and biomaterials engineering, nanostructured soft electronics.

- Microelectromechanical Systems (MEMS), Nanotechnology, Low Power VLSI design, VLSI Testing

- Low power VLSI, reconfigurable architectures, nanoelectronics and Modeling and simulation of nanoelectronic architectures.