Metallic Nano Electro Mechanically Actuated Gripper and Tunable Nano Photonic Device

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Objectives

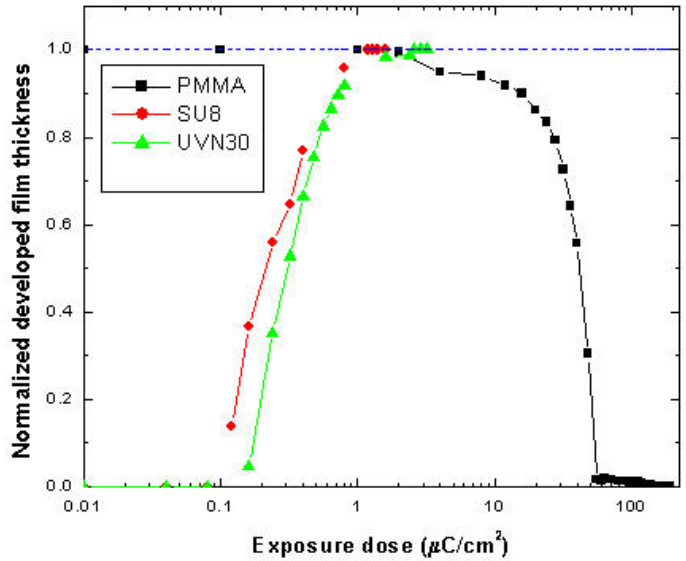
- Nanoelectromechanical systems (NEMS)
  - Possible to realize smaller mechanical, biological and chemical systems
- Nano grippers
  - Actuators for nano manipulation devices/systems
  - Relatively large displacement with low actuation voltages
- Tunable Nano Photonic Devices
  - New functionalities unachievable with passive nano photonic devices.
  - Real-time, on-demand control can greatly enhance the functionality of photonic devices and systems.

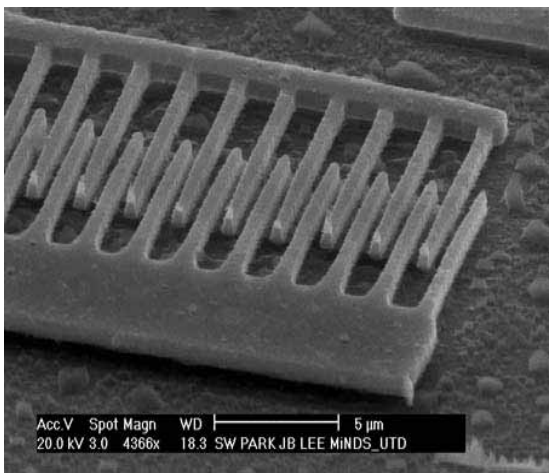
UTD's Nano Tech Related Facilities

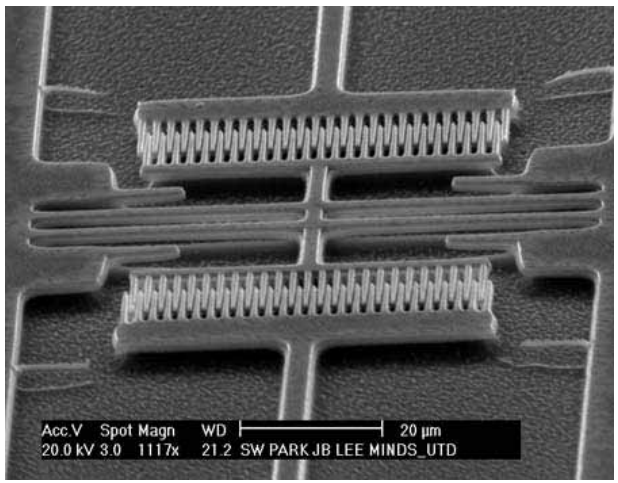
- UTD Clean Room
  - 5,866 sq. ft. class 1,000 and 100
  - Equipped with various processing and metrology equipment including evaporators, sputters, RIE, PECVD, LPCVD, mask aligners, e-beam lithography system, SEM, AFM, ellipsometer, Flexus, etc.
- UTD's Nano Research Facilities
  - Dual beam FIB, XPS, TEM, Field Emission SEM w/ E0beam Lithography System, Ultra High Vacuum Wafer Bonding System, Diamond coating CVD system

Sub-μm Metallic Structures

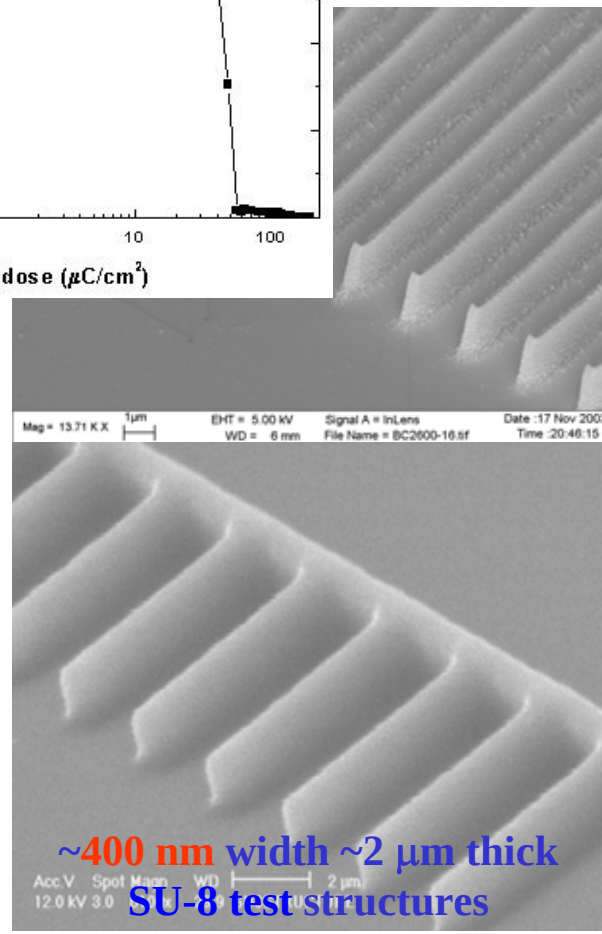
- E-beam lithography
  - Positive PR (e.g., PMMA)
    - Ideal for lift off.
  - Negative PR (SU-8, UVN-30)
    - Very small exposure dose (~1 μC/cm^2), a factor 100 times smaller dose (exp. time)!







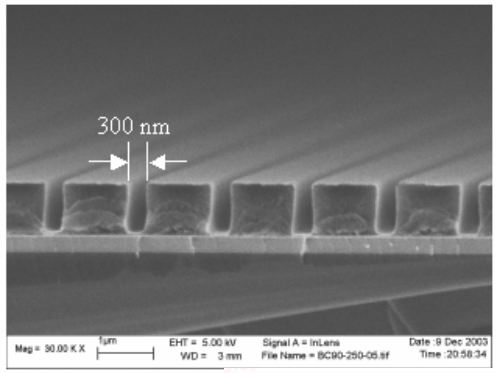
500 nm width/spacing and 500 nm thick gold comb-drive



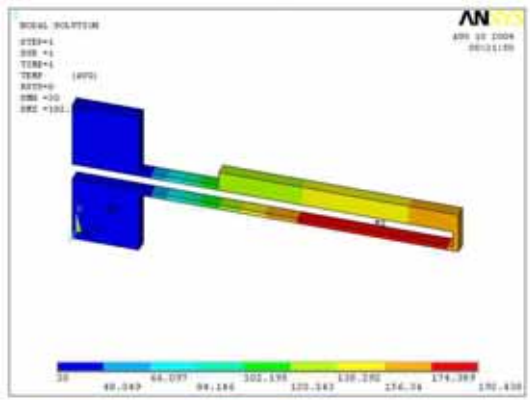
~400 nm width ~2 μm thick SU-8 test structures

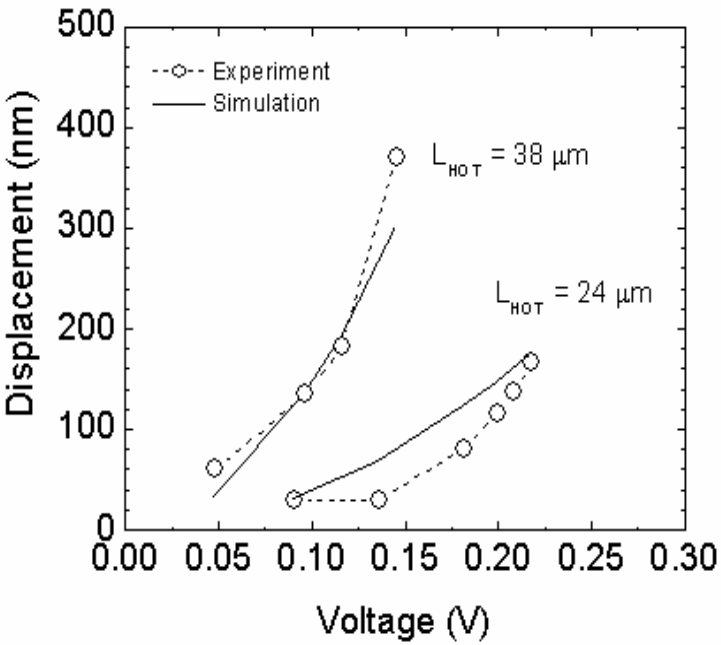
Sub- μm Thermal Actuator

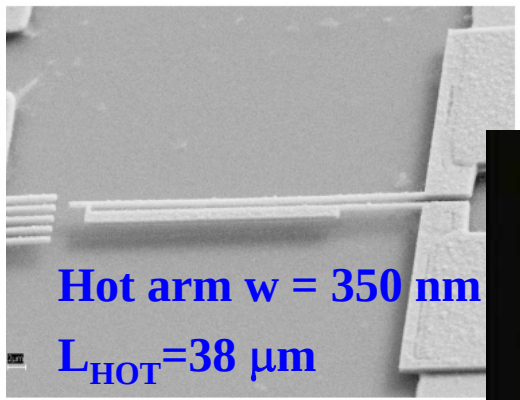
- Process
  - Electron beam exposure for PMMA
  - Electroplate nickel ~1 hr for 1 μm
  - Removal of PMMA by oxygen RIE
- Sub-micron thermal actuator
  - Reproducible displacement results
    - Type “A”: 370 nm by 146 mV



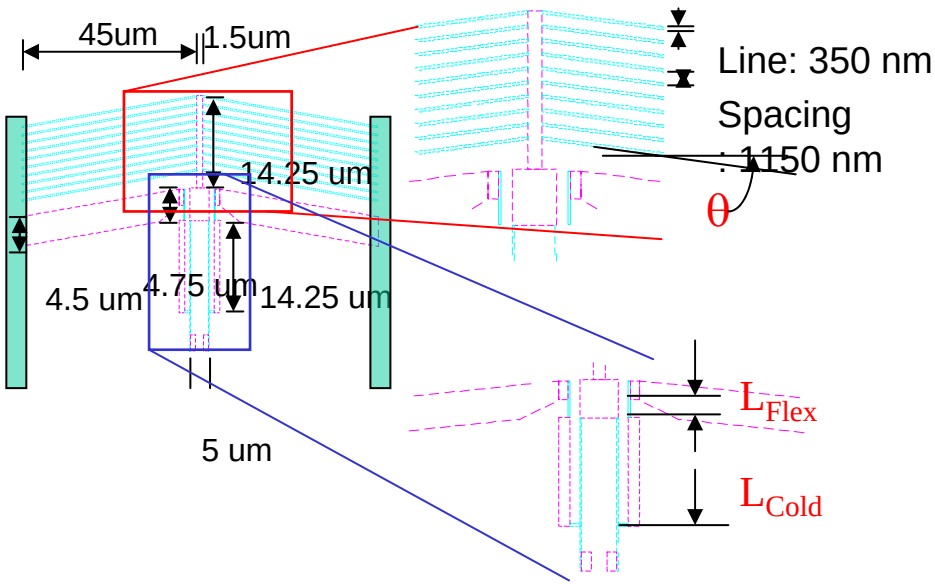
3:1 aspect ratio 1 μm thick PMMA mold

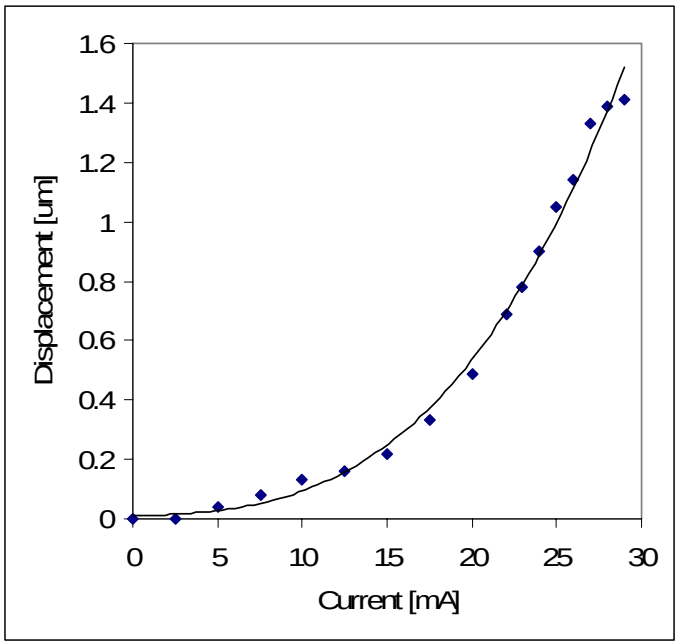


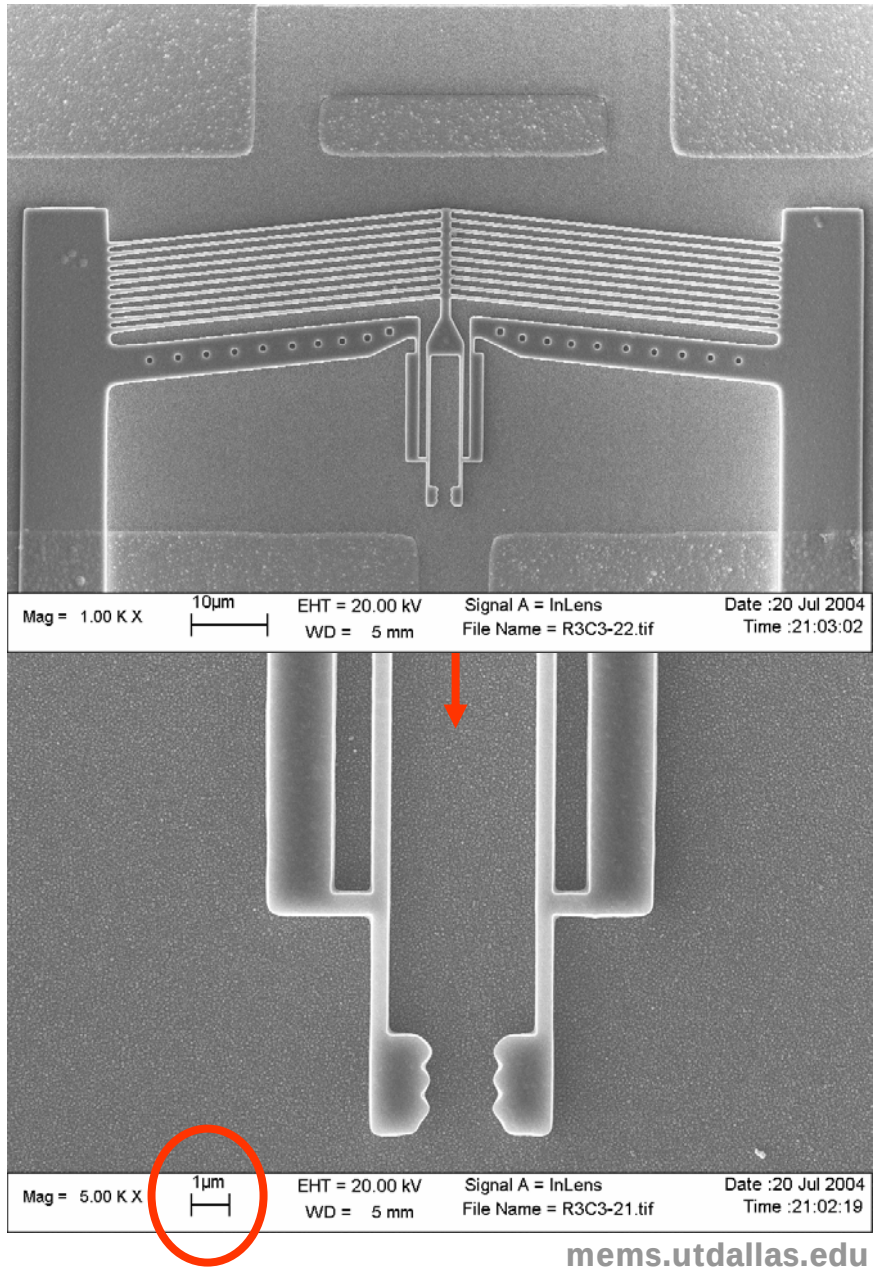




Sub- μm Gripper





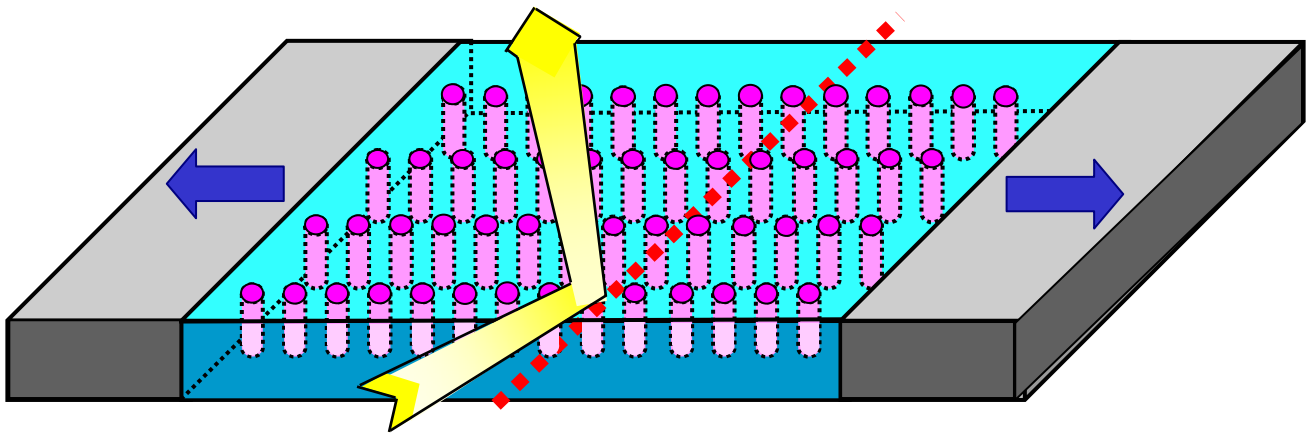


NEMS-Enabled Tunable Photonic Crystal

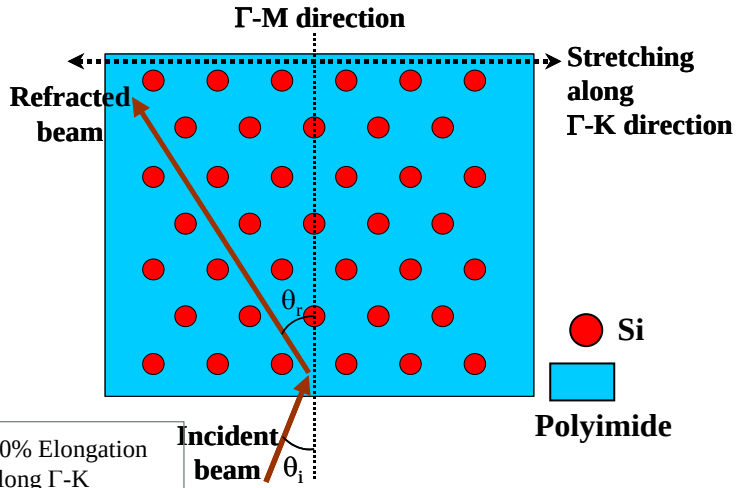
- What is photonic crystal?
  - Dielectric materials with a periodically varying index of refraction
  - Photons behaves similar to electrons in a semiconductor crystal; their behavior can be described by a photonic band structure
  - Ability to control/manipulate the flow of electromagnetic waves.
- Tunable Photonic Crystal: conventional approaches
  - Tuning by electro-optic materials (e.g. liquid crystal)
  - Tunability is very limited due to small attainable changes in refractive index ($\Delta n/n < 15\%$).
- Our approach
  - A radically different approach - Mechanical tuning
  - Photonic bands are extremely sensitive to physical changes in the photonic crystal structure.
  - Wide tunability by mechanical force
    → Mechanically Controlled Photonic Crystal (McPC)

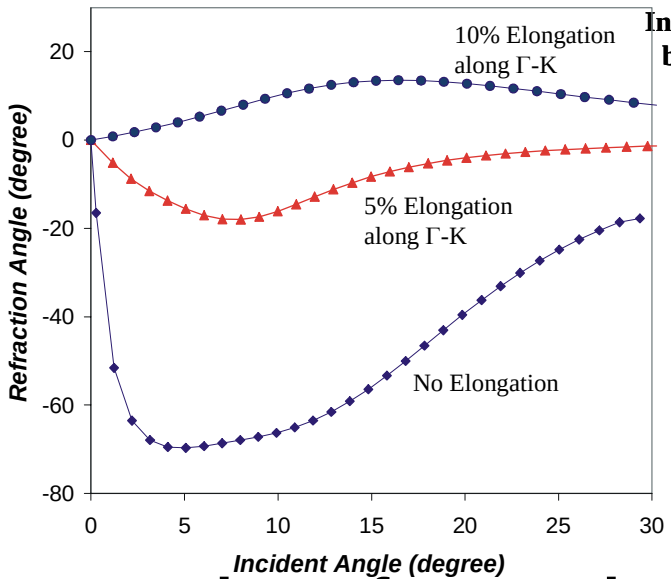
Mechanically Controlled Photonic Crystal

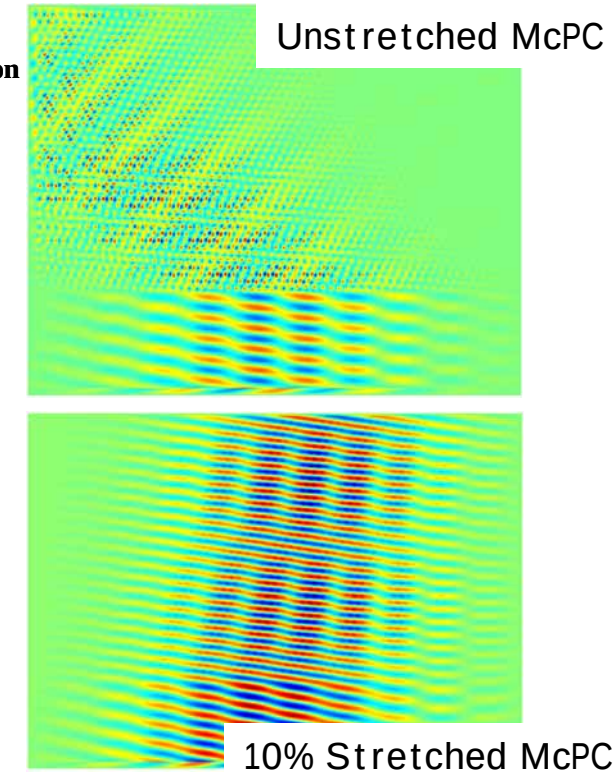
- McPC structure is
  - Composed of Si rods embedded in flexible polymer such as Polyimide
  - Mechanical tuning by stretching/releasing McPC with NEMS/MEMS actuators
- The new material structure is compatible with the conventional semiconductor technology
  - In terms of both fabrication process and materials



Widely Tunable Beam Steering Device







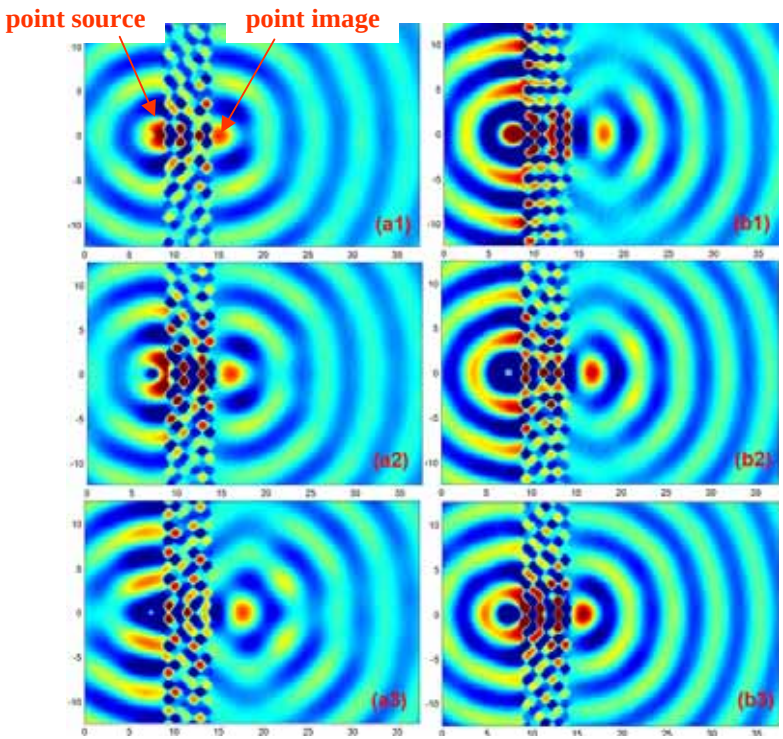
$\theta_i = 12^o$

$\omega a / 2\pi c = 0.39$

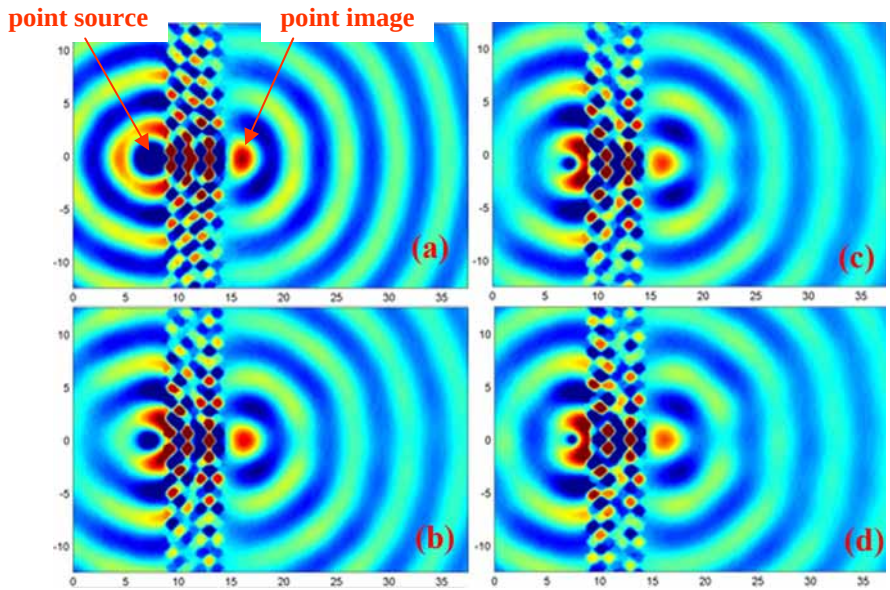
- **Tuning of more than 70º with small mechanical stress (~10%)**
- **Switching between positive & negative refraction regimes**

Tunable Negative Index Lens

- Sub-wavelength resolution, tunability allows
  - changing focal lengths for adjustable working distance and
  - dynamically selecting the desired wavelength or scanning over a range of frequencies.



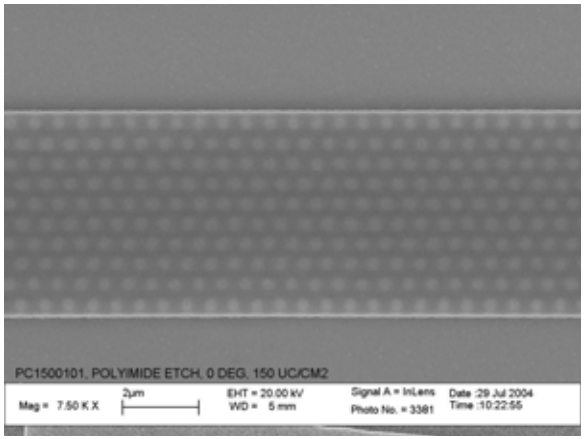
Can adjust focal length



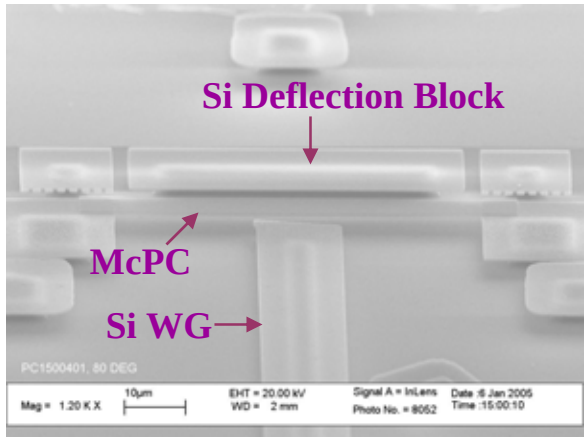
Can also maintain identical focusing characteristics over wide frequency Range with $\Delta\omega/\omega_o$ up to 30%.

McPC Structures

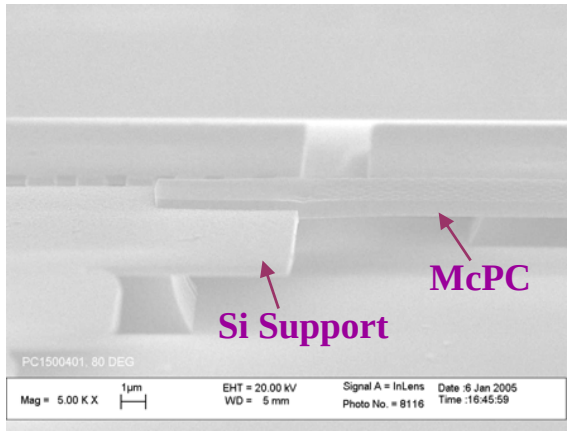
Si Pillar Matrix Embedded In Polyimide Film



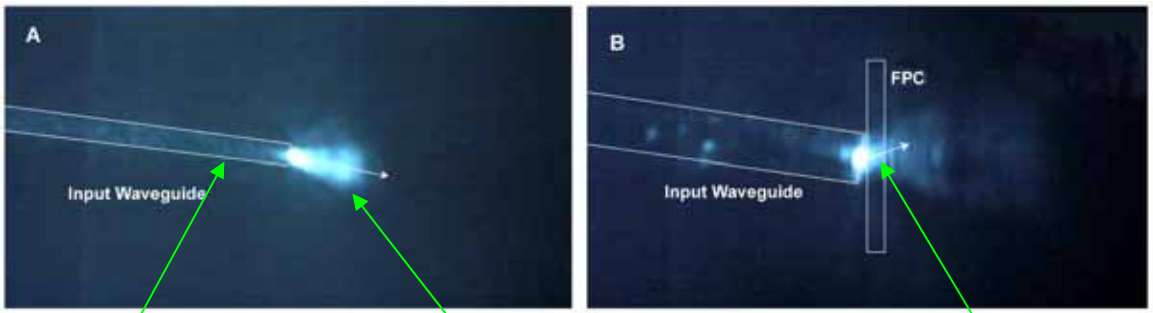
Air Suspended McPC Membrane with Si Ridge Waveguide for In-Coupling



Magnified View of Joint Region



Negative Refraction Observed in McPC

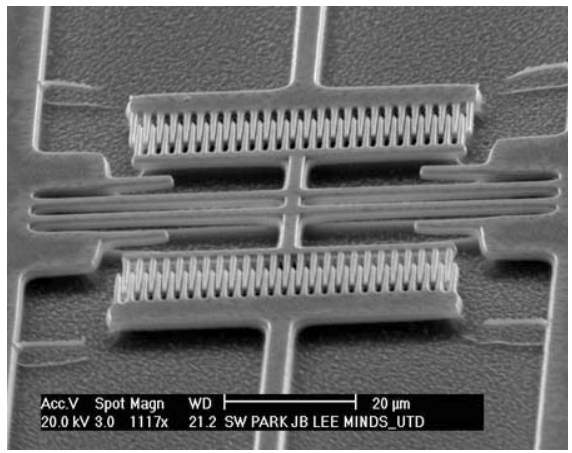


Si input waveguide inclined 6° from Horizontal (λ = 1.54 μm)

light coupling out to free space : no refraction

light coupling in to McPC : negative refraction

Sub-μm Comb Drive Actuator

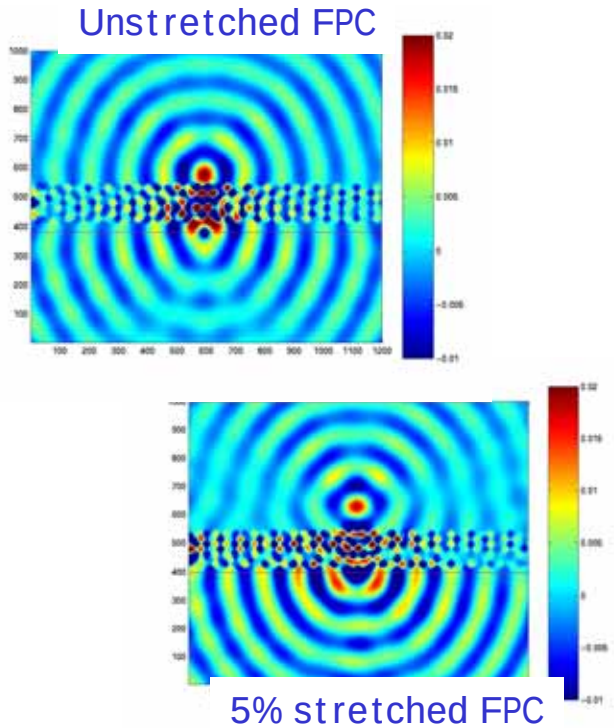


Tunable McPC Applications

- 3D FPCs
  - Multispectral sensing and detection over extremely wide range of frequency.

Operating Frequency	Feature size	Fabrication
Visible & Near-IR	200 ~ 500 nm	e-beam lithography, reactive ion etch (RIE)
Mid & Far-IR	0.5 ~ 10 μm	UV lithography, RIE
Terahertz	10 ~ 50 μm	UV lithography, Si Deep RIE

- Wide range beam steering device
  - Electronically tunable giant negative refraction in 2D slab PC
- Tunable sub-wavelength focusing lens
  - NIM can enable sub-wavelength focusing
  - But the focusing property is strongly wavelength-dependent.
  - Tunability allows dynamically selecting the desired wavelength or scanning over a range of frequencies.



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