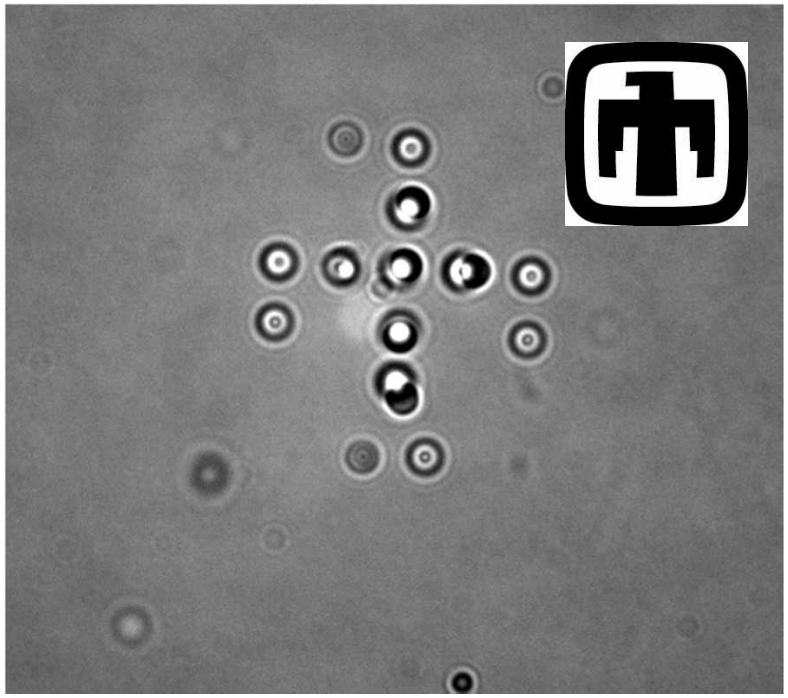
Laser Tweezers for Optically Directed Self-Assembly

SAND2008-4874P



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NNSA National Nuclear Security Administration

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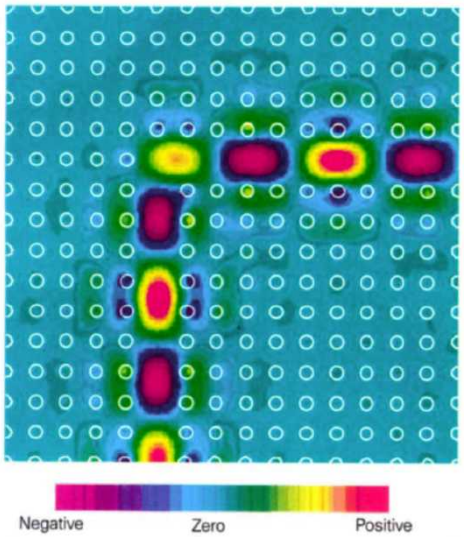
Optical Computing

- Computing in the 22nd century
- Importance of photonic crystals – semiconductor analog of photonics
- Advantages of optical computing
  - Bandwidth – terahertz for fiber optic vs. <megahertz for telephone
  - Photons not strongly interacting – fewer energy losses
  - Radiation sensitive environments
- Defects create optical computing elements
- Current limitation is *lack of robust manufacturing capability for photonic bandgap crystals*

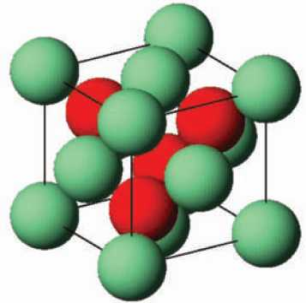
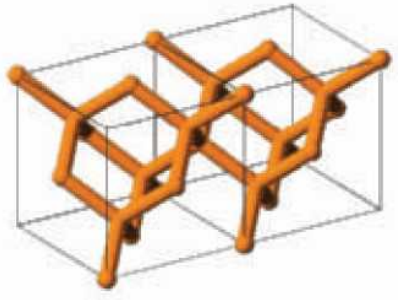
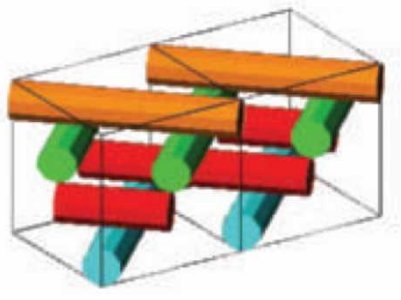
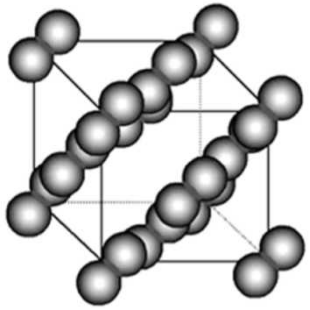


By introducing a line defect in the crystal, light is guided along photonic 'wires'

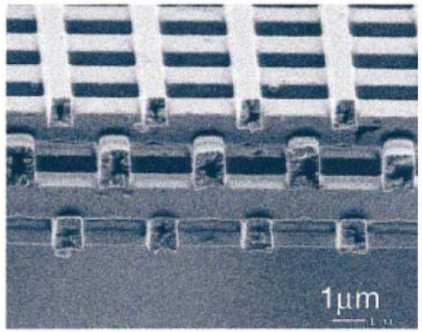
Joannopoulos, Villeneuve & Fan. *Nature* v386 (1997) p.143

Full Photonic Bandgap Crystals

Full Photonic Bandgap – blocks a range of frequencies at all orientations and polarizations of the light
Simple FCC/BCC crystals of spherical particles are not good photonic materials
Need symmetry – but not too much symmetry!

a) A4 diamond structure
b) rod connected diamond structure
c) woodpile
d) FCC peanut structure

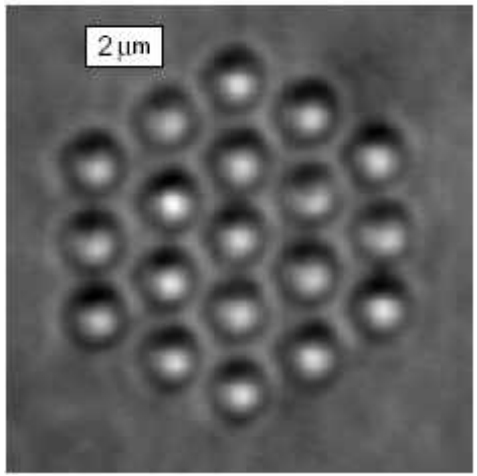


Woodpile structure manufactured using SUMMiT silicon patterns filled with tungsten for λ=6μm
Log spacing 3 μm
Log size 0.8x1 μm

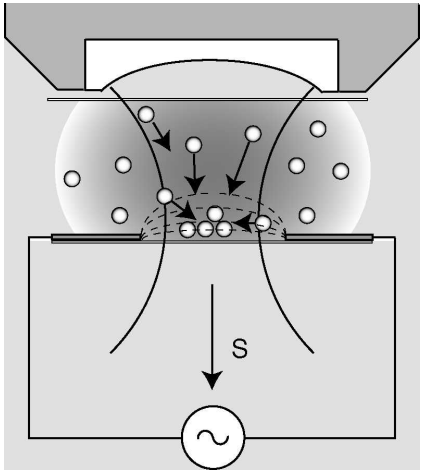
Maldovan & Thomas. *Nature Materials*, v3 (2004) p593.
Xia, Gates and Li. *Adv. Mater.* v13(6) (2001) p.409.
Fleming, El-Kady, Subramania, Clem, Chow & Wendt. SAND2005-6824.

How Can Laser Tweezers Help?

- Develop highly ordered structures using laser tweezers to optically direct assembly of nanoparticles
  - Synthesis and functionalization of nanoparticles
  - Assembly of ordered crystalline materials
    - Micromanipulation using laser tweezers
    - Directed assembly with external fields

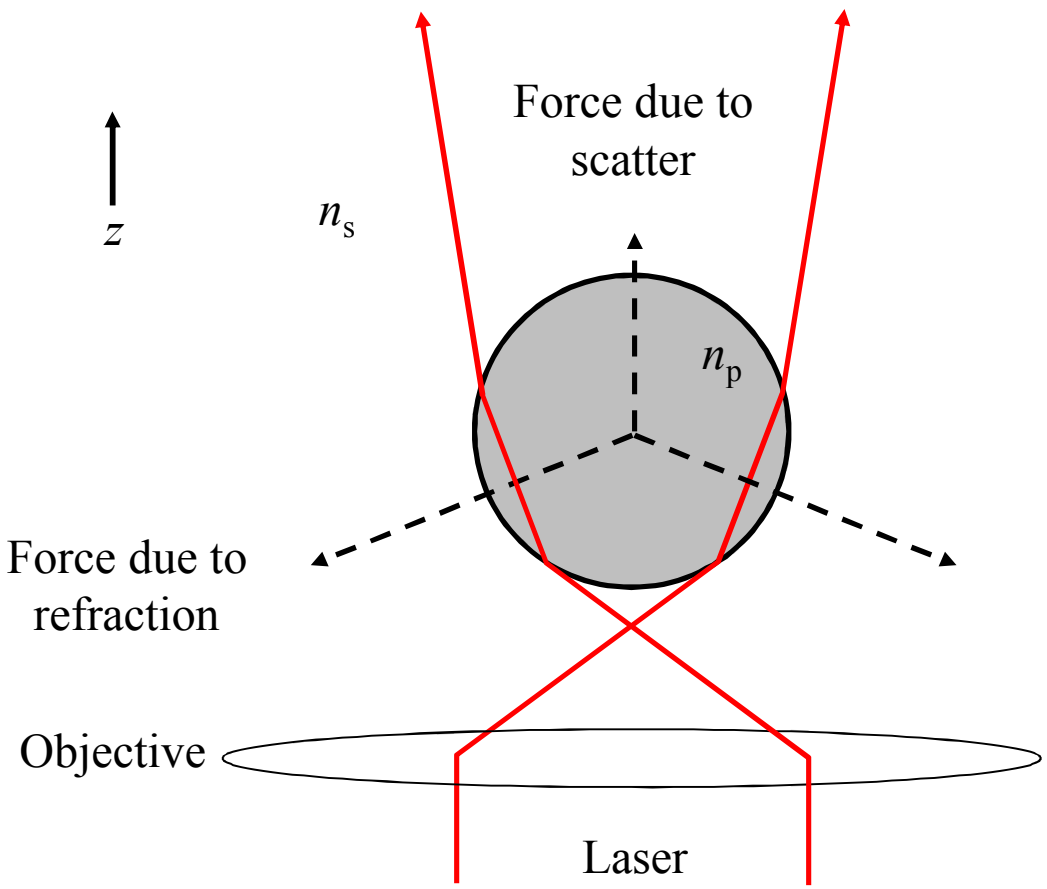


Micromanipulation to create ordered structures



Combine laser tweezers and electric fields to direct self-assembly

Laser Tweezers Overview



A. Ashkin, J.M. Dziedzic, J. E. Bjorkholm, and Sheven Chu, "Observartion of a single-beam gradient force optical trap for dielectric particles," *Optics Letters* (1989), **5**, 288-290.

Trapping fundamentals:

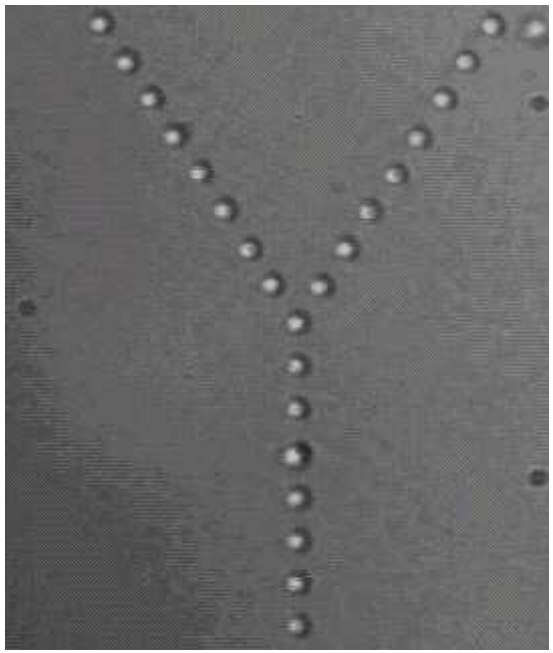
- Light refracted through a dielectric particle will impart momentum trapping the particle in 3 dimensions
- Force balance between the momentum change of the refracted light and light scattering off the surface of the particle

Applications:

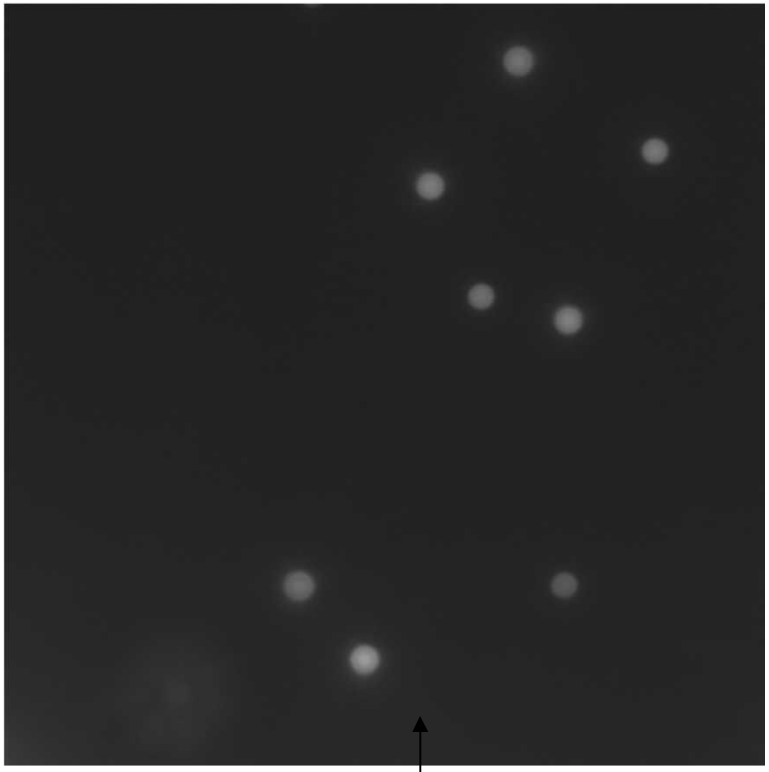
- General investigation of physics, biology, etc.
- Microfluidics
- *Directed self-assembly of photonic crystals*

Holographic Laser Tweezers

- Eric Dufresne & David Grier: Patent # 6055106
  Rev.of Sci. Inst. 69 1974 (1998)
- Enable study of anisotropic particles and real time construction of three dimensional structures



Courtesy Eric Dufresne, Yale University

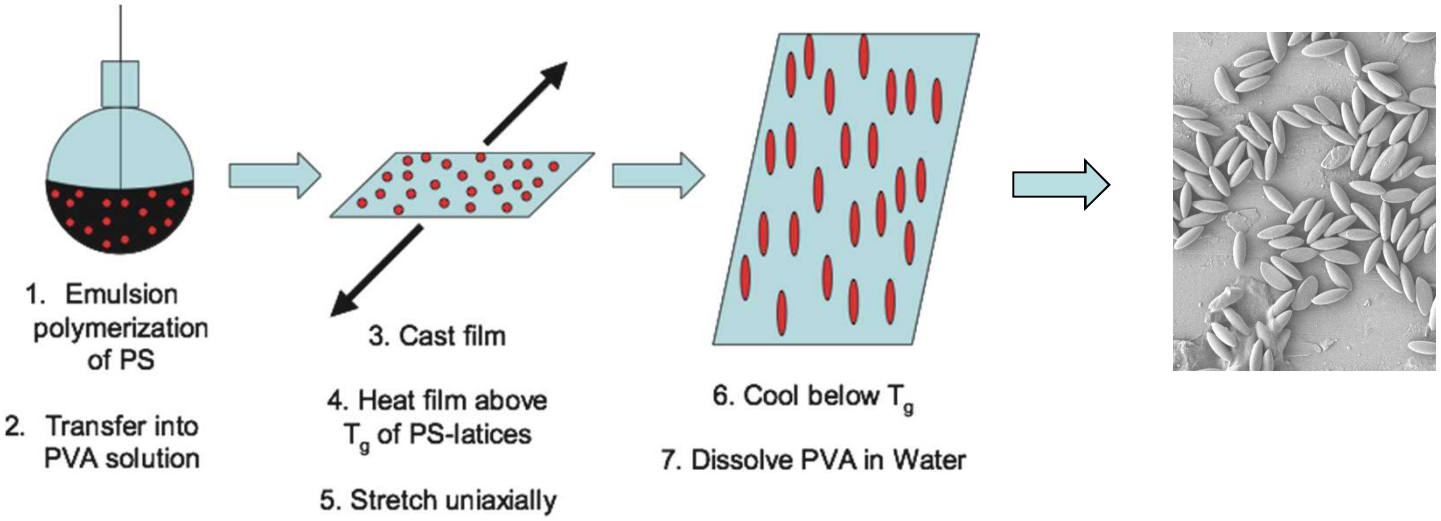


3D control and formation of diamond structures

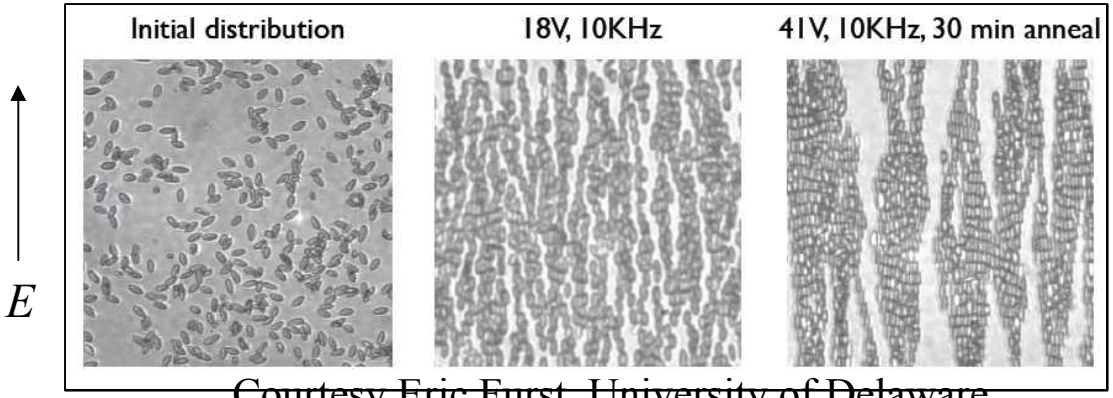
Large arrays of optical traps

Anisotropic Particles

- Production of 3:1 ellipsoidal particles, length = 6 μm



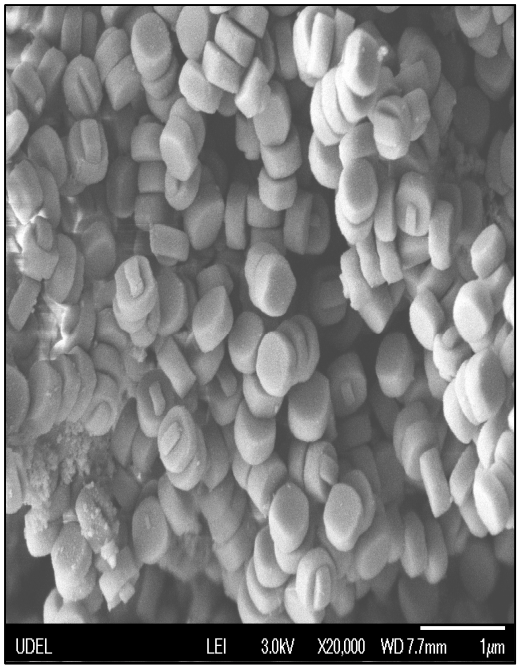
- Assembly under applied AC electric field

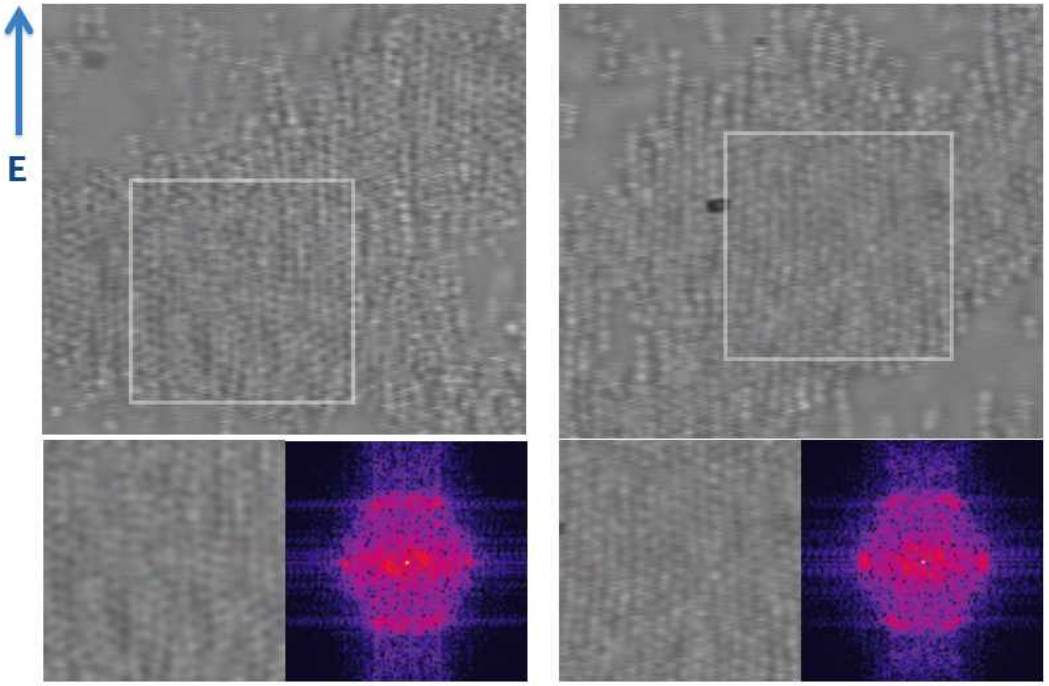


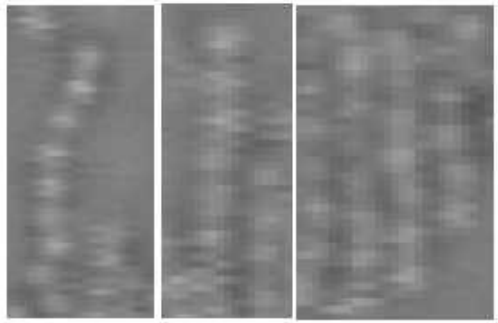
Courtesy Eric Furst, University of Delaware

Directed Self-Assembly of Nano-particles

- ZSM-5 aluminosilicate zeolite
  - Dia. = 300 nm, Thick. = 100 nm
- High frequency and field strength
  - 10kHz, 650 V/cm







Courtesy Eric Furst, University of Delaware

Summary

- Photonic bandgap crystals
  - Necessary for optical computing
  - Need robust manufacturing processes
- Laser tweezers and electric field directed self-assembly
  - Micromanipulation of particles
  - Large-scale ordered structures possible
- Anisotropic particles
  - Better photonic materials than spheres
  - Can be ordered and manipulated
- Fundamental understanding of particle interactions [O(fN)] is still lacking