Nanomaker

Lab #8: Doping

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Doping

Material Property

Examples of Doping
(electrical)

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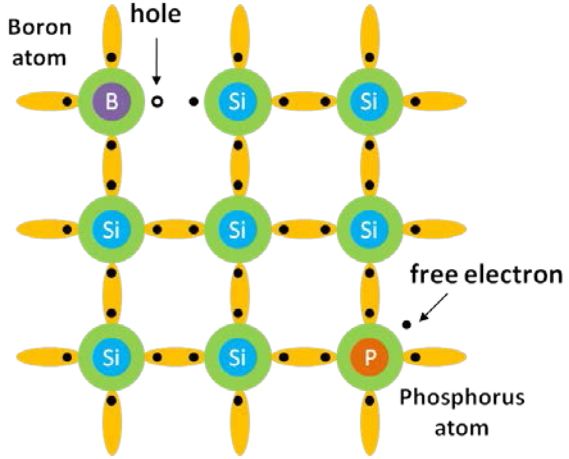
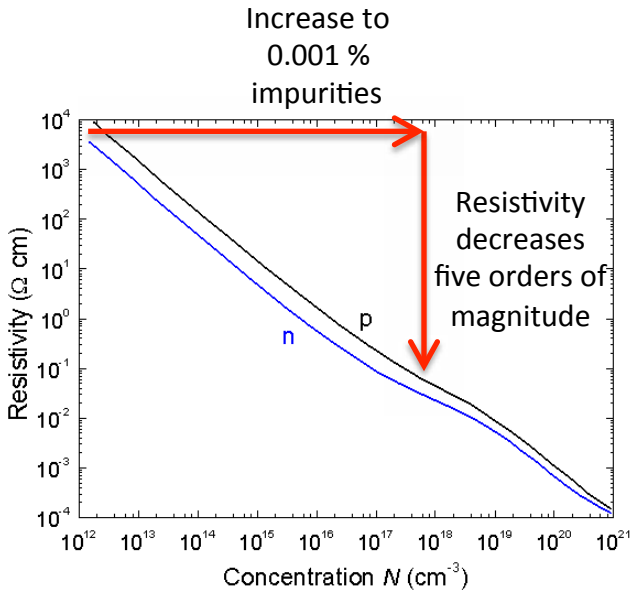
Silicon



Silicon lattice with Phosphorous/Boron dopants



1 P atom per 1 Million Si atoms
Changes resistivity by factor of 10,000
(5×10^{22} Si atoms/cm^3)
Insulator to Conductor

Adding dopants -> free electrons -> electron current with thermal energy

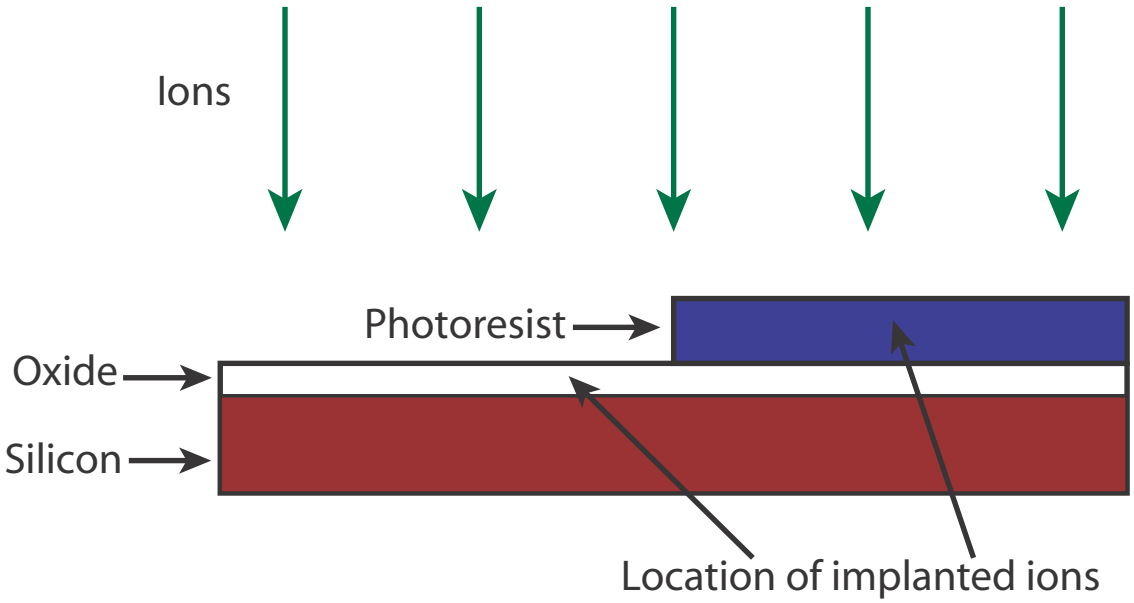
Ion Implantation

- A high voltage accelerator is used to shoot ions at the wafer
- The beam must be raster and the wafer must be rotated to achieve uniform dose
- Usually a thin **protective layer** is used to prevent sputtering of the surface and to reduce channeling
- The **depth** of the implant dose depends on energy
- Activation **anneal** after implantation allows dopants to reach proper positions in crystal

Illustration of ion implantation removed due to copyright restrictions.
Refer to: Ion implantation on Rusnano.

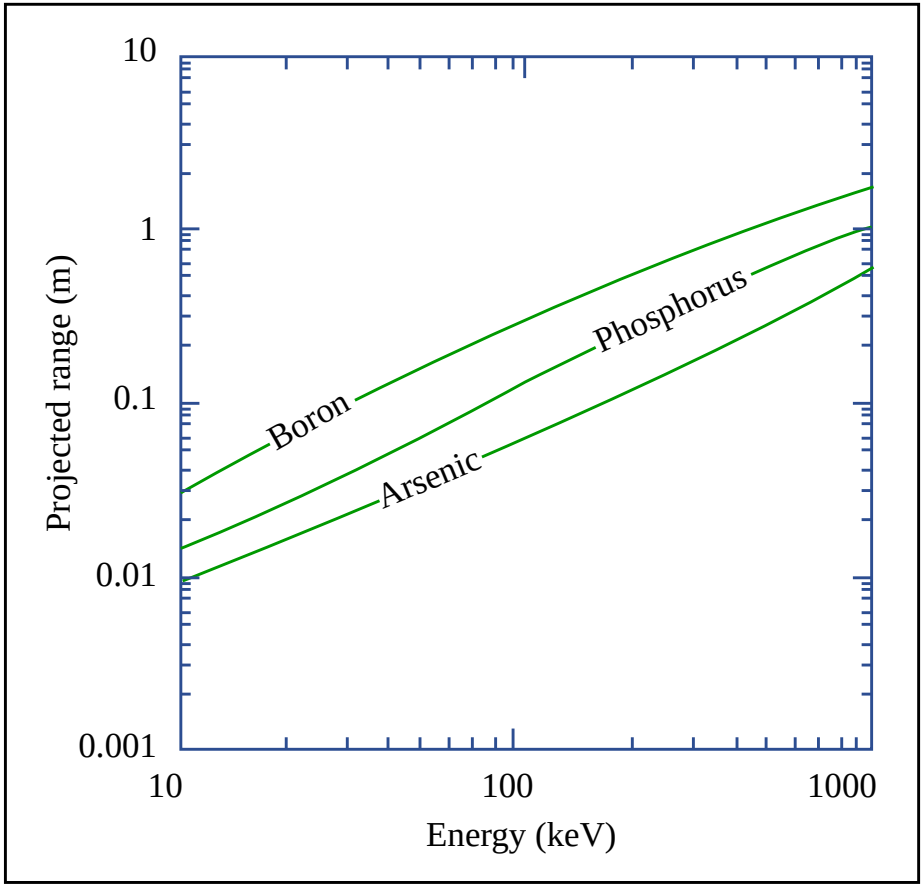
Masking

Control of which regions of a wafer receive the implant is achieved with masking layers



Effective Range

The effective range measured the location of the peak concentration of an implanted species.



Annealing

- After implantation, ions are driven deeper into the substrate by diffusion, a high-temperature process.
- The junction depth is the point at which the implanted ion concentration is equal to the substrate doping.

$$x_j = \sqrt{(4Dt)\ln\left(\frac{Q}{N_D\sqrt{\pi Dt}}\right)}$$

Implant dose

Background doping concentration

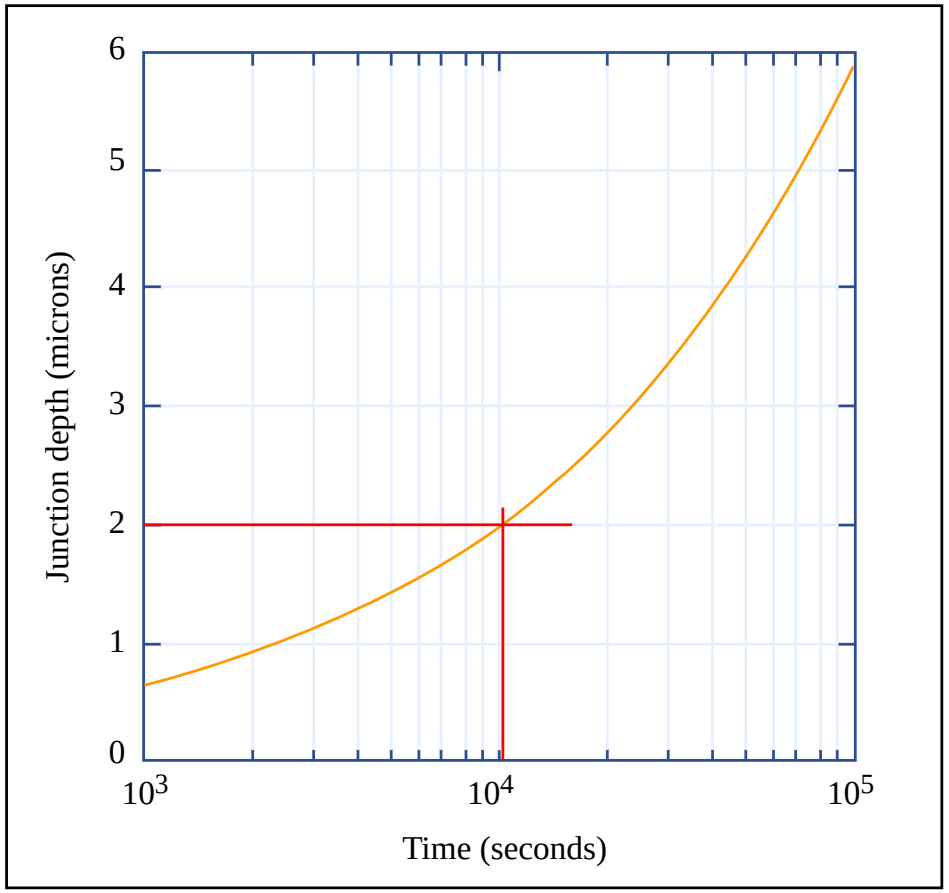


Image by MIT OpenCourseWare.

Examples of Doping
(optical)

Photo of laser glass amplifier slabs removed due to copyright restrictions.
Refer to: NIF Photo Gallery.

Photo of ER-doped fiber amplifier removed due to copyright restrictions.

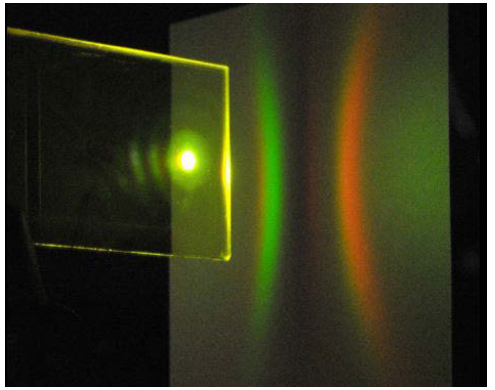
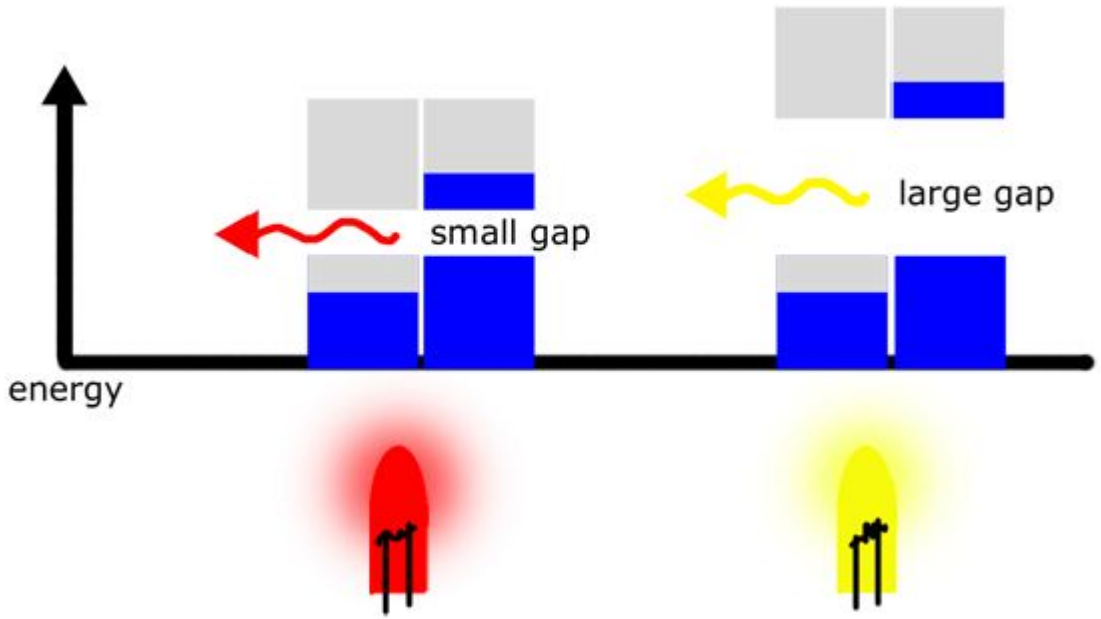


Photo courtesy of Argonne National Lab on Flickr.

Organic solar concentrators

Adding dopants -> absorbing certain wavelength -> change in color

Light Emitting Diode



The color of light emitted by an LED depends on the size of the band gap in the doped semiconductors. For instance, LEDs that emit red light have a smaller band gap than LEDs that emit yellow light.

Examples of Doping
(mechanical)

Photo courtesy of Naval History and Heritage Command on Wikimedia Commons.

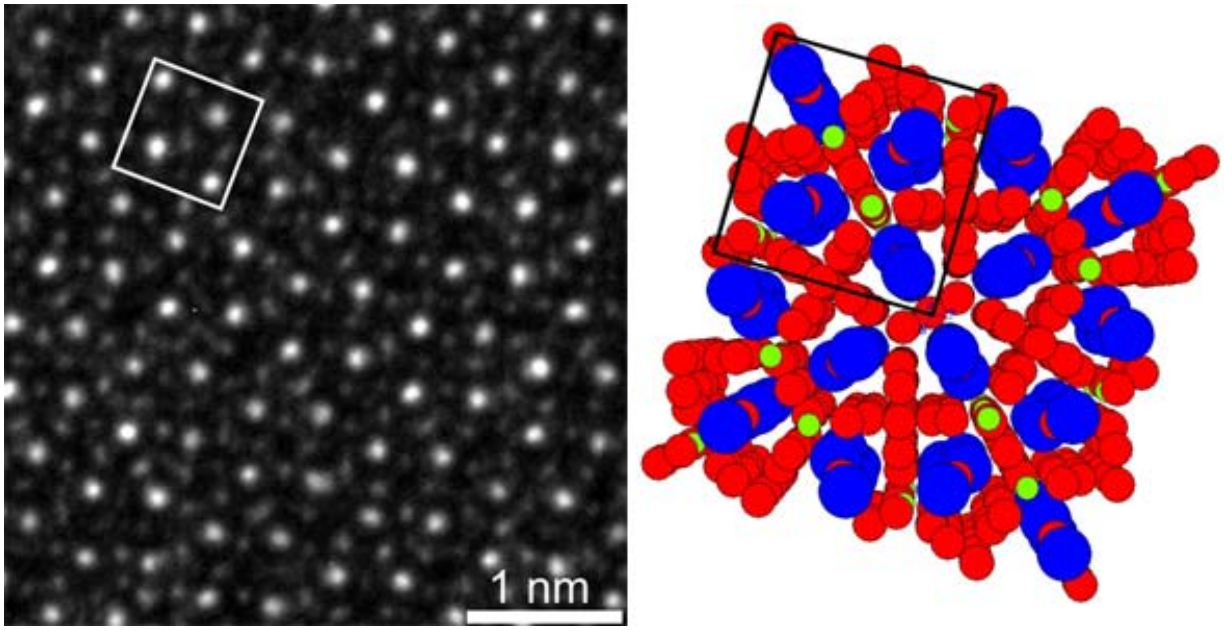
Photos of bike and tennis racquet removed due to copyright restrictions.

steel is an alloy that consists iron and carbon (0.2-2.1%)

Adding dopants -> distorting crystal lattice -> harder and stronger

Examples of Doping
(magnetic)

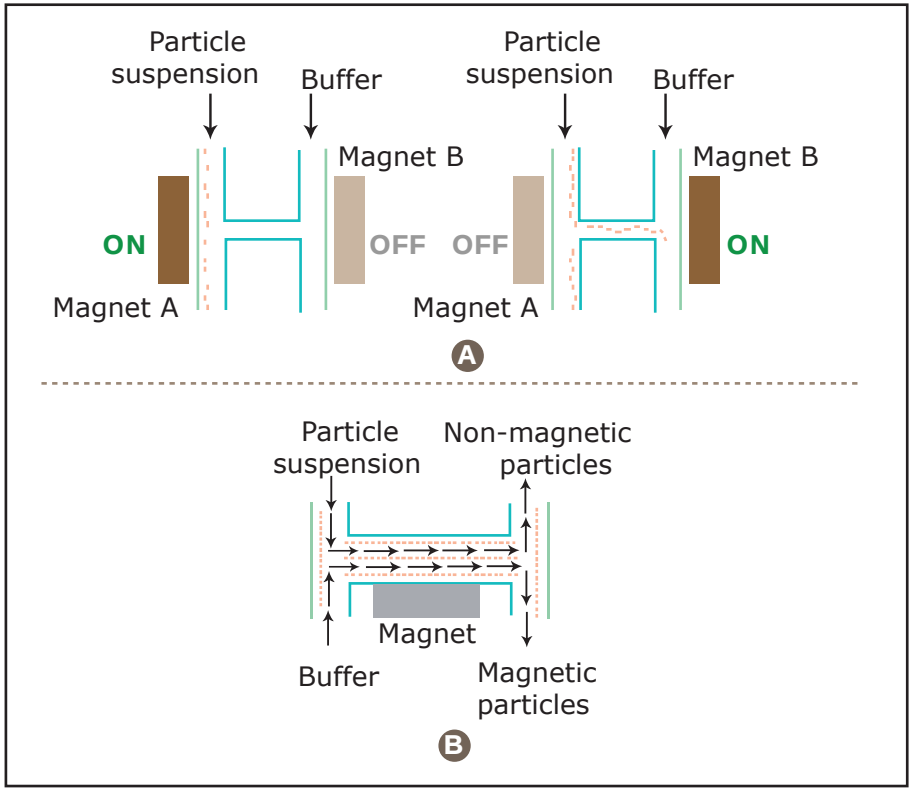
A neodymium, the most widely-used type of rare-earth magnet, is a permanent magnet made from an alloy of neodymium, iron, and boron to form the Nd2Fe14B tetragonal crystalline structure.



Neodymium Crystal Structure Nd2Fe14B

Examples of Doping
(magnetic)

Photograph of microactuator removed due to copyright restrictions.



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Microfluidic Filters

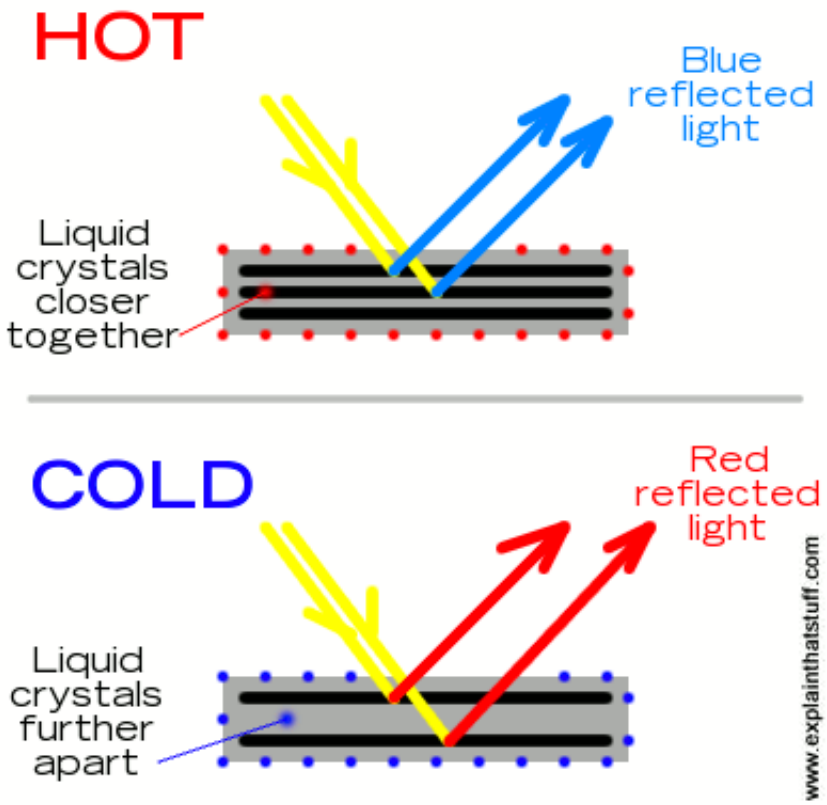
Examples of Doping
(thermal-optical)

Photograph of liquid crystal sheet removed due to copyright restrictions.

Photographs showcasing thermochromic pigment removed due to copyright restrictions.

Change in acidity -> change in molecular form -> change in color

Liquid Crystal Sheet



Incoming light rays hit the layers of liquid crystals and reflect back out again, with outgoing rays interfering to produce light of a particular color (Bragg diffraction). The color of the reflected light depends on how closely the crystal layers are together.

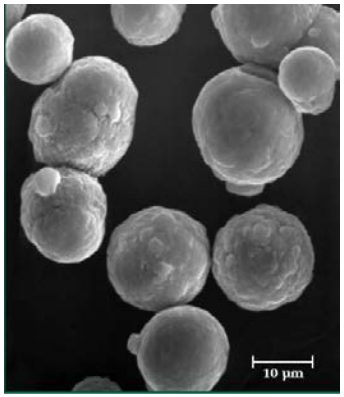
Doping

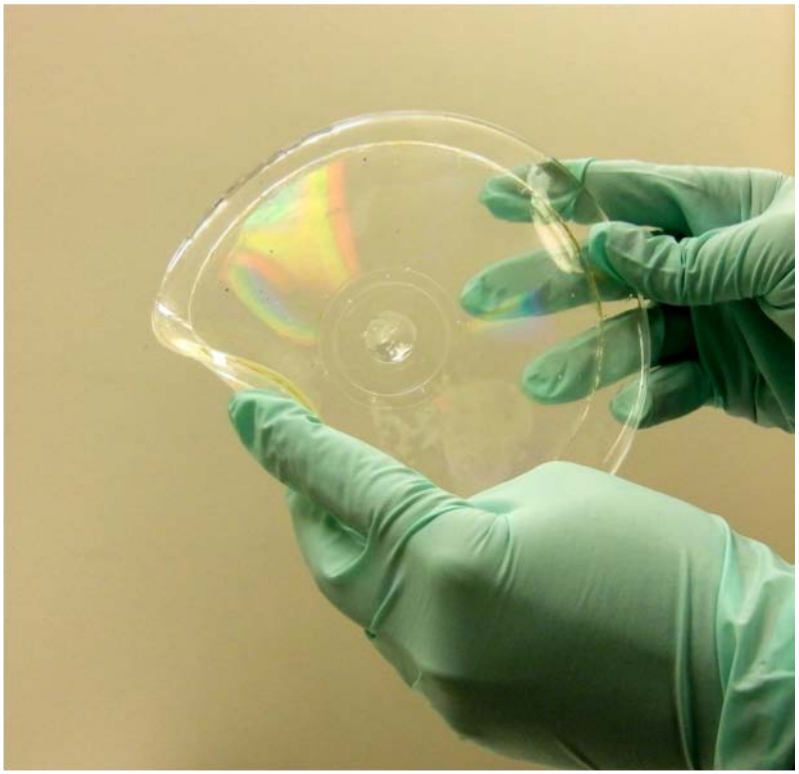
Material Property

Properties of PDMS

Electrical? Optical? Mechanical? Thermal? Magnetic?

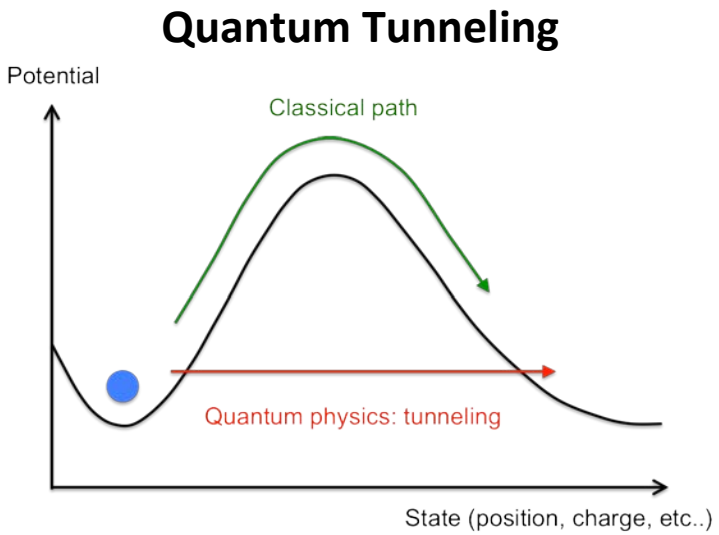
SEM picture of Nickel powder

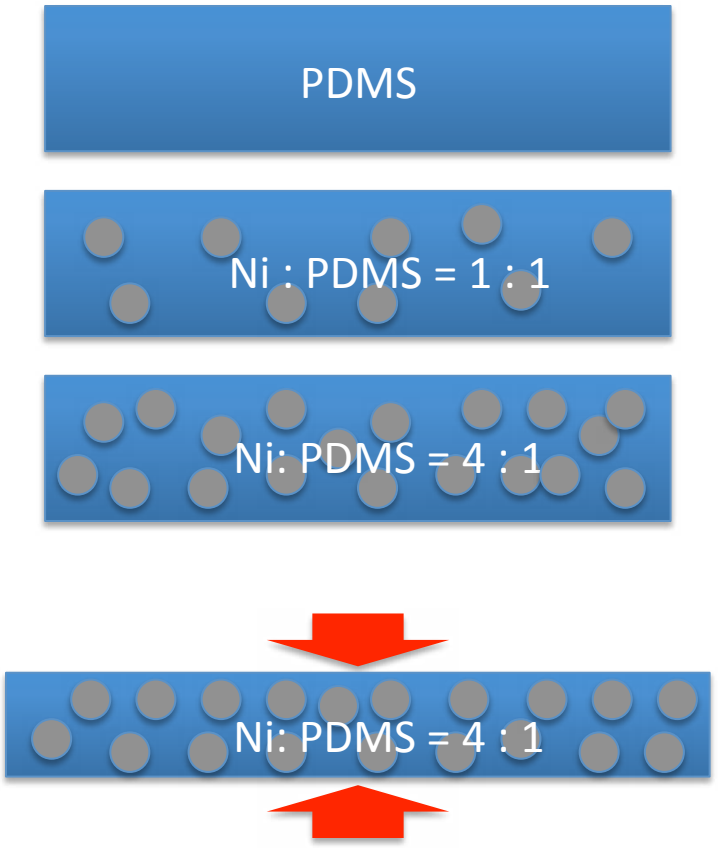




Today's topic "doping": changing properties of materials by adding impurities

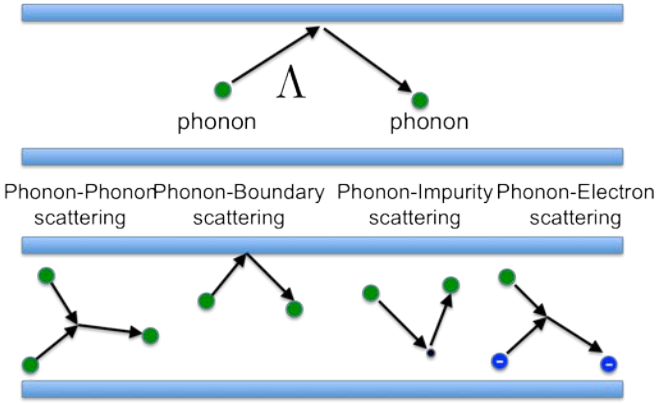
Electrical Conductivity





Thermal Conductivity

Mattiessen's Rule – Phonons



$$\kappa = \frac{1}{3} C v \Lambda$$

κ : thermal conductivity
C : specific heat
v : speed of sound
Λ : mean free path

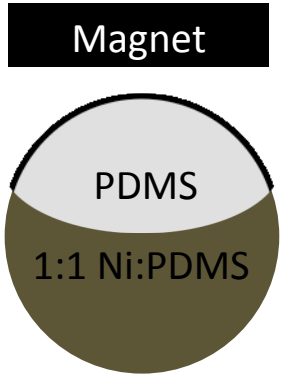
Photograph of modeled FCC structure removed due to copyright restrictions.

PDMS (spaghetti)

Self-Assembly

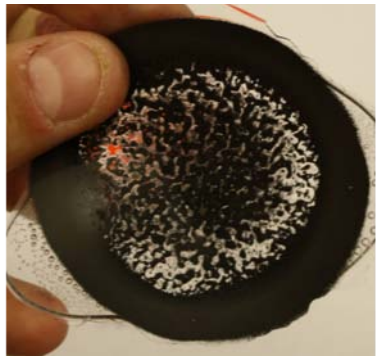
Molecular self-assembly is the spontaneous association of molecules under equilibrium conditions into stable, structurally well defined aggregates joined by non-covalent bonds.

Whitesides et al. Science 254 1312 (1991)



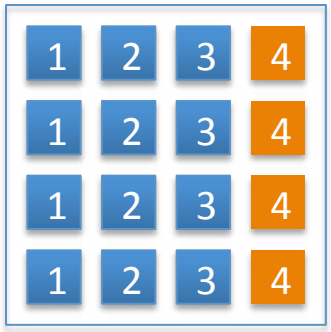
Ni-doped PDMS Ping Pong Ball

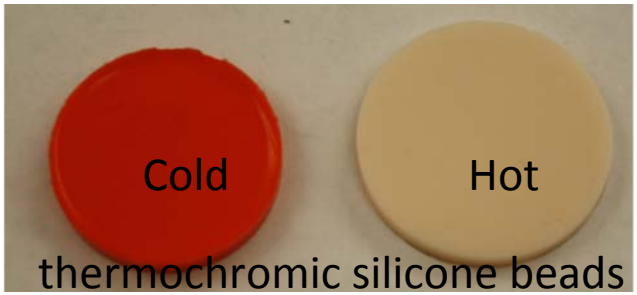
Photo courtesy of kenteegardin on Flickr.



Material Properties

1. PDMS
2. 1:1 Ni powder + PDMS
3. 4:1 Ni powder + PDMS
4. Thermochromic silicone beads + PDMS





- Compare stiffness
- Compare reflectivity
- Compare electrical resistivity using multimeter
- Compare thermal conductivity using thermochromic silicone beads

Conclusions

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electrical

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mechanical

Photograph of liquid crystal sheet removed due to copyright restrictions.

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