3.024

“Electronic, Optical, and Magnetic Properties of Materials”

3.024
Objectives and Approach

- **How can we understand and predict electrical, optical and magnetic properties?**

  Emphasis on fundamental physical models in lectures

- **Application to real life situations?**

  Emphasis on real life examples in HW and recitations

- **How do we measure EOM properties?**

  Emphasis on property measurements in labs using modern state-of-the-art tools

- **Can materials properties be engineered?**

  Property engineering labs

3.024 Topics

- Hamiltonian mechanics with application to normal vibrations in crystals
  Phonons: dispersion relations, normal modes.
- Introduction to Quantum Mechanics: Schrodinger’s Equation.
  Applications to quantum dots, tunneling devices
- Localized vs. delocalized states: from the free electron to the atom
- Electronic states in crystals: DOS, bandgaps, interpretation of band diagrams.
- Fermions, symmetrization and Pauli’s exclusion principle:
  Electrons in bands and the classification of solids.
- “Free electron” description of metals: response to EM fields
- The chemical potential: Fermi energy, statistics of electron distribution
- Electronic structure of semiconductors: intrinsic and extrinsic
- Electronic devices
- Optical properties of semiconductors, insulators and metals
- Opto-electronic and optical devices
- Magnetic properties of materials

Materials Shaping the World

Steel

Aluminum

Polymers

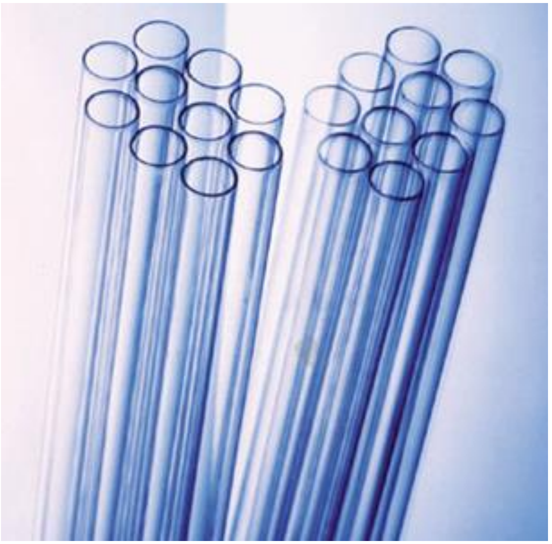
Silicon

Silica

AlNiCo

What's Next?

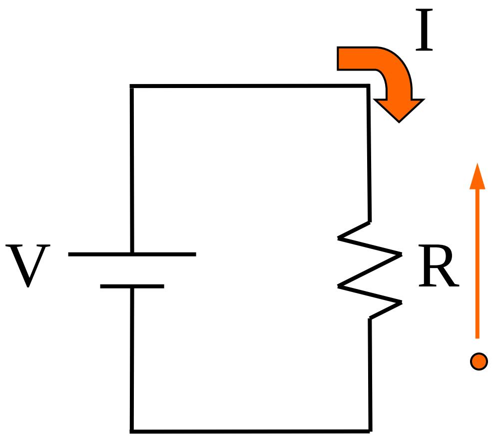
How Do Materials Properties Interact?

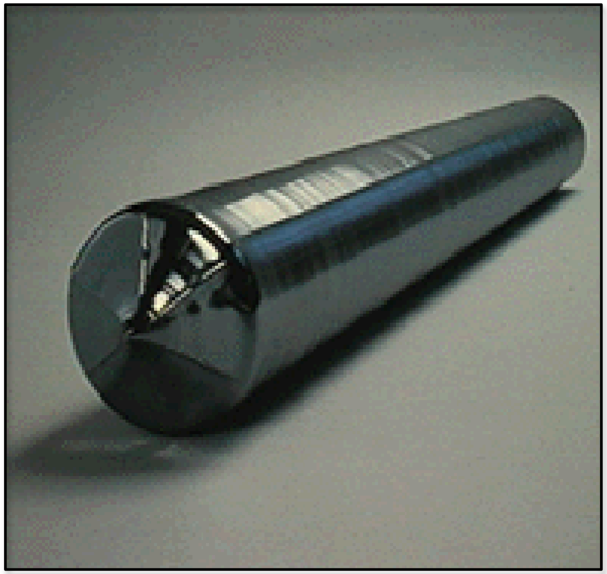


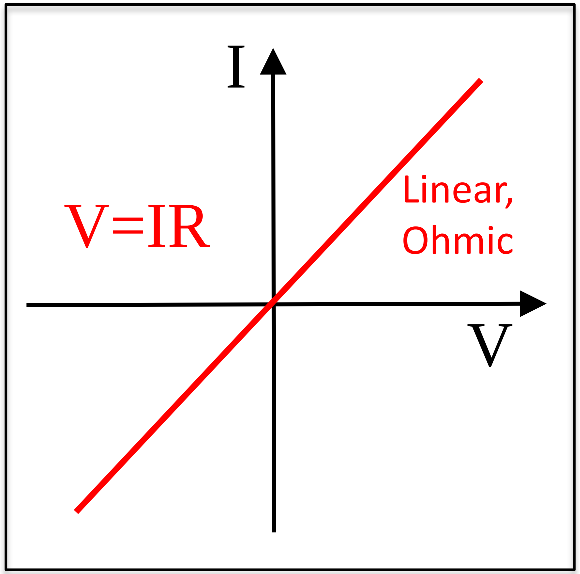
vs.

Low	Electrical Conductivity?	High
Low	Thermal Conductivity?	High
Real	Refractive Index?	Complex

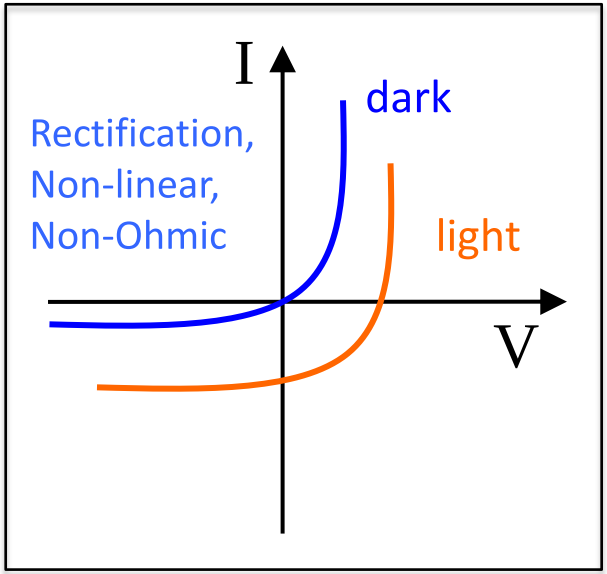
Materials Under Voltage





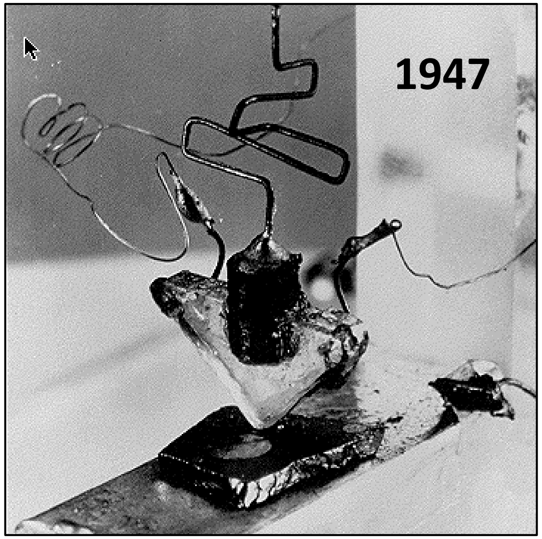


- What determines whether material be a resistor or a diode?
- How would you predict it?
- How much voltage or current can material handle?
- What happens if we shine light onto a material?



Materials in Modern Electronics

Silicon: Material that enabled the World as we know it

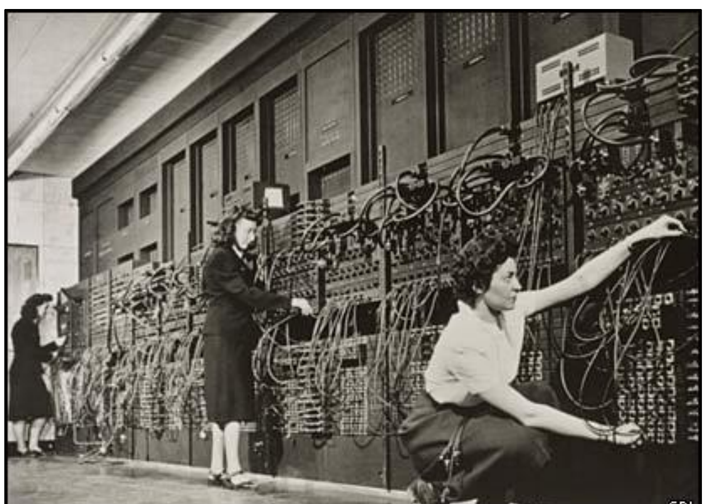


The first transistor, invented at Bell Labs, December 23, 1947. (This image is in the public domain)

Si processing
Diode
Transistor

Image removed due to copyright restrictions. Three photos of transistor gates circa 2000, 2001, and 2012 in nanometers.

1950s



Three of the women programmers of the ENIAC computer. (This image is in the public domain)

vs.

Today

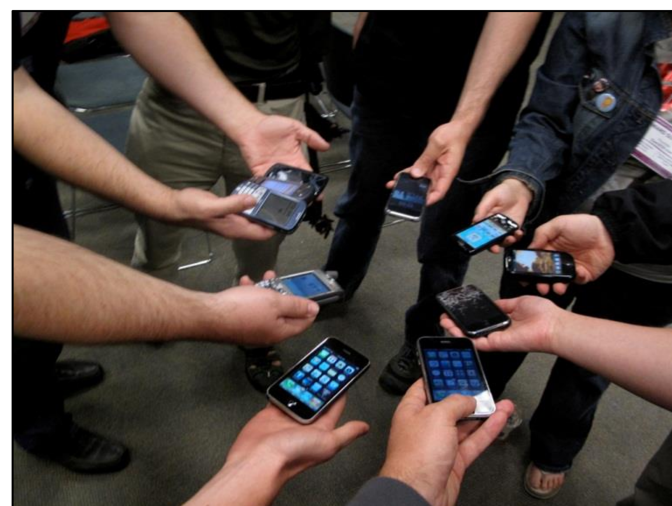


Photo courtesy of Craig Saila on Flickr.

Does Size Matter?

Photo courtesy of Kerrythis on Flickr.

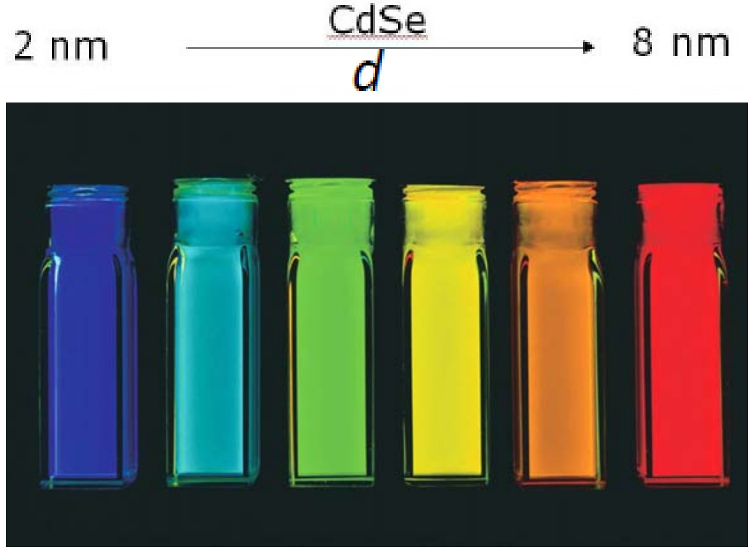
Could materials properties be size dependent?

What Happens When Materials Become NANO?

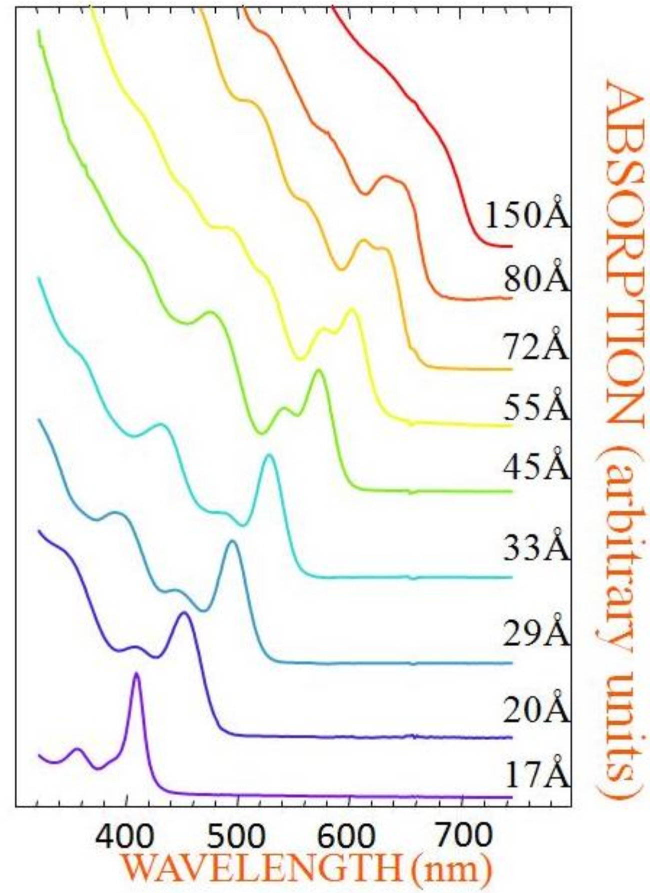
Size dependent absorption and emission of CdSe nanocrystals (quantum dots)

CdSe is a tetrahedral semiconductor with a Wurtzite structure absorption edge at 1.741eV (@295K):

1. How does it become transparent?
2. Why does it emit light upon excitation?
3. Why does the wavelength of emission depend on the size?



Courtesy of Felice Frankel. Used with permission.



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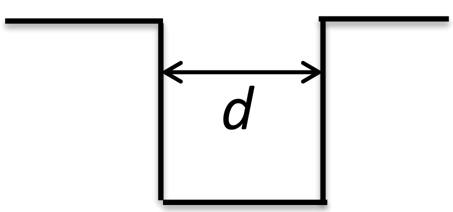
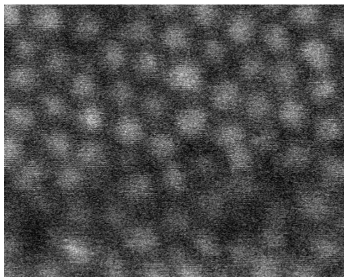
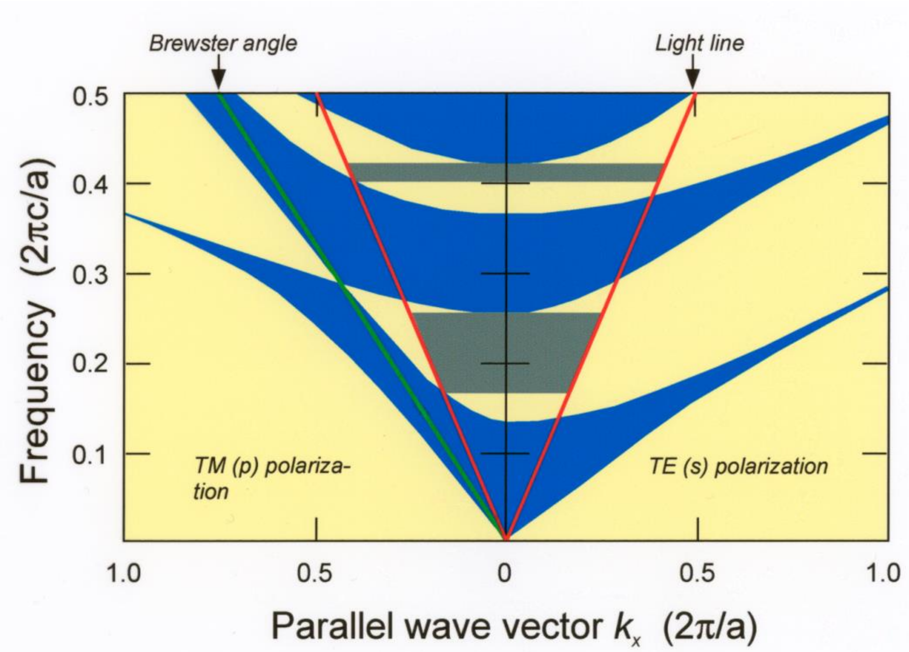


"Particle in a box"



Engineering Materials Properties to Manipulate Light

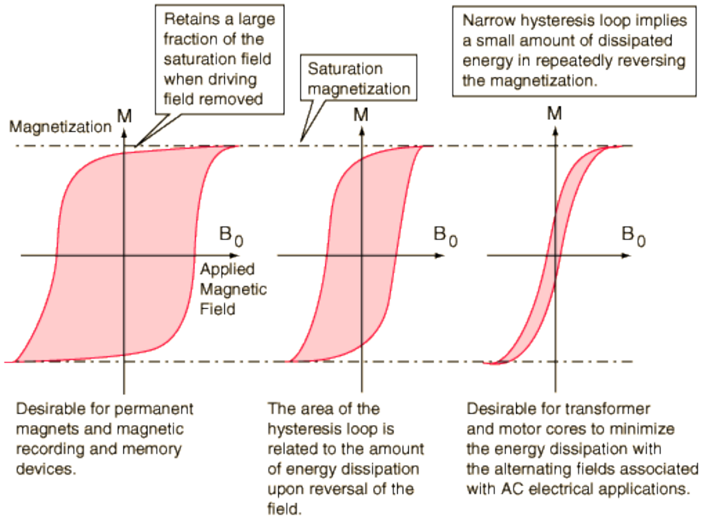


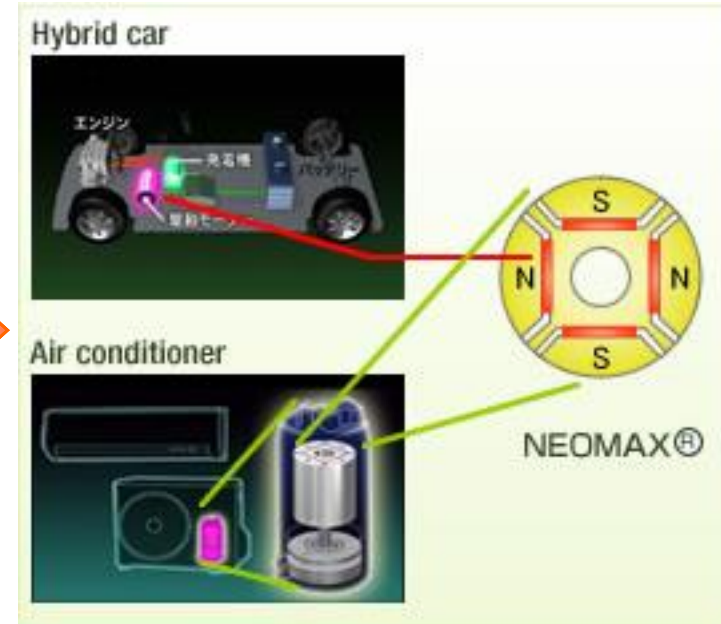
Figures and graph removed due to copyright restrictions.

Periodic structures yield to "optical bandgap":

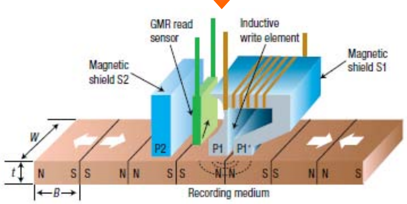
- This implies that we can create waveguides transporting various wavelengths of light from UV to deep IR without loss.
- We can use these waveguides in telecommunication and medicine.

Magnets Around Us



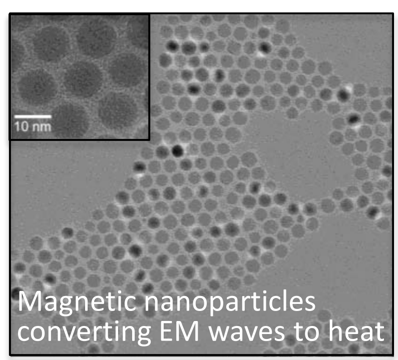


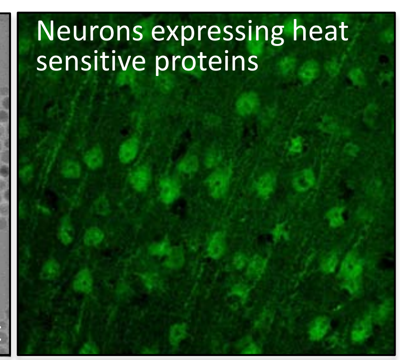
From Prof. Beach



From Prof Beach

Can energy dissipation be useful?





Use magnetic nanoantennae to stimulate neurons: Non-invasive treatments of neuro-disorders

Anikeeva Lab @ DMSE

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