

What is Condensed Matter Physics?

Can we manipulate materials?

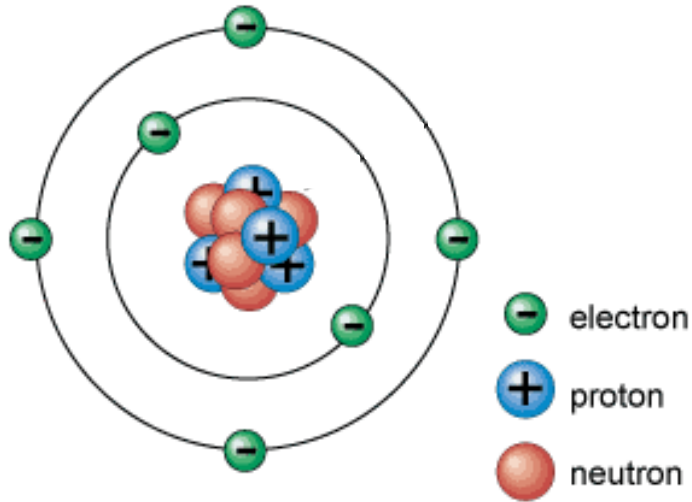
Can we design new materials?

Christianne Beekman

FSU Physics Department

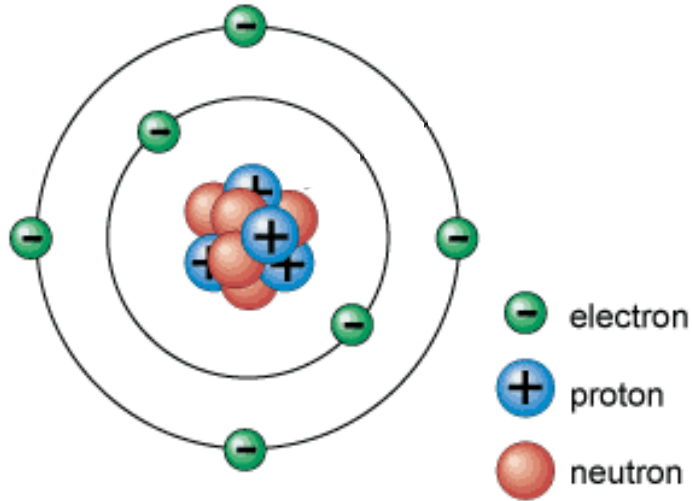


The Building Blocks: Atoms

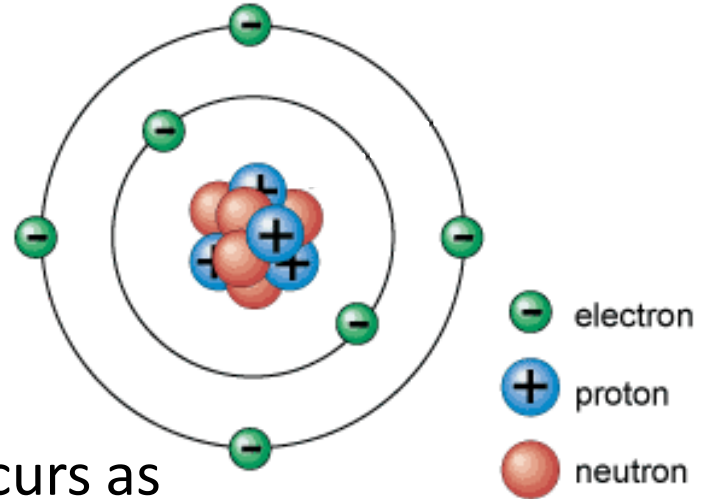


Translational and rotational invariance

The Building Blocks: Atoms



~~Translational and rotational invariance~~



Interaction is a kind of action that occurs as two or more objects have an effect upon one another.

Emergent properties

According to Wikipedia:

*“Condensed matter physics is the field of physics that deals with the macroscopic and microscopic physical properties of matter. In particular, it is concerned with the “condensed” phases that appear whenever the number of constituents in a system is **extremely large** and the **interactions** between the constituents are **strong**. The most familiar examples of condensed phases are solids and liquids, which arise from the electromagnetic forces between atoms. “*

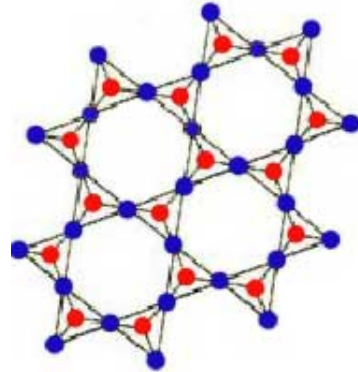
Why do we study it?

Interactions → complexity

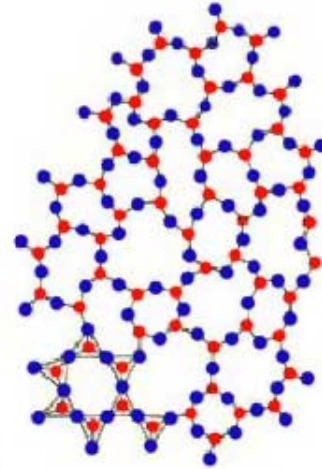
Complexity → functionality

Crystalline Materials

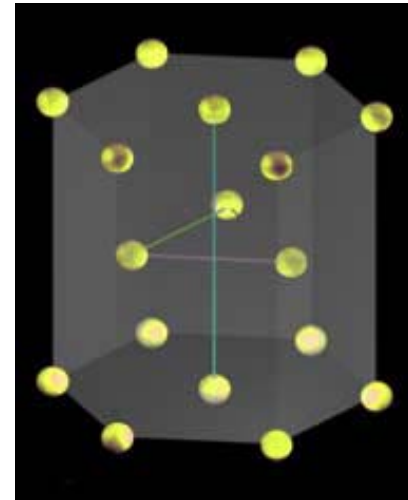
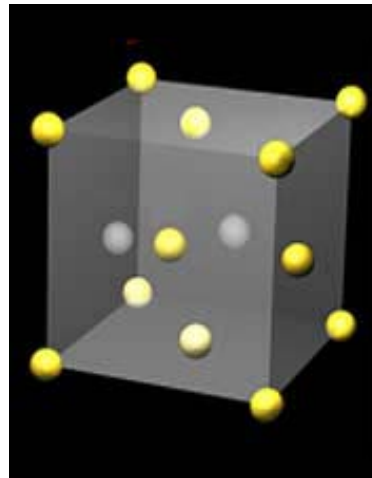
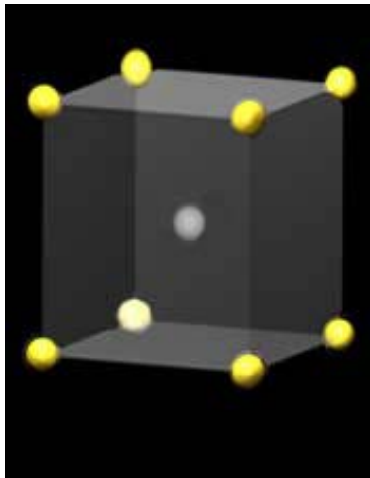
Crystalline SiO₂
(Quartz)



Amorphous SiO₂
(Glass)

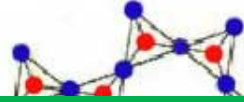


• Si • O

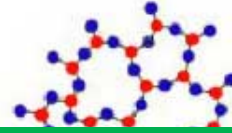


Structure and Properties

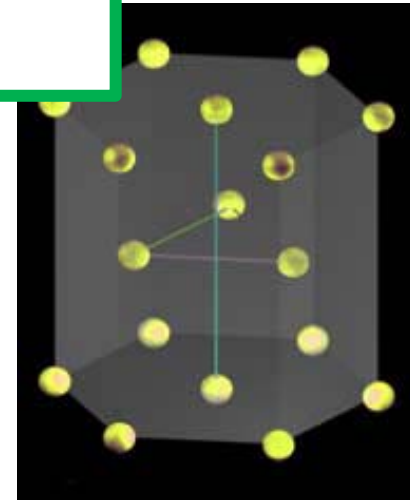
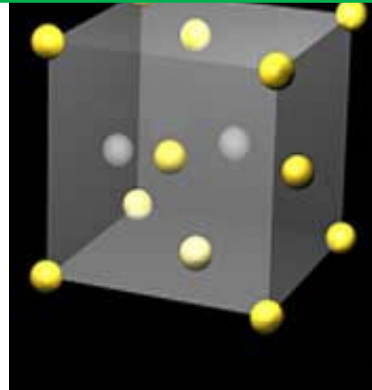
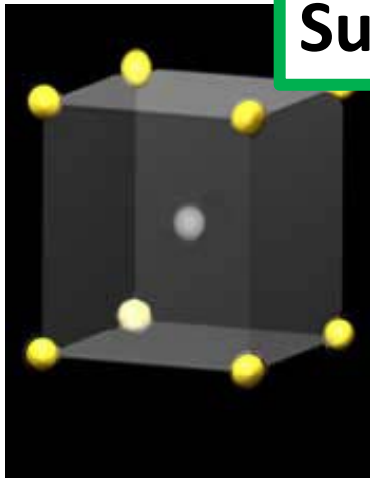
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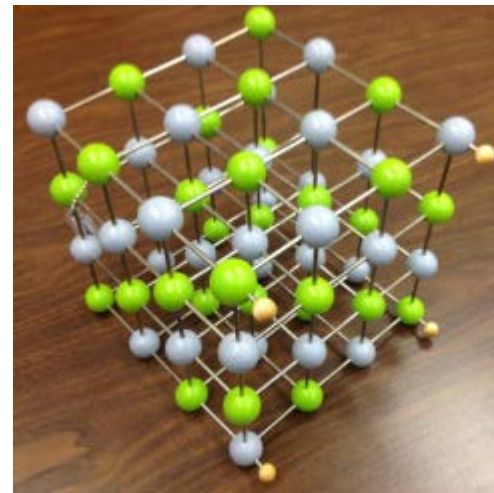
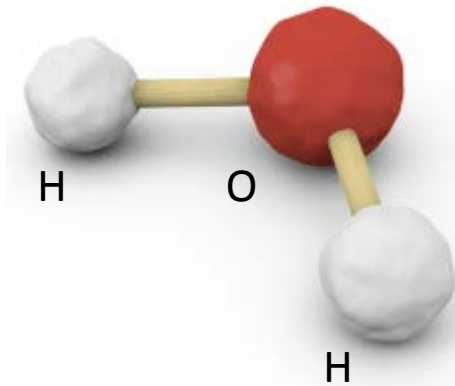
Amorphous SiO₂
(Glass)



Structure:
Optical properties
Magnetism
Conductivity
Superconductivity

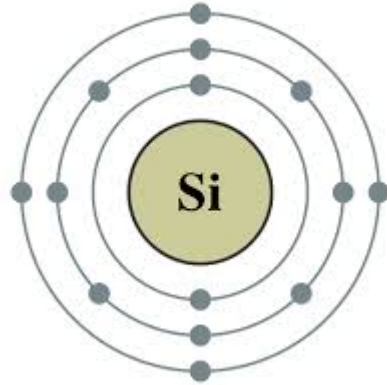


Structure and Symmetry

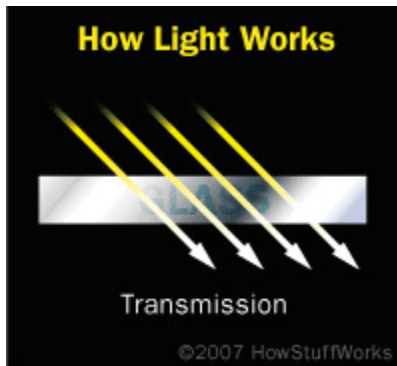
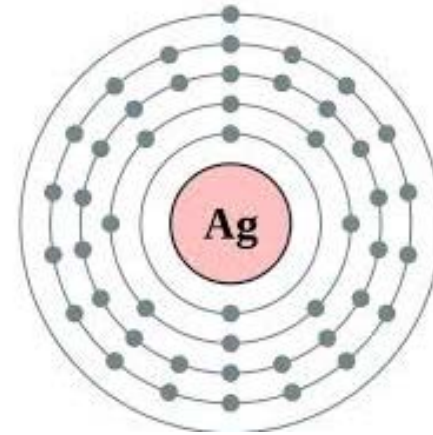


Why is glass transparent?

Glass = amorphous solid



Why are metals shiny?



It is ubiquitous

It is useful, we can use it to explain processes and objects that surround us

The knowledge from research and discovery are used to improve our everyday lives.

Can we Manipulate Materials?



Materials in the human hand



can become a technology.

Further improvement of craft



Frances Martinez

The “Iceman” Lived at the Transition from Neolithic Age to Copper Age

The Iceman’s Axe

At the top of the carefully smoothed **yew** haft is a forked shaft into which the 9.5 cm blade was fixed with **birch tar** and tightly bound with thin **leather straps**. The blade is made of almost pure **copper**. The narrow end was produced by cold-hammering after the blade was cast.

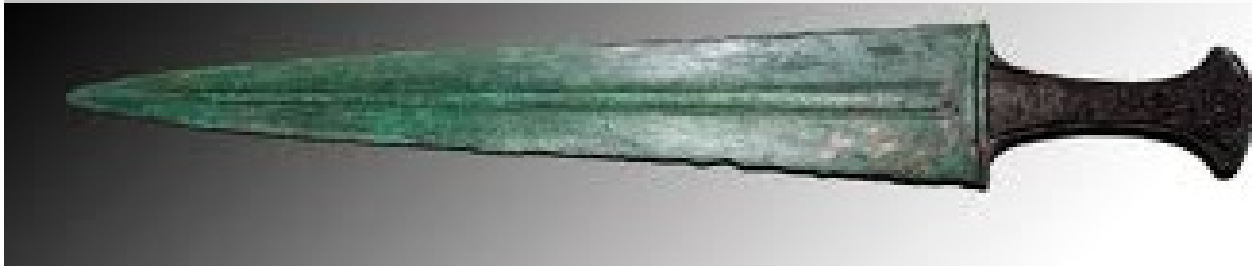
ALL OF THESE MATERIALS ARE FOUND MATERIALS



3300 B.C.E.

The Bronze Age (c. 3000 BCE – c. 1200 BCE)

Bronze = Copper + 10% Tin **Required long-distance trade routes**



From Saphar-Kharaba Late Bronze Age Cemetery (c. 1300 BCE)
in Southern Georgia *(The country, not the state)*

Iron Age (c. 1200 BCE – 400 AD)

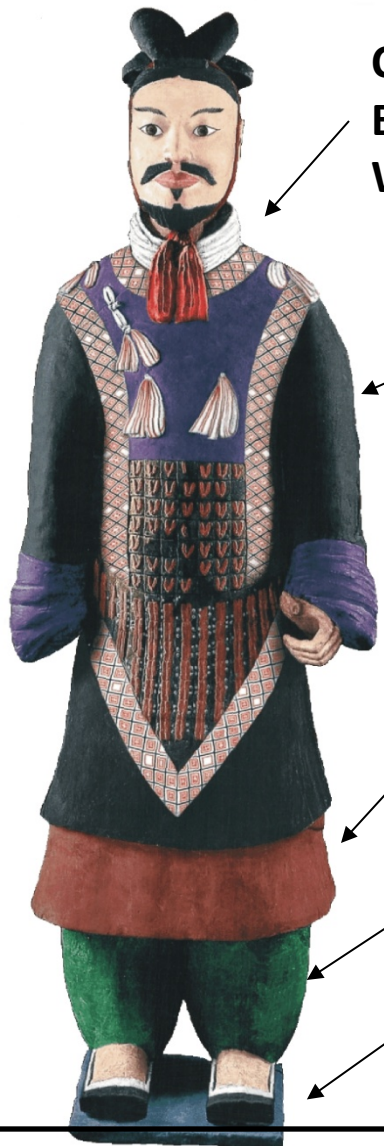


From Tutankhamun's Tomb (c. 1323 BCE)

Human Invention of Materials for Aesthetic Reasons (700 BCE – 200 AD)



Han Purple: the first synthetic purple pigment. Likely made from a mix of barium and copper minerals, quartz, and a lead salt as an extra ingredient that acts as a catalyst and flux. The mixture needed to be heated to between 900 and 1000 C – any hotter and Han blue results, which is closely related to Egyptian blue ($\text{CaCuSi}_4\text{O}_{10}$), the oldest known synthetic pigment in the world.



Calcite - CaCO_3
 Bone White - $\text{Ca}_5(\text{CO}_3)_2(\text{OH})_2$
 White Lead - $2\text{Pb}(\text{CO}_3)_2 \cdot \text{Pb}(\text{OH})_2$

Soot - carbon black

Han Purple* - $\text{BaCuSi}_2\text{O}_6$**
 *** human-made pigment

Cinnabar - HgS
 Hematite - Fe_2O_3
 Red Lead - Pb_3O_4

Malachite - $\text{Cu}_2\text{CO}_3(\text{OH})_2$
Han Blue* - $\text{BaCuSi}_4\text{O}_{10}$**
 *** human-made pigment

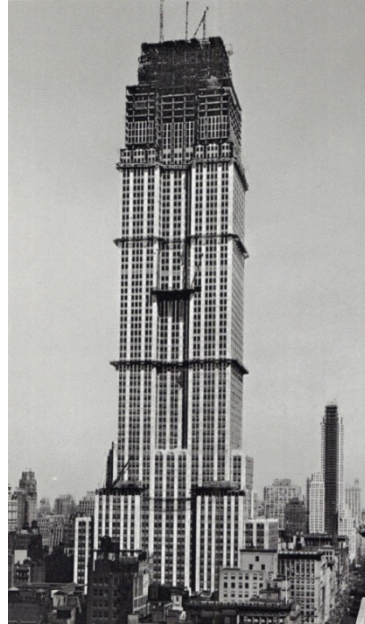


**Limitation of the then
State-of-the-Art
Material...
CAST IRON**

**Cast iron building
architecture
reaches six stories**

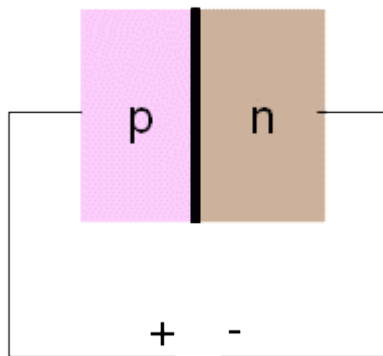
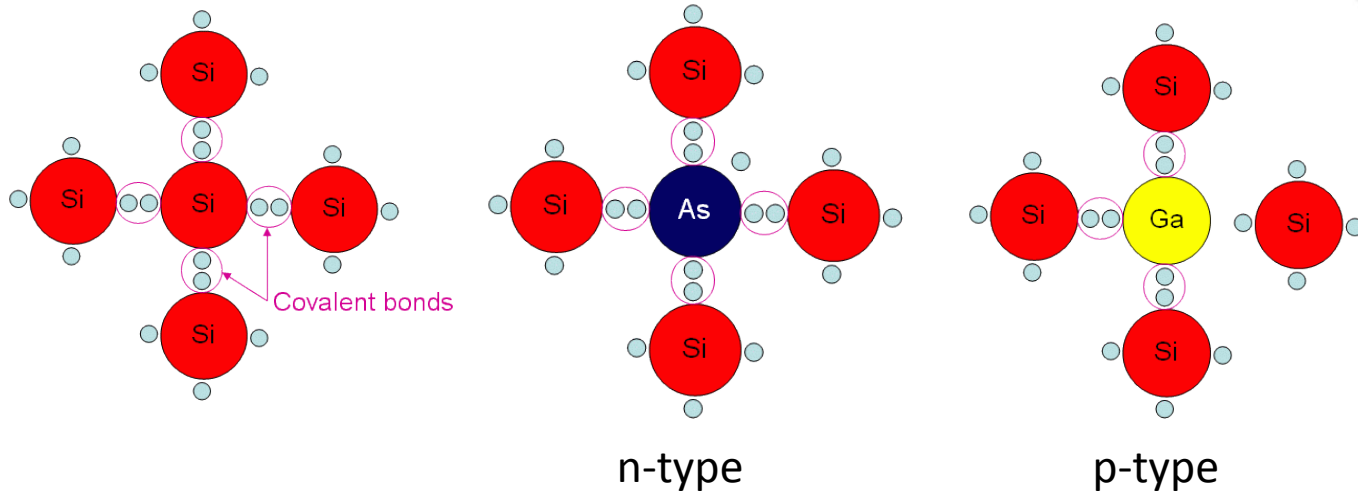
...Cast Iron can build Soho

It takes STEEL to build Midtown



Research and development to improve steel continues at the MagLab

Doping: semiconductors to control electrical properties



Diode, Transistors → iPhones etc.

Whenever you put different atoms together interesting properties emerge

Can we Design New Materials?

PERIODIC TABLE OF THE ELEMENTS

<http://www.periodni.com>

RELATIVE ATOMIC MASS (1)

GROUP IUPAC

GROUP CAS

ATOMIC NUMBER

SYMBOL

ELEMENT NAME

■ Metal ■ Semimetal ■ Nonmetal
■ Alkali metal ■ Chalcogens element
■ Alkaline earth metal ■ Halogens element
■ Transition metals ■ Noble gas
■ Lanthanide ■ Actinide

STANDARD STATE (25 °C; 101 kPa)

Ne - gas Fe - solid
Hg - liquid Tc - synthetic

PERIOD	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	IA	IIA											IIIA	IVA	VA	VIA	VIIA	VIIIA
1	1 H HYDROGEN																	2 He HELIUM
2	3 Li LITHIUM	4 Be BERYLLIUM											5 B BORON	6 C CARBON	7 N NITROGEN	8 O OXYGEN	9 F FLUORINE	10 Ne NEON
3	11 Na SODIUM	12 Mg MAGNESIUM											13 Al ALUMINIUM	14 Si SILICON	15 P PHOSPHORUS	16 S SULPHUR	17 Cl CHLORINE	18 Ar ARGON
4	19 K POTASSIUM	20 Ca CALCIUM	21 Sc SCANDIUM	22 Ti TITANIUM	23 V VANADIUM	24 Cr CHROMIUM	25 Mn MANGANESE	26 Fe IRON	27 Co COBALT	28 Ni NICKEL	29 Cu COPPER	30 Zn ZINC	31 Ga GALLIUM	32 Ge GERMANIUM	33 As ARSENIC	34 Se SELENIUM	35 Br BROMINE	36 Kr KRYPTON
5	37 Rb RUBIDIUM	38 Sr STRONTIUM	39 Y YTTRIUM	40 Zr ZIRCONIUM	41 Nb NIOBIUM	42 Mo MOLYBDENUM	43 Tc TECHNETIUM	44 Ru RUTHENIUM	45 Rh RHODIUM	46 Pd PALLADIUM	47 Ag SILVER	48 Cd CADMIUM	49 In INDIUM	50 Sn TIN	51 Sb ANTIMONY	52 Te TELLURIUM	53 I IODINE	54 Xe XENON
6	55 Cs CAESIUM	56 Ba BARIUM	57-71 La-Lu Lanthanide	72 Hf HAFNIUM	73 Ta TANTALUM	74 W TUNGSTEN	75 Re RHENIUM	76 Os OSMIUM	77 Ir IRIDIUM	78 Pt PLATINUM	79 Au GOLD	80 Hg MERCURY	81 Tl THALLIUM	82 Pb LEAD	83 Bi BISMUTH	84 Po POLONIUM	85 At ASTATINE	86 Rn RADON
7	87 Fr FRANCIUM	88 Ra RADIUM	89-103 Ac-Lr Actinide	104 Rf RUTHERFORDIUM	105 Db DUBNIUM	106 Sg SEABORGIUM	107 Bh BOHRIUM	108 Hs HASSIUM	109 Mt MEITNERIUM	110 Ds DARMSTADIUM	111 Rg ROENTGENIUM	112 Cn COPERNICIUM	113 Uut UNUNTRIUM	114 Fl FLEROVIUM	115 Uup UNUNPENTIUM	116 Lv LIVERMORIUM	117 Uus UNUNSEPTIUM	118 Uuo UNUNOCTIUM

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(1) Pure Appl. Chem., 81, No. 11, 2131-2156 (2009)
Relative atomic masses are expressed with five significant figures. For elements that have no stable nuclides, the value enclosed in brackets indicates the mass number of the longest-lived isotope of the element. However three such elements (Th, Pa and U) do have a characteristic terrestrial isotopic composition, and for these an atomic weight is tabulated.

LANTHANIDE														
57 La LANTHANUM	58 Ce CERIUM	59 Pr PRASEODYMIUM	60 Nd NEODYMIUM	61 (145) Pm PROMETHIUM	62 Sm SAMARIUM	63 Eu EUROPIUM	64 Gd GADOLINIUM	65 Tb TERBIUM	66 Dy DYSPROSIUM	67 Ho HOLMIUM	68 Er ERBIUM	69 Tm THULIUM	70 Yb YTTERIUM	71 Lu LUTETIUM
ACTINIDE														
89 (227) Ac ACTINIUM	90 232.04 Th THORIUM	91 231.04 Pa PROTACTINIUM	92 238.03 U URANIUM	93 (237) Np NEPTUNIUM	94 (244) Pu PLUTONIUM	95 (243) Am AMERICIUM	96 (247) Cm CURIUM	97 (247) Bk BERKELIUM	98 (251) Cf CALIFORNIUM	99 (252) Es EINSTEINIUM	100 (257) Fm FERMIUM	101 (258) Md MENDELEVIUM	102 (259) No NOBELIUM	103 (262) Lr LAWRENCIUM

Ways to Manipulate the Lattice

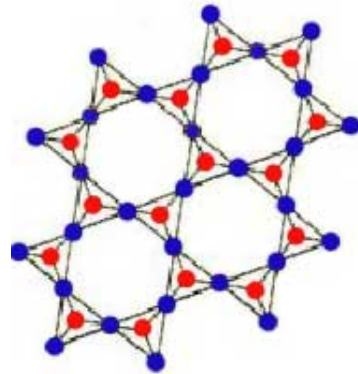
Doping and impurities

External perturbations: temperature and applied fields

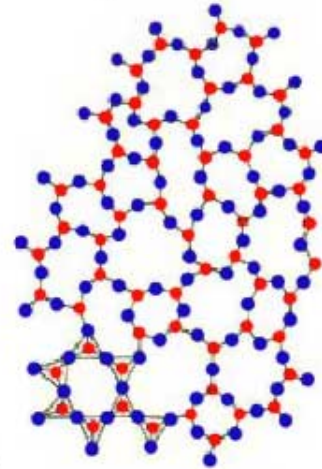
External pressure: hydrostatic and strain

Unit Cell

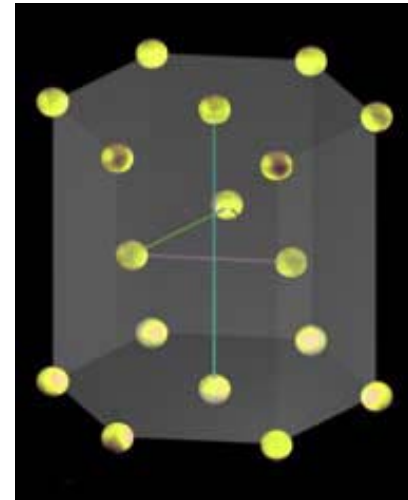
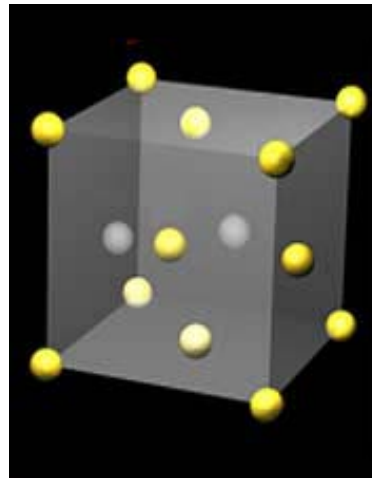
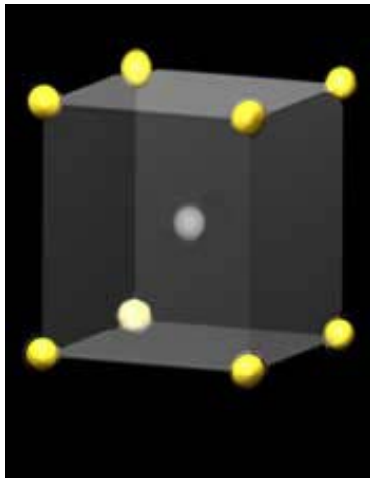
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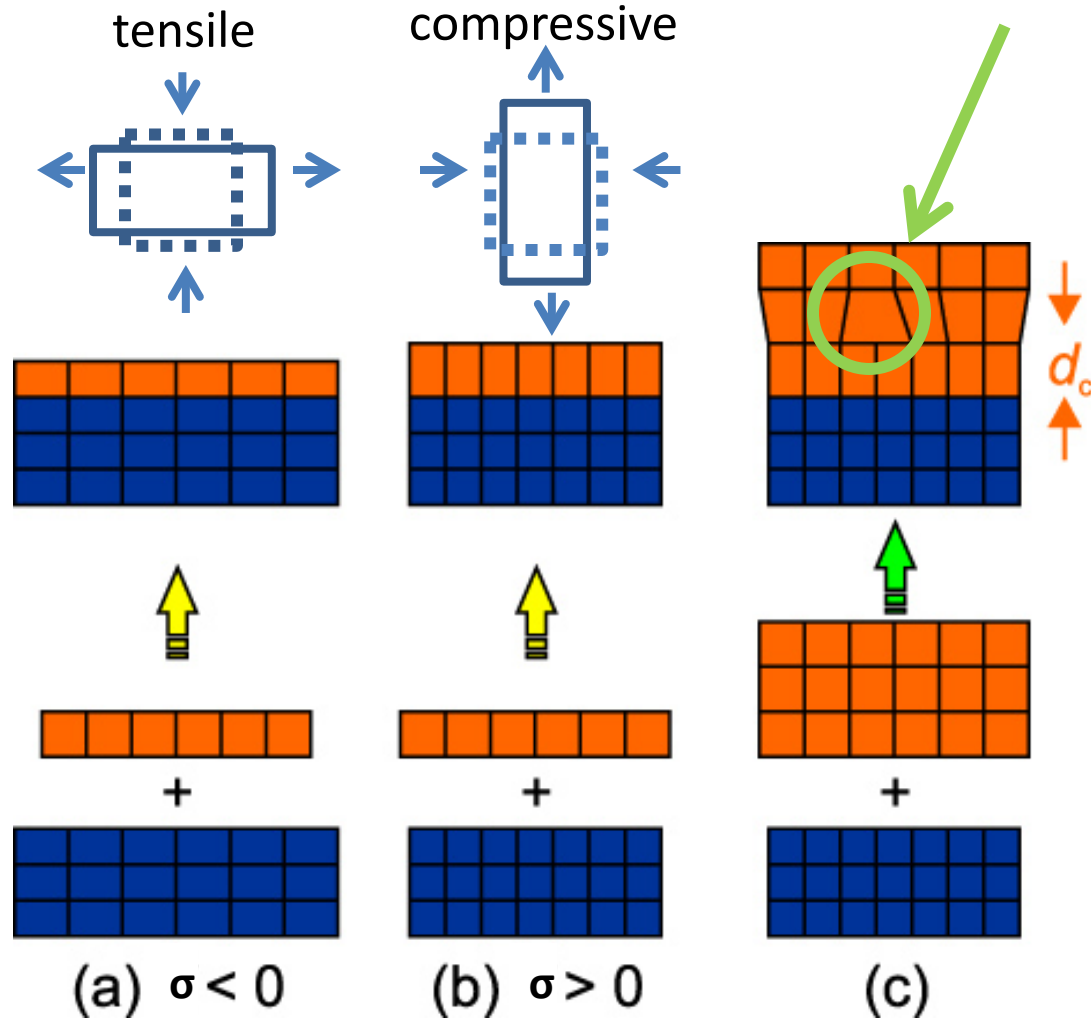
Amorphous SiO₂
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● Si ● O

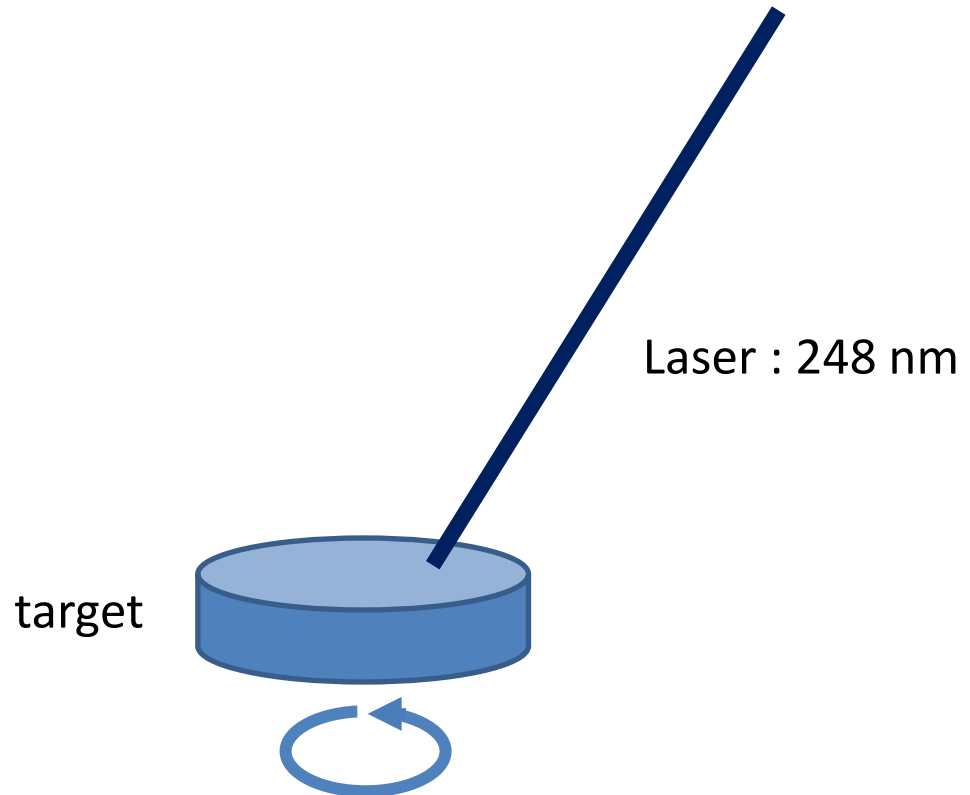
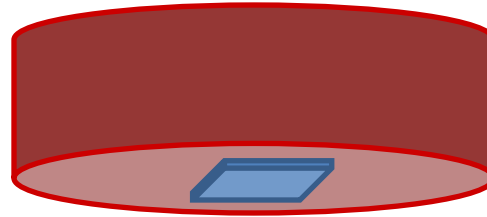


Thin Films Growth: Epitaxial Strain



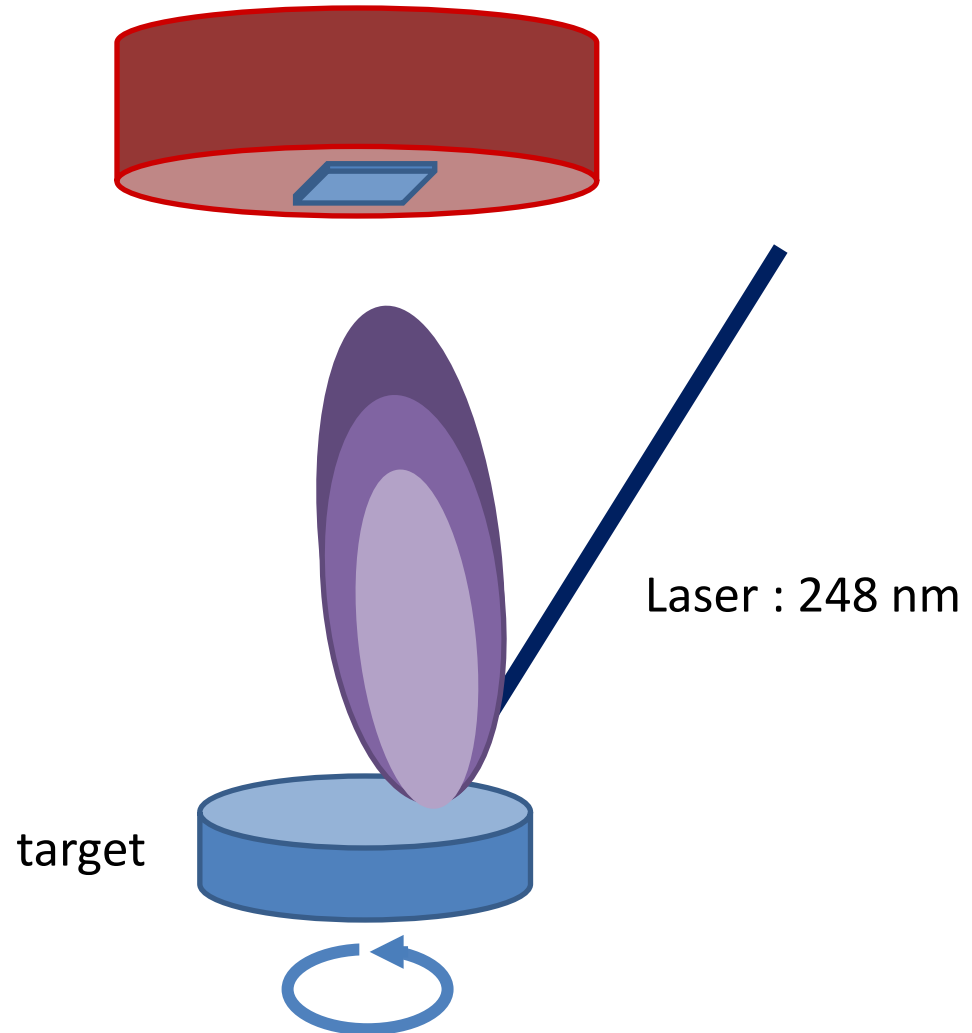
How do we make thin films?

Substrate on heater
Typically $\sim 600 - 800$ °C

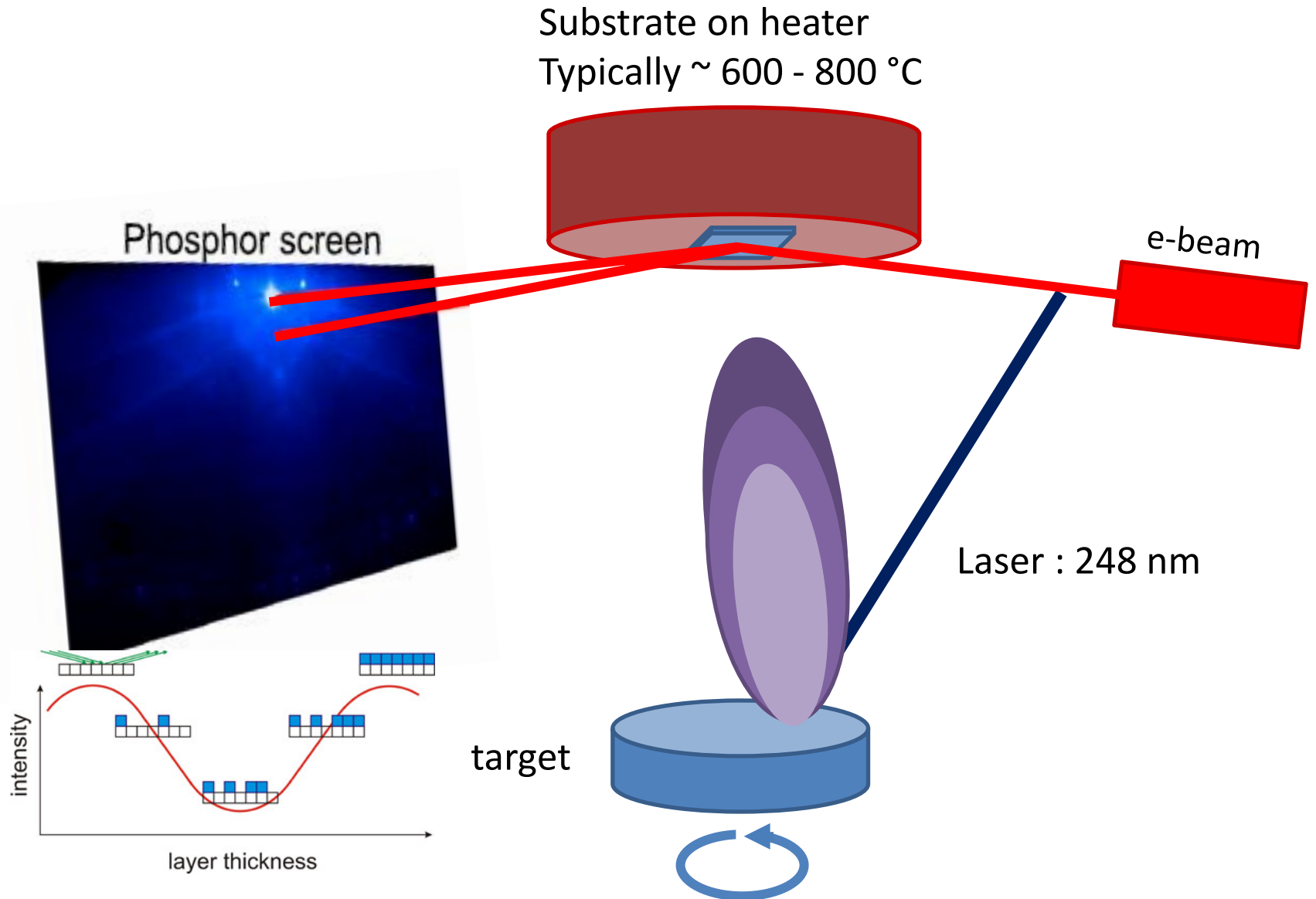


How do we make Materials?

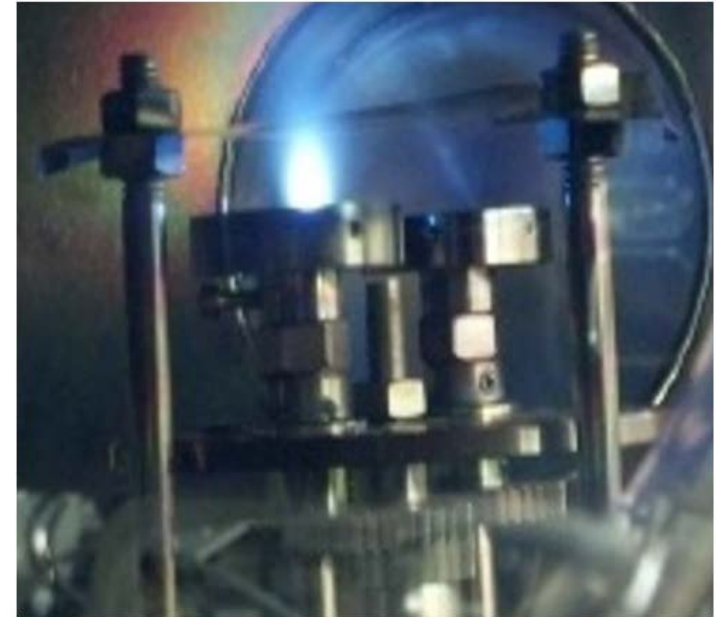
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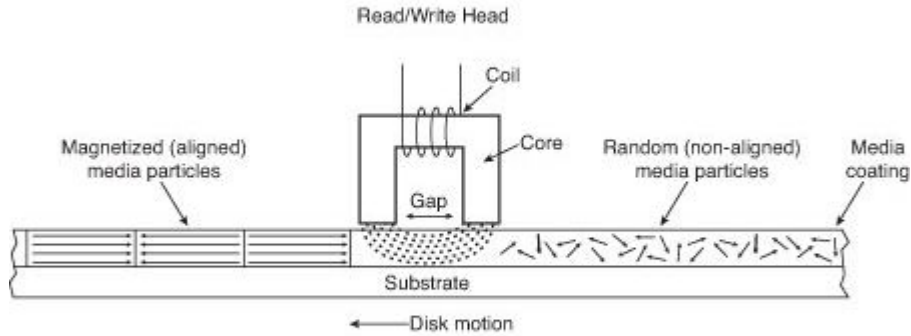
How do we make Materials?



Thin Film Growth: Pulsed Laser Deposition Setup

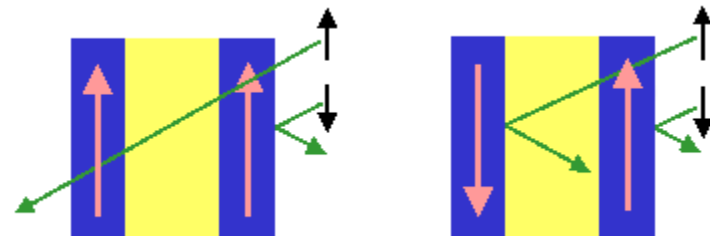
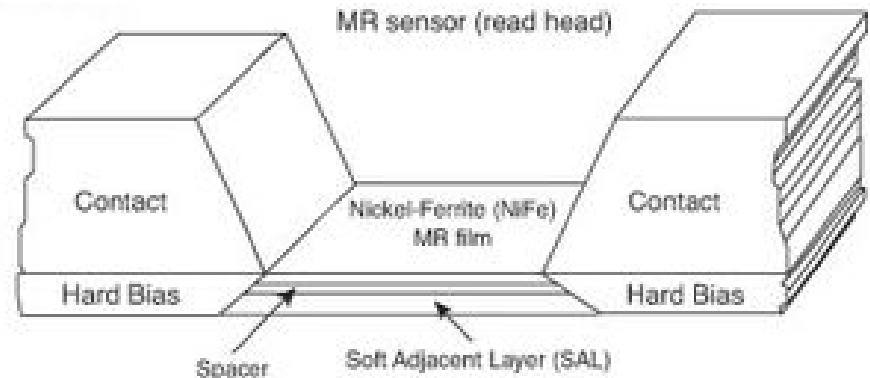


Thin Films: Applications



Older Hard drive
Locally change magnetization in a magnetic particles through applied magnetic field. Basically an electromagnet

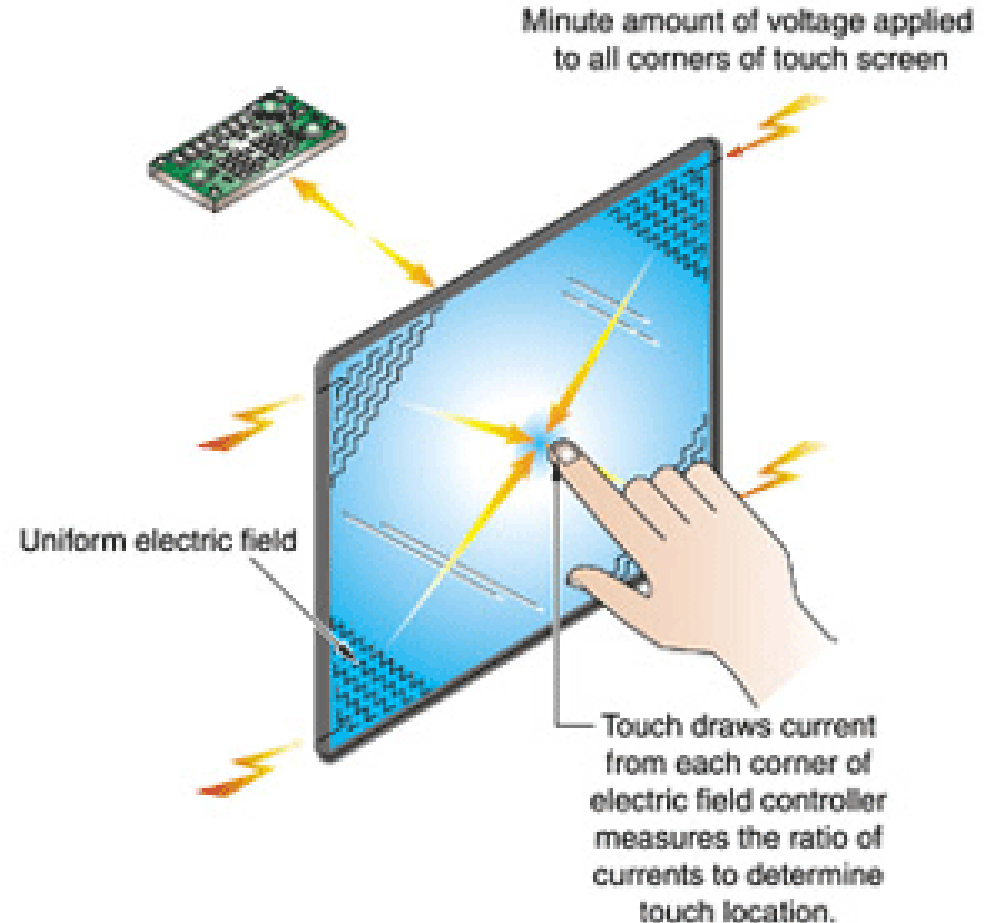
GMR Hard drive
Much more expensive to fabricate but much more sensitive and higher density



Thin Films: Applications

Touchscreen

Indium Tin Oxide is transparent like glass but is also conductive. Oxygen stoichiometry determines the conductivity. Basically n-type semiconductor.

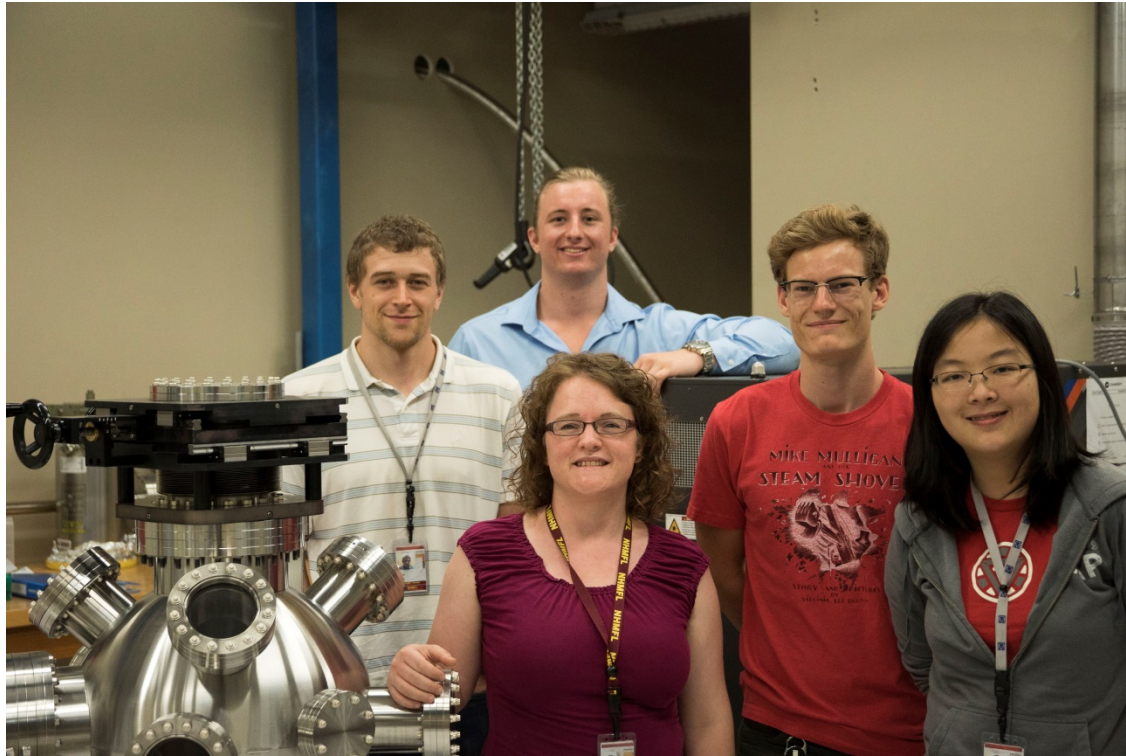


Investigate the effect of doping and impurities

Apply Strain to materials that have never been grown in thin film form

External perturbations: temperature and applied fields

Expand our knowledge about the Physics of materials



We are constantly making new materials and pushing the boundaries of condensed matter physics