PHYS 7363 - Condensed Matter Physics

Instructor: Prof. Rongying Jin, 229B Nicholson Hall, **E-mail**: rjin@lsu.edu, Tel: 578 0028

Time & Place: TuTh 9:00-10:30 AM, 307 Frey Building (polycom with Hillsdale College-Prof. Cyrill Slezak)/106 Nicholson Hall (when polycom is not needed)

Office Hours: TuTh 10:30-12:00 PM or by appointment

Lecture Notes: http://www.phys.lsu.edu/classes/fall2010/phys7363/

Prerequisites: Undergraduate level quantum mechanics and statistical mechanics

Textbook: N. Ashcroft / N.D. Mermin, "**Solid State Physics**"
(additional reading material: C. Kittel "**Introduction to Solid State Physics**"
S.R. Elliott "**The Physics and Chemistry of Solids**")

Homework: Assignments will be due every 2nd Thursday.

Exams: We will have one in-class midterm exam, and one final exam, that will be either a take-home or in-class final.

Grading: Homework 40%, Midterm 30%, and Final 30%

Outline: The course schedule below is approximate and will be adjusted as the course proceeds, especially if we get behind or ahead of schedule.

Week	Dates	Notes	Chapters
1	Aug. 23-27		add: Crystal Growth; 4: Crystal Lattices;
2	Aug. 30-Sept.3		5: Reciprocal Lattice; 6: X-Ray Diffraction
3	Sept. 4-10	Mon. holiday	1: Drude Theory; 2: Sommerfeld
4	Sept. 13-17		2: Sommerfeld; 8: Bloch's Theorem
5	Sept. 20-24		8: Bloch's Theorem; 9: Electrons in a Weak Periodic Potential
6	Sept. 27-29		10: Tight binding
7	Oct. 4-8		12: Semiclassical Dynamics; 14: Measuring Fermi Surface
8	Oct.11-15	Midterm Exam (Thursday)	14: Measuring Fermi Surface; 17: Beyond the Independent Electron Approximation
9	Oct. 18-22	Thurs. & Fri. Fall break	22: Classical Harmonic Crystal; 23: Quantum Crystal
10	Oct. 25-29		23: Quantum Crystal; 26: Phonons
11	Nov. 1-5		28: Homogeneous Semicond.
12	Nov. 8-12		29: Inhom. Semicond.; 30: Defects in Crystals
13	Nov. 15-19		31: Diamagnetism and Paramagnetism
14	Nov. 22-24	Fri. holiday	32: Magnetic Interactions; 33: Magnetic Ordering
15	Nov.29-Dec.3	Classes end	34: Superconductivity
16	Dec. 6-10	Final Exam	

Chapter Add I:
Materials Synthesis & Preparation

Synthesis: formation of a new chemical product from different starting materials

chemical process

Preparation: the same chemical formula but different physical forms

---- bulk versus nano/film

---- single crystals versus polycrystals

physical process

Why do we need to know how materials are synthesized and prepared ?

No materials

↓

No solid-state physics

Synthesis & preparation procedure

Gas to solid

Liquid to solid

Solid to solid

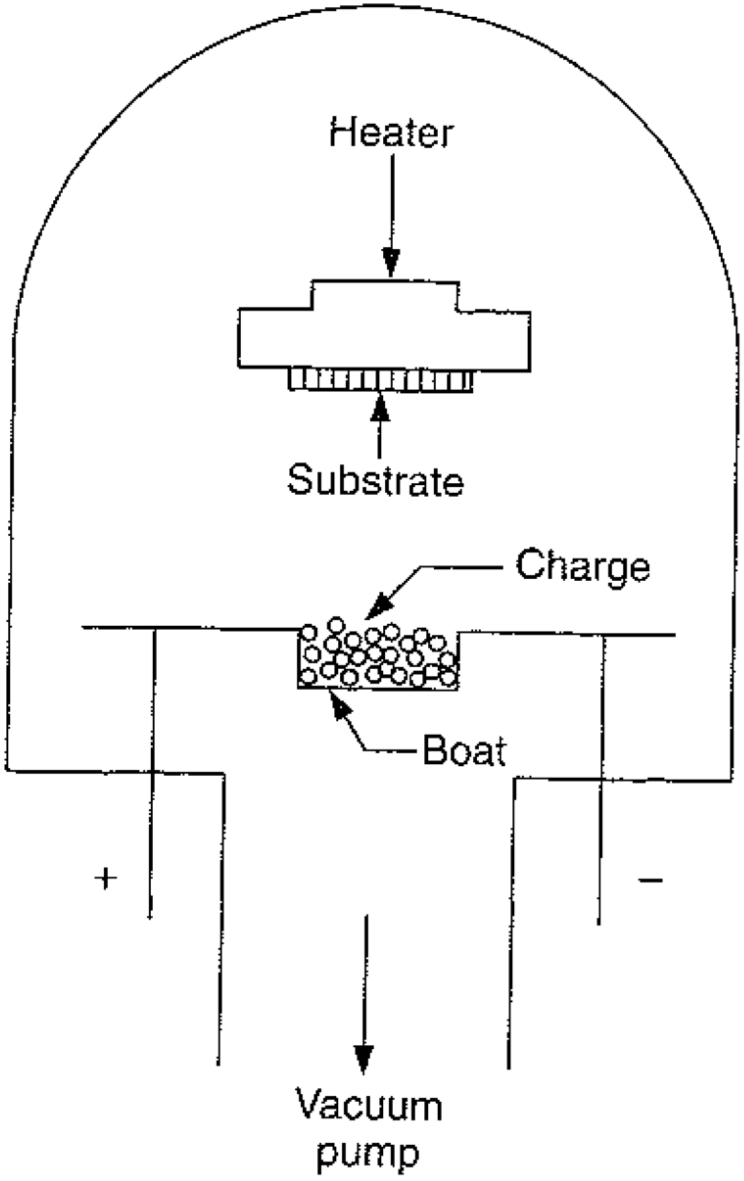
Gas to solid synthesis and preparation

Vapor deposition

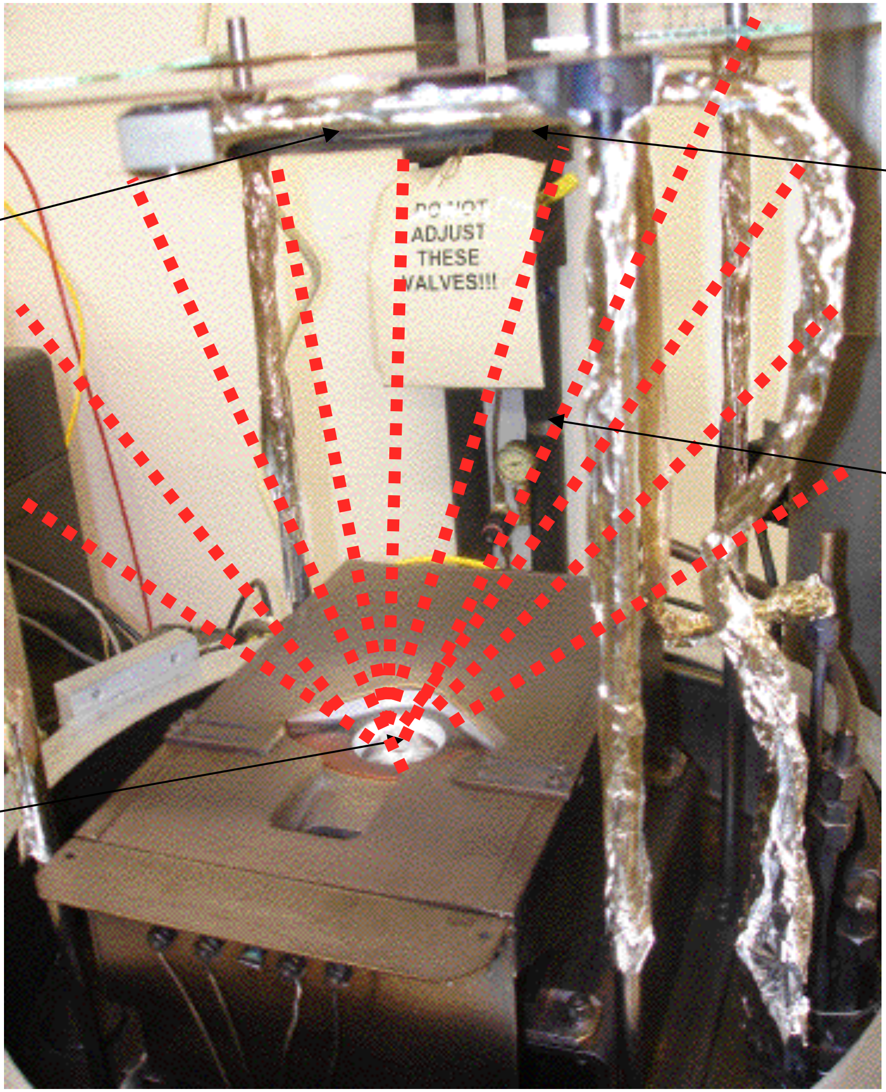
Chemical vapor deposition (CVD)

Sputtering

Vapor Deposition



Vapor Deposition (continued)



Substrate
(T_{cold})

condensation

Evaporated material

Source
(T_{hot})

Vapor Deposition (continued)

Vacuum chamber

WHY?

Vapor deposition

Material from one form to another form

Vapor Deposition (continued)

Other Issues: **Contaminations**

Chemical decomposition

Vapor Deposition (continued)

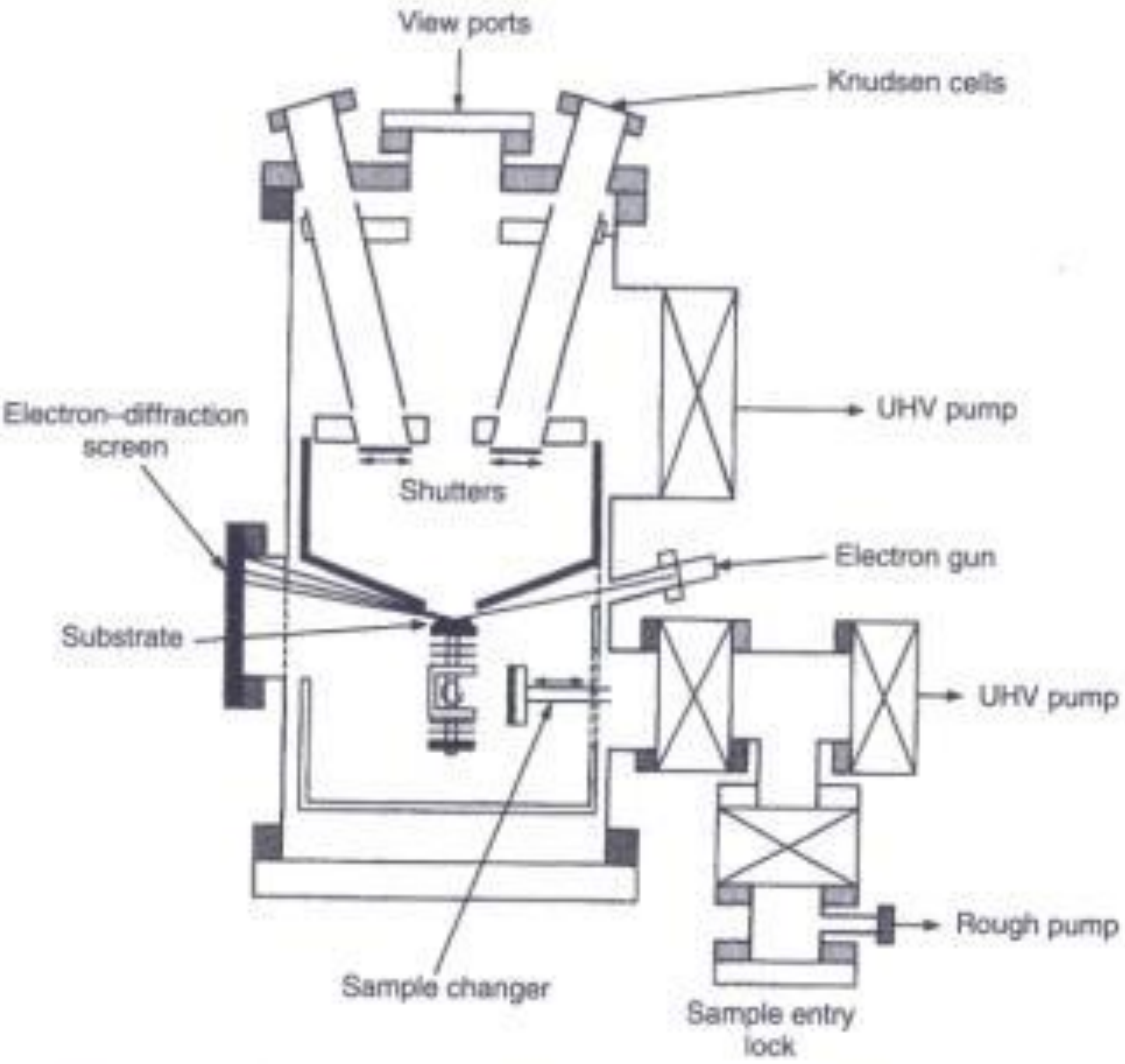
Composition Control

Molecular-beam epitaxy (MBE)

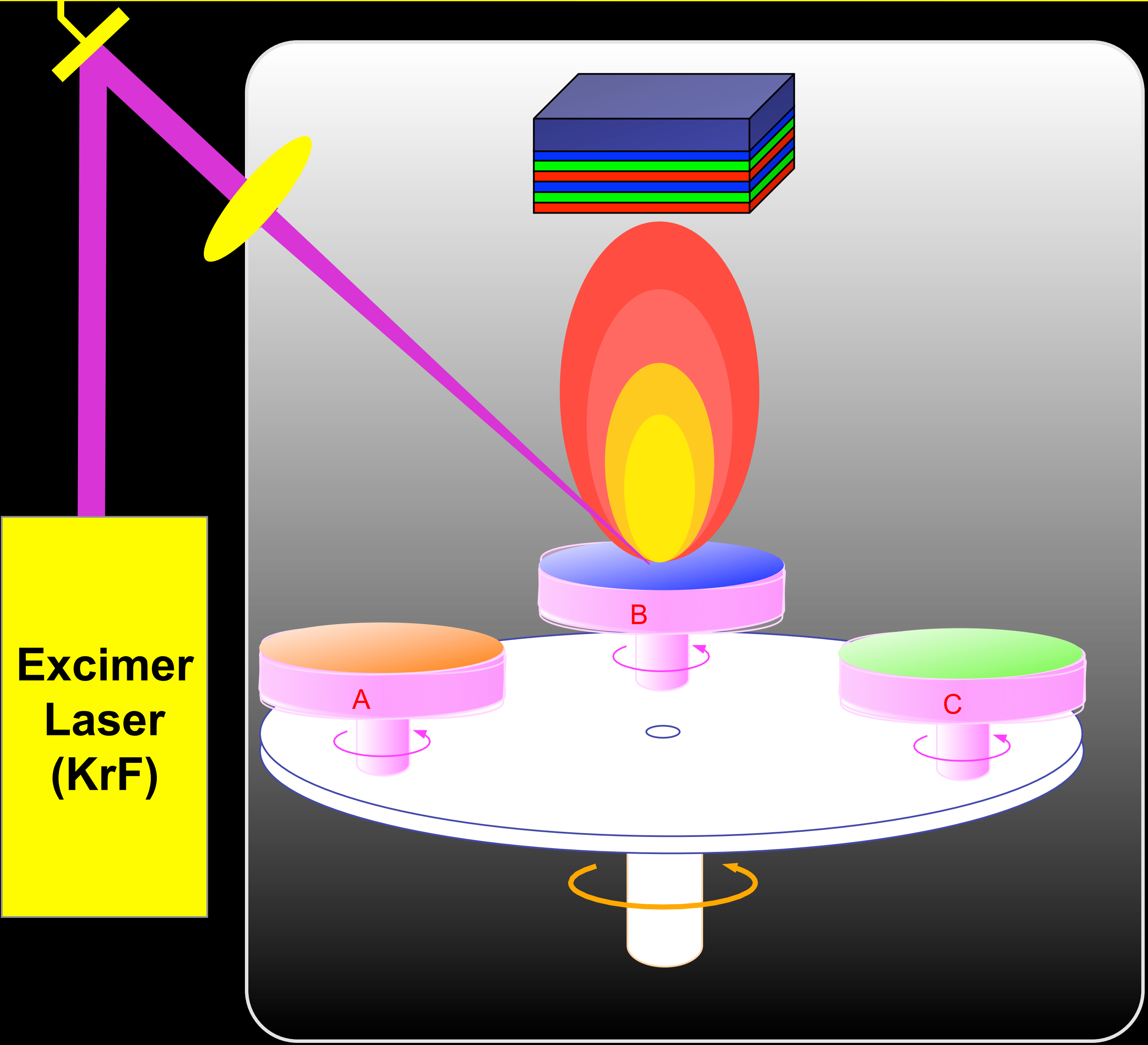
Pulsed-laser deposition (PLD)

Synthetic techniques

Molecular-Beam Epitaxy (MBE)



Pulsed-Laser Deposition



Chemical Vapor Deposition (CVD)

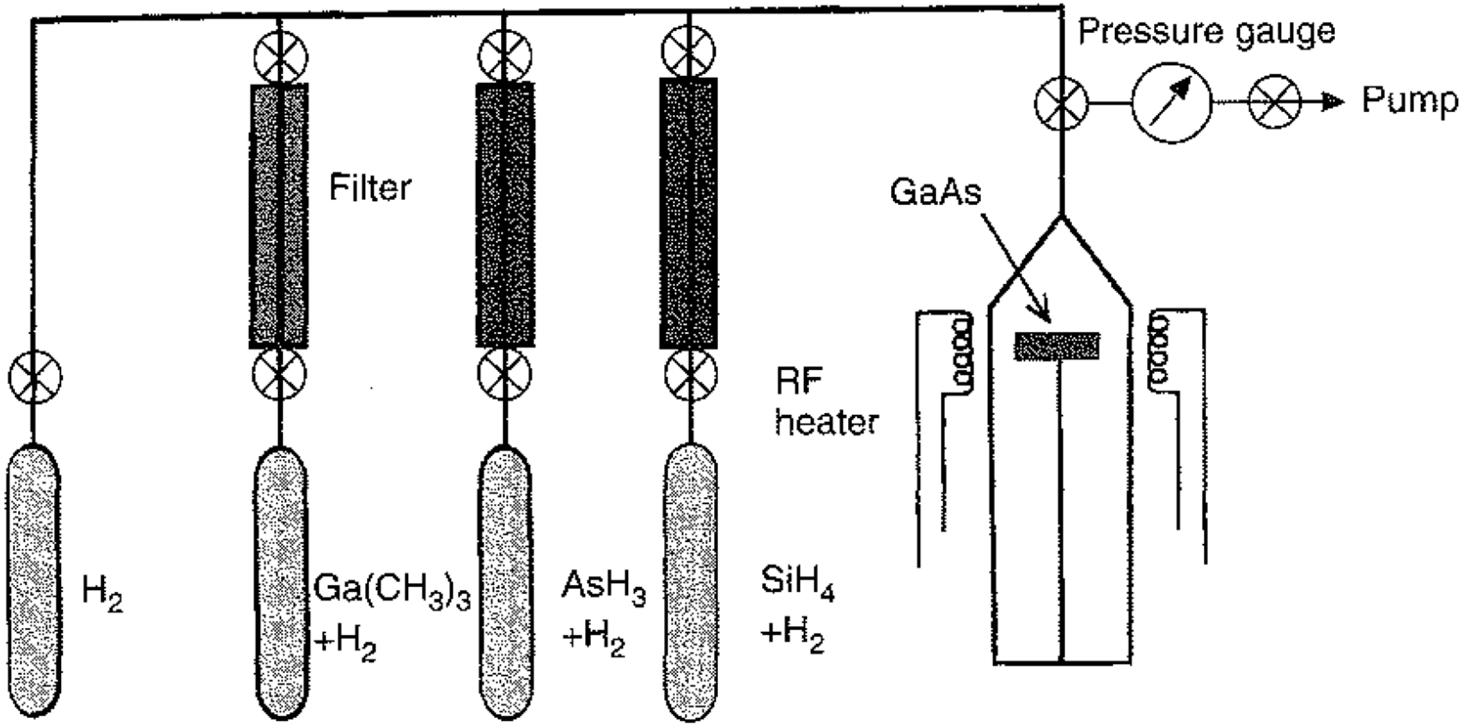
A + B + … → wanted product + unwanted

usually in gas form

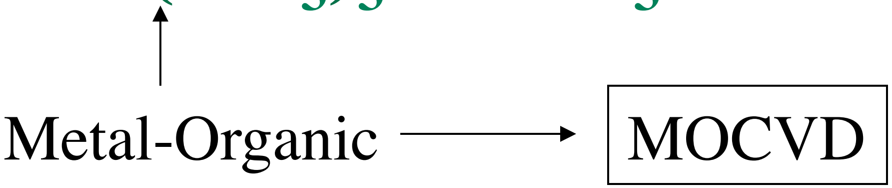
Different from: MBE and PLD techniques

A + B + … → C (includes all elements from A & B)

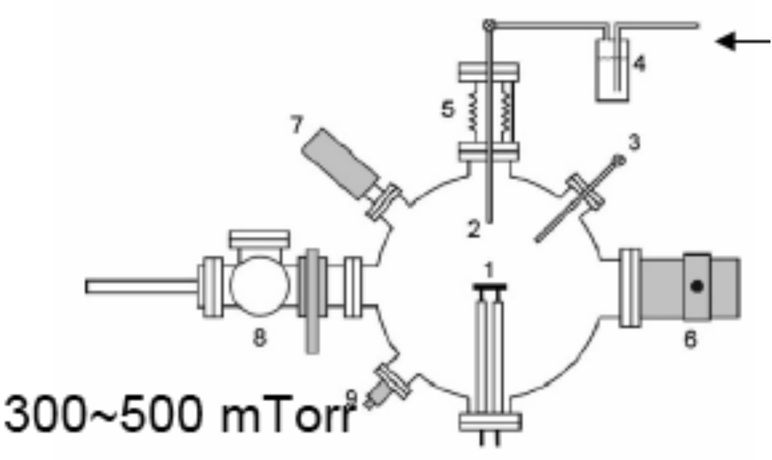
Chemical Vapor Deposition: Example I



$$Ga(CH_3)_3 + AsH_3 \rightarrow GaAs \text{ (solid)} + 3CH_4 \text{ (gas)}$$



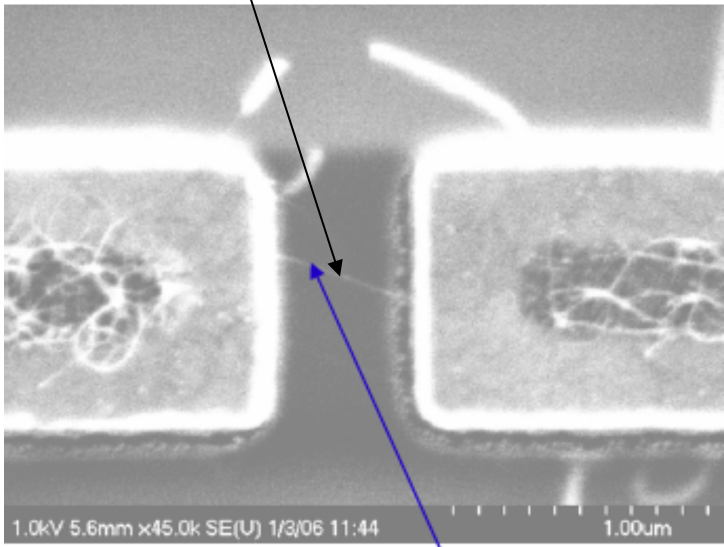
Chemical Vapor Deposition: Example II



2% C_2H_2 → C + H_2

10% H_2

88% He



Single-wall Carbon nanotube

Chemical Vapor Deposition (continued)

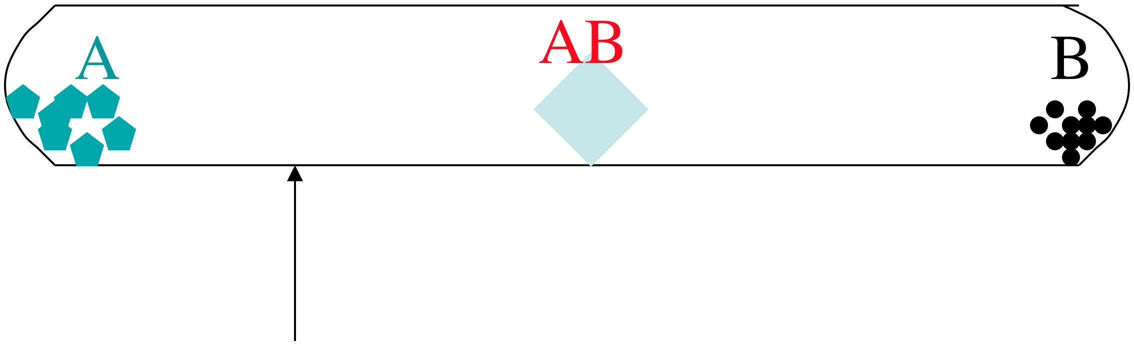
Be familiar with special terms:

Thermal - CVD
Photo - CVD
Plasma-enhanced - CVD

MOCVD
MOMBE/MOCBE

Vapor-phase transport/chemical transport technique

Vapor-Phase/Chemical Transport Technique



Sealed tube (glass, quartz, stainless steel…)

Example: $$2Cd + Re_2O_7 \xrightarrow{950°C} Cd_2Re_2O_7$$

Boiling T <800°C

Sputtering Deposition

Difference from vapor deposition:

The target material is usually electrically conductive so that it can act as an electrode

↓

attract positively charged ions from the plasma

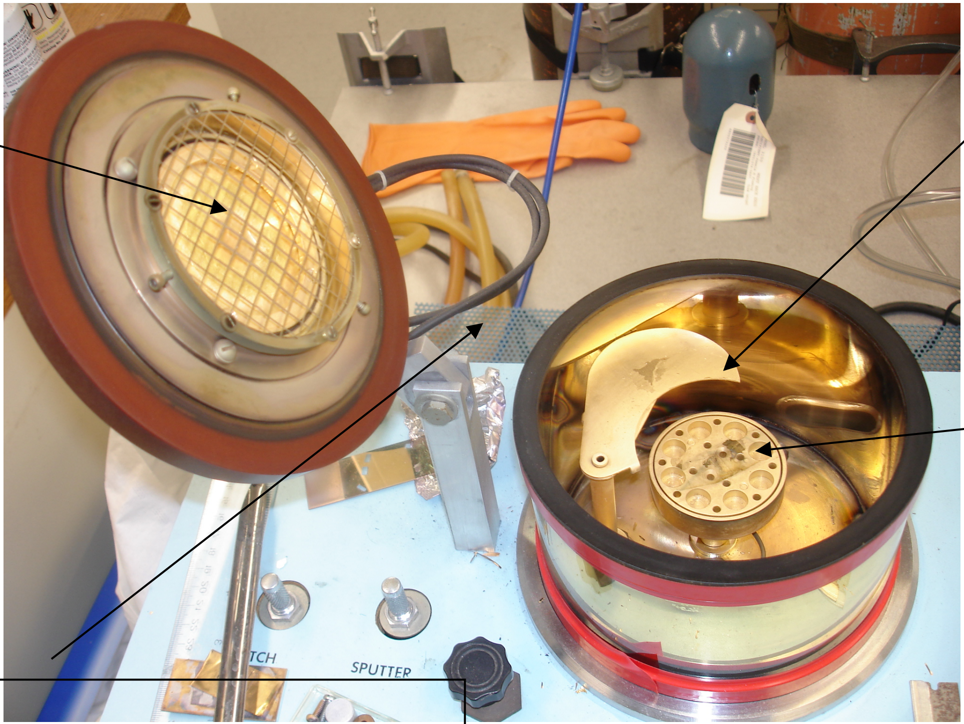
↓

sputter target materials

For insulating target materials, a.c. electrical field has to be applied -- using half circle

Sputtering Deposition:
A Simple Appartus in Our Lab

Sputtering Deposition (continued)



target

shutter

substrate

Ar^+ plasma
will be generated in the chamber
when sputtering

Summary of Gas - Solid Synthesis and Preparation Techniques

Vapor deposition

Chemical vapor deposition

Sputtering

Liquid to Solid Synthesis and Preparation

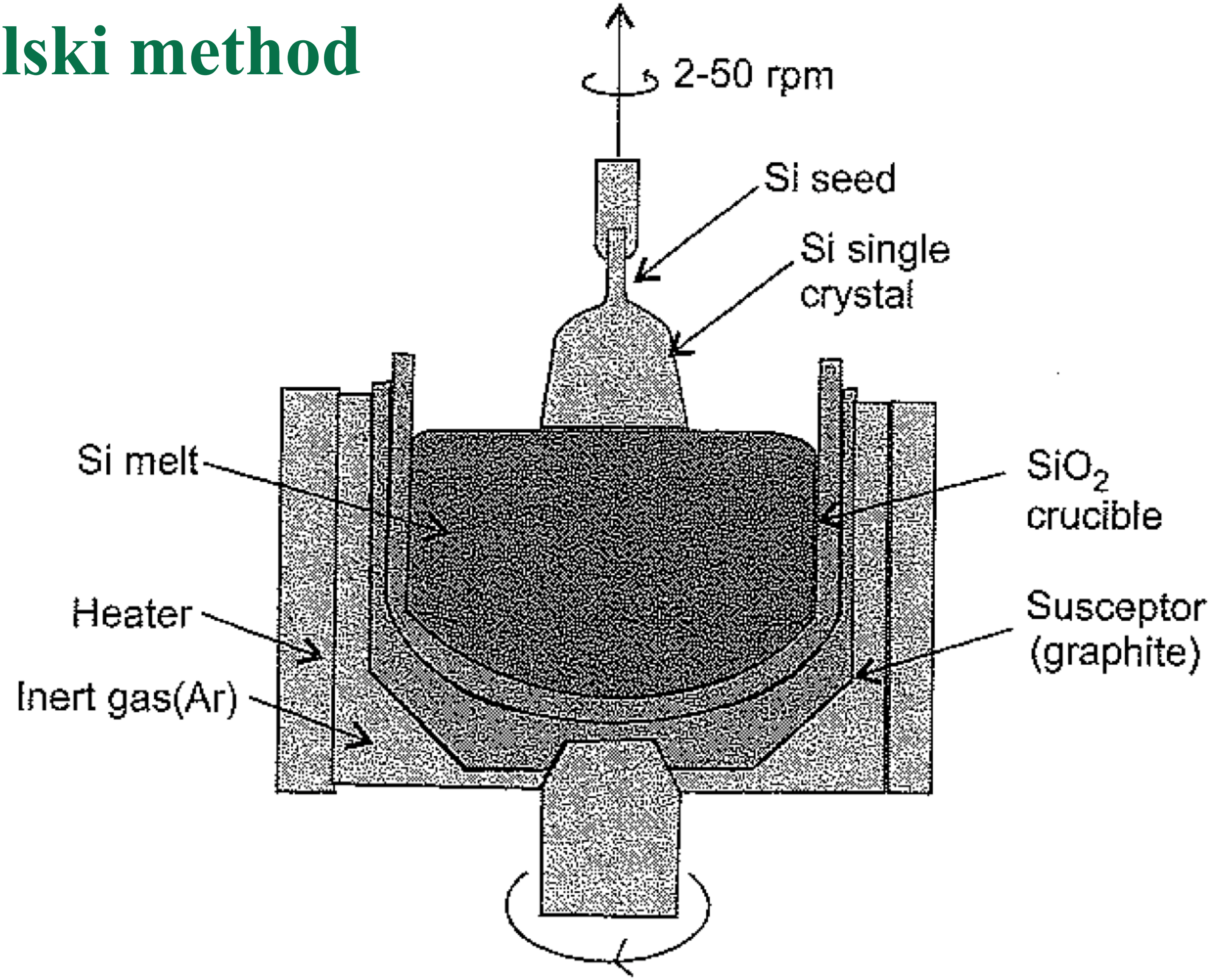
Solidifying materials from:

- **Melt**
- **Liquid quenching**
- **Solution**
- **Sol-gel**
- **Ion exchange and intercalation**

Single Crystal Growth from Melt

Czochralski method

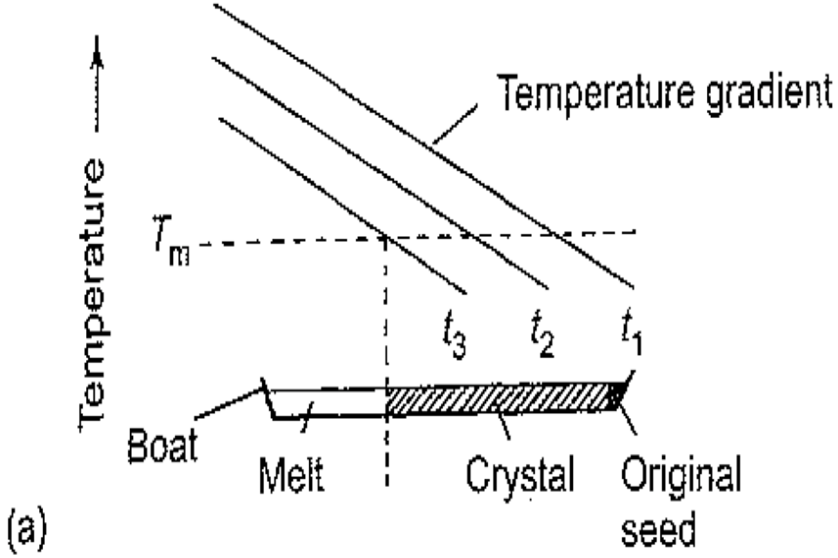
constant T

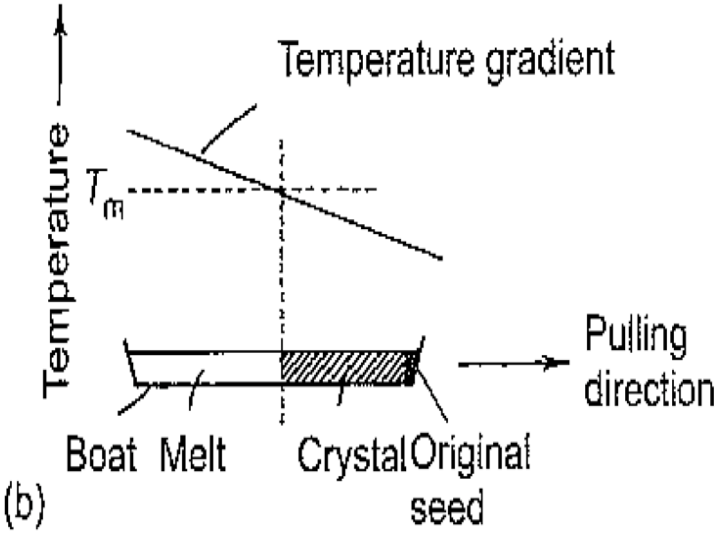


Single Crystal Growth from Melt

Czochralski method

Single Crystal Growth from Melt (continued)



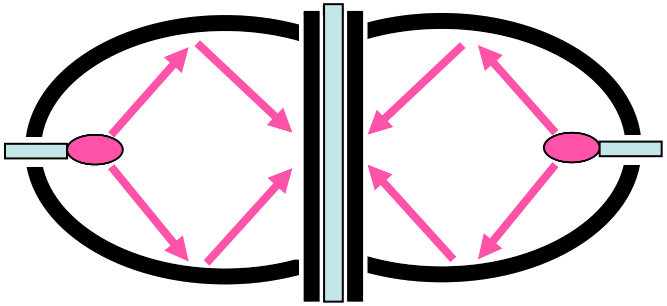


Bridgeman technique: maintain constant ΔT, while cooling down T

Stockbarger technique: move the crucible constant ΔT

Single Crystal Growth from Melt (continued)

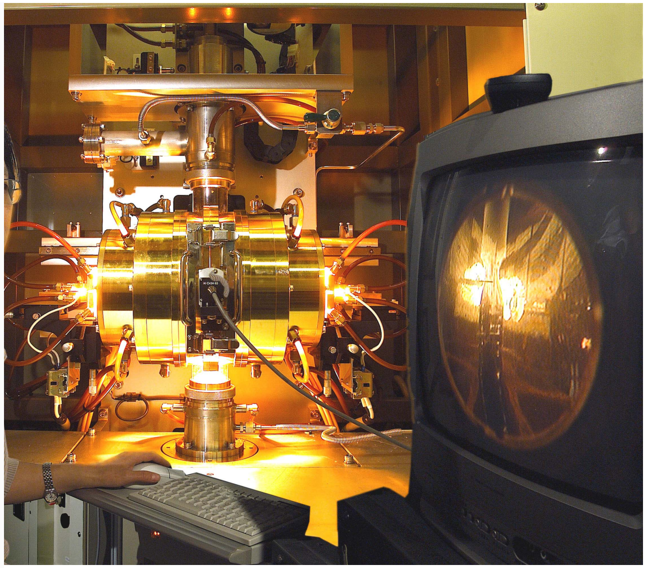
Floating-Zone technique



There is one in my lab – room 62

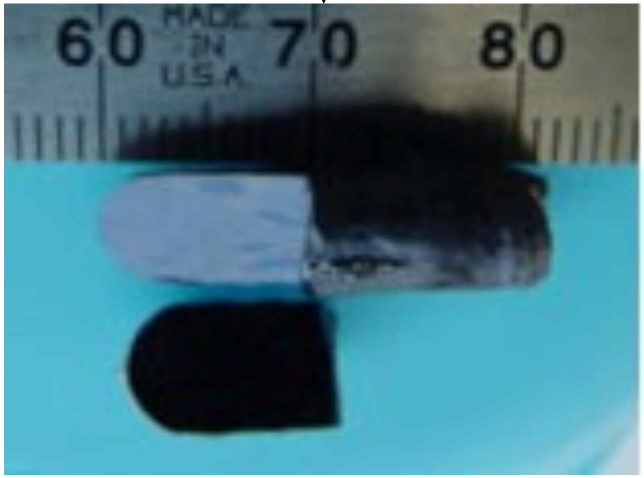
Floating-Zone Technique

Crucible Free →

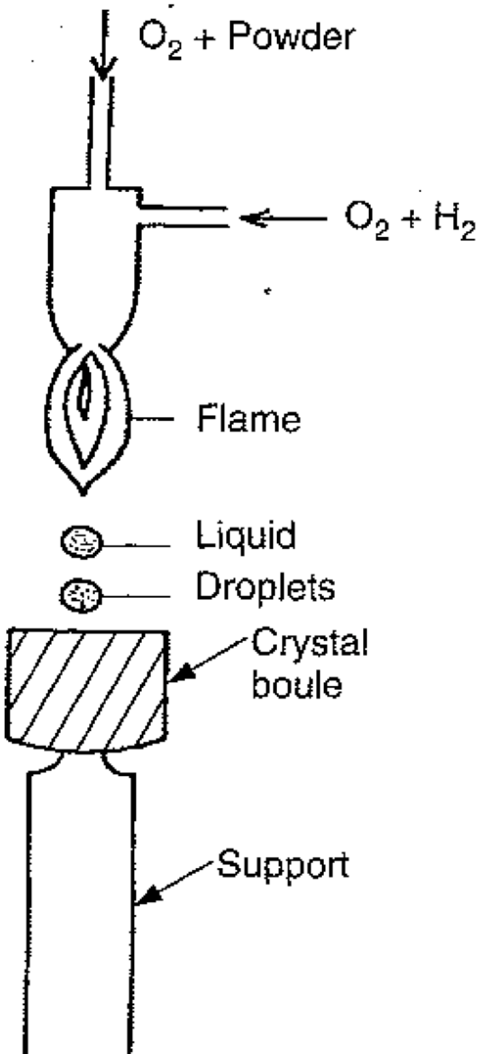


↓

Contamination Free →

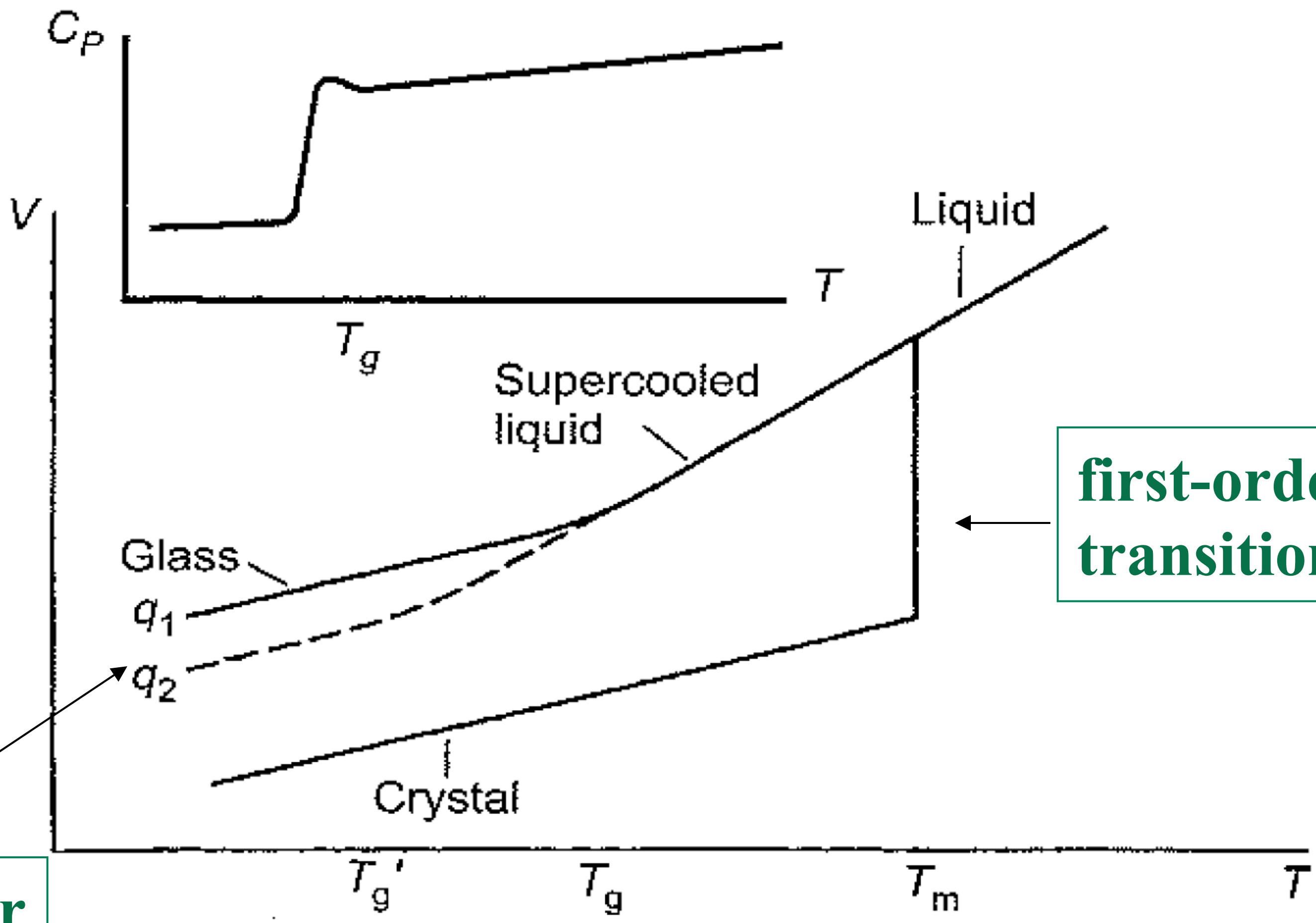


Verneuil Method
-- another crucible-free technique



Arc Melt Method

Final Form Depends on Cooling Rate



first-order transition

second-order transition

Single Crystal Growth from Solution (flux method)

Solution (flux):

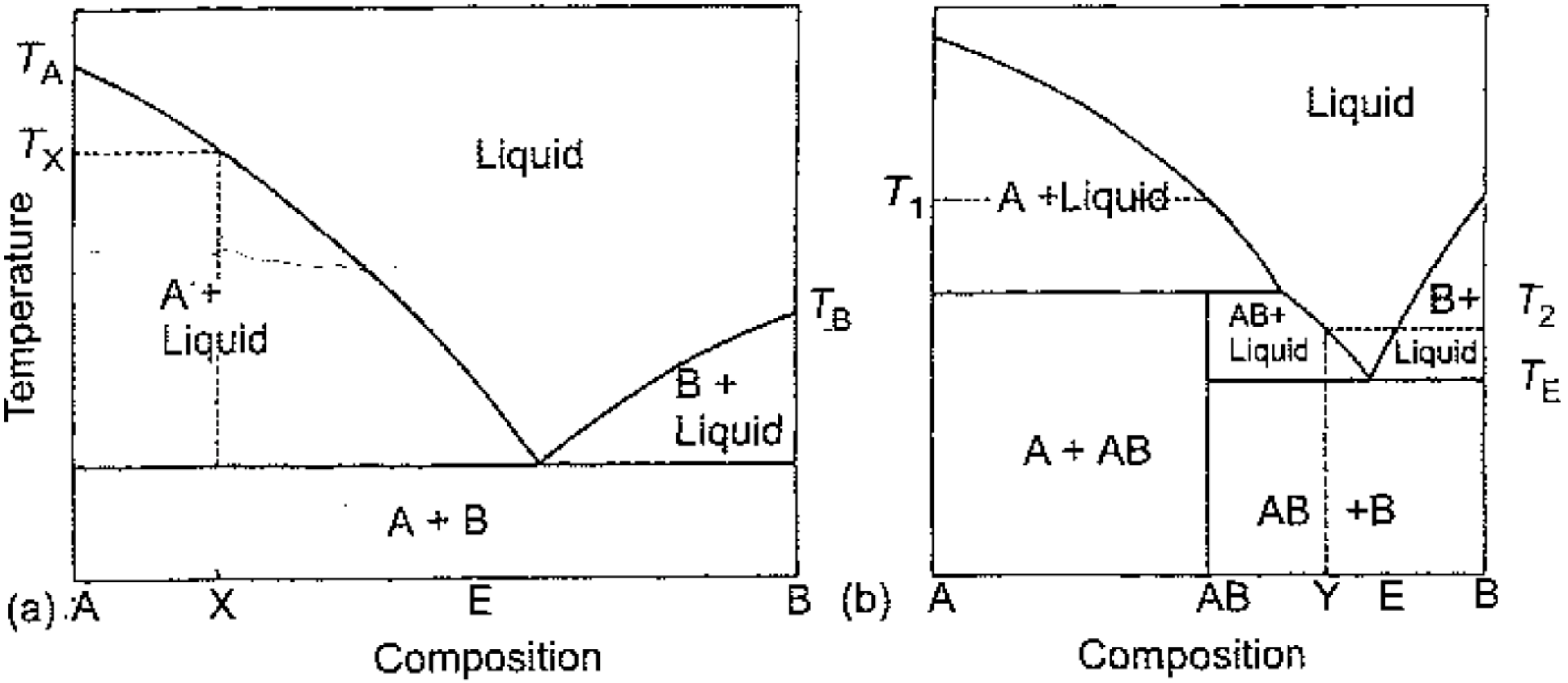
dissolve the material to be crystallized

Crystallization:

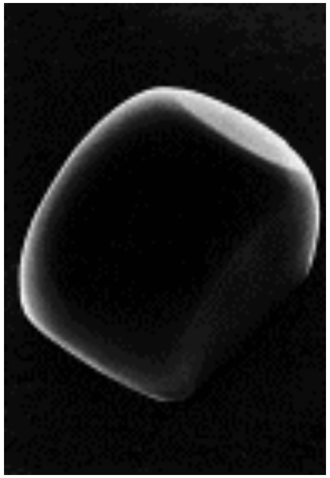
by reducing the temperature;

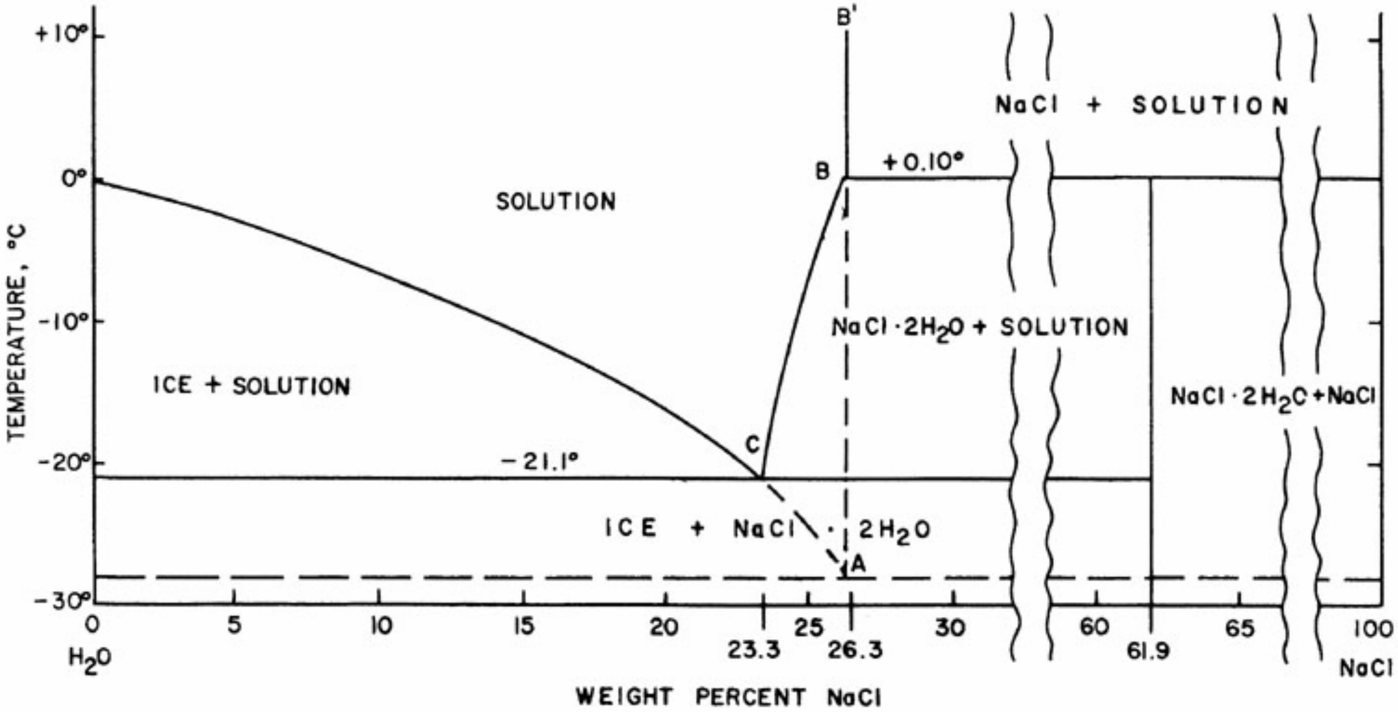
by removing some of the solvent (flux)

Single Crystal Growth from Solution (flux method)



Example I: NaCl Single Crystals Grown from H_2O





The system H_2O-NaCl. Data from various sources (Int. Crit. Tables IV, p. 235, 1928).

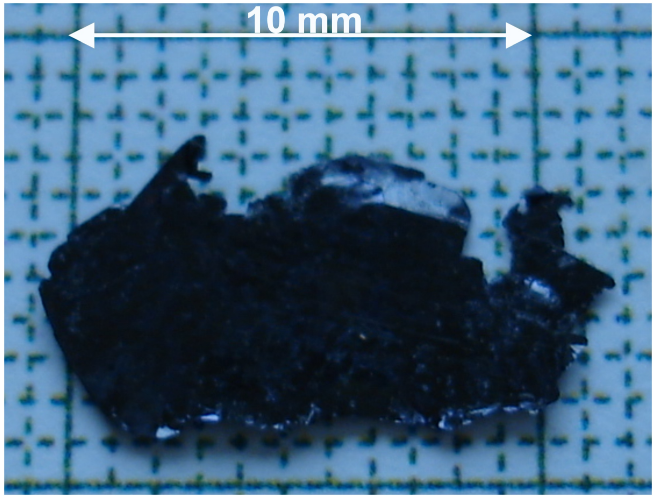
Example II: $Ca_3Co_4O_9$ Single Crystals Grown from K_2CO_3 and KCl

$$Ca_3Co_4O_9 + \underline{(K_2CO_3+KCl)} \rightarrow Ca_3Co_4O_9$$

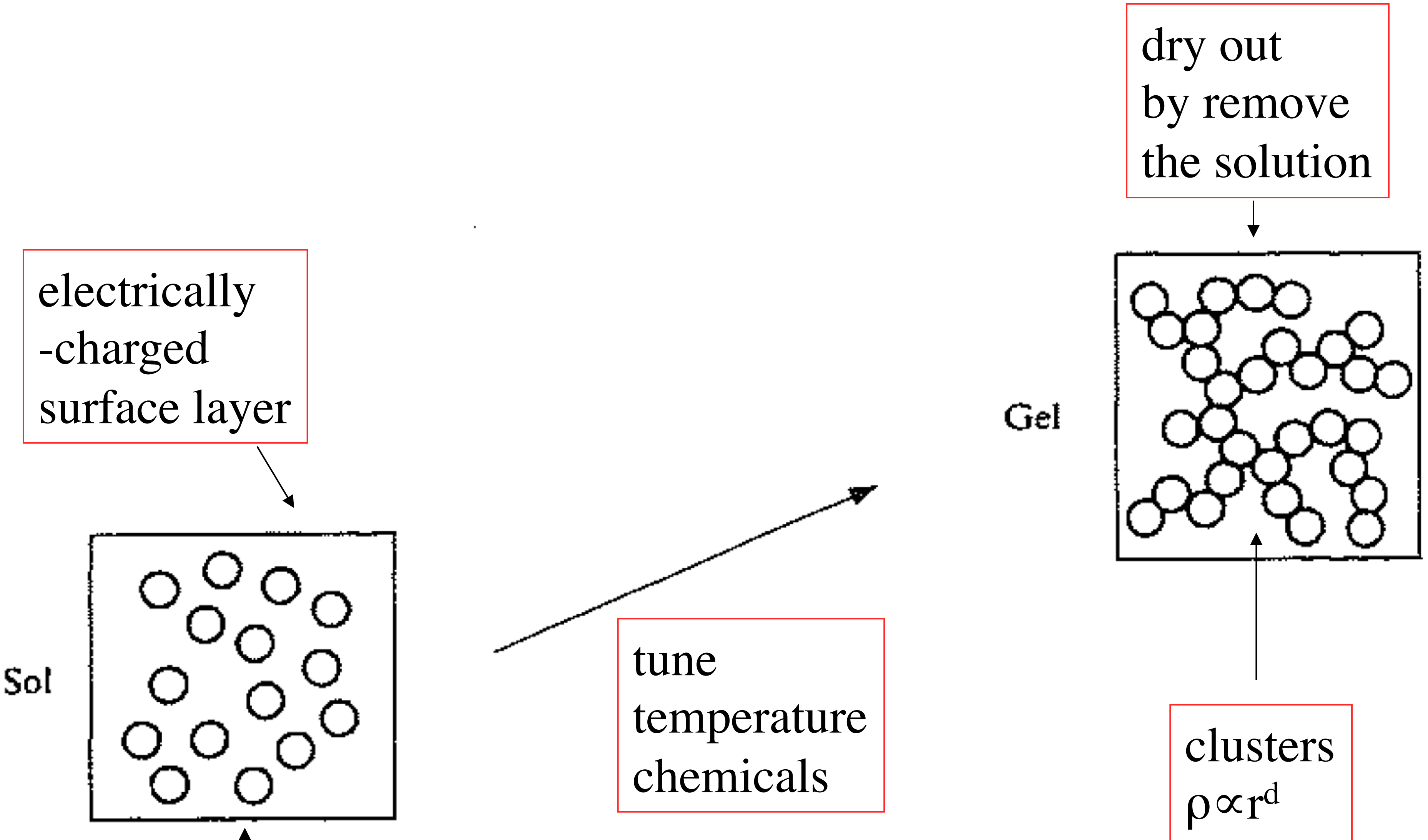
polycrystal

flux (solution)

Single crystals



Materials with Flexible Shapes and Forms Using Sol-Gel Method



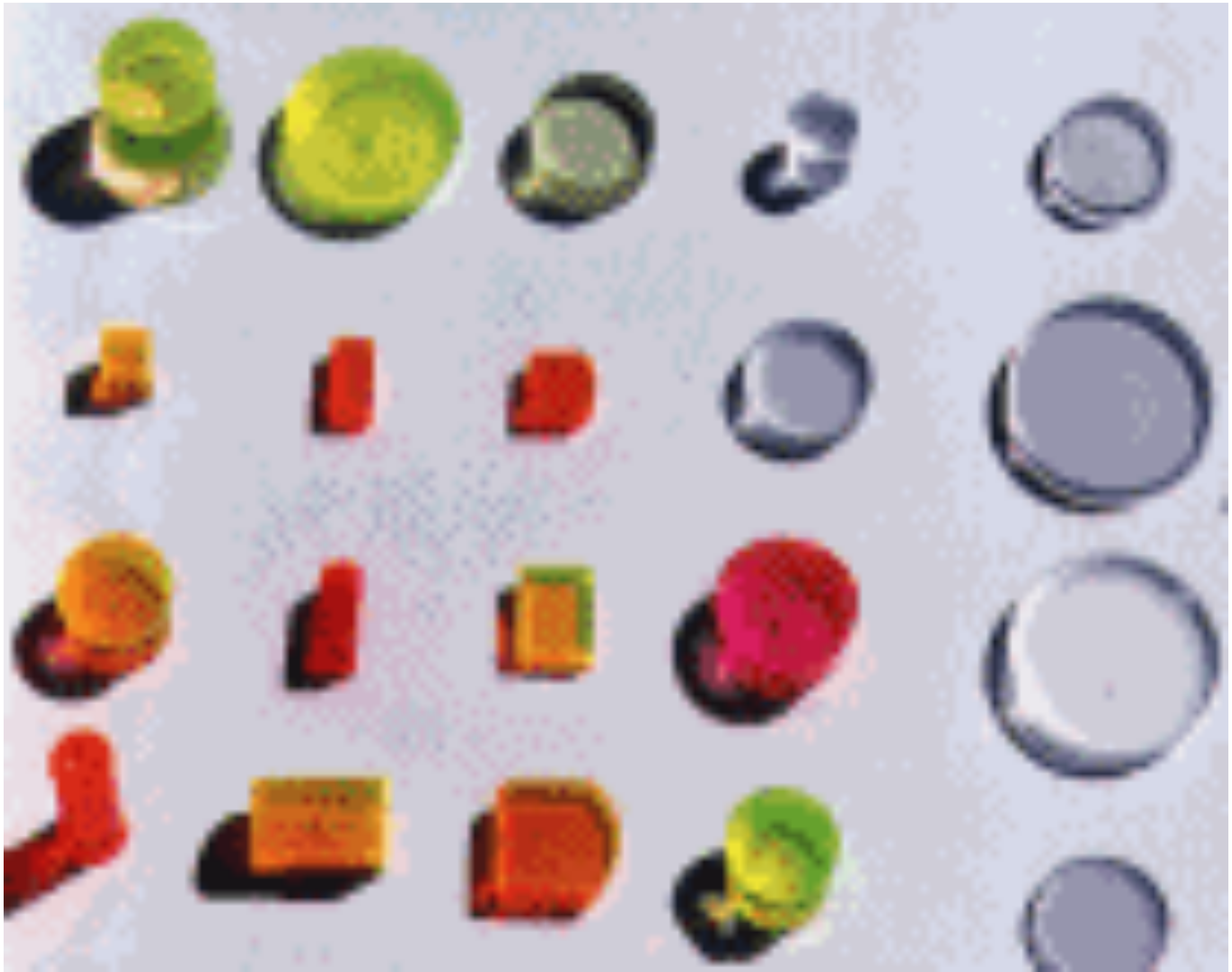
electrically
-charged
surface layer

tune
temperature
chemicals

dry out
by remove
the solution

clusters
$\rho \propto r^d$

Smart Optical Materials by Sol-Gel Method

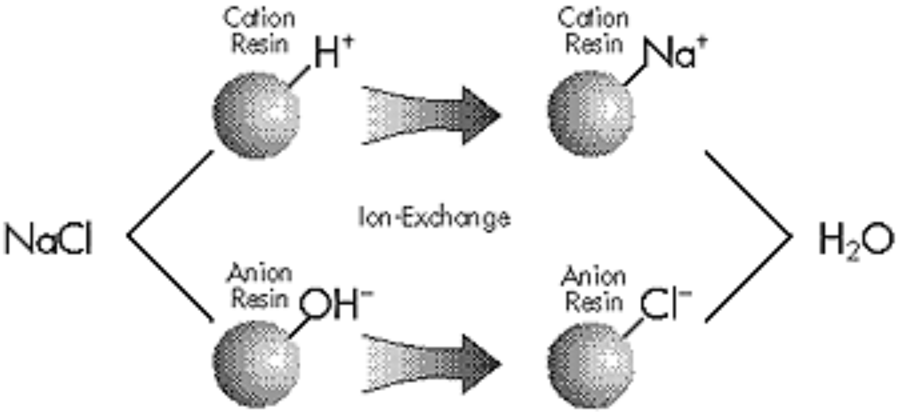


Single Crystal Growth from Ion Exchange

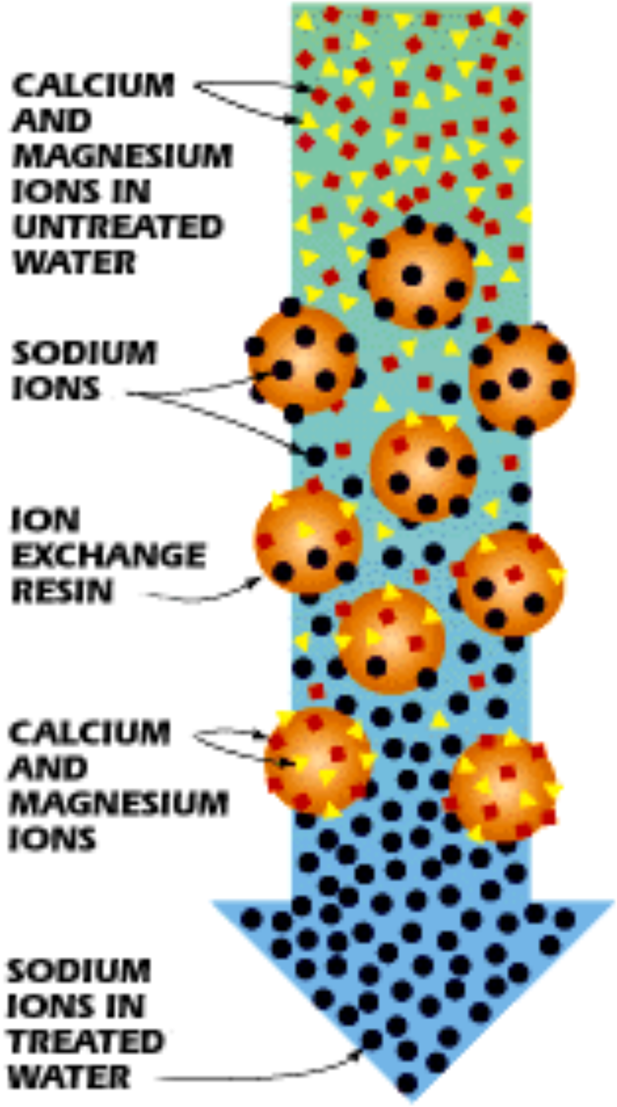
The replacement of one type of ion present in the structure of a material by another type

Easily exchangeable cations are monovalent

Example:
Water Softening via Ion Exchange



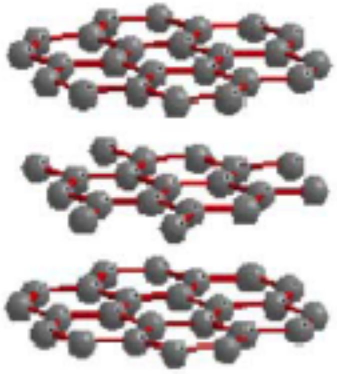
$2Na^+ \rightarrow Ca^{2+}$ or Mg^{2+}



Single Crystal Growth from Intercalation

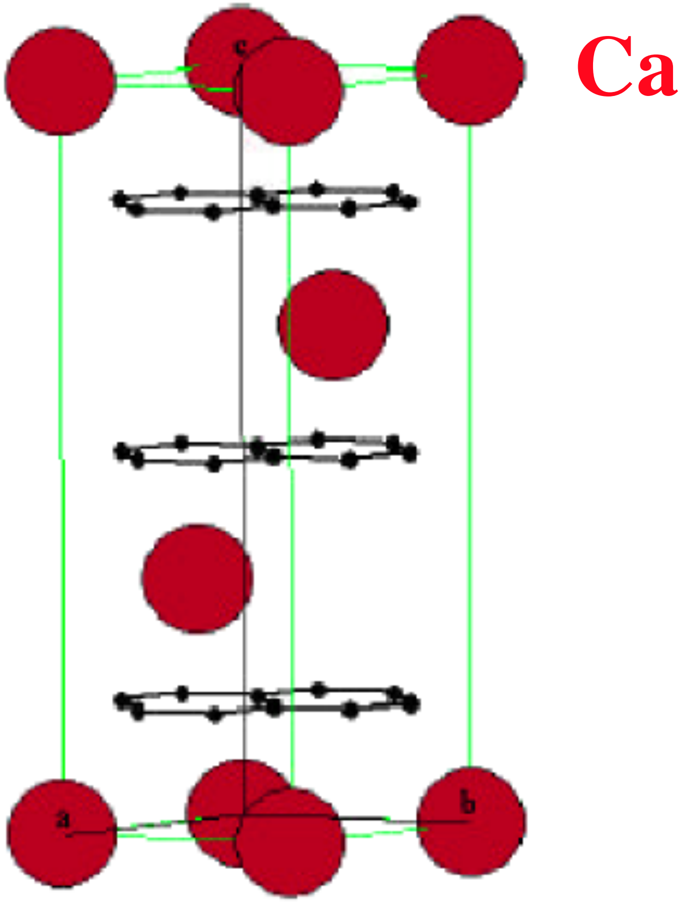
The insertion of a chemical species into the structure of a material which did not exist before

Example I: Ca Inserts into Graphite



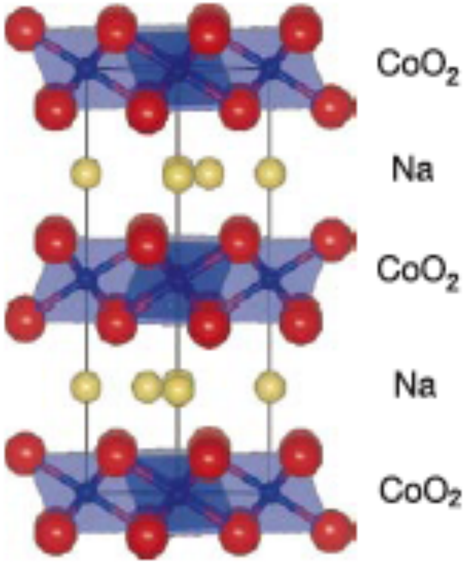
graphite

+ Ca →



Example II: Water Inserts into $Na_{0.35}CoO_2$

$Na_{0.35}CoO_2$

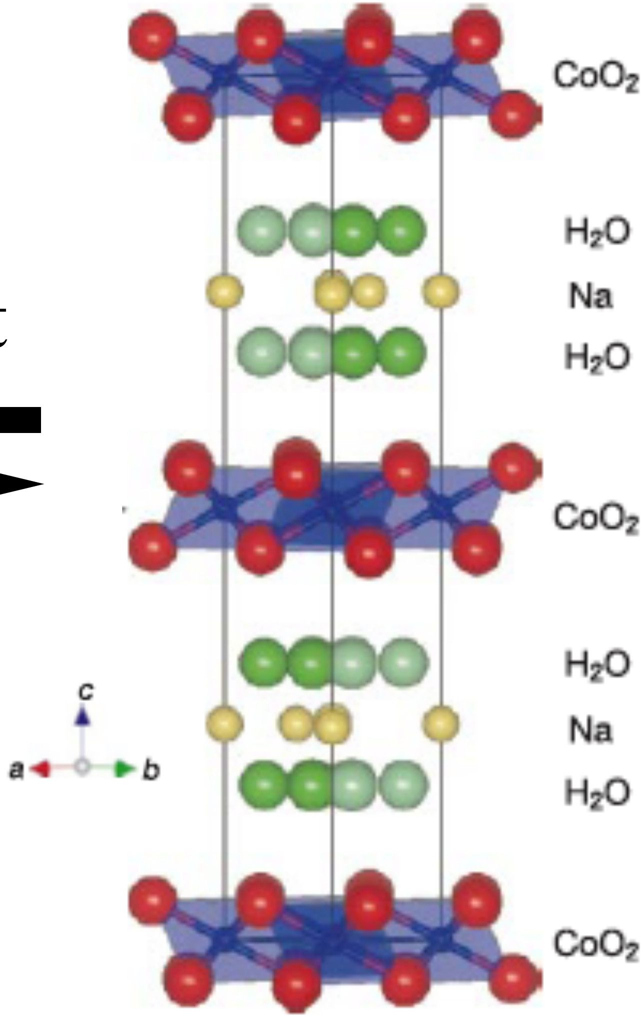


NO S.C.

water out

water in

$Na_{0.35}CoO_2 \cdot 1.3H_2O$



S.C.

Summary: Liquid to Solid Synthesis and Preparation

Melt

Liquid quenching

gentle chemistry (*chimie douce*)

- **Solution**
- **Sol-gel**
- **Ion exchange and intercalation**

Solid to Solid Synthesis and Preparation

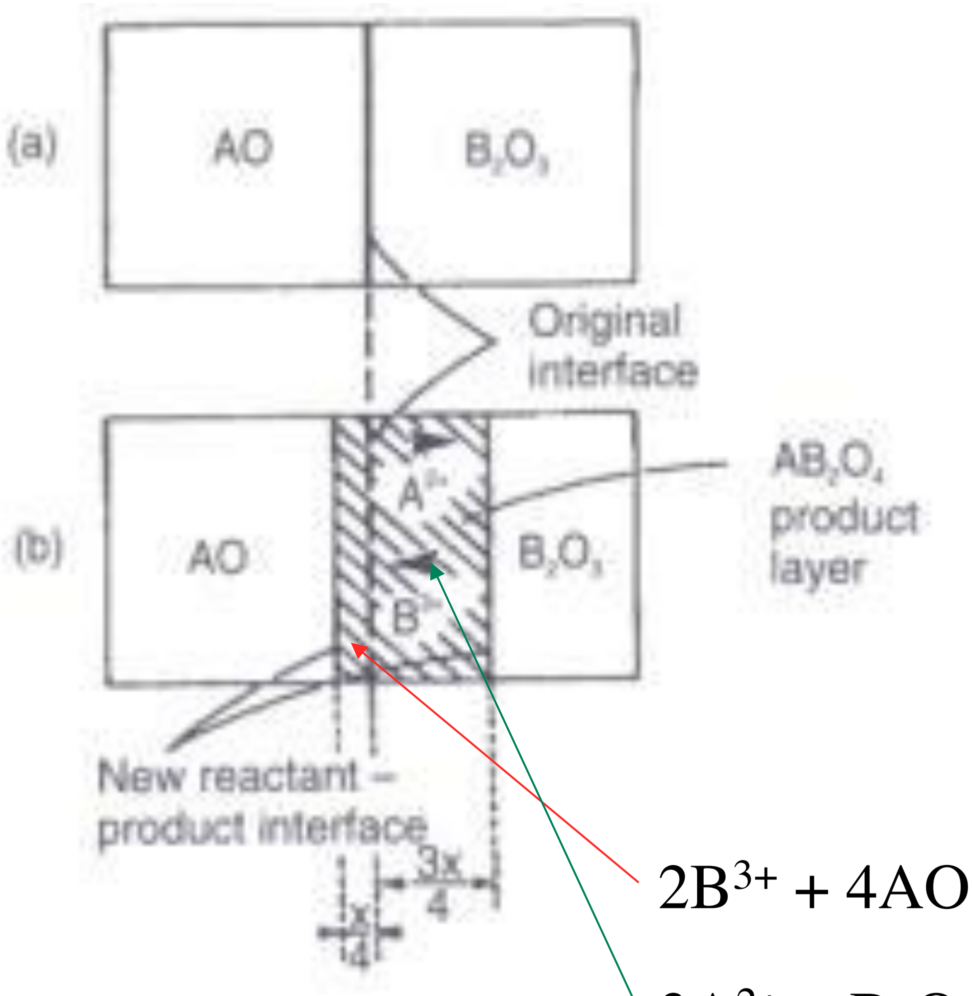
Solid-state reactions

High-pressure synthesis and preparation

Glass ceramics

Solid State Reactions: Slow

$AO + B_2O_3 \rightarrow AB_2O_4$



In practice, try to mix starting materials AO and B_2O_3 as well as possible, so that there are more interfaces (contact) for reaction

$2B^{3+} + 4AO - 3A^{2+} \rightarrow AB_2O_4$

$3A^{2+} + B_2O_3 -2B^{3+} \rightarrow 3AB_2O_4$

High-Pressure Synthesis and Preparation

solid

high pressure

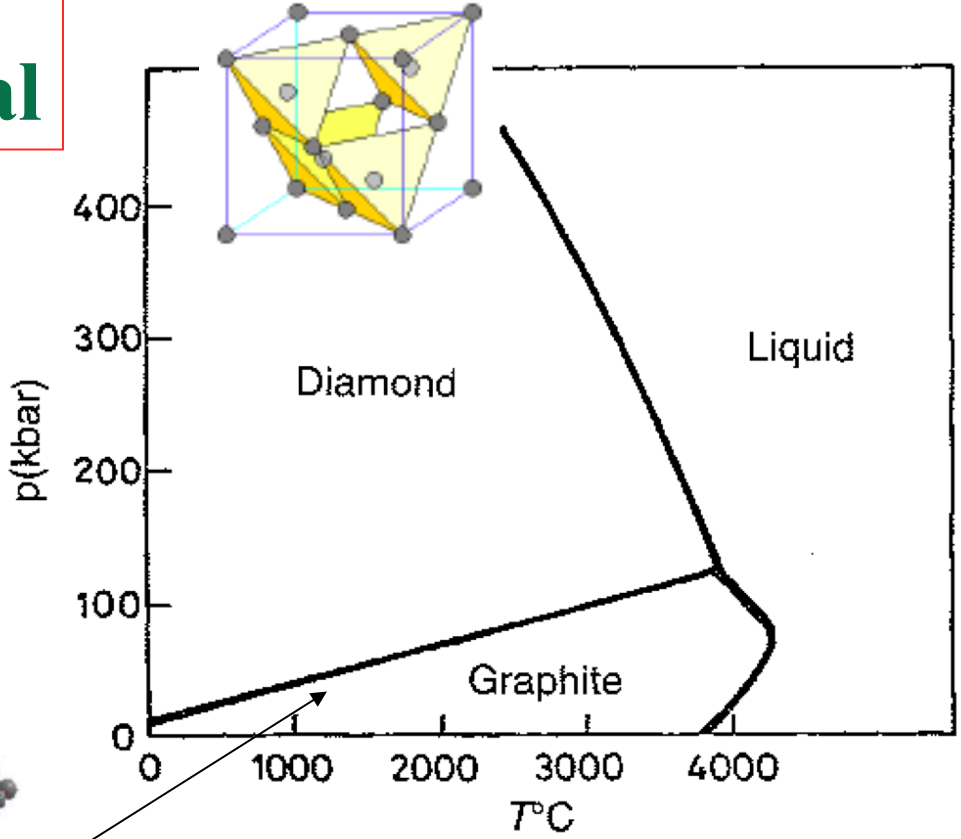
solid with
higher density or
higher coordination number

pressure quenching

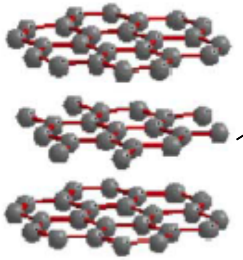
stabilized at ambient pressure

Example: Diamond Formation via High-Pressure

hardest bulk material



soft



Glass-Ceramics Synthesis and Preparation

fine-grained (~ 0.1 μm) polycrystalline microstructure

nuclei-size control

$T_{nucleation}$, T_{growth}

Summary:
Solid to Solid Synthesis and Preparation

Solid-state reactions

(widely used by condensed-matter physicist)

High-pressure synthesis and preparation

Glass ceramics

Homework today (due on Sept. 2, 2010)

1. Problems 1.4 in pages 39 of the copy (Synthesis and Preparation of Materials);
2. Problems 1.6 in pages 40 of the copy (Synthesis and Preparation of Materials);
3. From a consideration of the phase diagram for carbon (Fig. 1.26), how would you try to synthesize diamond?
4. If you are asked to make 1 mole $MgAl_2O_4$ through solid-state reaction (eqn.1.26), what kinds of starting materials (composition and amount for each material) do you need?