MATERIALS SCIENCE

MS31007

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and
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Class Schedule

Wednesday :	**9:30 – 10:30**
Friday:	**10:30 – 12:30**

An introduction to the world of materials!

What is the structure of materials?

How does this influence the properties we observe?

What is the interplay between structure, properties and processing?

Syllabus: Structure and Bonding, Defects and their influence on properties, Thermodynamics of Materials, Kinetic Processes, Heat and Mass Transport, Mechanical Properties and Composites, Electrical, Magnetic and Optical Properties, Materials Processing, Case Studies and Advanced Topics

Text: AN INTRODUCTION TO MATERIALS ENGINEERING AND SCIENCE
FOR CHEMICAL AND MATERIALS ENGINEERS
Brian S. Mitchell
A JOHN WILEY & SONS, INC., PUBLICATION

Other references:

William Callister Jr., Materials Science and Engineering - An Introduction Wiley

Donald Askeland and Pradeep Phule, The Science and Engineering of Materials (4th Edition) // Thomson

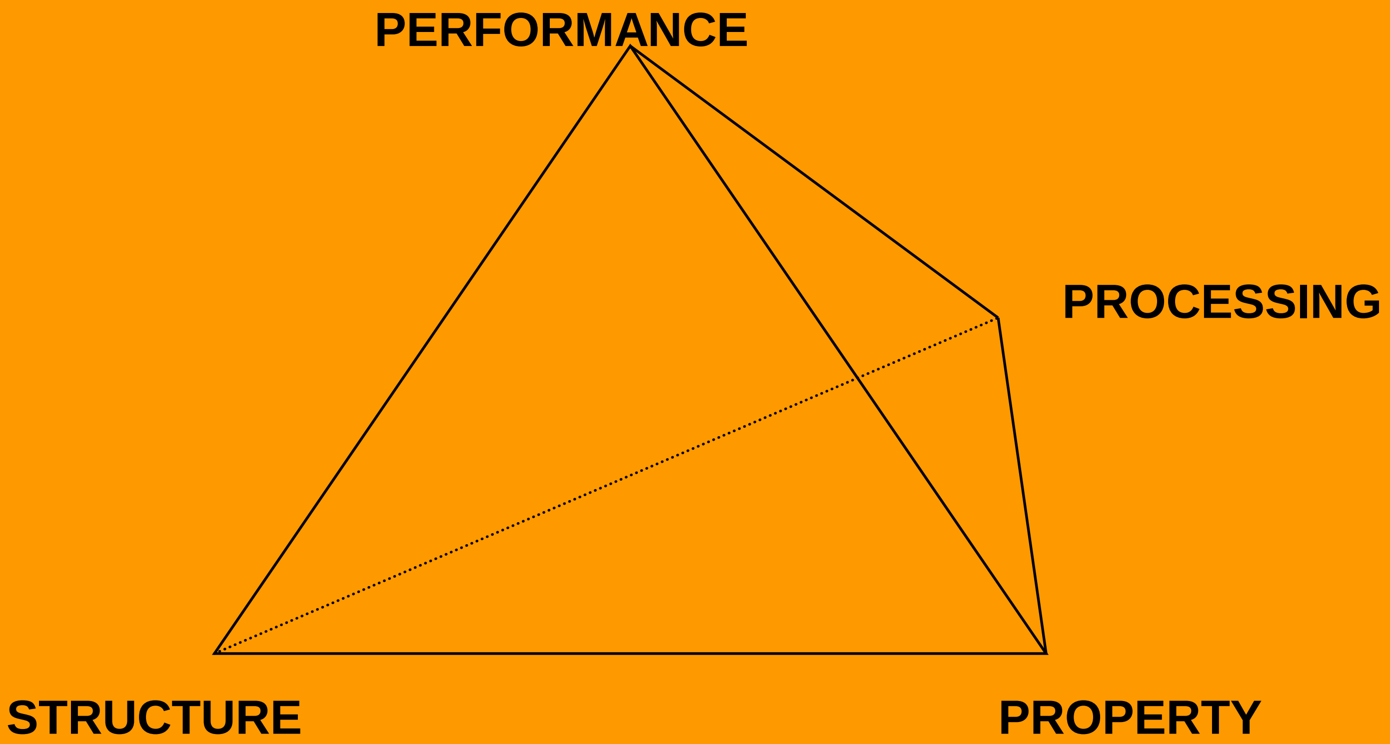
William F. Smith, Principles of Materials Science and Engineering, McGraw Hill

Various Internet Websites

<u>Policies:</u>

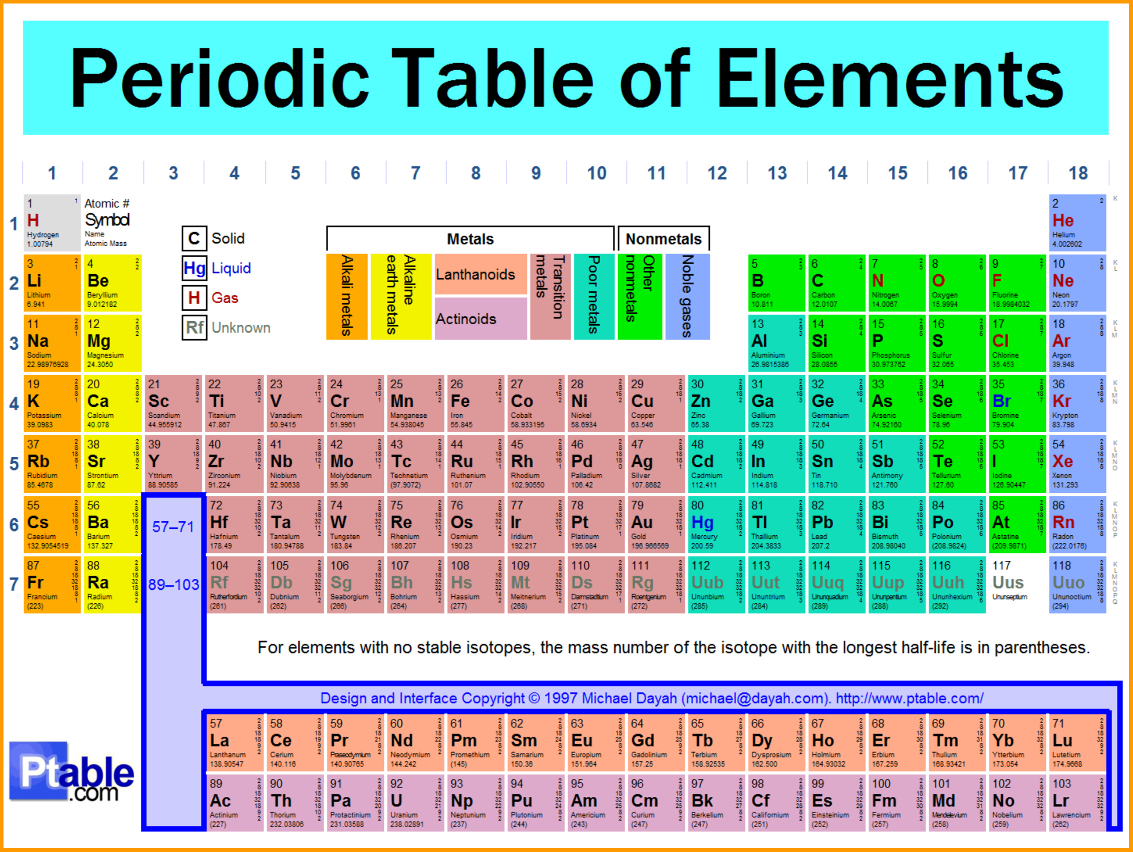
1. **Attendance will be taken**
2. **Interactive classroom: I expect you to ask questions and I will do the same.**
   The teacher is not always right
   The teacher does not always have the right answers
3. **Exams will in general be closed book unless otherwise stated. Formulas will be given (except the simplest ones). It will test your understanding and not your ability to memorize everything.**
4. **Zero tolerance of plagiarism and cheating. If I suspect someone has copied from someone else, <u>both</u> will get zero. It is up to you to convince me that there was no copying. You can discuss problems for homeworks, but you cannot simply copy the solutions.**
5. **Make sure your handwriting is legible and your English is understandable. I will not waste time trying to ‘decode’ bad handwriting and poor English!**
6. **Absolutely NO MOBILES!!!! You will be expelled from the course!**

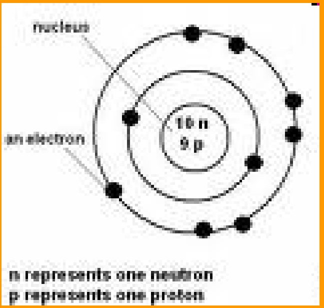
MATERIALS SCIENCE



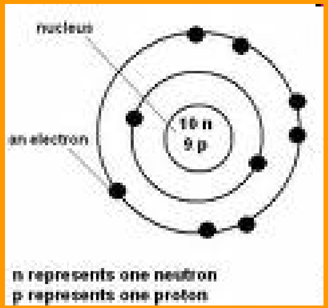
STRUCTURE

- Electronic Structure

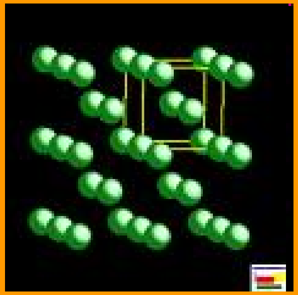




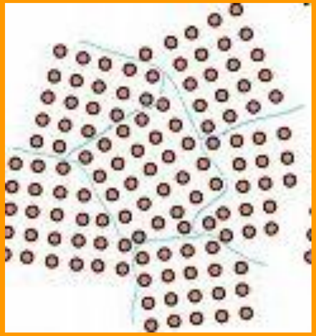
STRUCTURE



- Electronic Structure

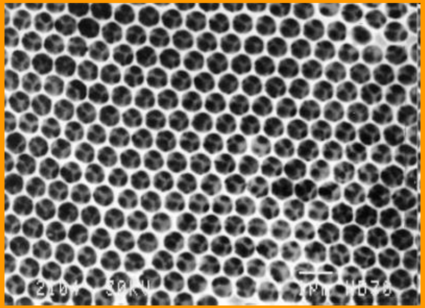


- Atomic Structure

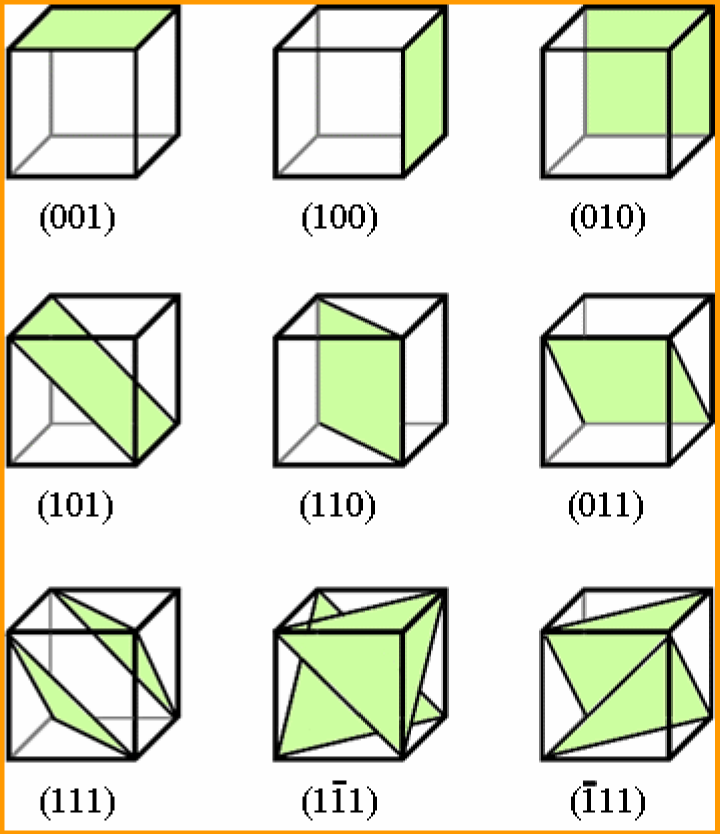


- Microscopic Structure

- Macroscopic Structure

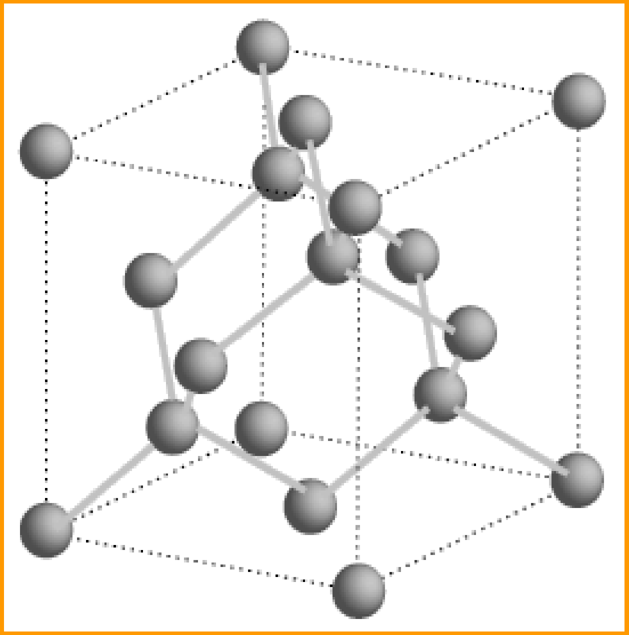


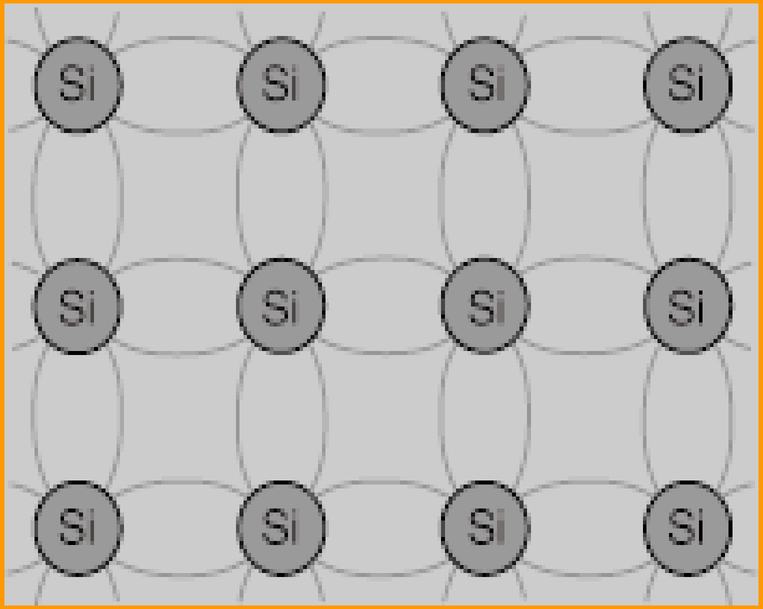
MILLER INDICES



Covalent Bonding

What is Covalent Bonding ?

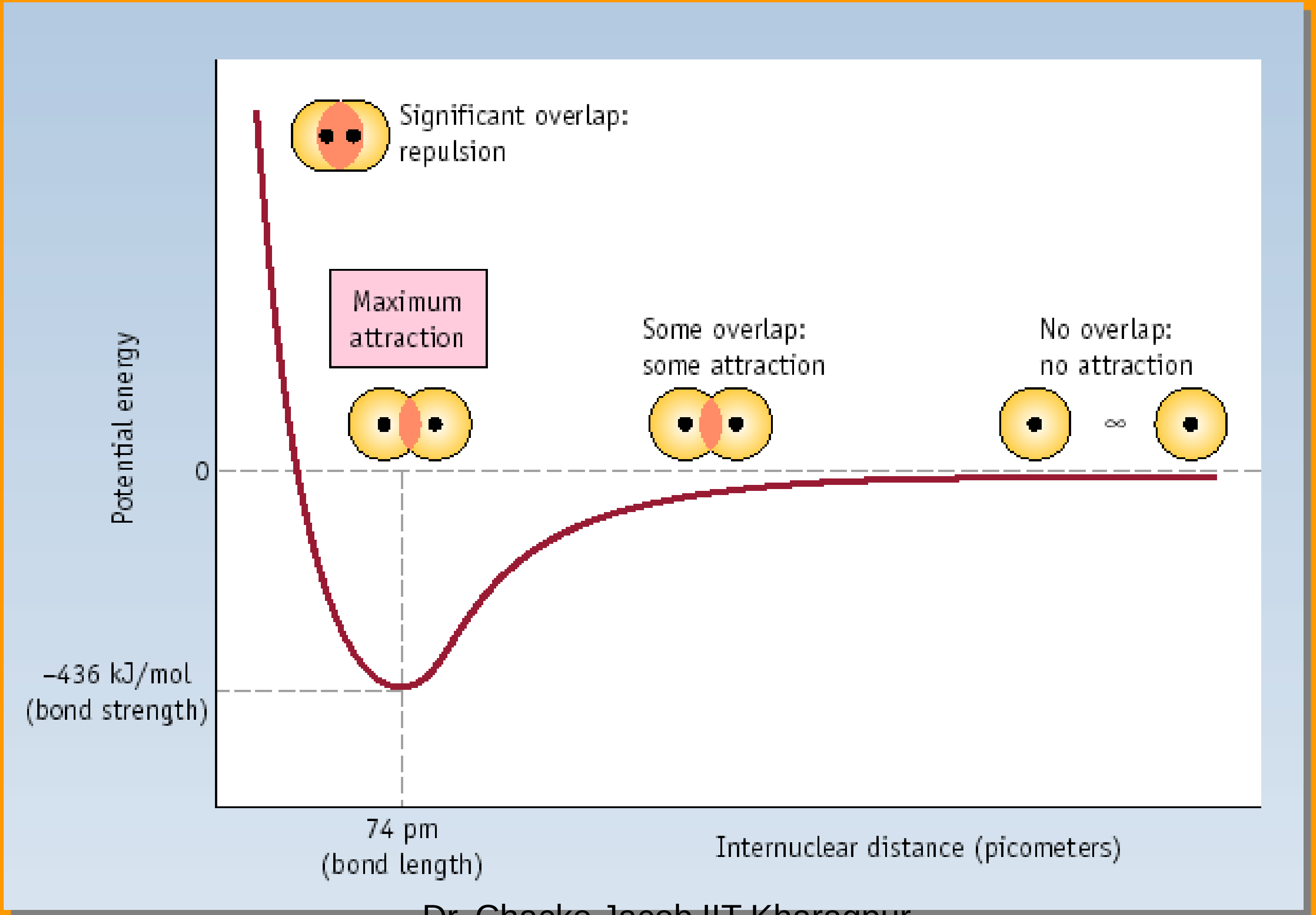




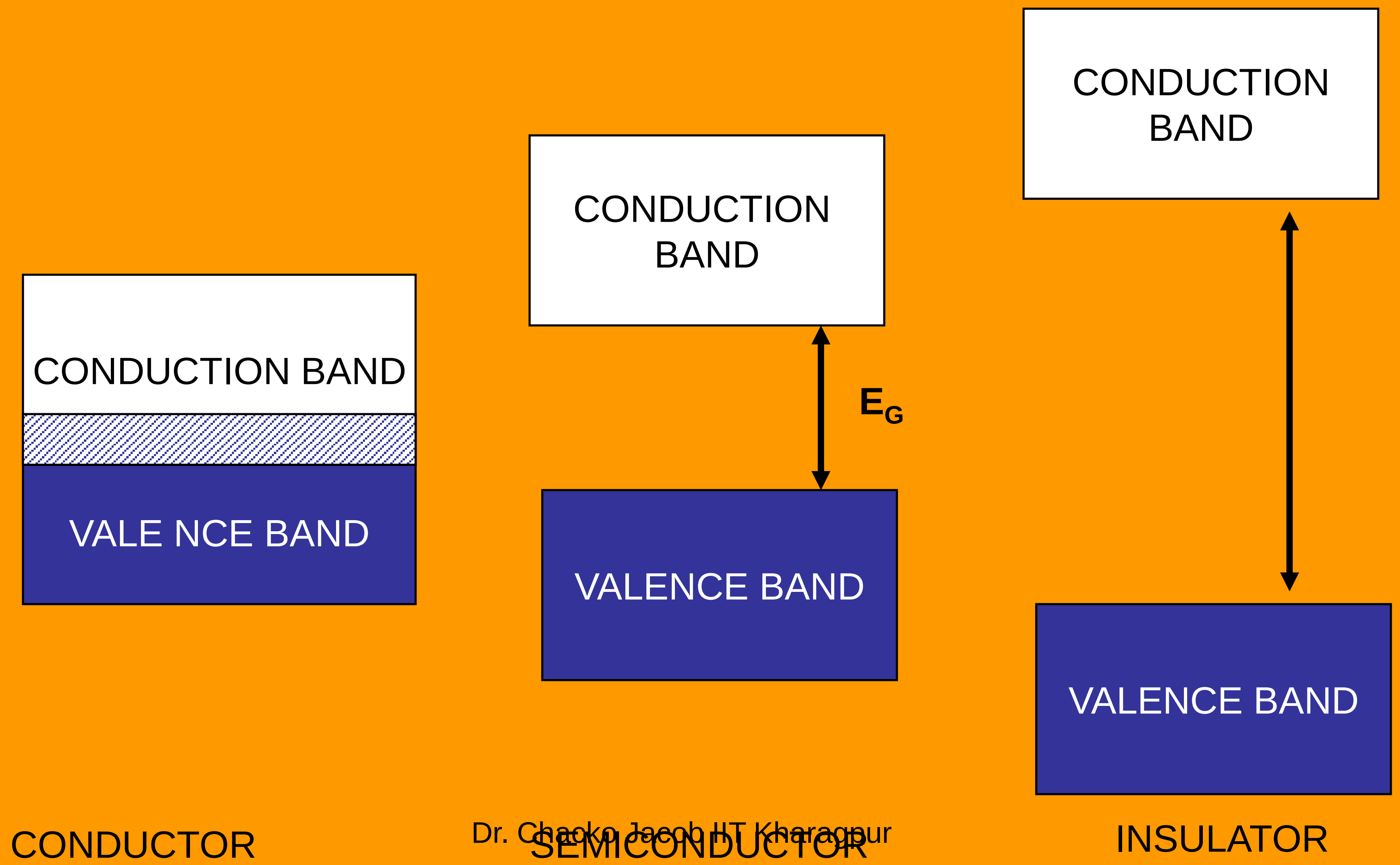
- **Bonds are filled lower energy orbitals**
- **Two electrons per bond**
- **(4 electrons per Si) + (1 electron from each of 4 neighbors) = 8 electrons**

BONDING PRODUCES BANDS

Energy Diagram of Sigma Bond Formation by Orbital Overlap



BAND STRUCTURE OF MATERIALS



BONDING PRODUCES STRUCTURE

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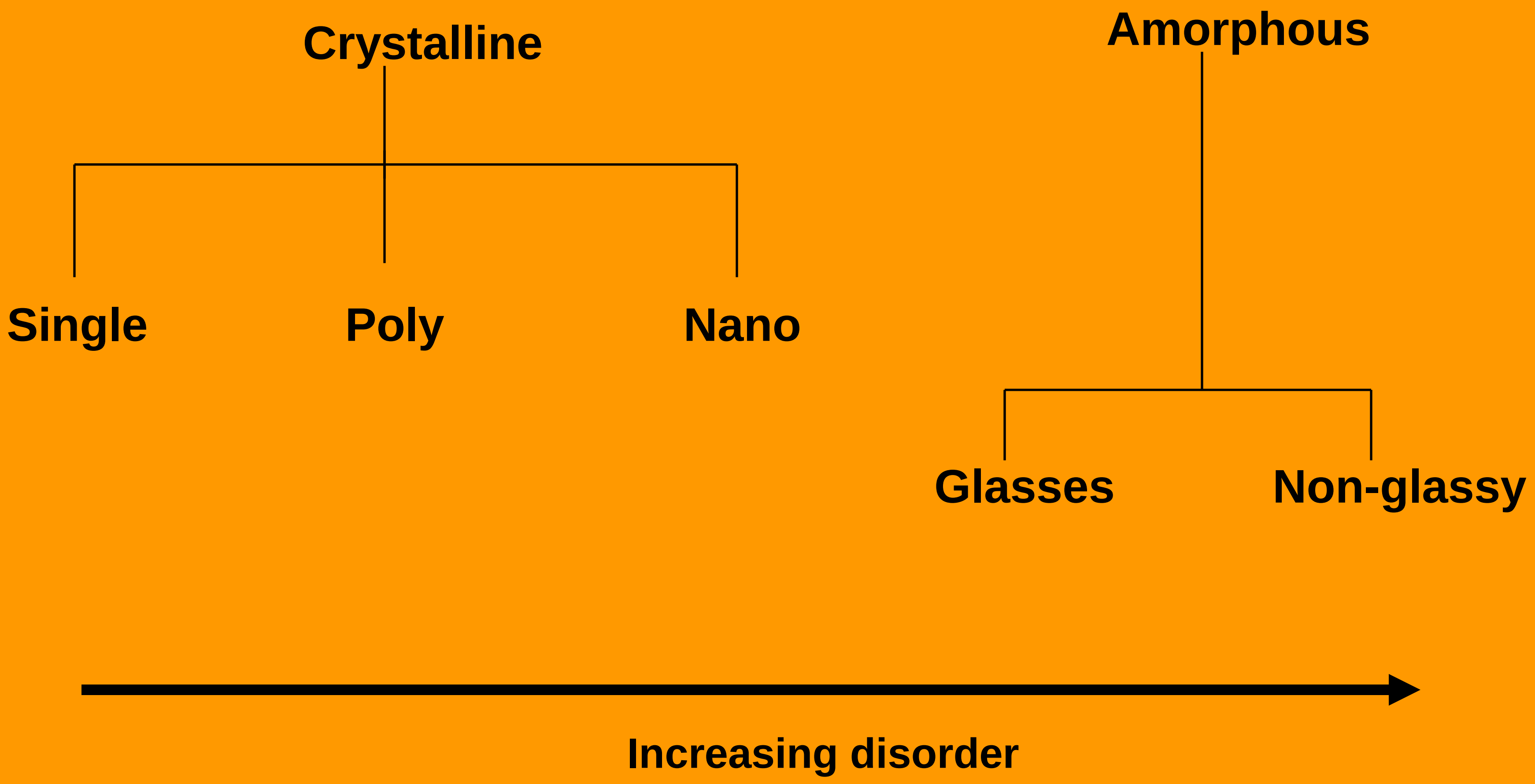
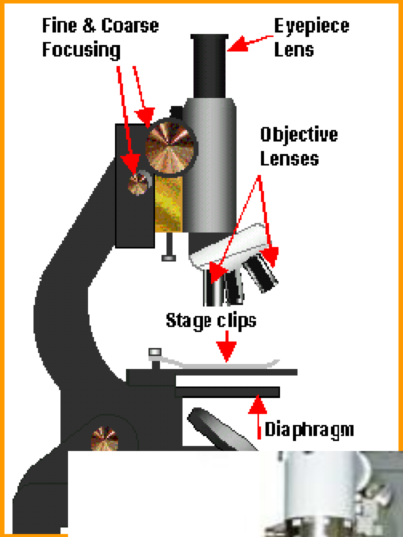
CRYSTAL STRUCTURE



A Bit of Microscopy History

Optical Microscope ~1700



TEM:1931

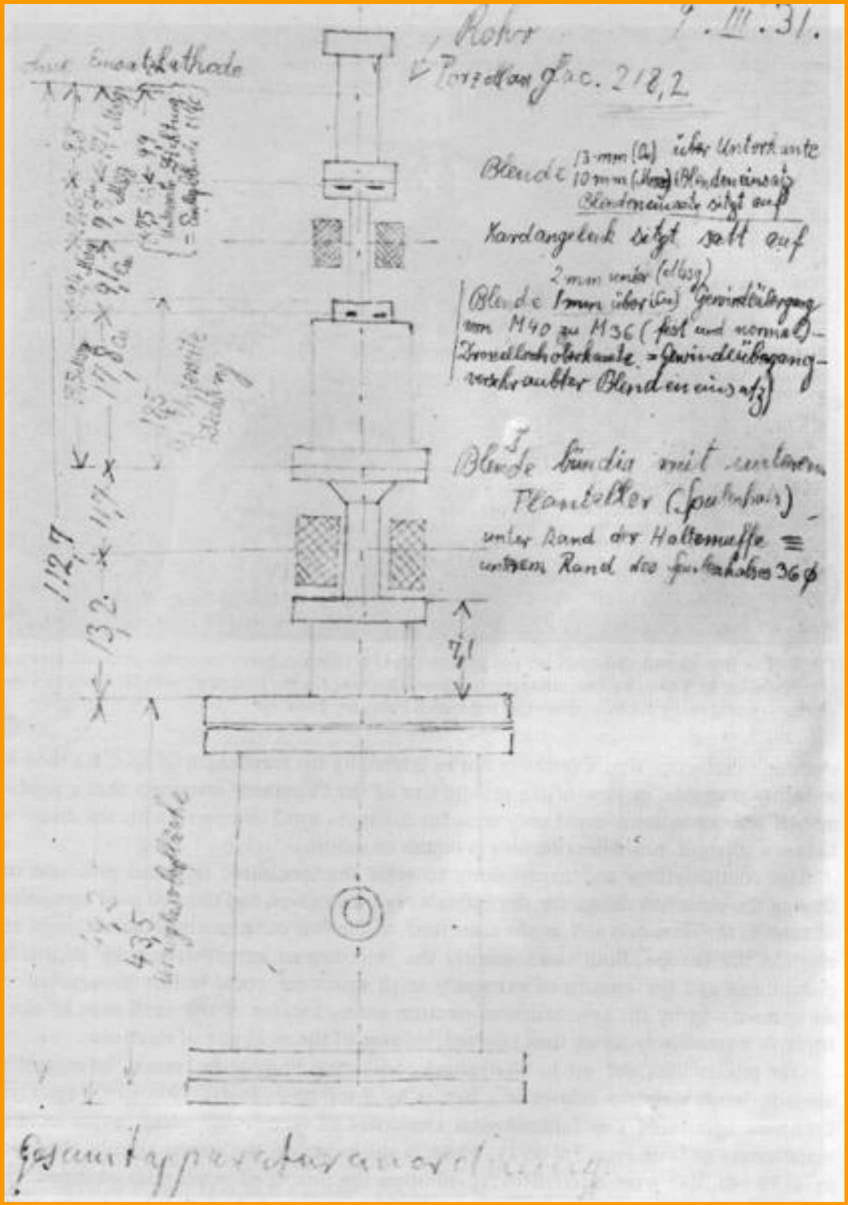
SEM: 1942

AFM: 1986

STM: 1981

Ernst Ruska Electron Microscope - Deutsches Museum - Munich

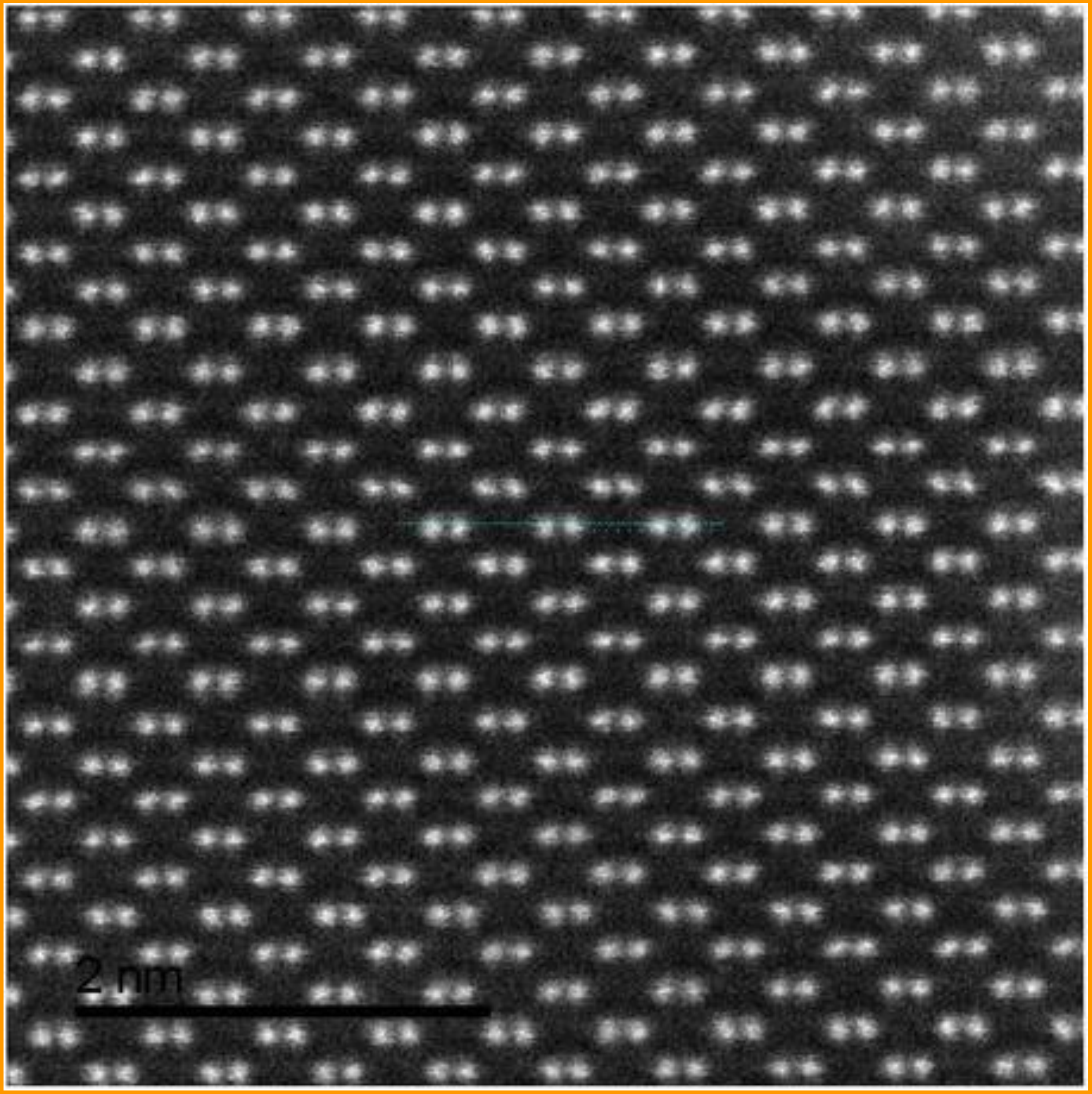
First Electron Microscope with Resolving Power Higher than that of a Light Microscope. Ernst Ruska, Berlin 1933 Replica by Ernst Ruska, 1980. For the first time the apparatus had a condensor in front of the specimen and two magnifying lenses. Magnification is around 12,000 times



A sketch from Ernst Ruska's laboratory book, depicting the design of an early TEM prototype. Sketch: 9th March 1931. Scan from "The early development of Electron lenses and Electron Microscopy, Ernst Ruska. Translation by Thomas Mulvey.

The DA-1 was JEOL's first commercial transmission electron microscope. Produced as a prototype prior to the founding of JEOL, it was completed and shipped to Mitsubishi Chemical Industry late in 1947.

JEM-ARM 200F



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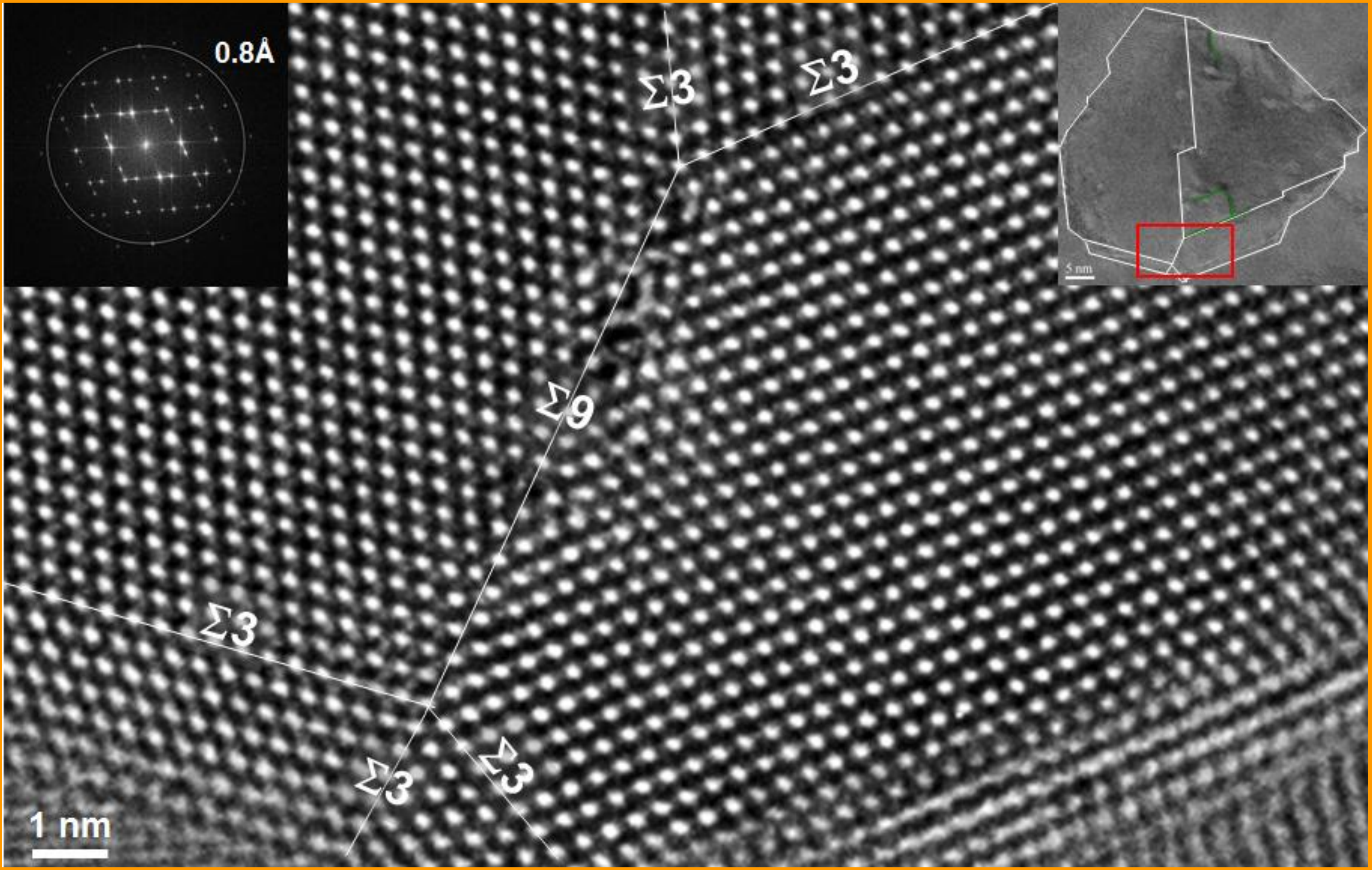
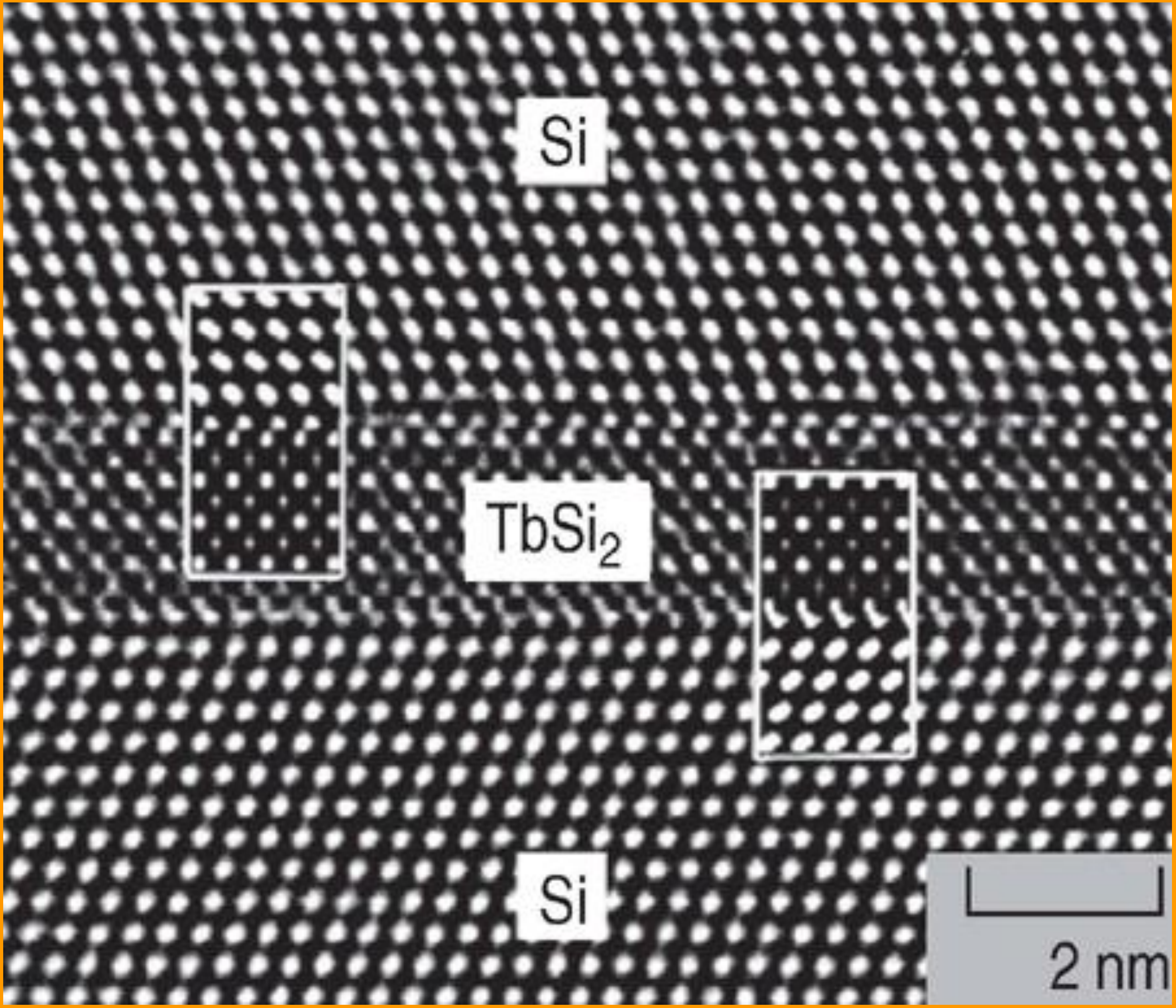
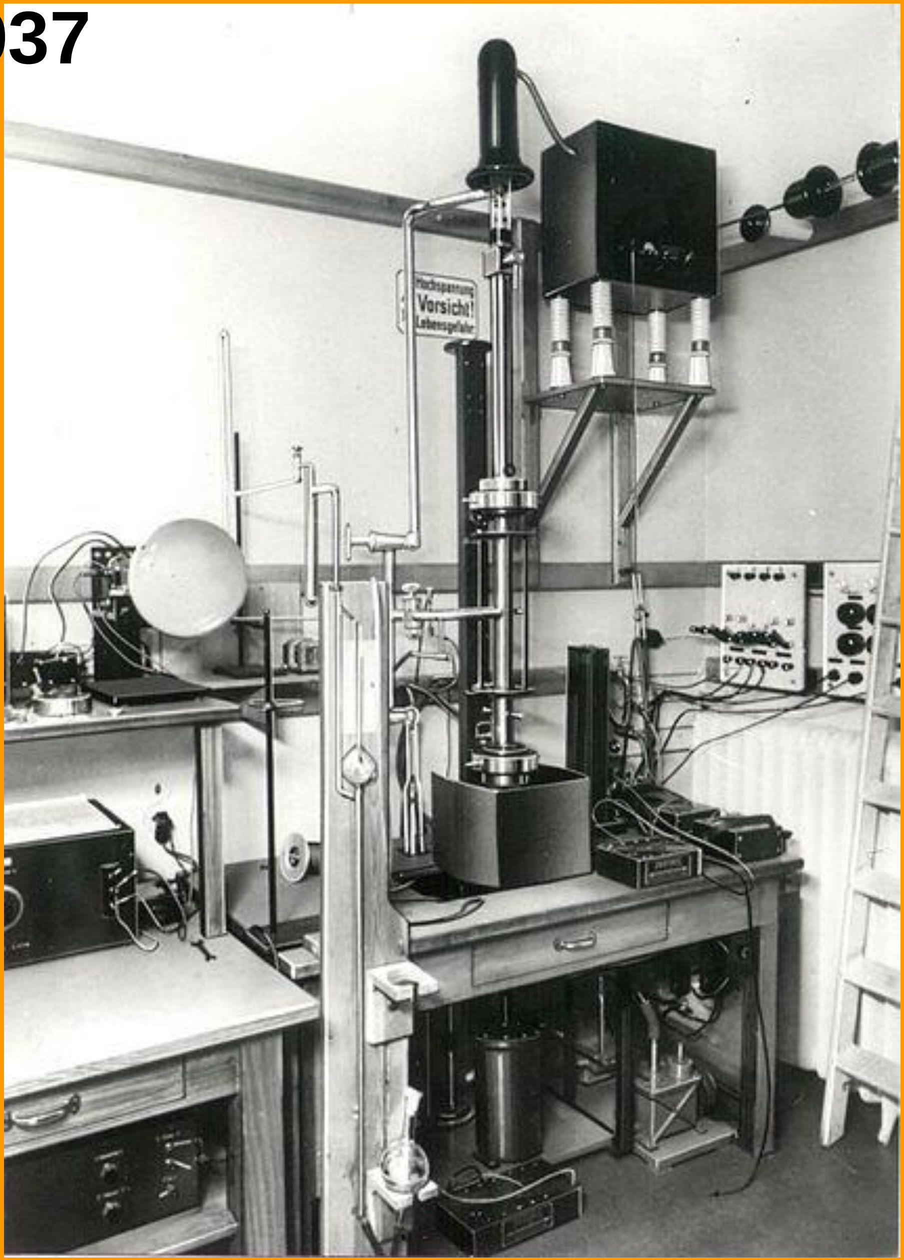
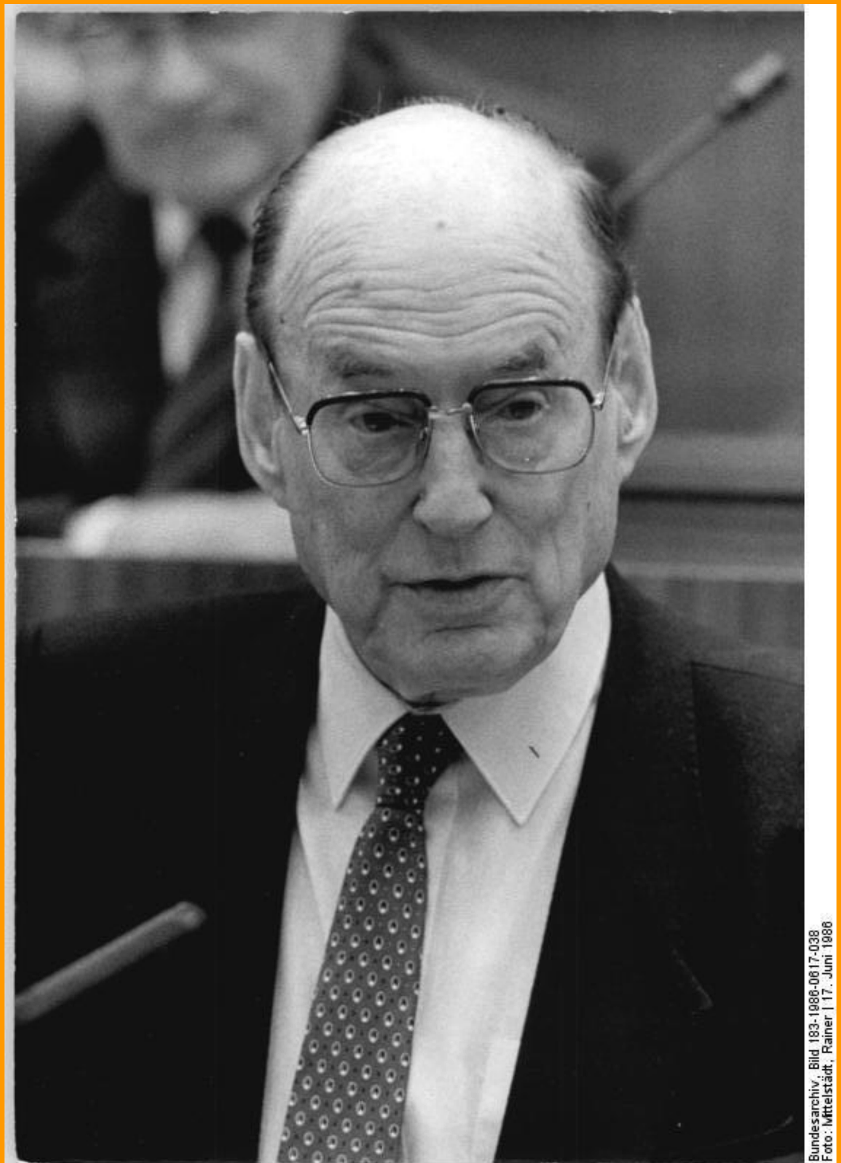

0.8Å
Σ3
Σ3
Σ9
Σ3
Σ3
Σ3
1 nm
5 nm


Si
TbSi$_2$
Si
2 nm

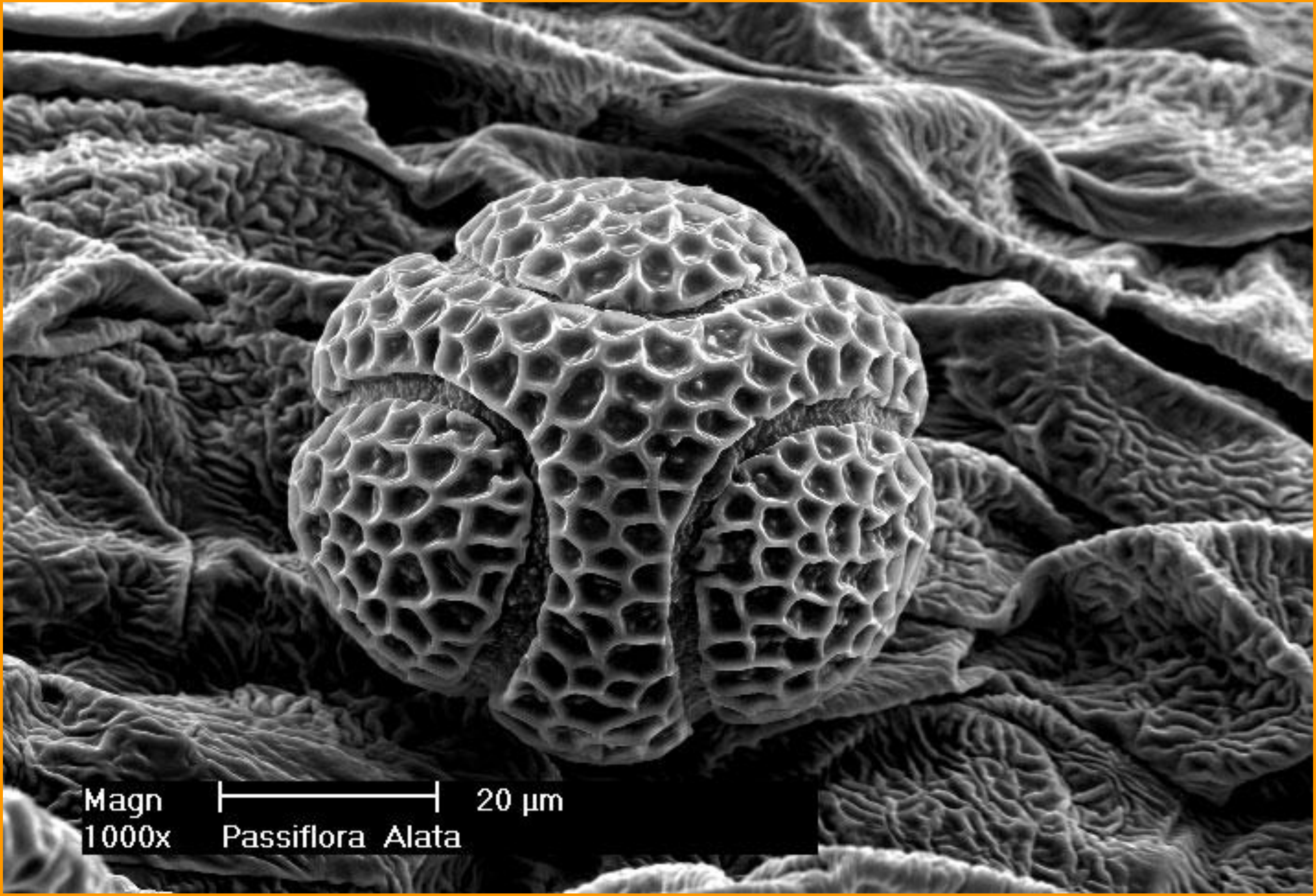
First scanning electron microscope of high resolution 1937




Bundesarchiv, Bild 183-K0017-500
Foto: o.Ang. | 1930


Bundesarchiv, Bild 183-1986-0617-038
Foto: Mittelstädt, Rainer | 17. Juni 1986

Prof. Dr. h. c. mult. Manfred von Ardenne
(1907 – 1997)
32 scientific Monographs
4 popular scientific books
autobiography in 14 mostly revised editions
about 700 scientific works and publications
about 600 patents



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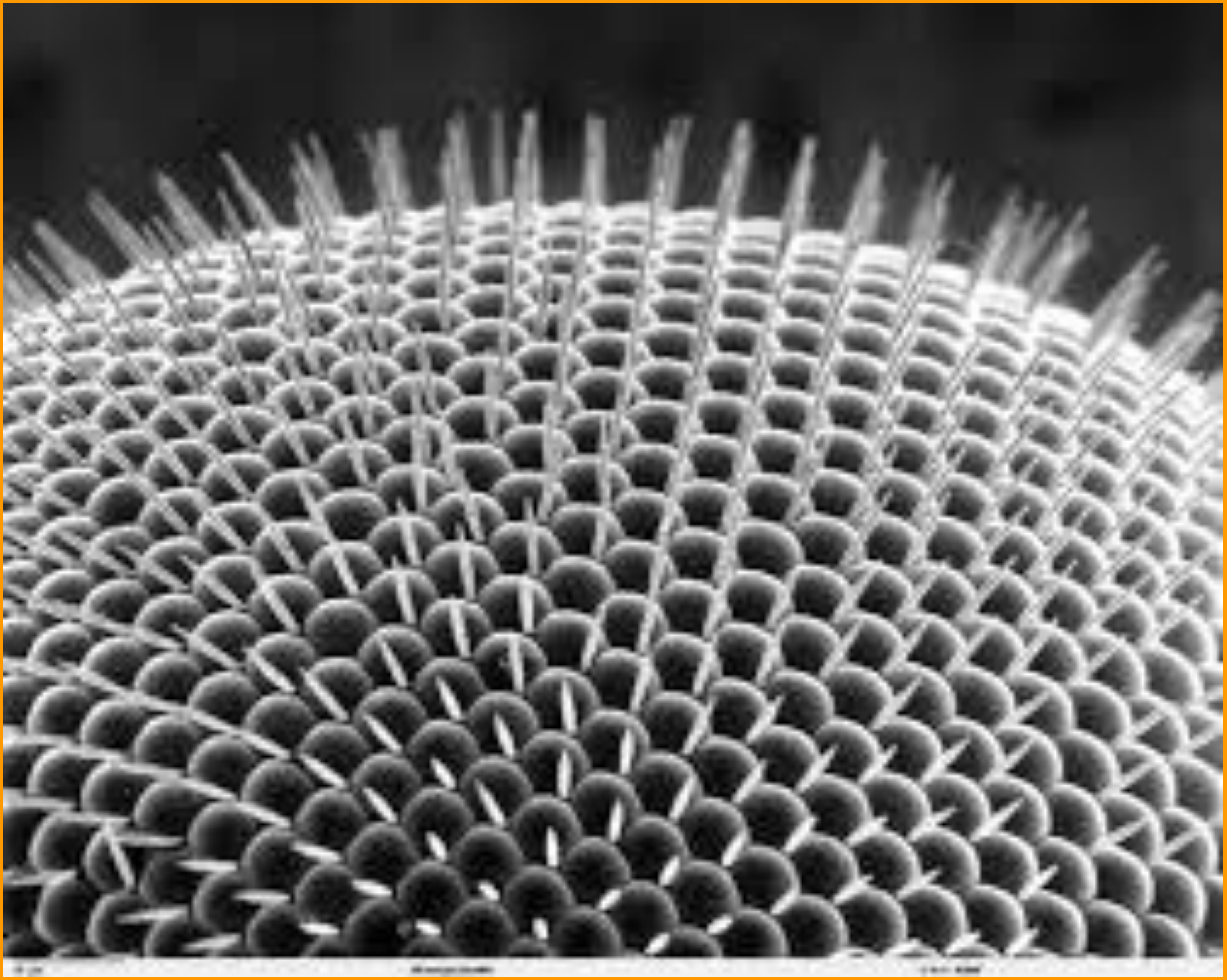

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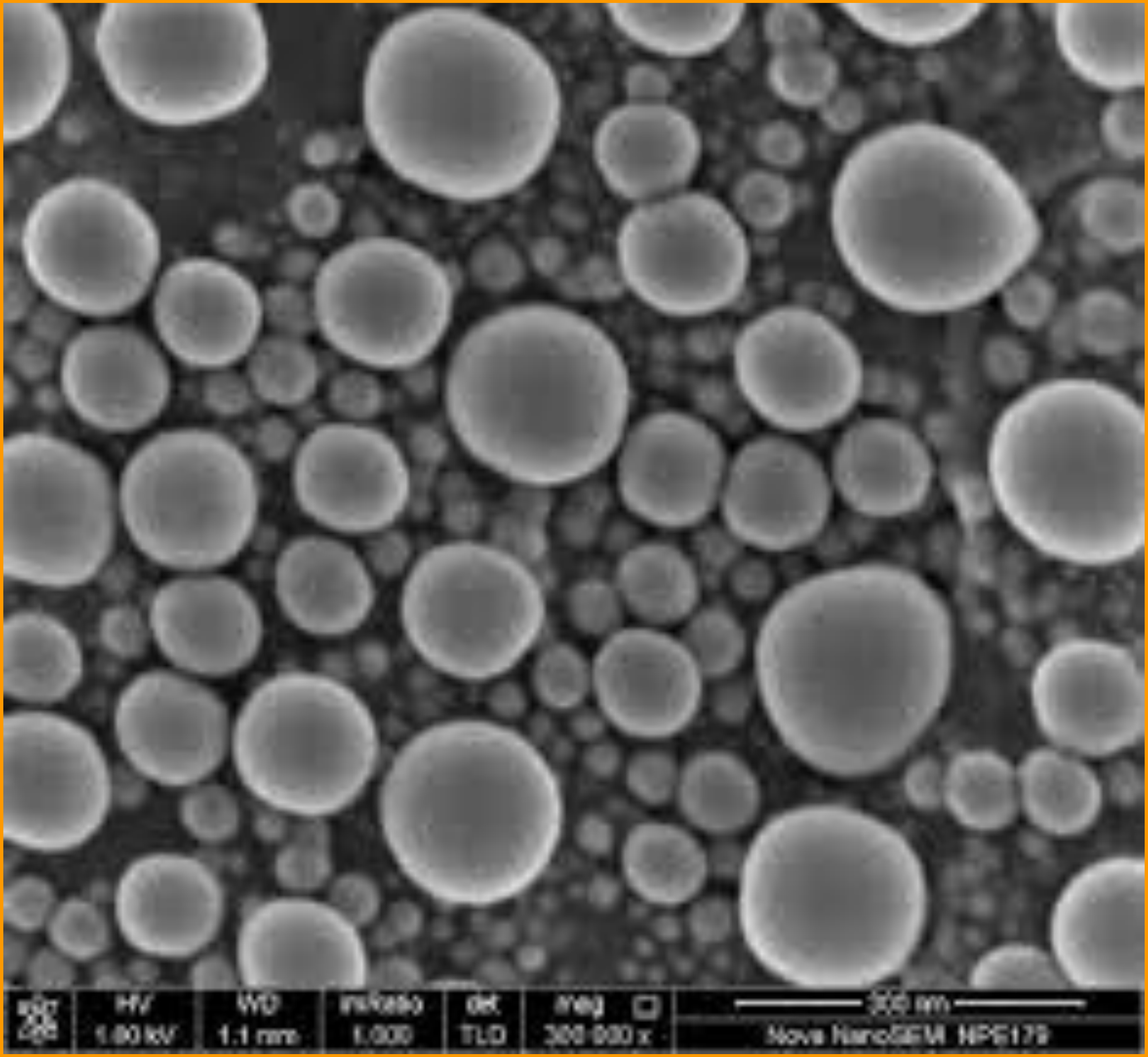
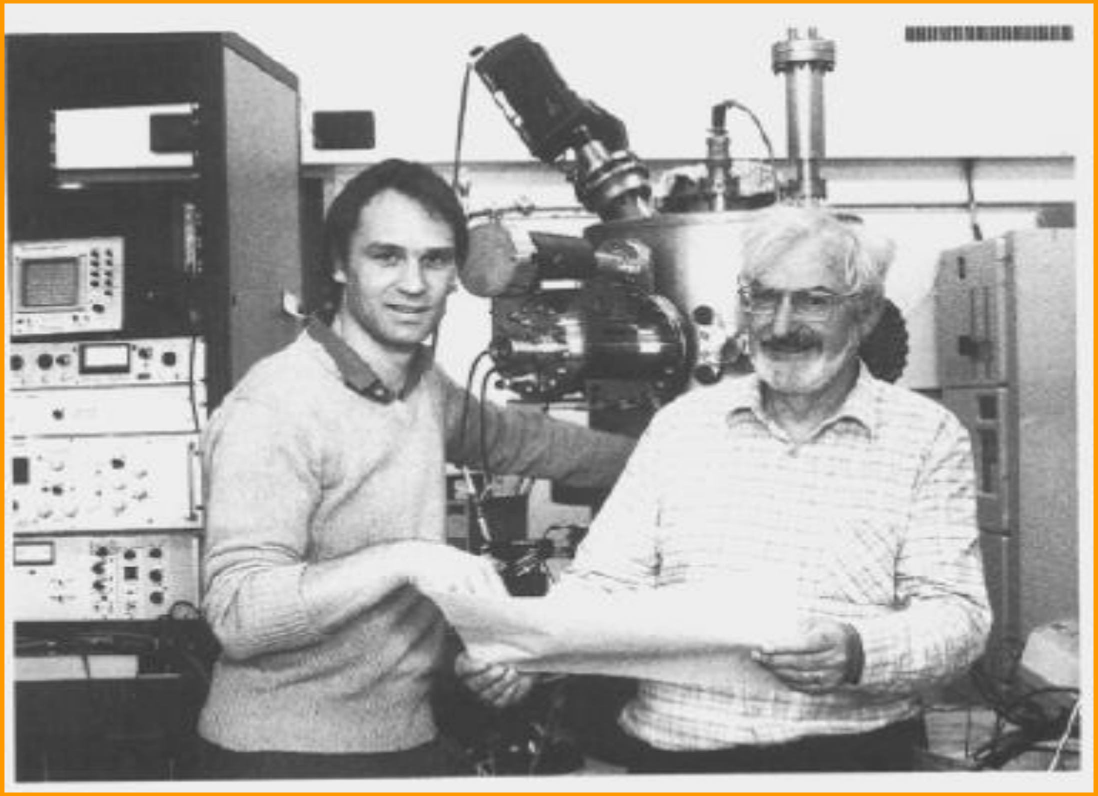

HV
WD
1.1 mm
det
TLD
mag

Atomic Force Microscopy

- The **atomic force microscope** (AFM) is a very powerful microscope invented by Binnig, Quate and Gerber in 1986.



Gerd Binnig (Left) and Heinrich Rohrer (Right) who were awarded the Nobel prize for the invention of STM

SPM “ Family Tree”

Scanning Tunneling microscopy
1981-2

Scanning Near field Optical Microscopy

Atomic Force Microscopy 1986

Magnetic Force Microscopy

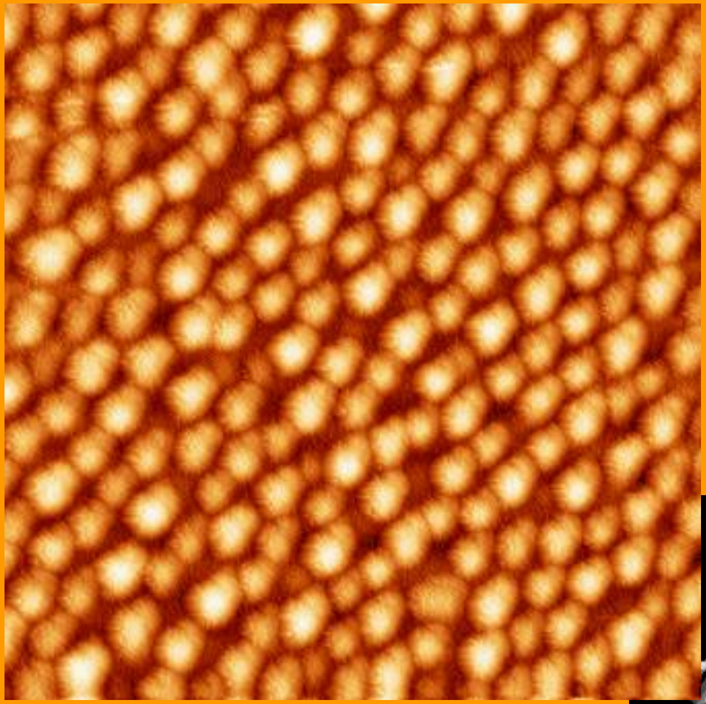
Electrostatic Force Microscopy

Lateral Force Microscopy

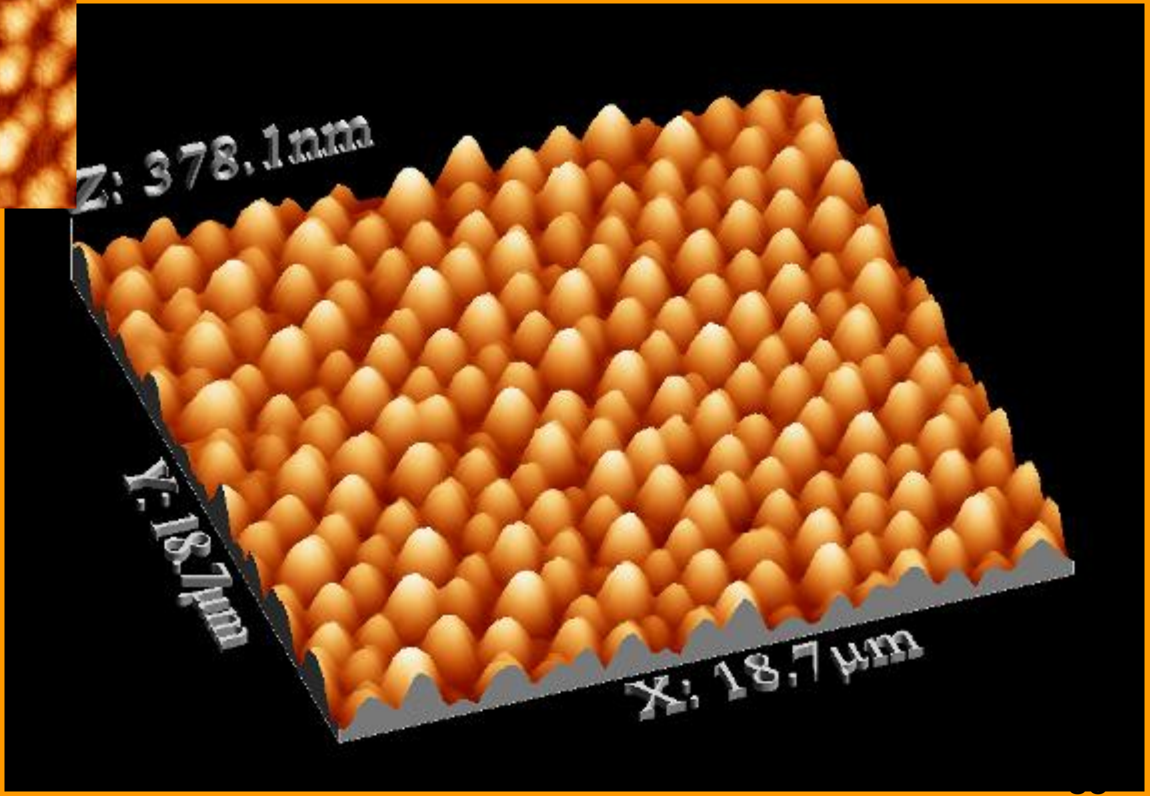
Scanning Capacitance Microscopy

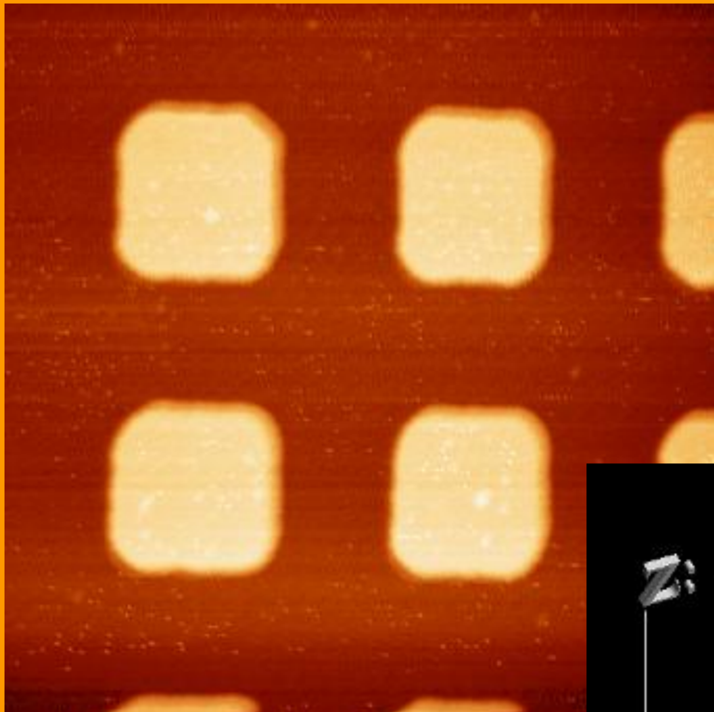
Scanning Chemical Potential Microscopy

Scanning Thermal Microscopy

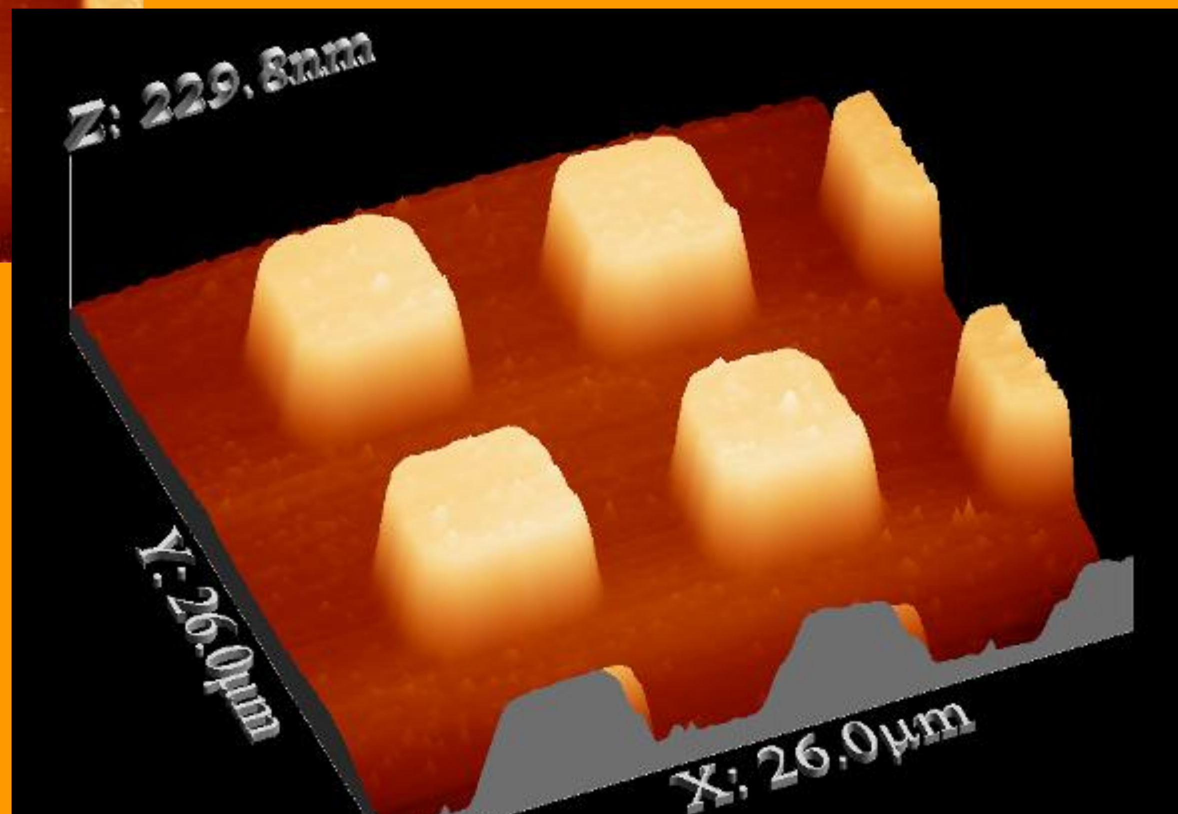


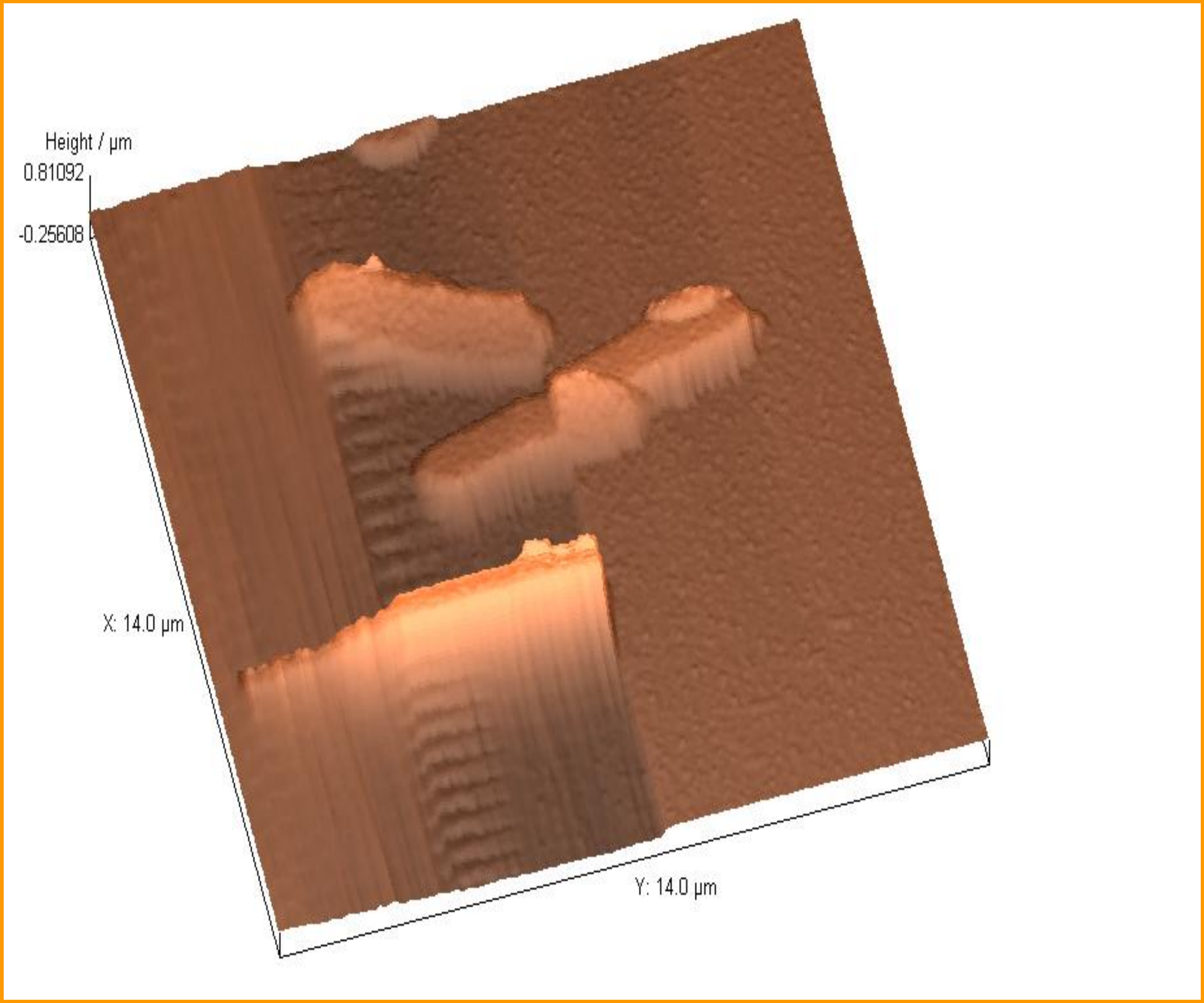
Iron on Si (111)





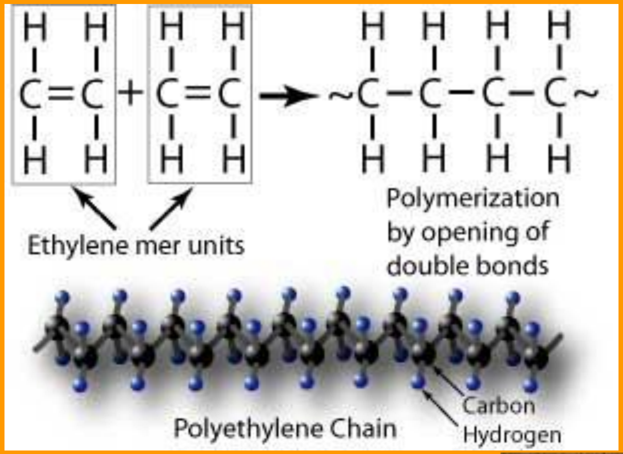
Calibration Grid





AFM image of Surface of Ceramic Sample in 3D

CRYSTAL STRUCTURE - POLYMERS



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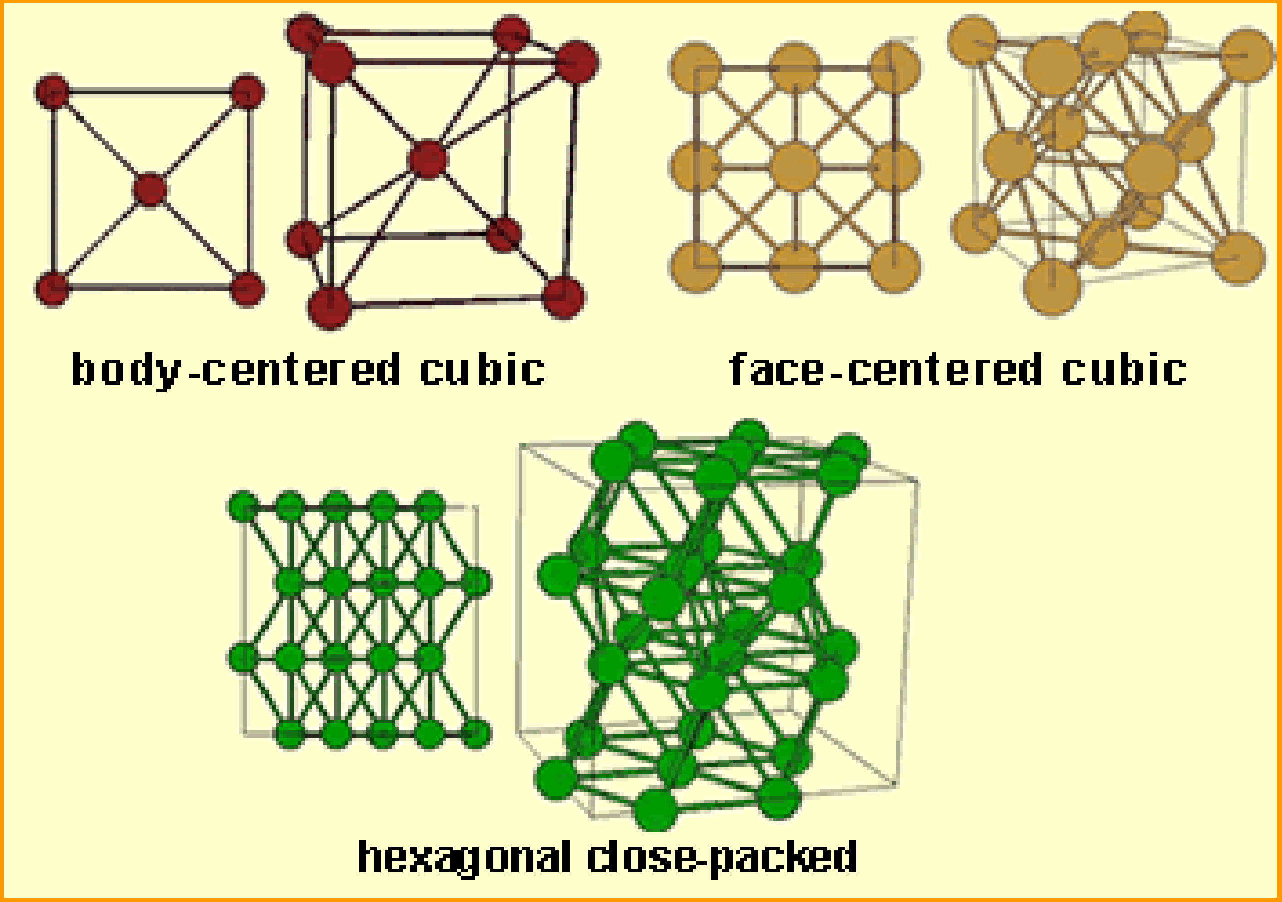
The Smallest Repeated Structure in the Crystal is the Unit Cell

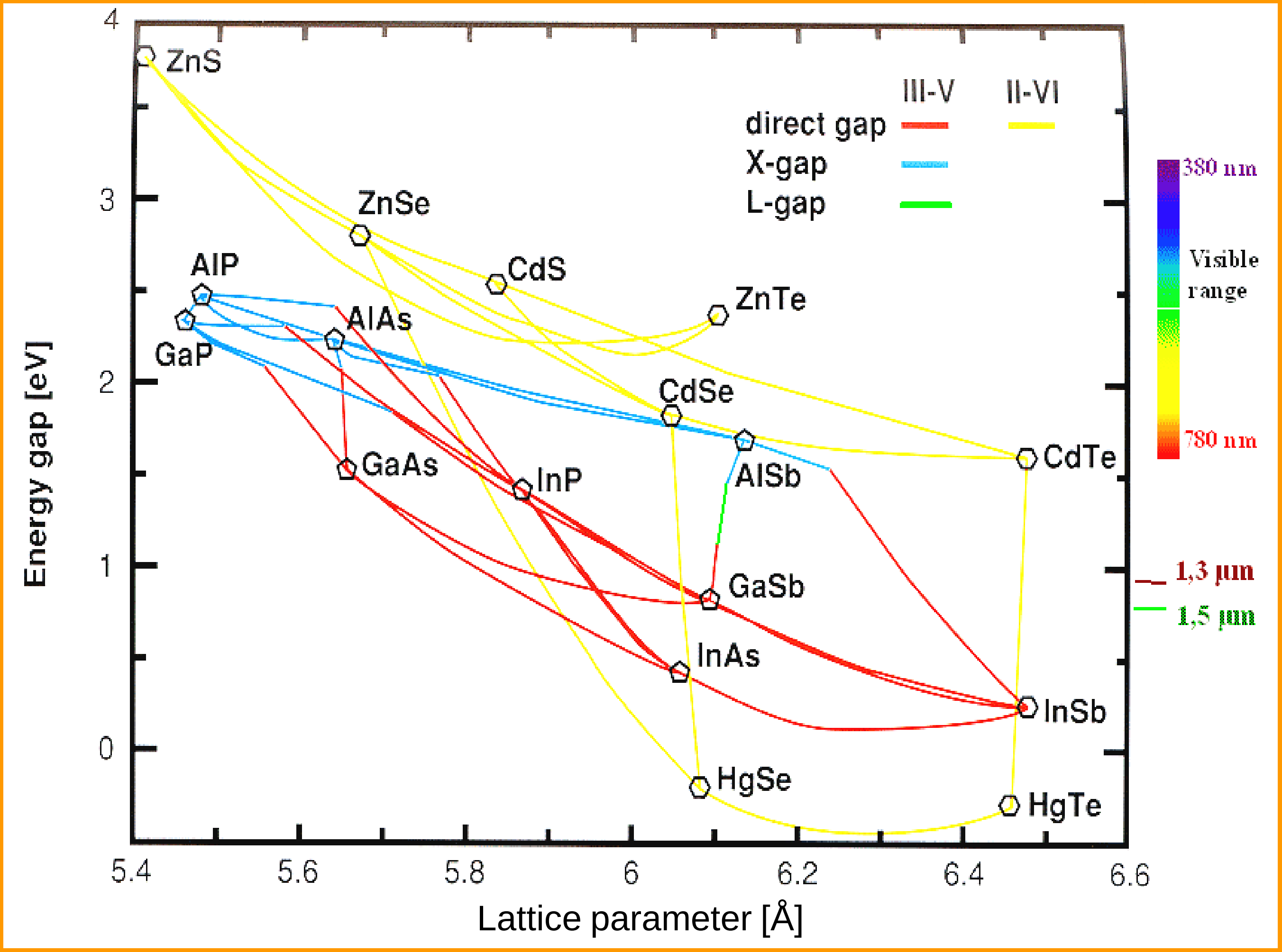


STRUCTURE – PROPERTY RELATIONSHIP

- Most common materials contain many grains.
- Within each grain the orientation of the crystal structure is the same.
- The intersection of grains which have different crystallographic orientations creates a grain boundary. Grain boundaries are typically high energy, disordered areas.
- Grain size depends on processing; grain size can influence strength. In general finer grain size results in higher strength.

Energy Band Gap

Band Gap Engineering



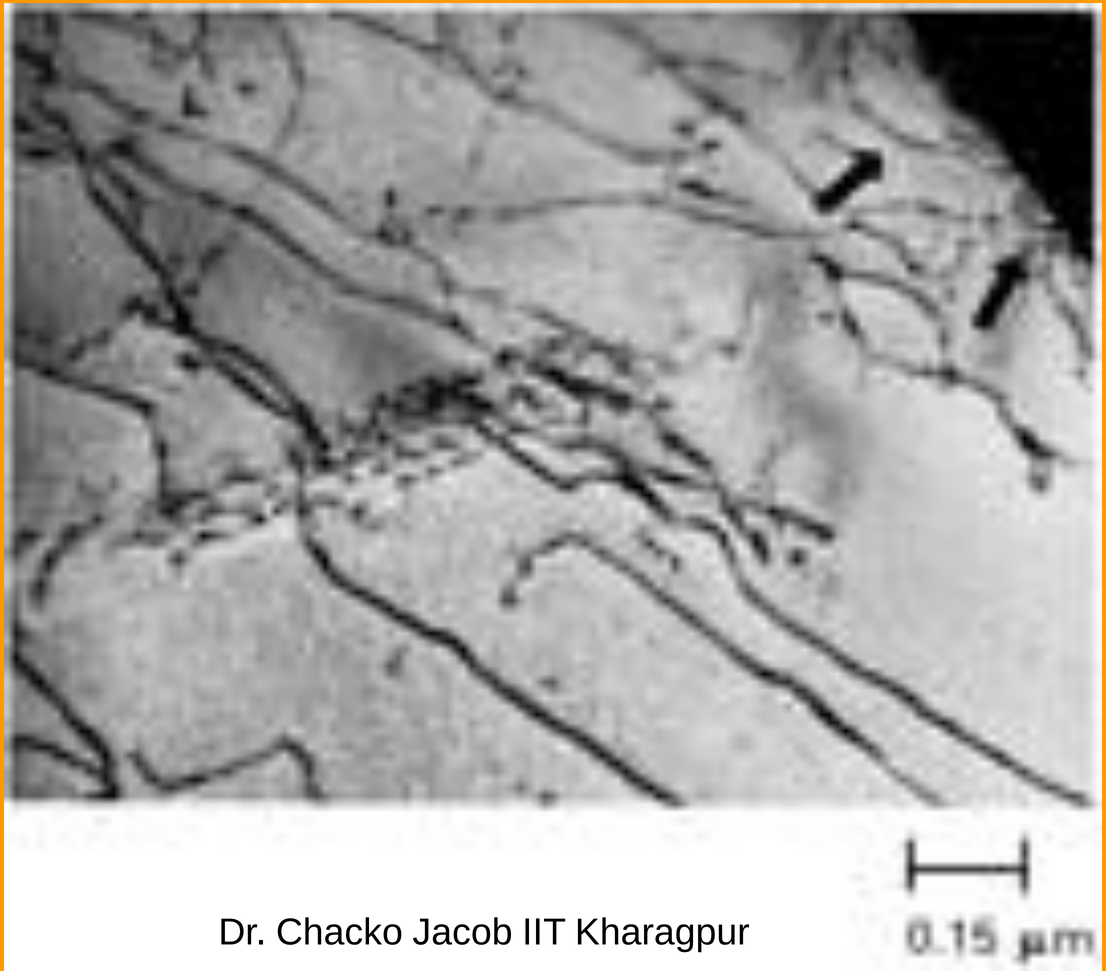
DEFECTS

- Calculations of mechanical strength based on atomic bonding forces indicate perfect crystal structures (i.e. no imperfections in the stacking of atoms) would be ~ 10X stronger than observed strengths.
- This discrepancy led to a theory that materials must contain flaws in the structure that lead to lower strengths. The theoretical models were developed long before there were adequate experimental methods to confirm the theory.

TYPES OF DEFECTS

0D	POINT DEFECTS	VACANCIES, INTERSTITIALS, etc
1D	LINE DEFECTS	DISLOCATIONS
2D	SURFACE DEFECTS	SURFACES, GRAIN BOUNDARIES
		STACKING FAULTS, TWINS
3D	VOLUME DEFECTS	VOIDS, INCLUSIONS, PRECIPITATES

Dislocations Can Be Observed at High Magnification with Transmission Electron Microscopy



DEFECTS- ARE THEY ANY GOOD?

- **HELP DIFFUSION**
- **INVOLVED IN ELECTRICAL CONDUCTION**
- **AFFECT OPTICAL PROPERTIES**
- **CAN (INCREASE!) OR DECREASE MECHANICAL STRENGTH**

THERMODYNAMICS

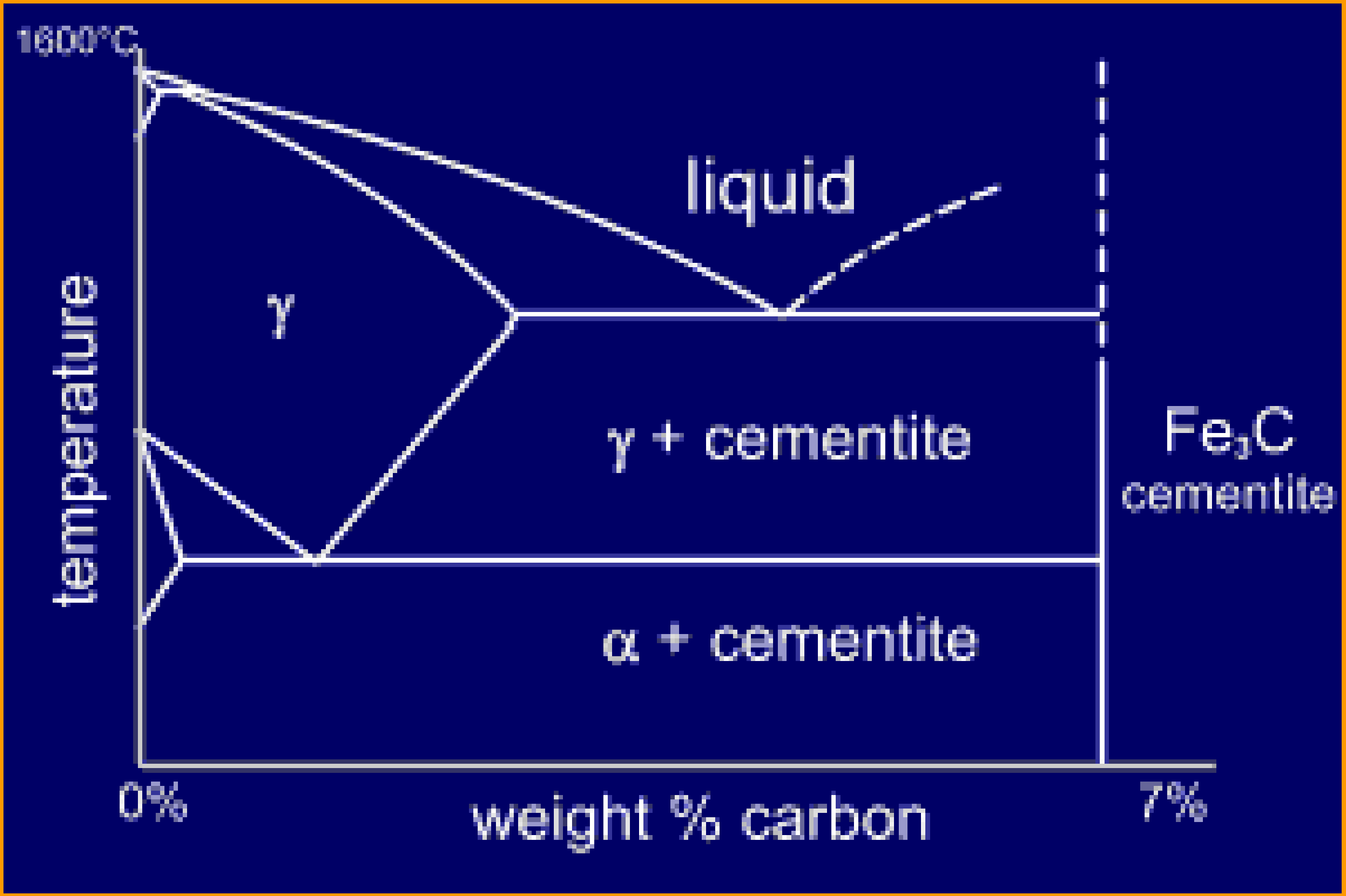
THE CORRECT ANSWER IS:

MINIMIZATION OF ENERGY

Phase Diagrams

- Phase diagrams show the phases present in a metallic alloy under equilibrium conditions (i.e. very slow heating and cooling).
- Different phases are formed at different temperatures due to energy considerations.
- Phase diagrams are determined experimentally or by computer modeling if sufficient thermodynamic data is available.
- Phase diagrams with more than 3 elements are quite complex.

Iron Carbon Phase Diagram



KINETICS AND TRANSPORT

How fast do reactions occur?
Activation energy barriers

- Mass Transport $J = -D\, dC/dx$
- Heat Transport $Q = -k\, dT/dx$
- Momentum Transport $\tau = -\mu\, dv/dy$

- Charge Transport $V = IR$

$\boxed{J = \sigma E = \sigma\, dV/dx}$

MECHANICAL PROPERTIES

- Stresses
- Strains
- Moduli
- Yield

MECHANICAL PROPERTIES

- Elastic Deformation
- Plastic Deformation
- Fracture
- Fatigue
- Creep

ELECTRICAL PROPERTIES

- Electrons and their motion
- Conductivity and Resistivity
- Band structure and Quantum Mechanics
- Conductors, Semiconductors and Insulators
- Holes and Electrons
- Doping of semiconductors
- Junctions and Control

ELECTRICAL PROPERTIES

- DIELECTRIC
- PIEZOELECTRIC
- FERROELECTRIC
- PYROELECTRIC

OPTICAL PROPERTIES

- Refraction/Reflection/Transmission
- Color
- Light emission
- Light detection
- Defects

MAGNETIC PROPERTIES

Magnetism and spin
Ferromagnetism
Ferrimagnetism
Antiferromagnetisn
Diamagnetism
Paramagnetism
Magnetoresistance

PROCESSING

- ROLLING
- EXTRUSION
- FORGING
- MACHINING

- DEPOSITION
- LITHOGRAPHY
- ETCHING

- SELF ASSEMBLY