Introduction to Materials Science and Engineering

Chapter 1. Introduction

- Materials are ... engineered structures.
- Structure ... has many dimensions ...

Structure features	Dimension (cm)
Atomic bonding	< 10^{-8} cm
Missing/extra atoms	10^{-8} cm
Crystals (ordered atoms)	10^{-6} - 10^{1} cm
Second-phase particles	10^{-6} - 10^{-2} cm
Crystal texturing	> 10^{-4} cm

지난 25년 동안 세상을 바꾼 신기술 25가지

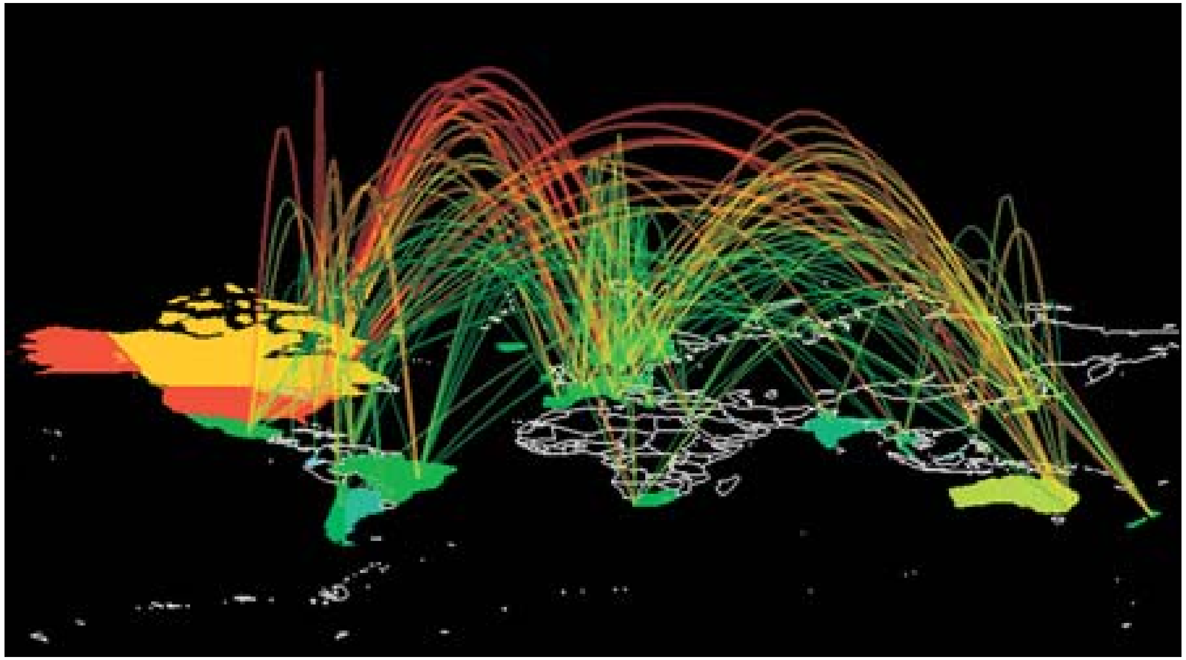
러멜슨-MIT 프로그램

의료 및 의약 분야 기술 제외

테크노피아 만든 혁신 기술 25

① 인터넷 ② 휴대전화 ③ 개인용 컴퓨터(PC) ④ 광통신 케이블 ⑤ e메일 ⑥ 상용 GPS ⑦ 휴대용 컴퓨터(노트북) ⑧ 메모리 저장 디스크(CD) ⑨ 디지털 카메라 ⑩ 무선인식표(RFID) ⑪ 미소 전자 기계 시스템(MEMS) ⑫ DNA 지문 ⑬ 에어백 ⑭ 자동현금지급기(ATM) ⑮ 진보된 배터리 ⑯ 하이브리드 승용차 ⑰ 유기발광다이오드(OLED) ⑱ 디스플레이 패널 ⑲ 고화질 텔레비전(HDTV) ⑳ 우주왕복선 ㉑ 나노 기술 ㉒ 플래시 메모리 ㉓ 음성 메일 ㉔ 현대적 보청기들 ㉕ 단거리 고주파 라디오

지난 25년 동안 세상을 바꾼 신기술 25가지



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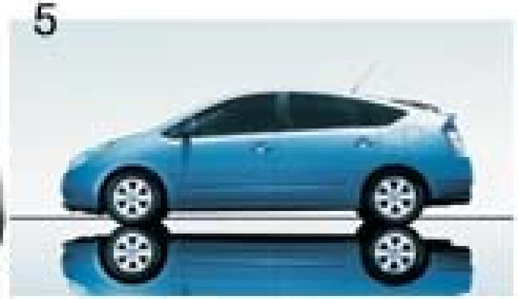

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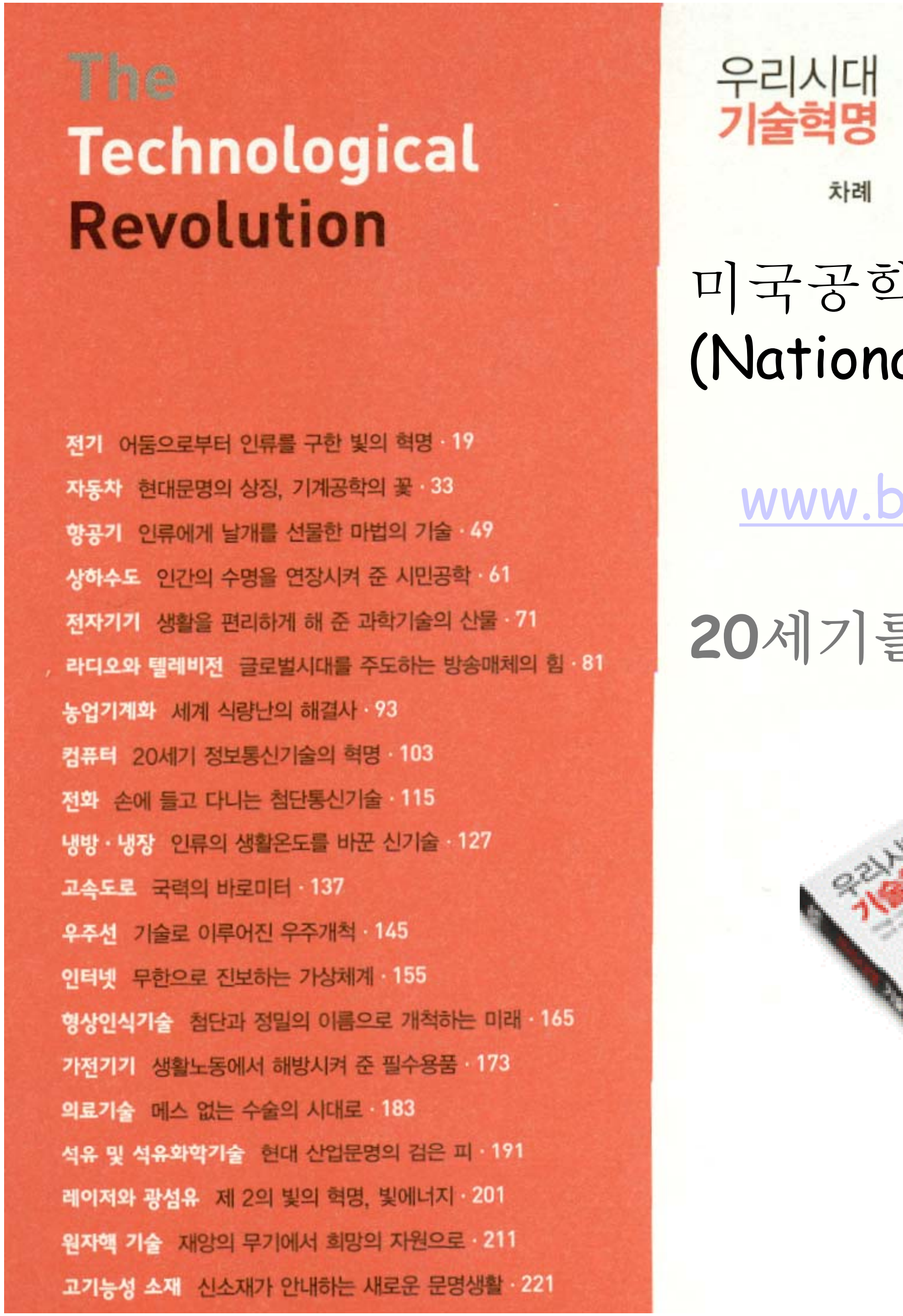


The Technological Revolution

우리시대 기술혁명

차례

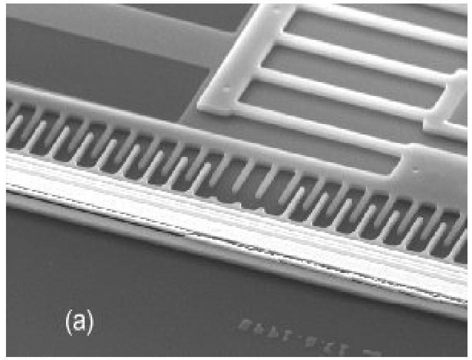
미국공학한림원
(National Academy of Engineering)

www.beengineers.com

20세기를 바꾼 20번의 기술 혁명

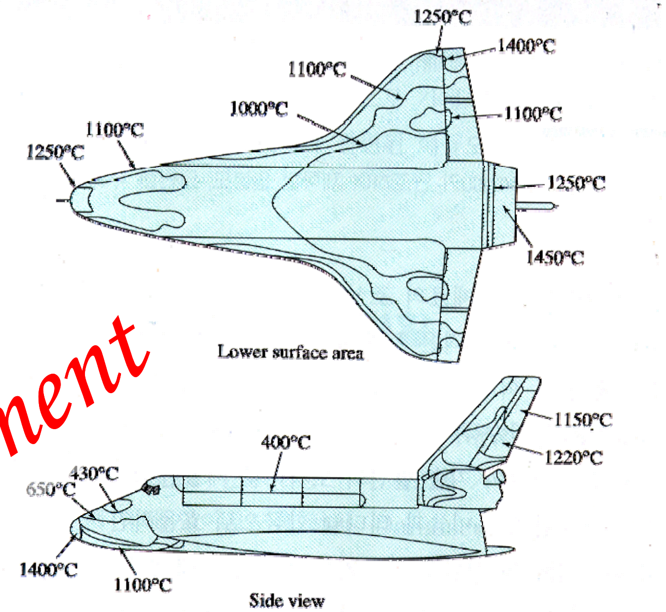
Why do we need to study Materials Science & Engineering ?

Material Failure

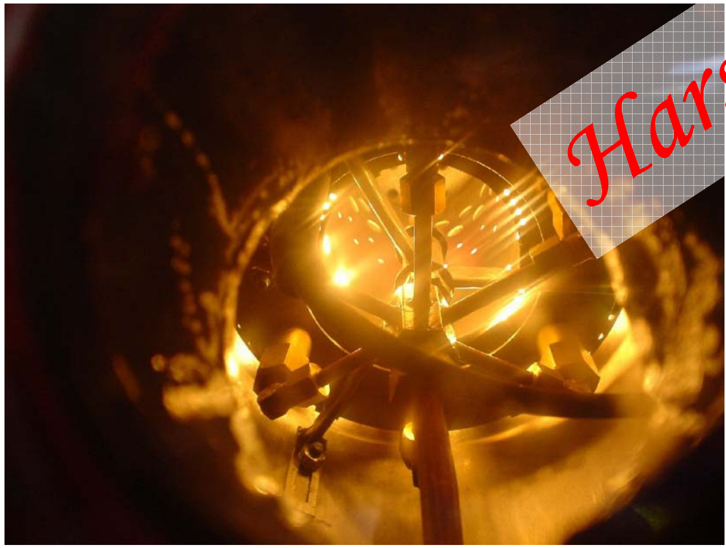


- 2009/09/02

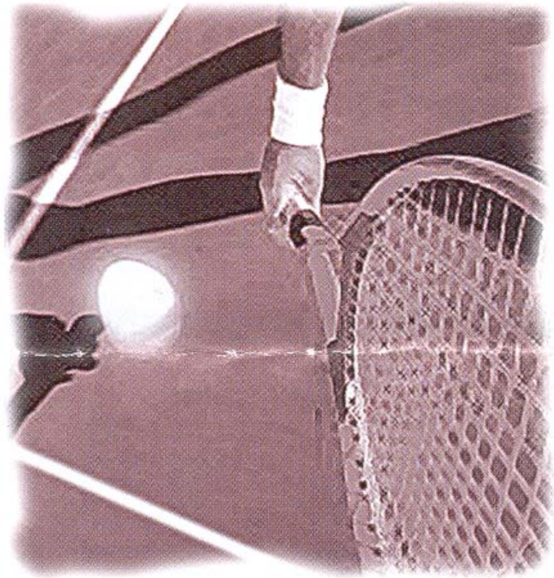
Why do we need to study MSE?

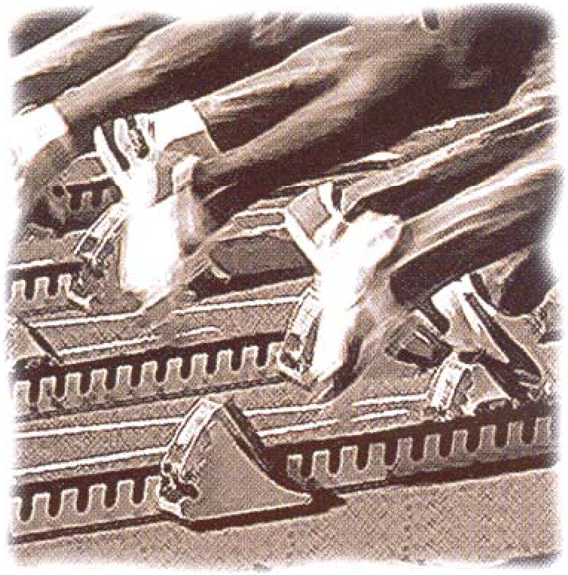


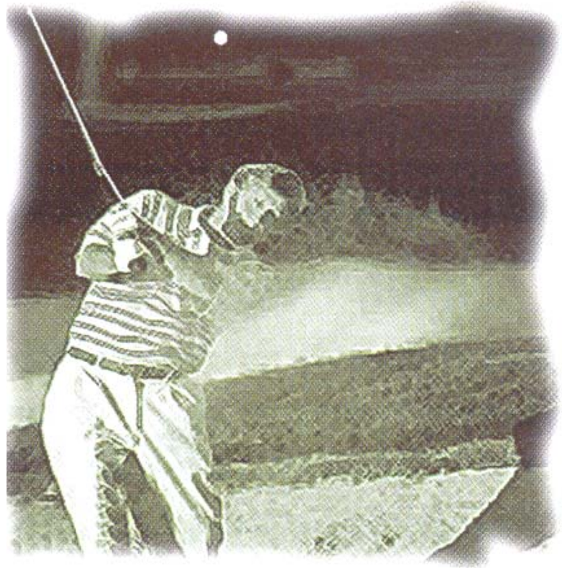
Harsh Environment

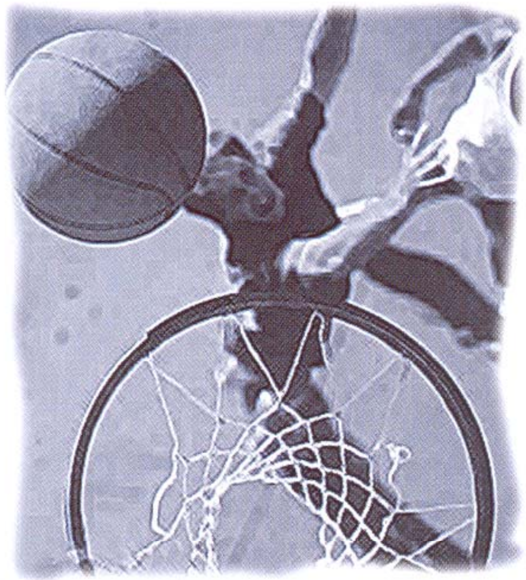


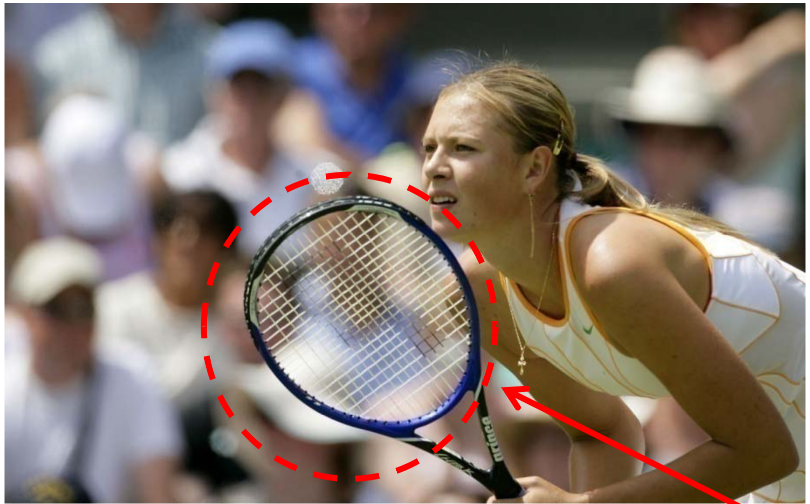
Engineering in Sports !







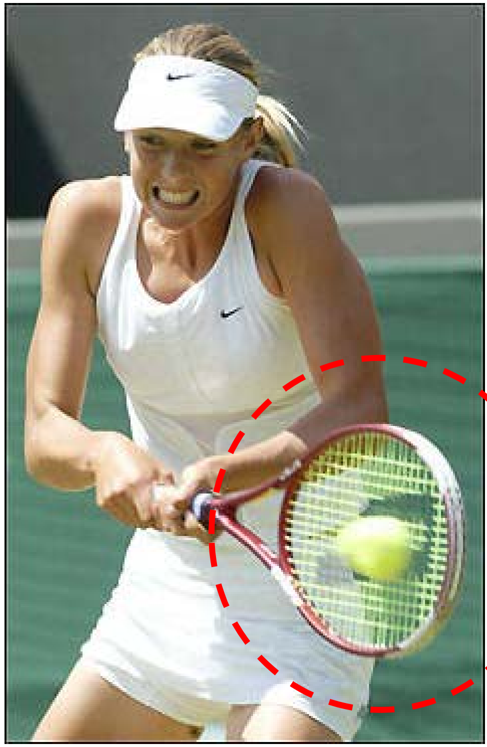




Note !!

Not Maria, But Racket.

(우리끼리 이야기)



Maria Sharapova

Moment of Impact

If the racket is weak
or if its head is small,

…

Maria cannot win alone.
A good racket is needed.

Tennis Racket

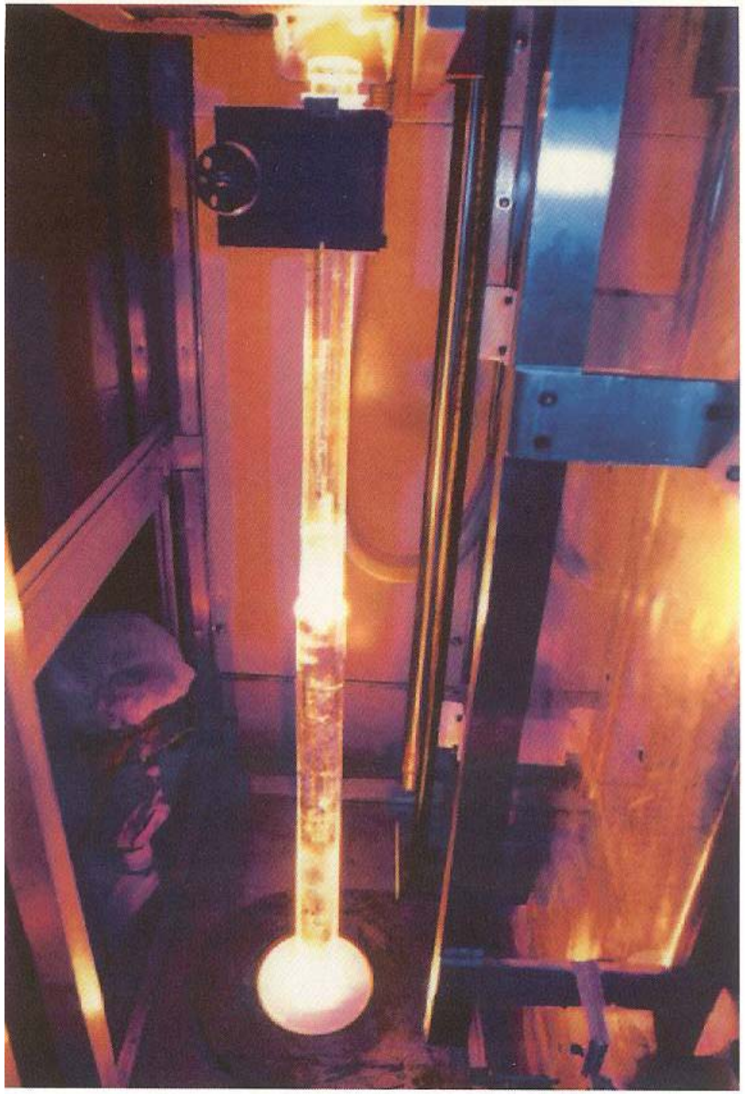
Stronger and lower density material → **Bigger head** → **More Comfortable play**

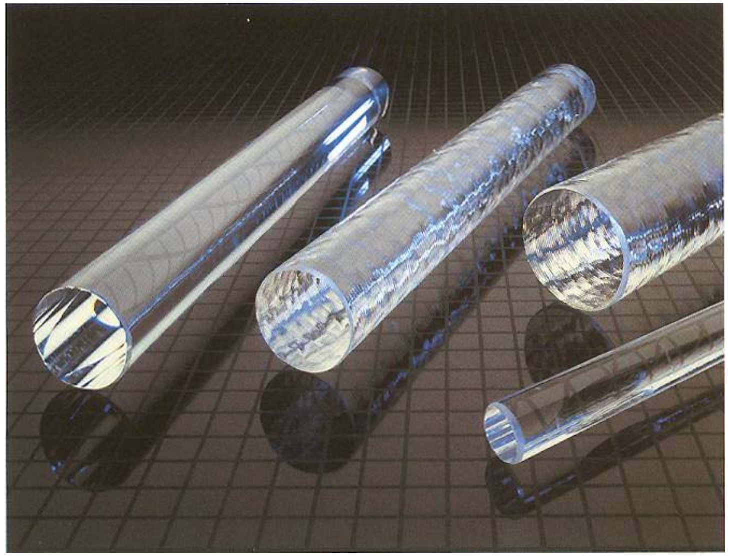
1700's

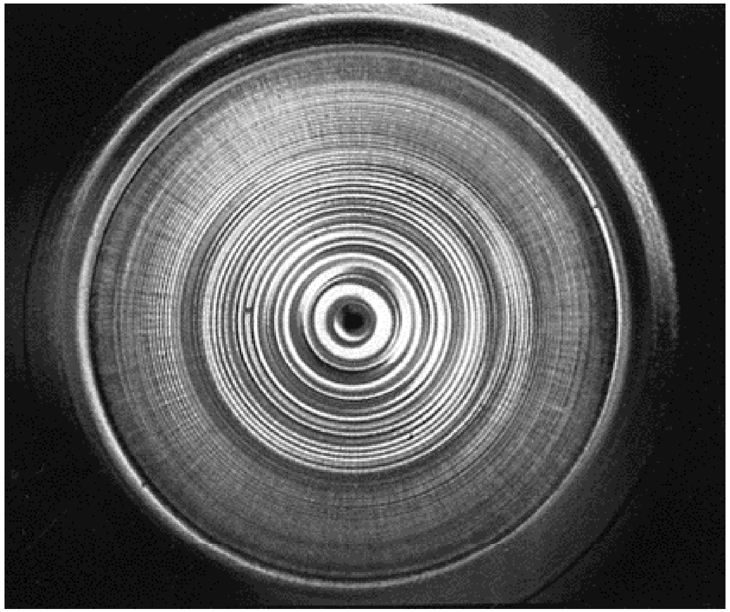
1970's

today

Optical Fiber

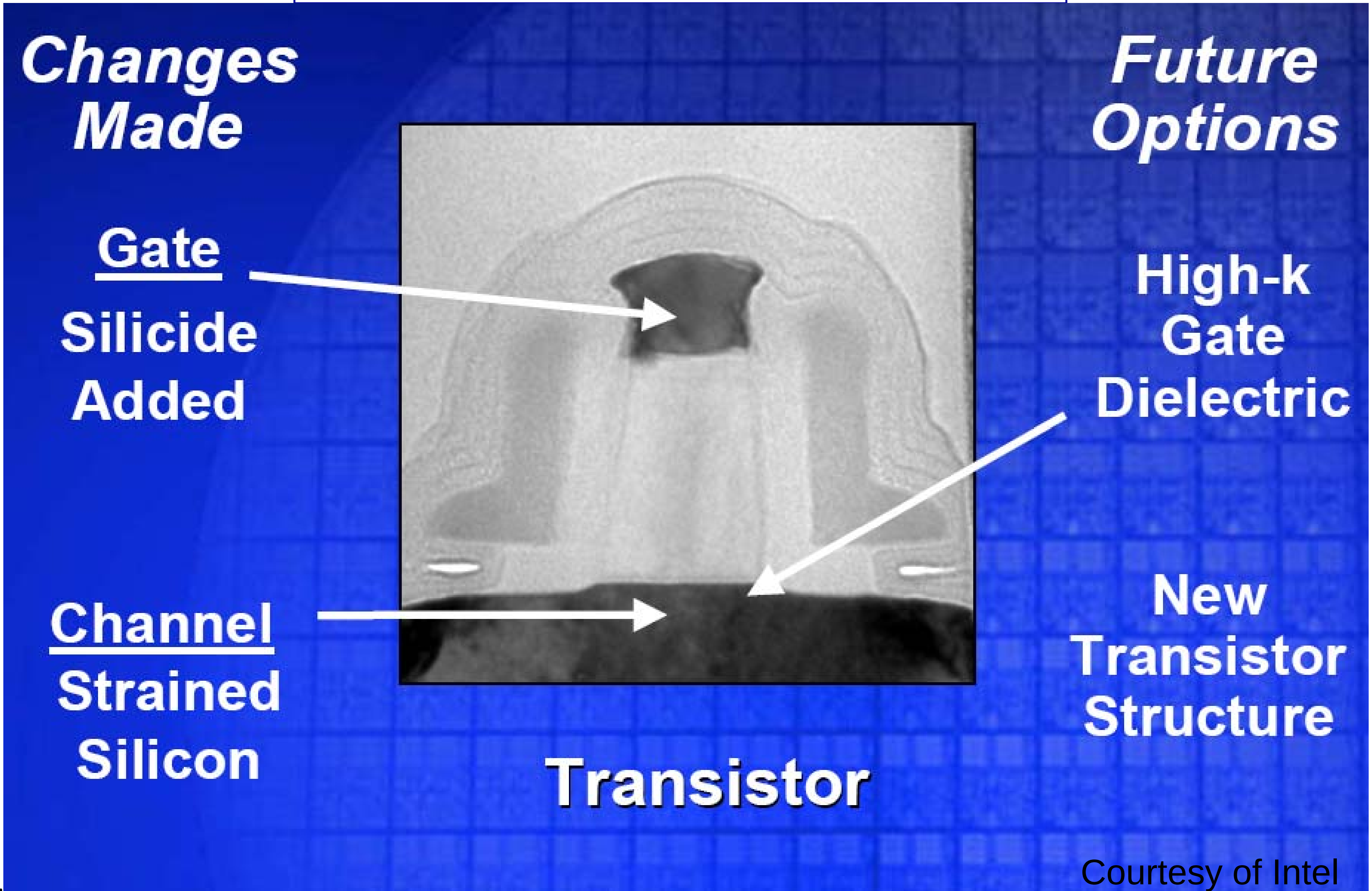






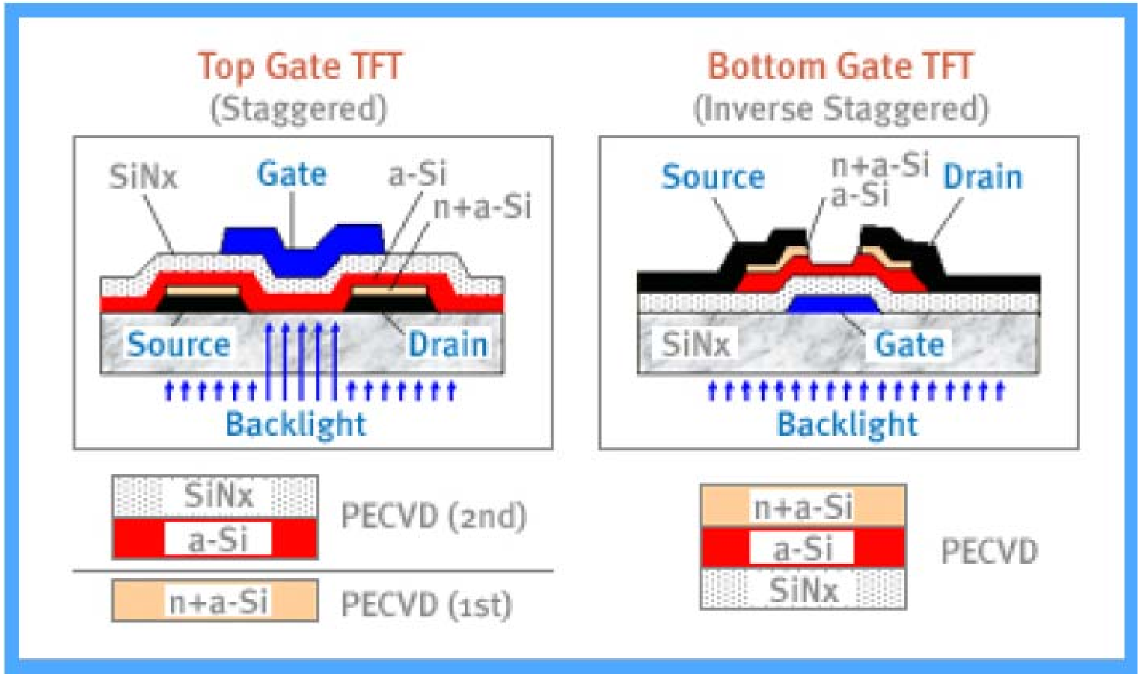
125 μm

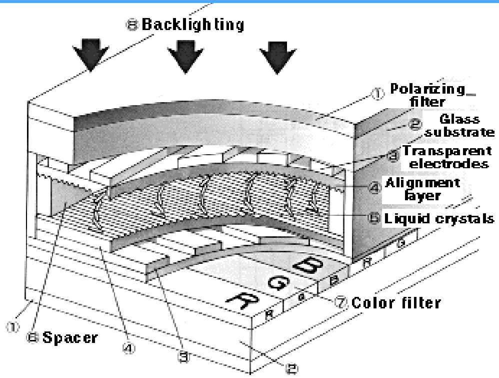
Combination of Materials



Combination of Materials

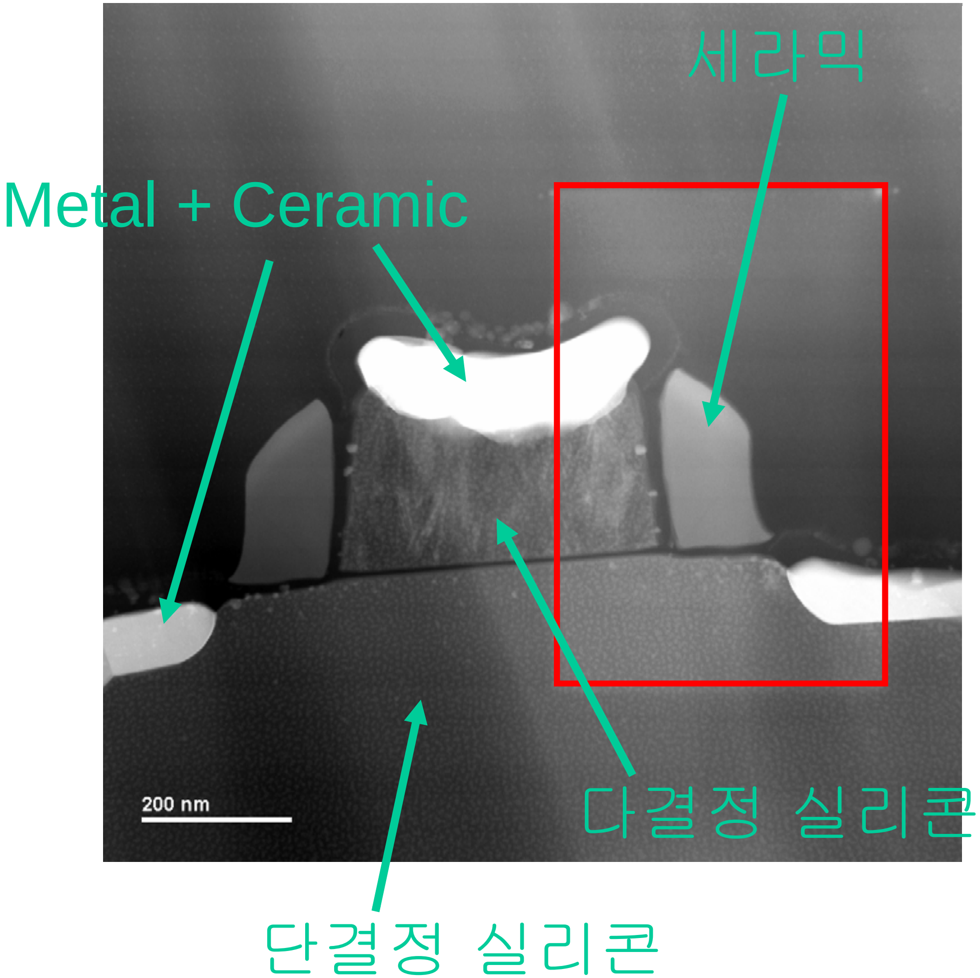
Polymer + Metal + Ceramics



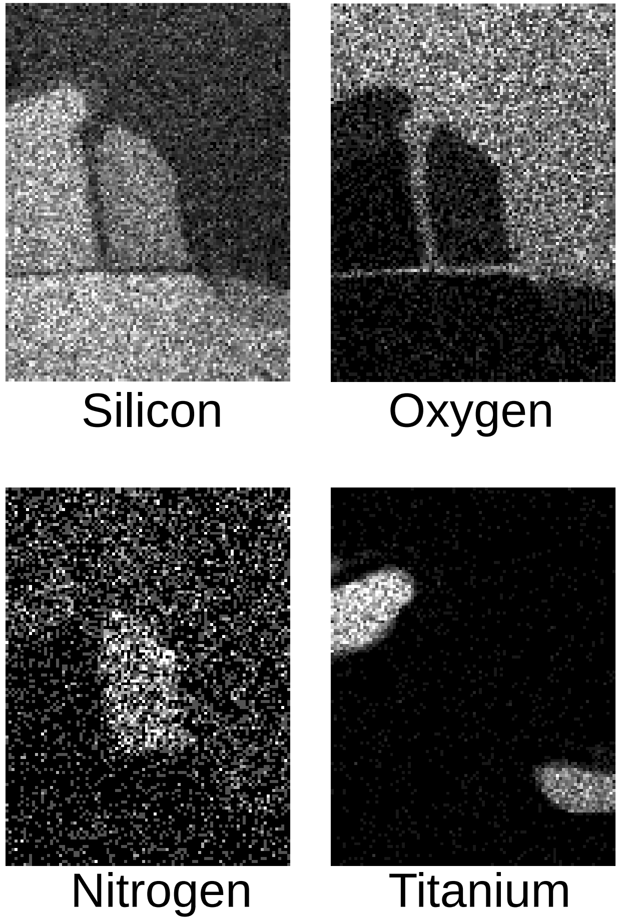


Detailed View of Transistor

<u>*ADF image*</u>



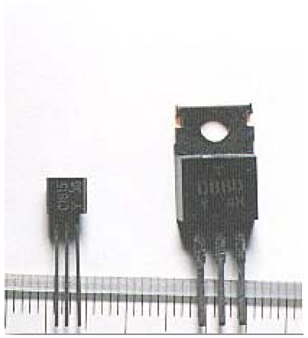
<u>*EDS mapping*</u>



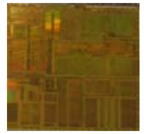
Macroscopic and Microscopic

- Top-down approach

Vacuum tube

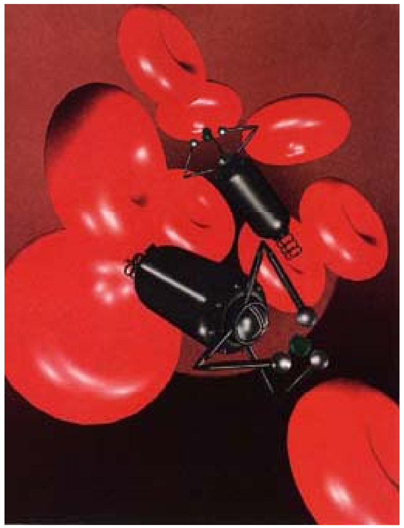


Transistor



Integrated Circuit

- Bottom-up approach

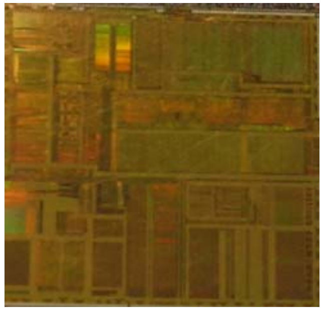


나노로봇

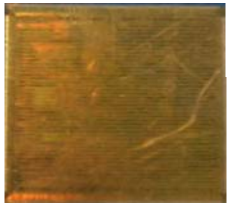
Moore's Law

"The number of transistors incorporated in a chip
will approximately double every 24 months"

10 mm

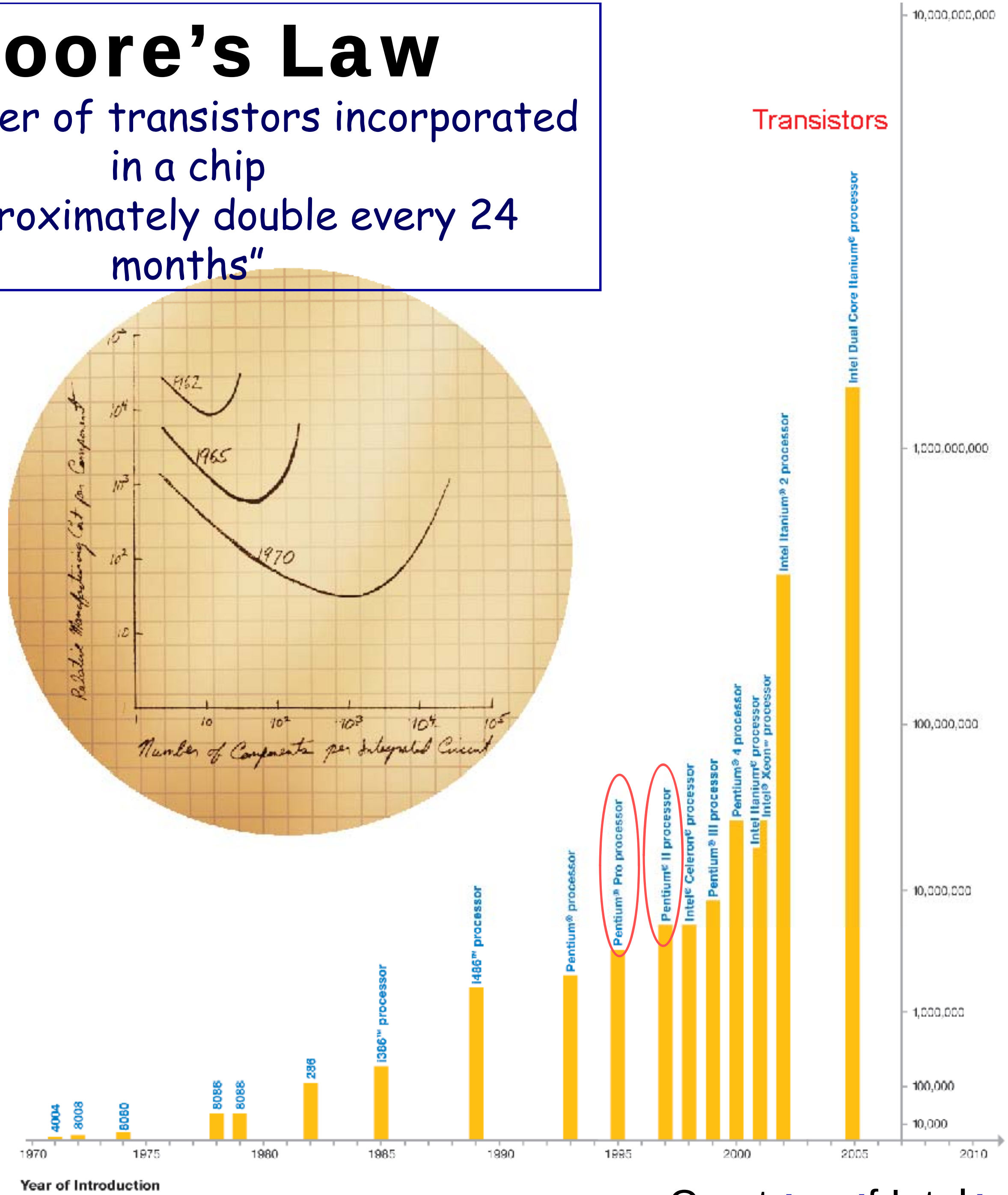


Pentium, 0.8 μm 선폭



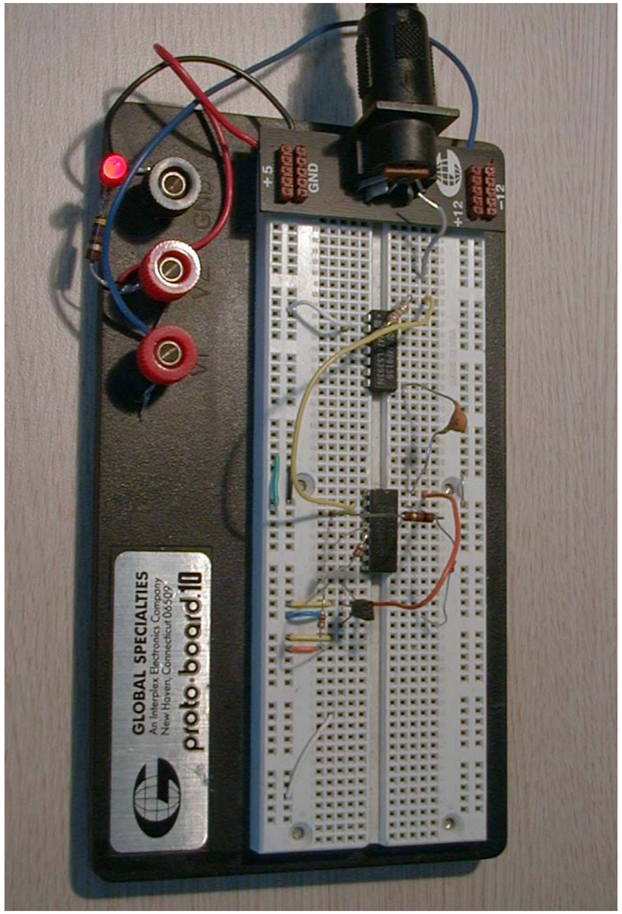
Pentium, 0.5 μm 선폭

Pentium II, 0.25 μm 선폭

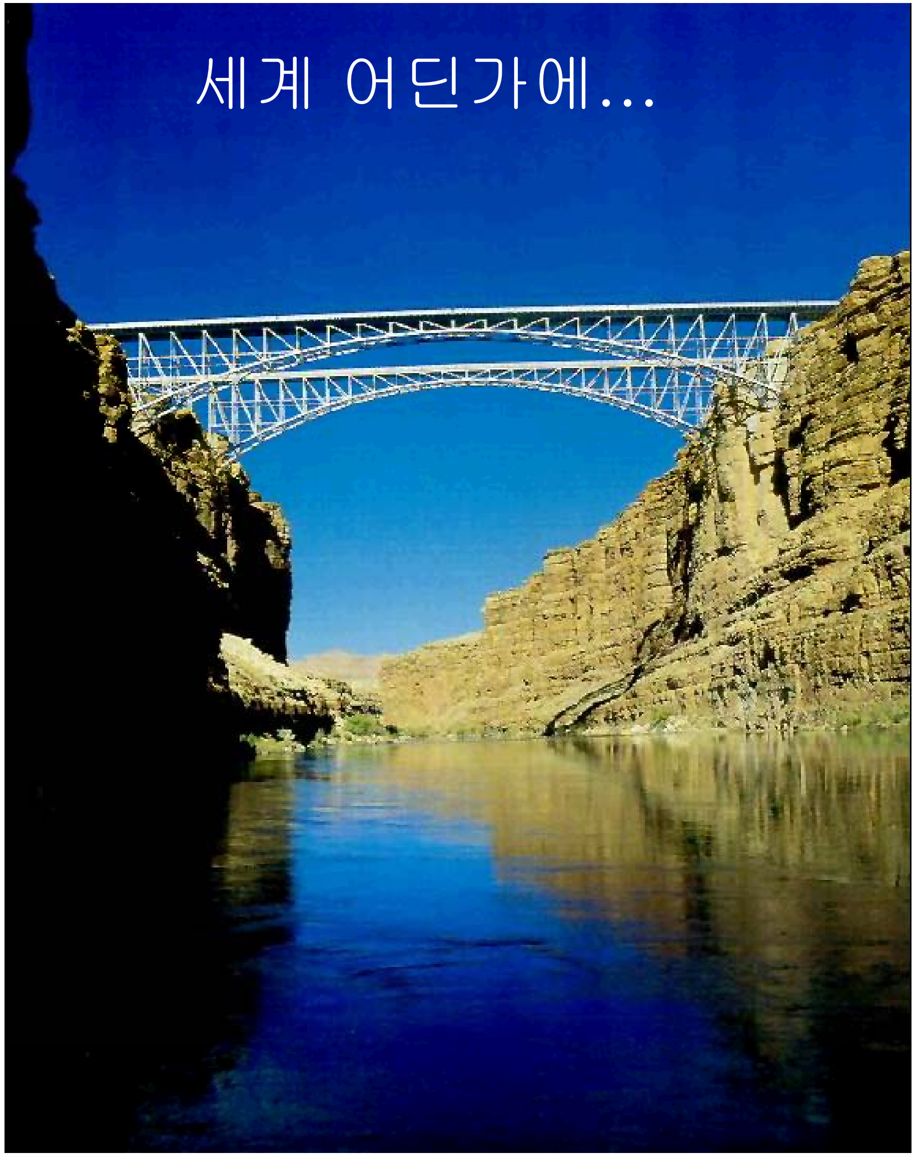


Courtesy of Intel

Combination of Materials



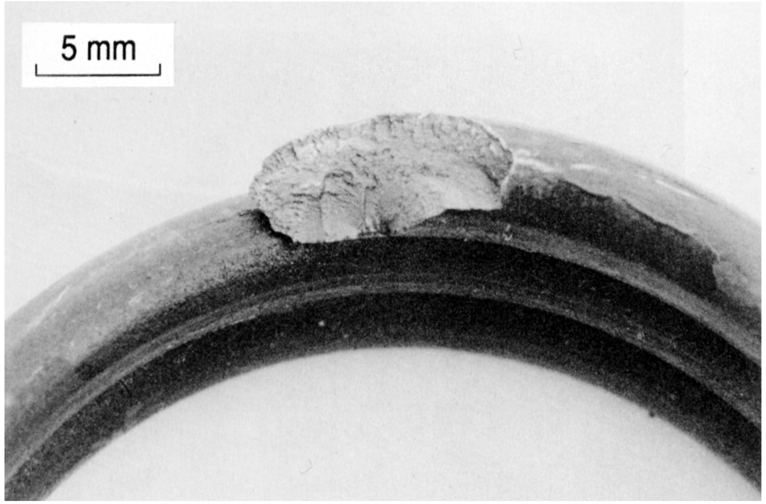
고강도 구조용 재료

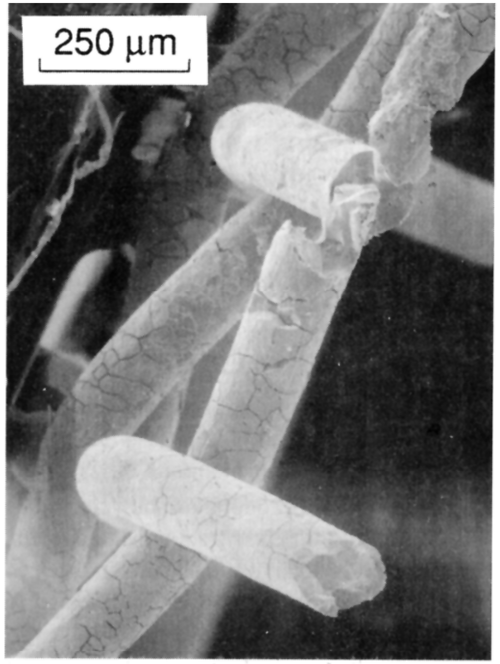


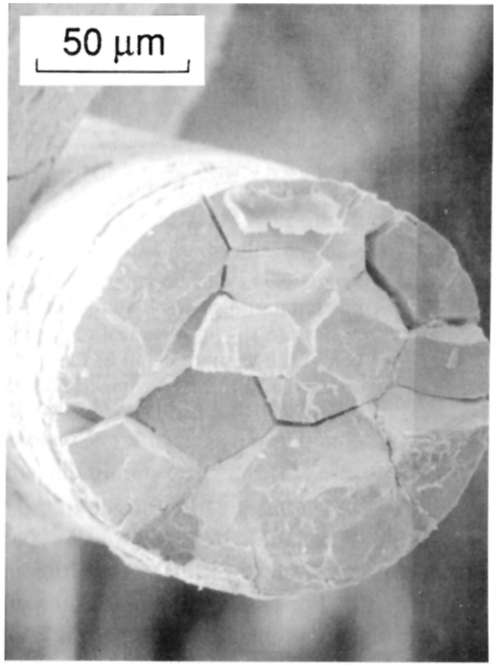
세계에서 제일 높은 빌딩 (452 m)
– 타이페이금융센터

세계에서 제일 긴 다리
동하이 대교 35.2 km

파괴 (Fracture)

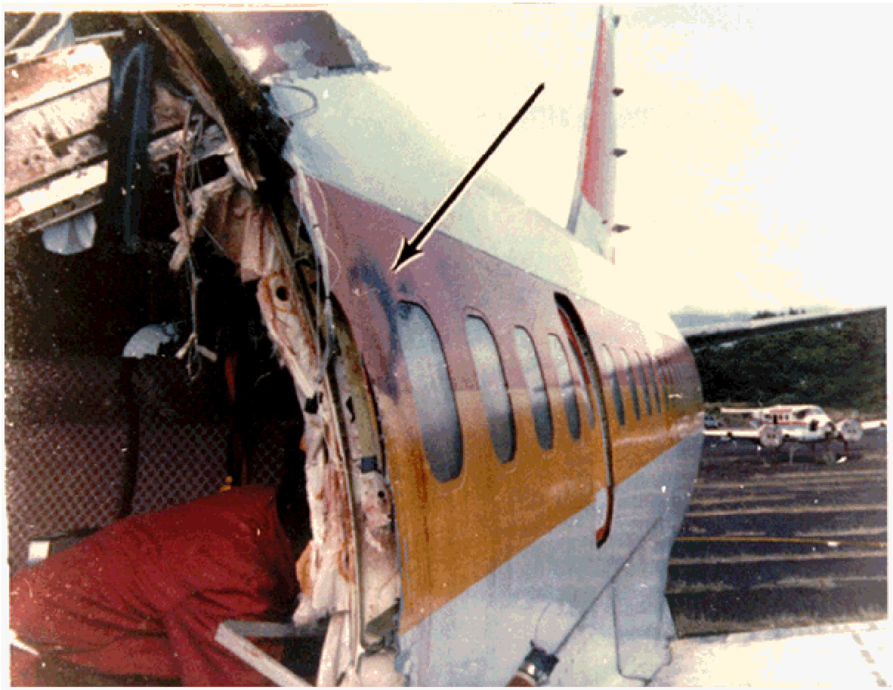

5 mm


250 μm

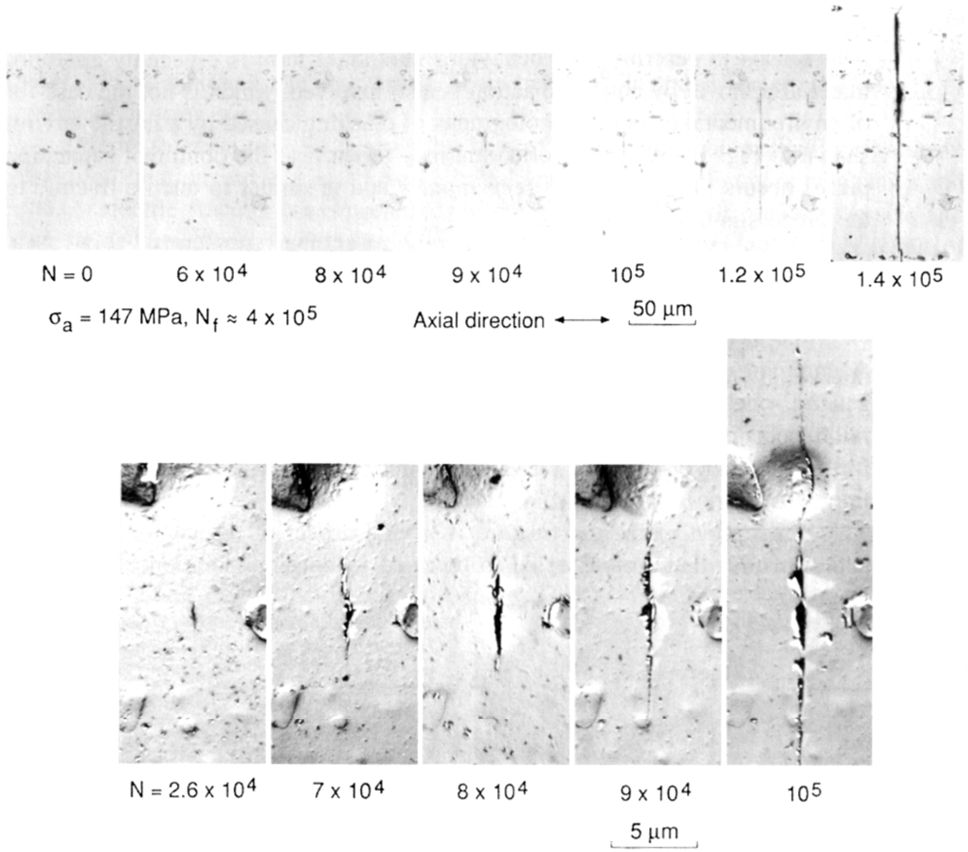

50 μm


Cold Water Sinks TITANIC
Iceberg Gets Bum Rap in TITANIC Sinking

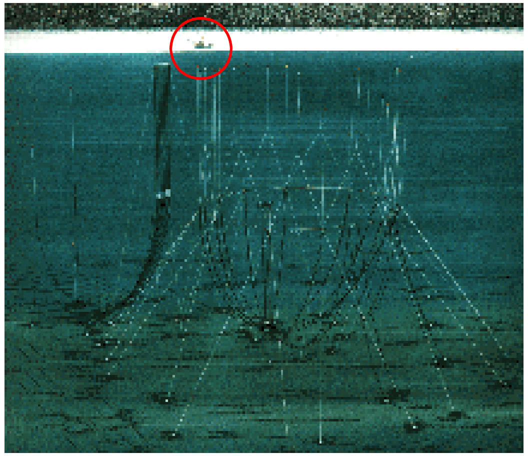
반복 응력에 의한 파괴 (Fatigue)

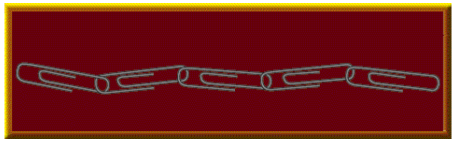


ALOHA FLIGHT #243
KAHULUI, MAUI, HAWAII
NTSB PHOTOGRAPH

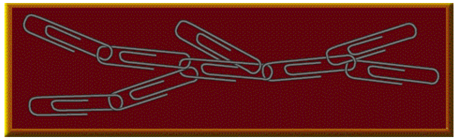


Improvement: Lighter and Stronger

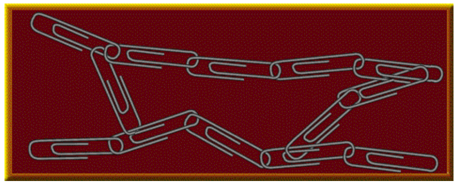




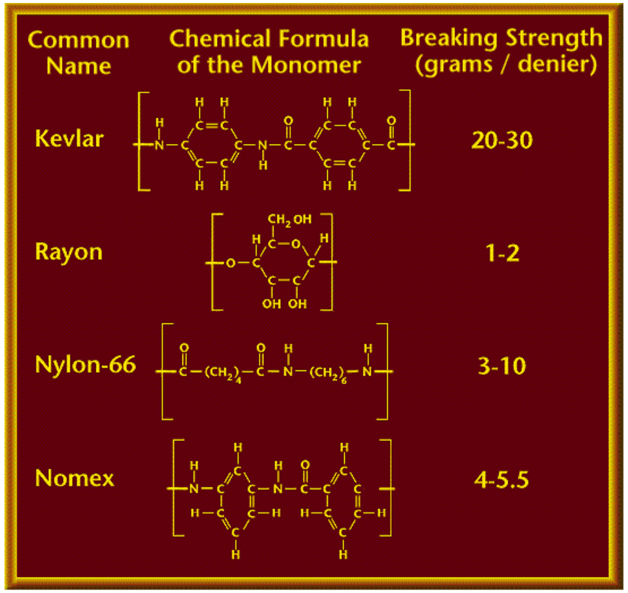
Linear polymer : Microwaveable food containers, Dacron carpets and Kevlar ropes



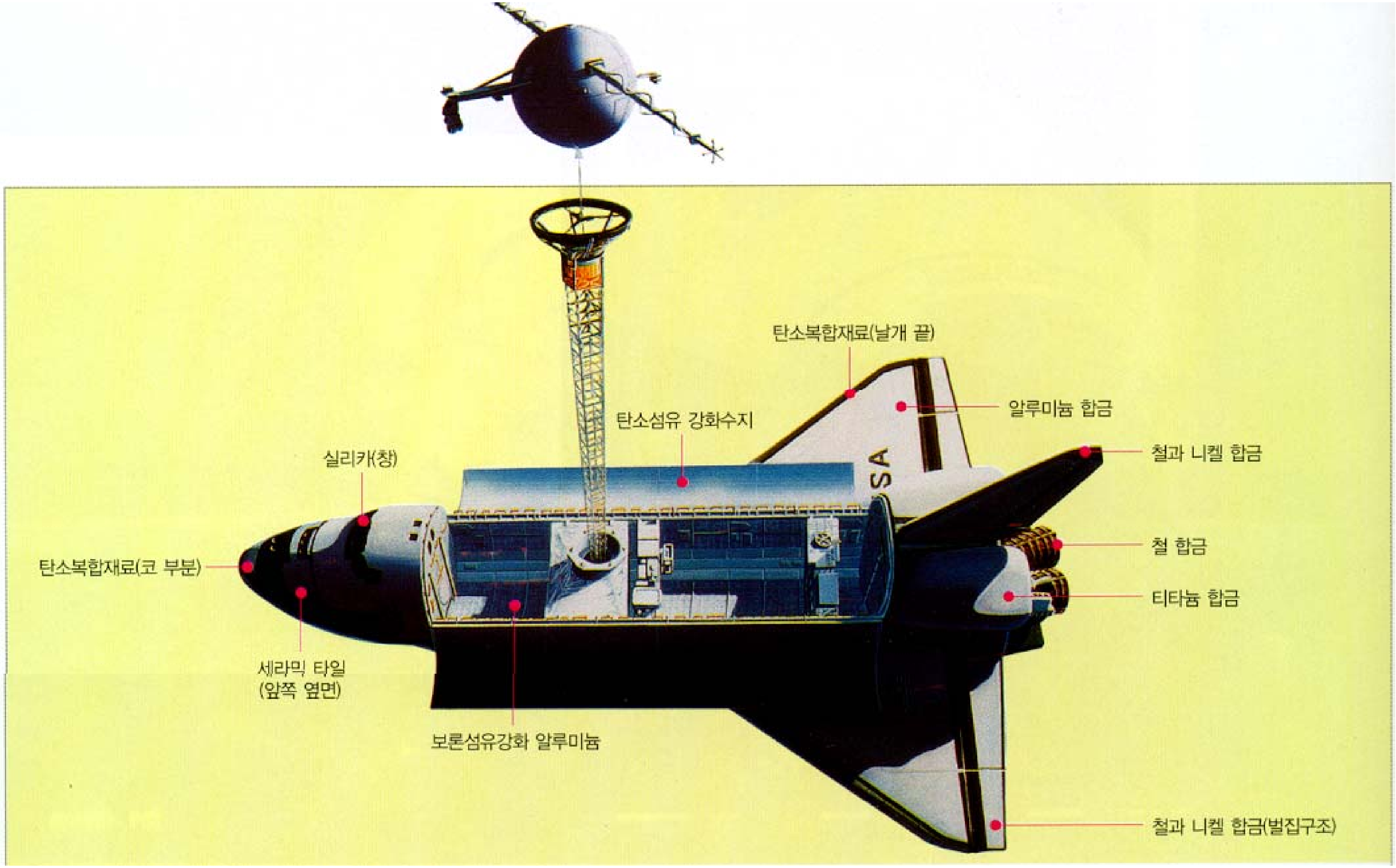
Branched polymers : flexible shampoo bottles and milk jugs



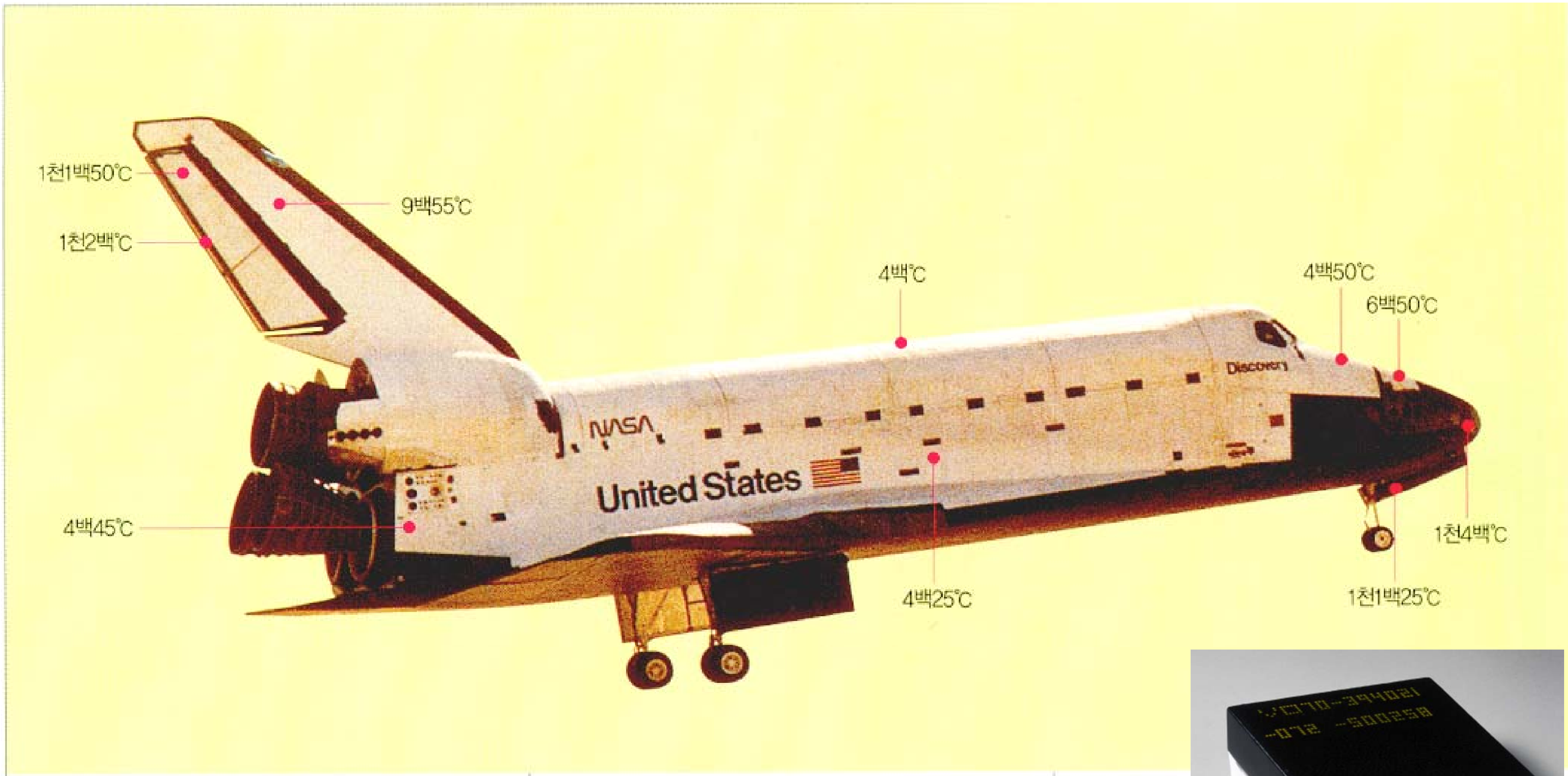
Cross-linked polymers : Car tires and bowling balls

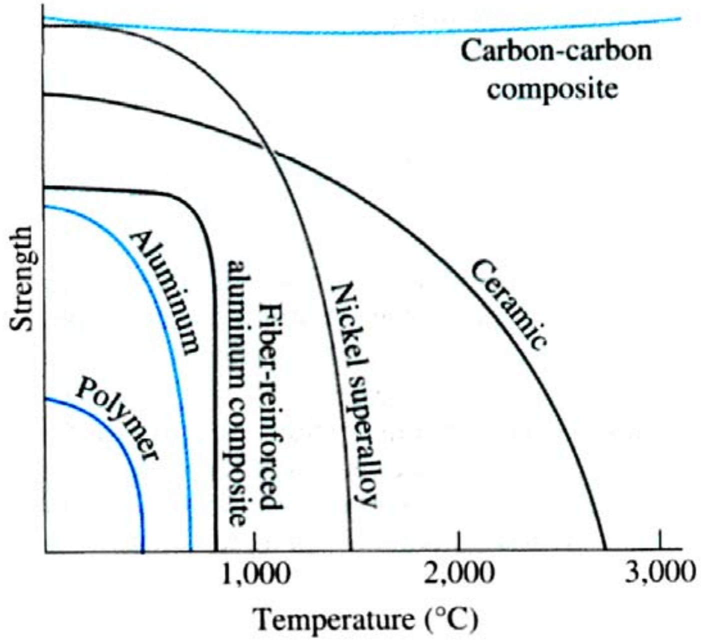


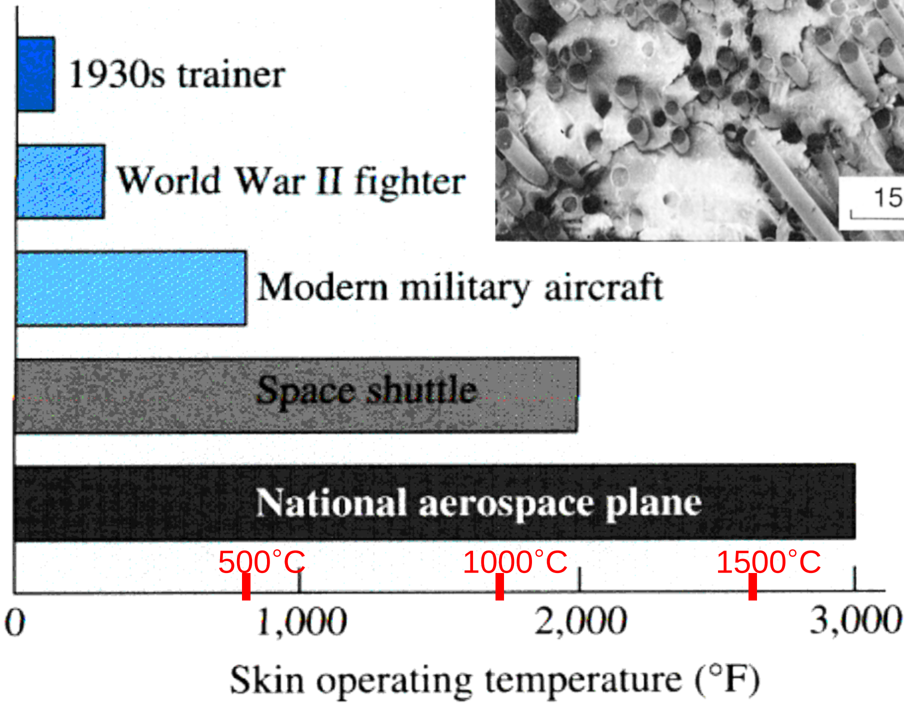
Space Shuttle

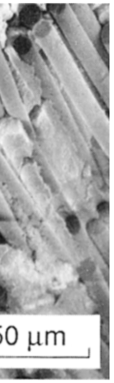


Space Shuttle



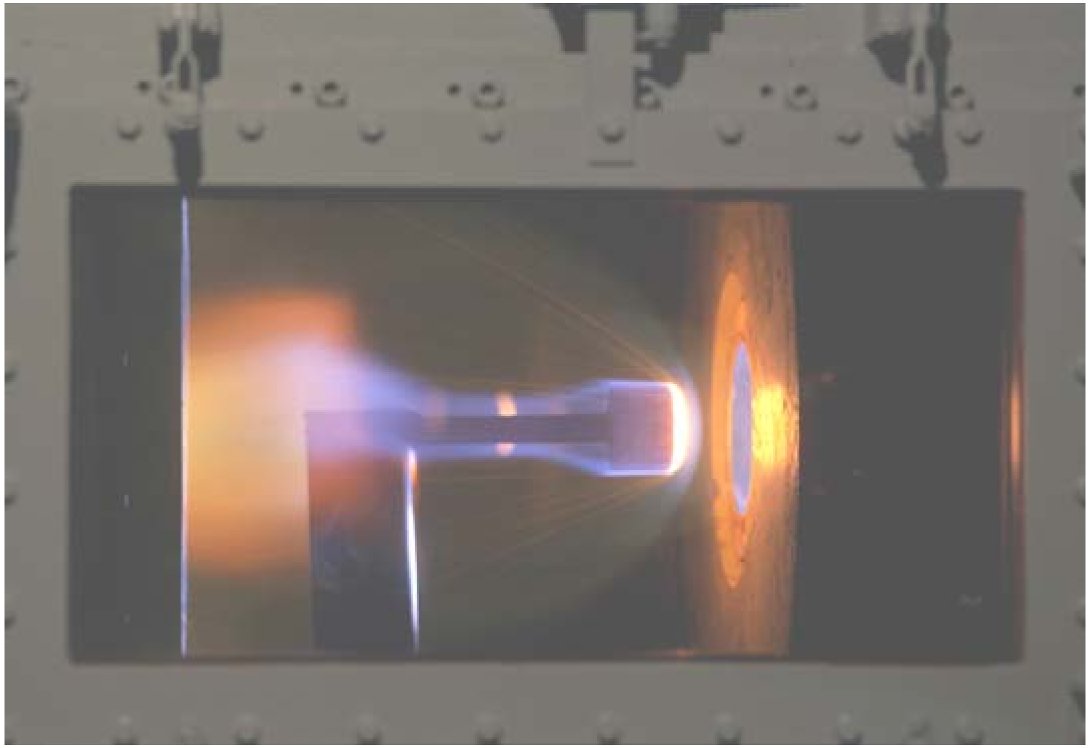






- NASA selected four basic materials for the original design used on Columbia, the first operational orbiter. Each was designed to insulate the orbiter's aluminum and/or graphite epoxy skin against a wide range of extreme temperatures, including a low of minus 250 degrees F.
- The basic materials were Reinforced Carbon-Carbon, Low- and High-Temperature Reusable Surface Insulation tiles, and Felt Reusable Surface Insulation blankets.
- Subsequent design improvements included use of advanced materials in certain areas. These materials are Flexible Insulation Blankets and Fibrous Refractory Composite Insulation. There are approximately 24,300 tiles and 2,300 Flexible Insulation Blankets on the outside of each orbiter.

Space Shuttle



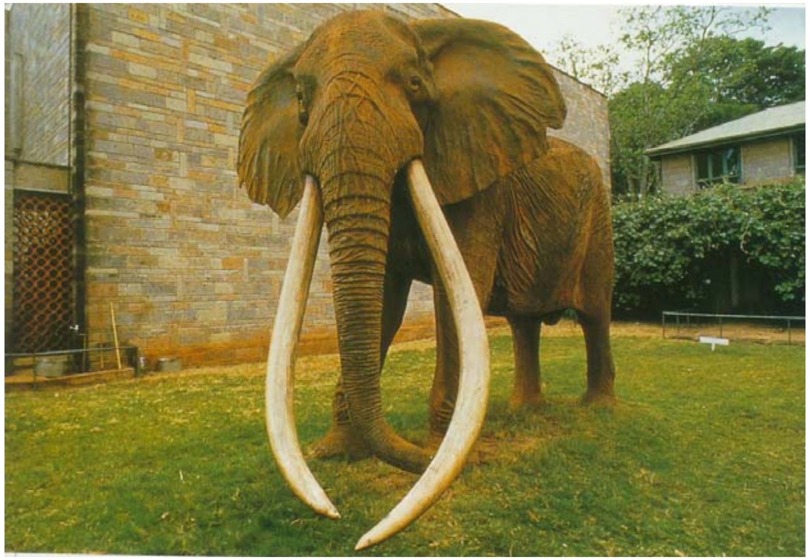
The high temperatures that were to be encountered by the Space Shuttle were simulated in the wind tunnels at Langley in the 1975 test. These thermal-insulation materials were used on the Space Shuttle Orbiter in 1982.

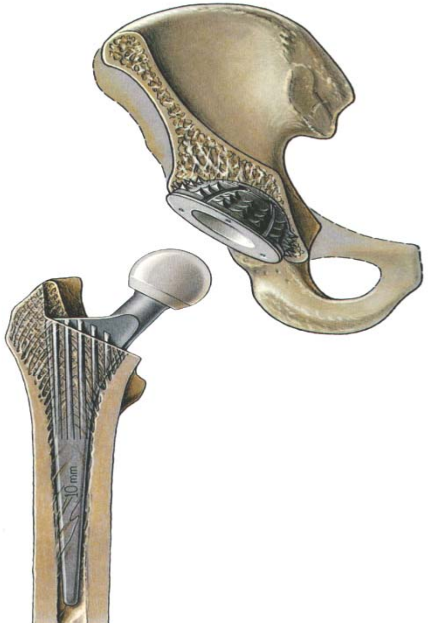
from NASA

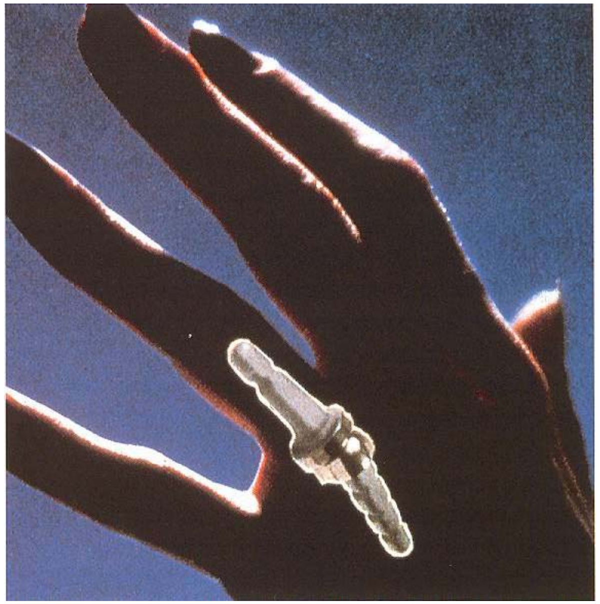
Military Materials

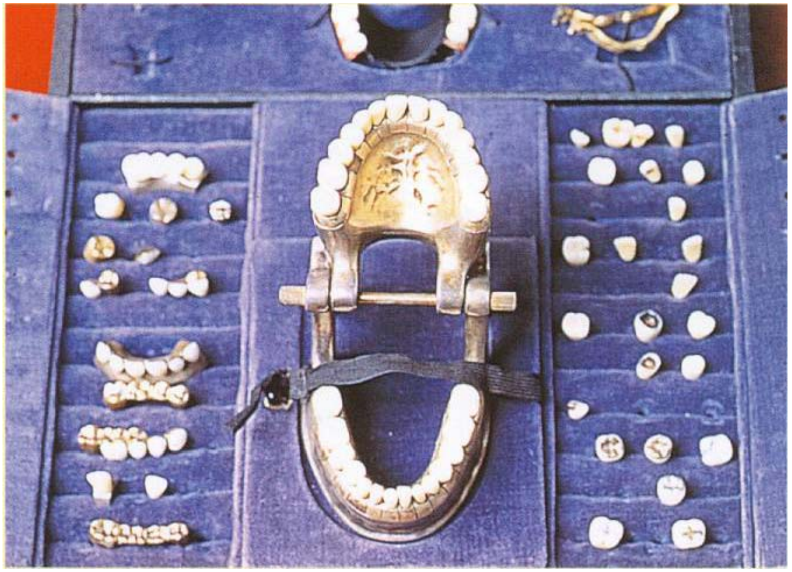
- Money is not an object.

Biomaterials



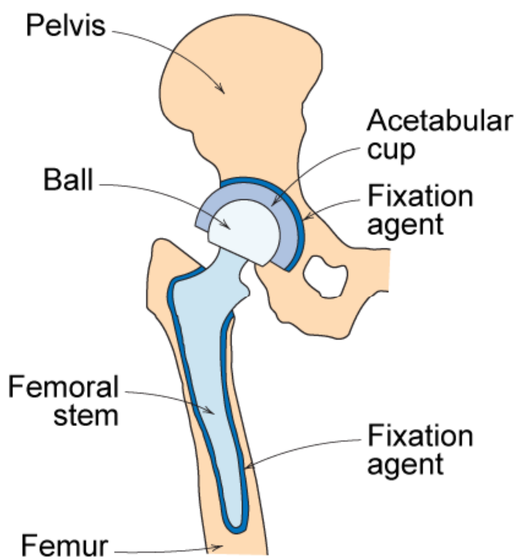




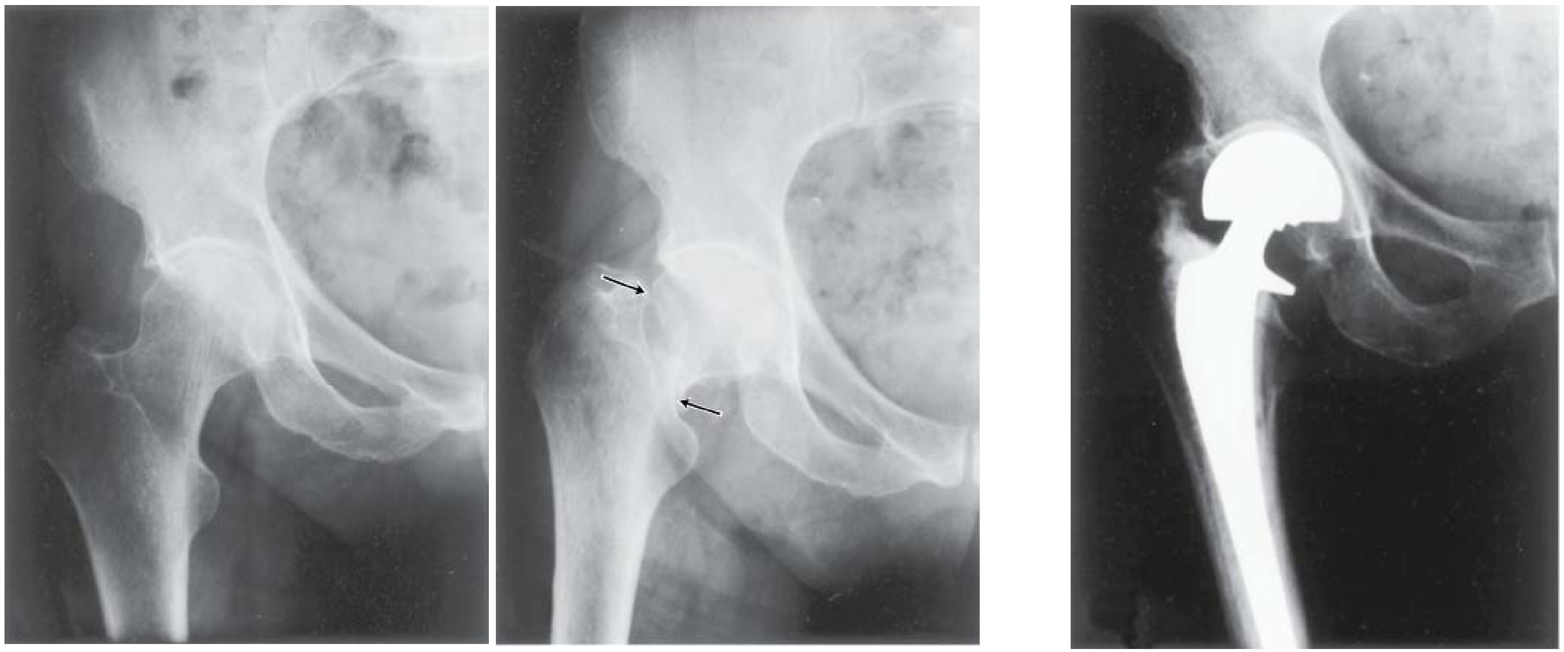


Biomaterials - Hip Implant

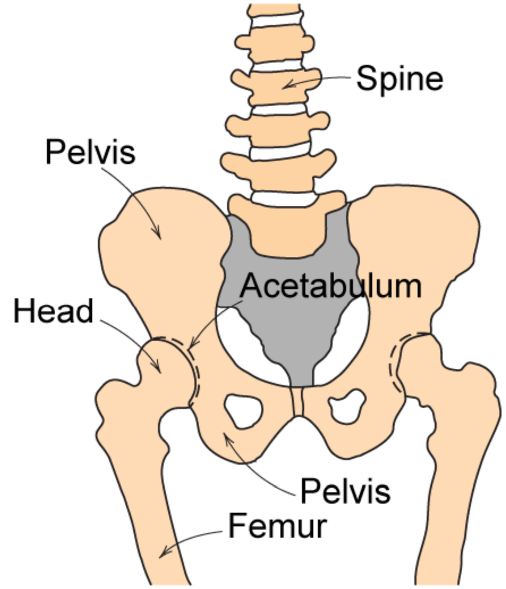
- With age or certain illnesses, some joints deteriorate. Particularly those with large loads (such as hip).



(a)

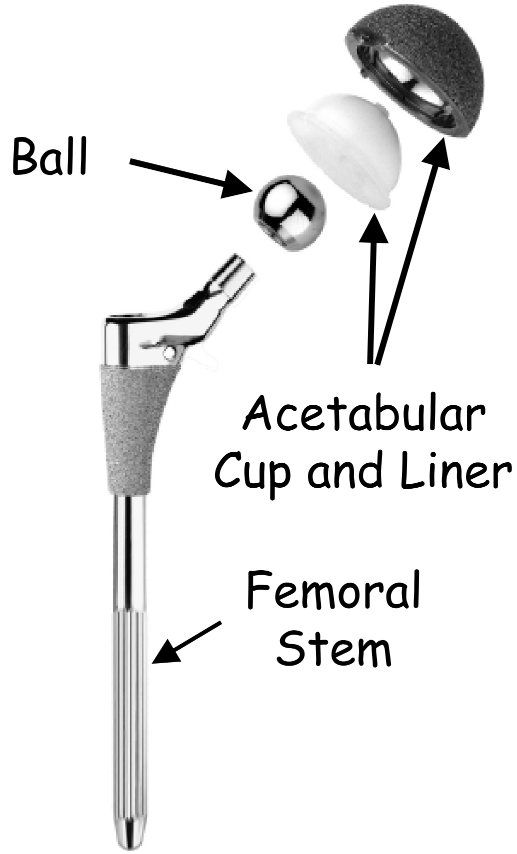

(b)

Biomaterials – Hip Implant



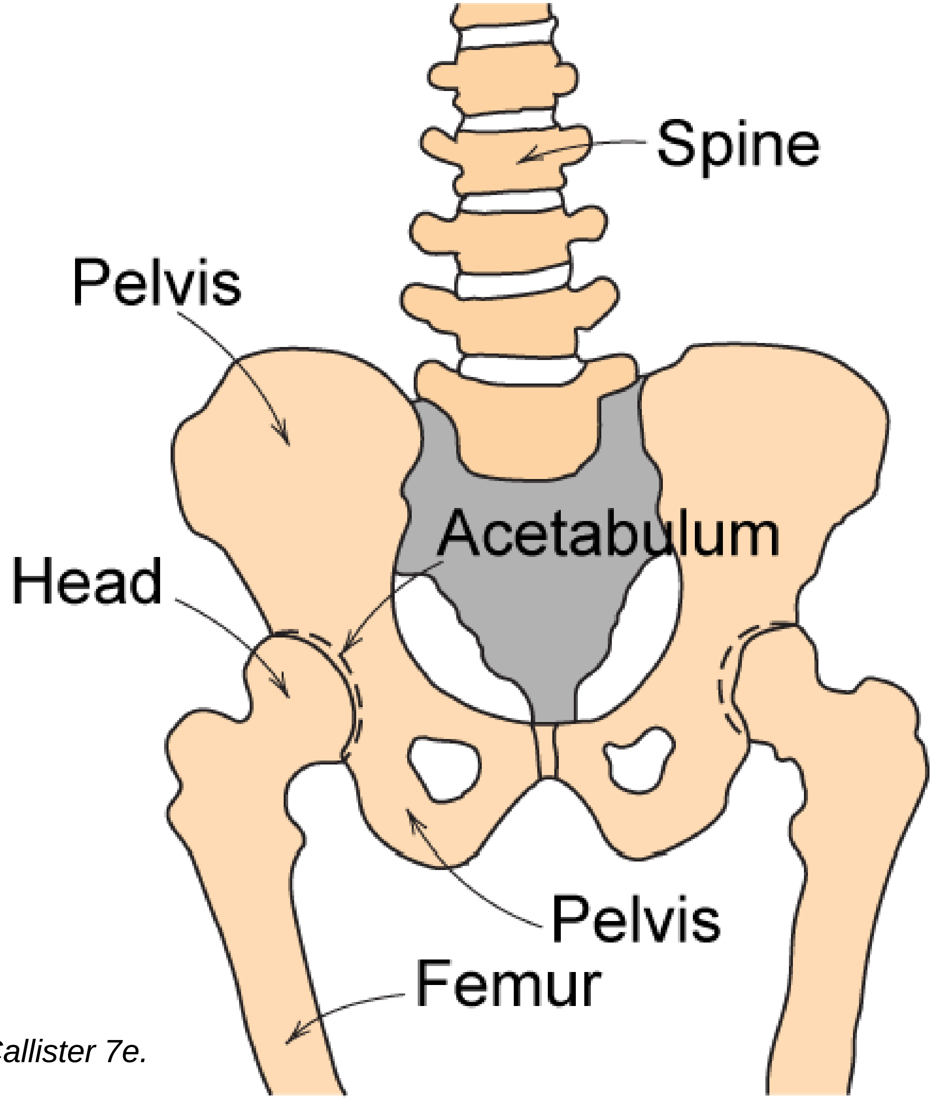
- Requirements
  - ✓ Mechanical strength (many cycles)
  - ✓ Good lubricity
  - ✓ Biocompatibility

- Key problems to overcome
  - ✓ Fixation agent to hold the acetabular cup
  - ✓ Cup lubrication material
  - ✓ Femoral stem – fixing agent ("glue")
  - ✓ Must avoid any debris in cup



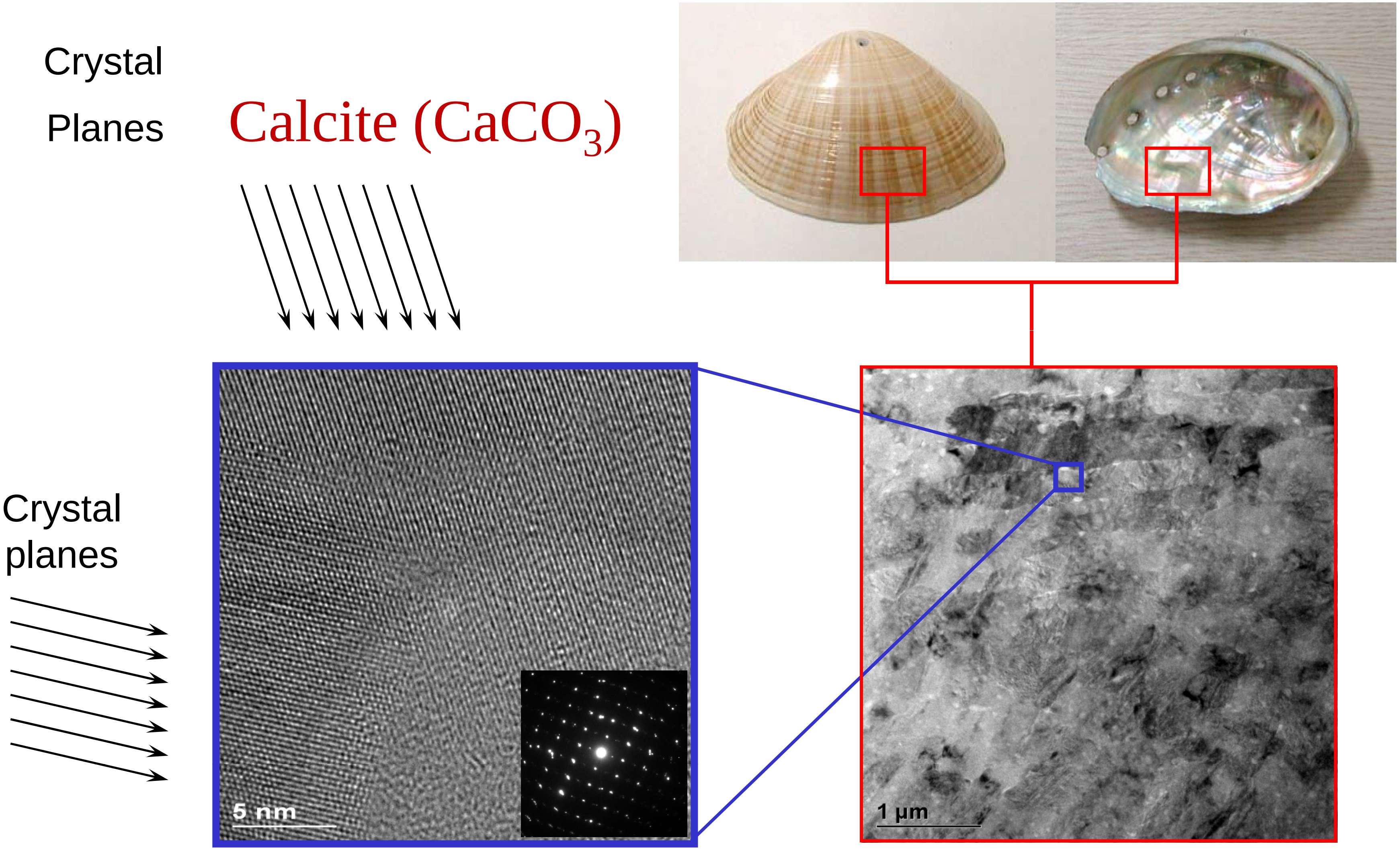
Example – Hip Implant

- **Requirements**
  - ✓ mechanical strength (many cycles)
  - ✓ good lubricity
  - ✓ biocompatibility



Adapted from Fig. 22.24, *Callister 7e.*

Improvement: Copying from the Nature

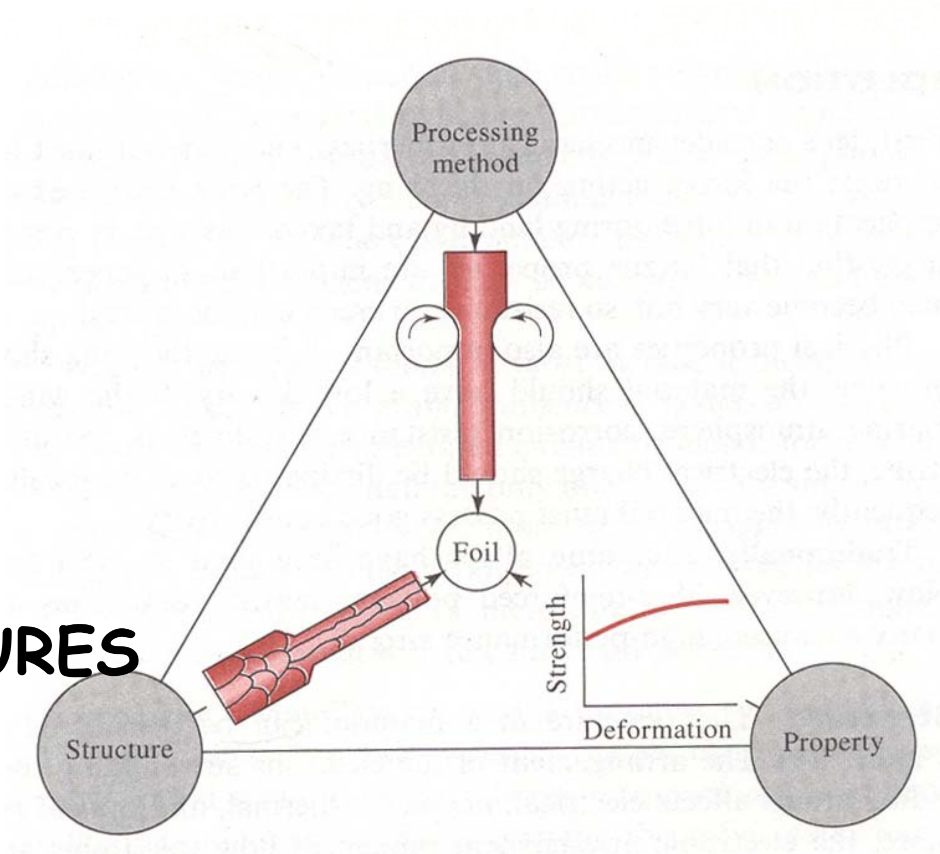


Materials Science & Engineering

➢ Relation between the STRUCTURE, PROPERTIES & PROCESSING

SYNTHESIS (PROCESSING)

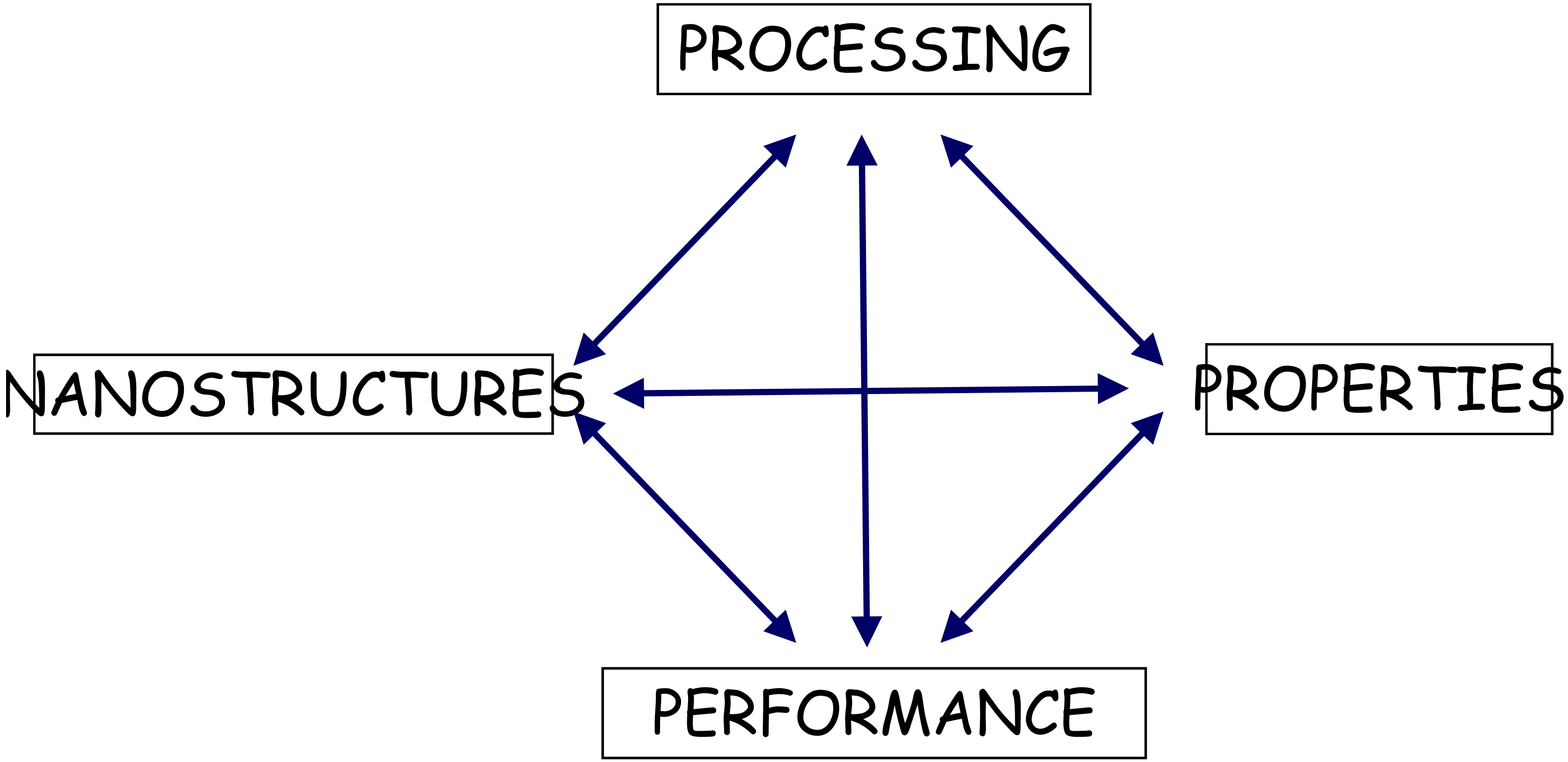
NANOSTRUCTURES



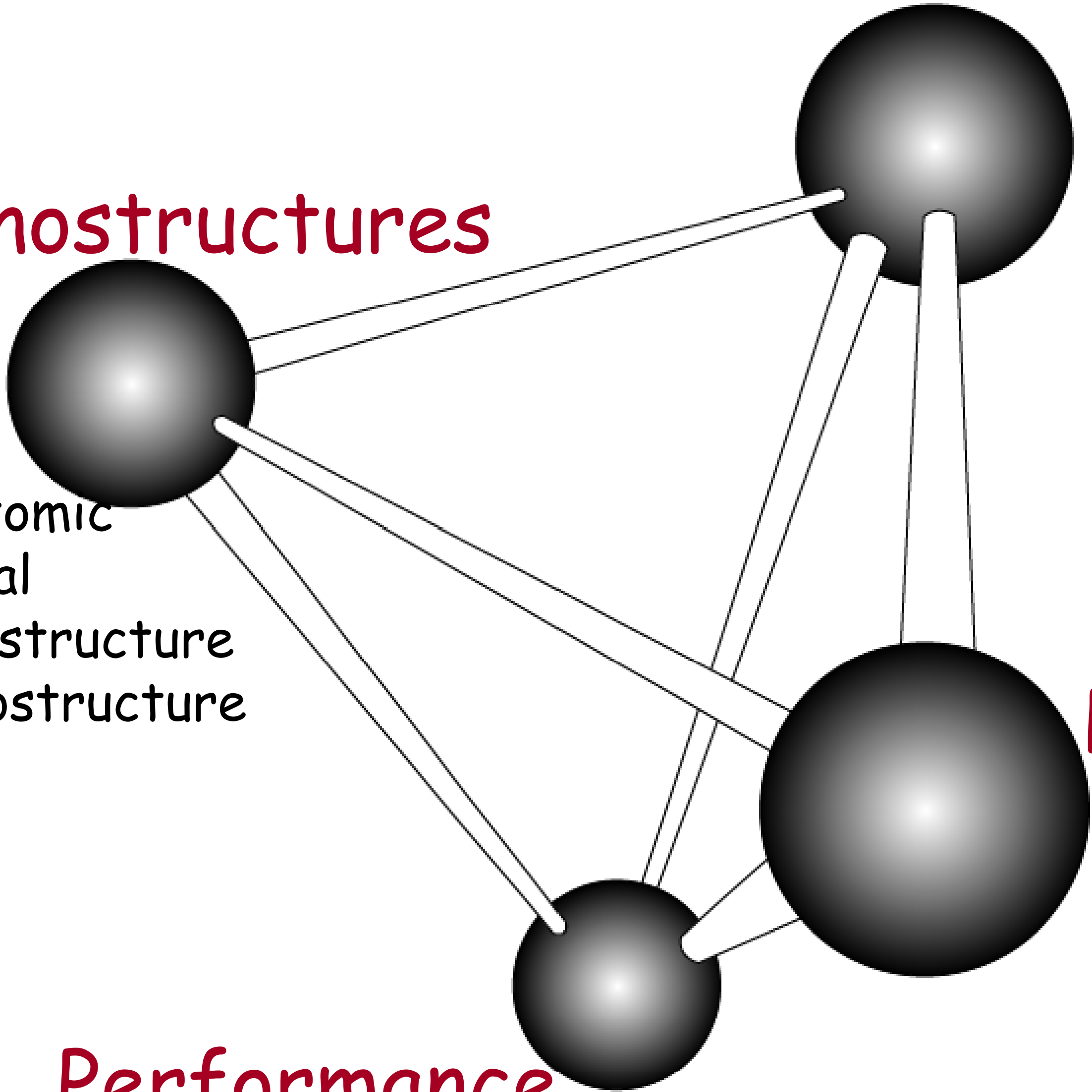
PROPERTIES

MSE

- Relations among the
  Nanostructures, Properties, Processing, & Performance



Materials Science and Engineering



Processing

- ✓ Sintering
- ✓ Heat treatment
- ✓ Thin Film
- ✓ Melt process
- ✓ Mechanical

Nanostructures

- ✓ Subatomic
- ✓ Crystal
- ✓ Microstructure
- ✓ Macrostructure

Properties

- ✓ Electrical
- ✓ Magnetic
- ✓ Thermal
- ✓ Optical
- ✓ Mechanical

Performance

Materials Science, Materials Engineering

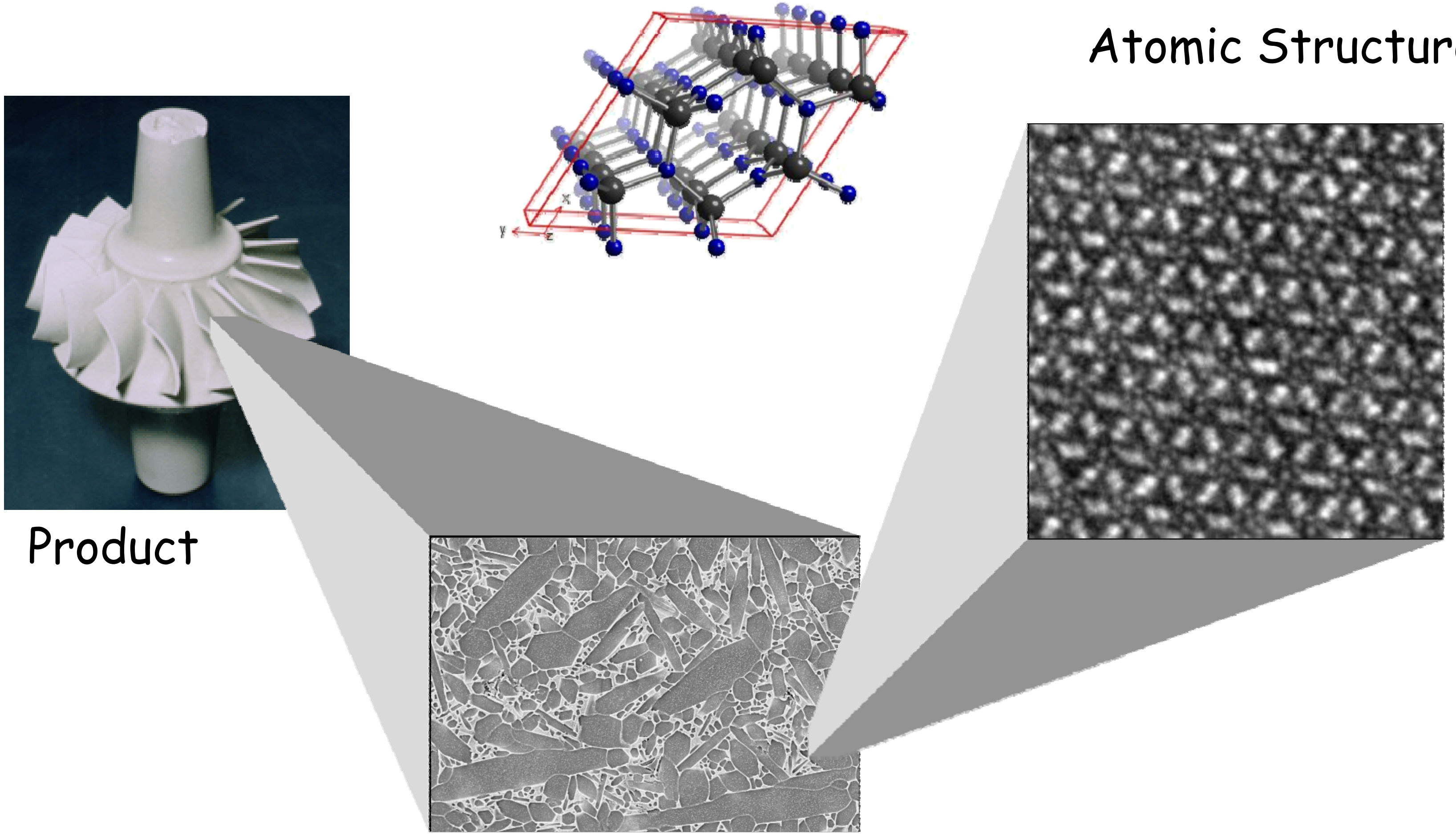
- Materials Science
  - ✓ Investigating the relationships that exist between the nanostructures and properties of materials.

- Materials Engineering
  - ✓ Designing or engineering the structure of a material to produce a predetermined set of properties.

- Structure
  - Subatomic structures
    - Involves electrons within the individual atoms and interactions with their nuclei.
  - Crystal structures
    - Organization of atoms or molecules relative to one another.
  - Nanostructures
  - Macrostructures

- Properties
  - A materials trait in terms of the kind and magnitude of response to a specific imposed stimulus **(*E*, *H*, *hv*, stress, etc.)**.

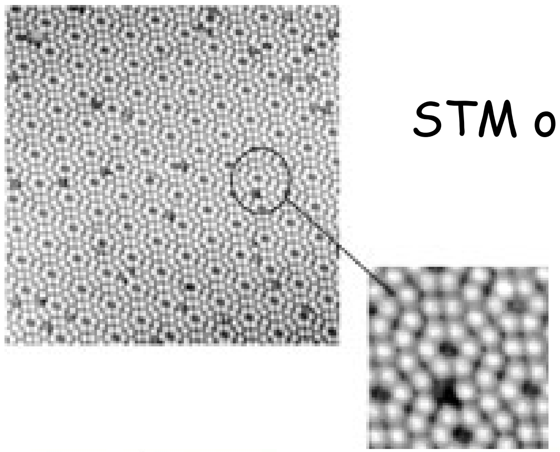
Inside Materials…



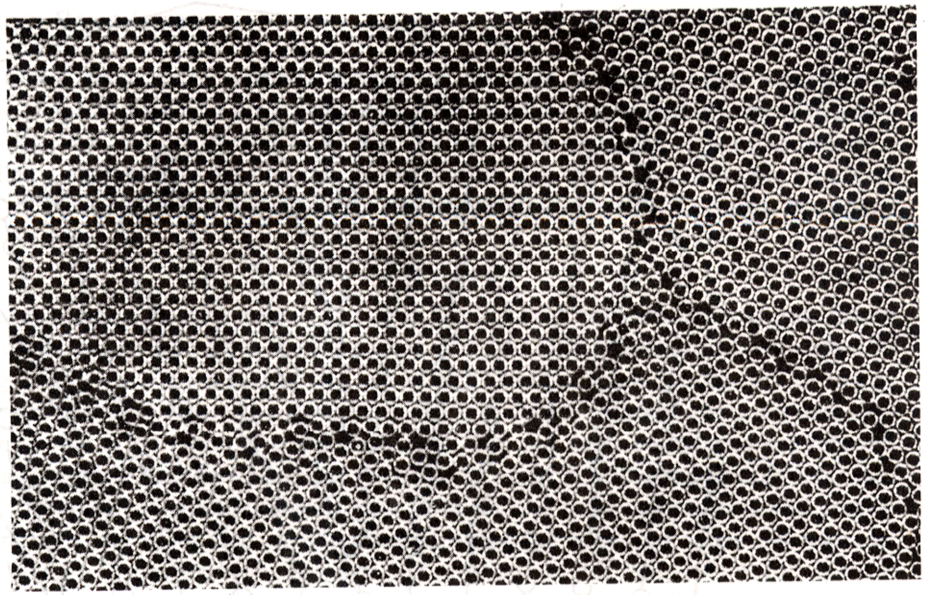
Key Concern…

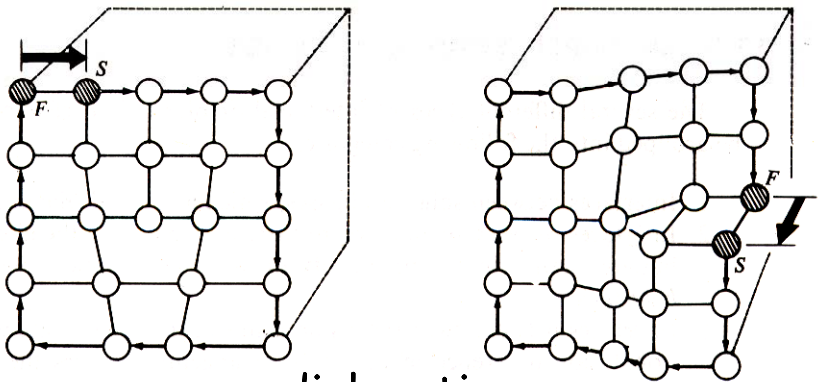
Solids are constituted with an ordered arrangement of atoms.

What if the order breaks down… → Defects



STM on Si





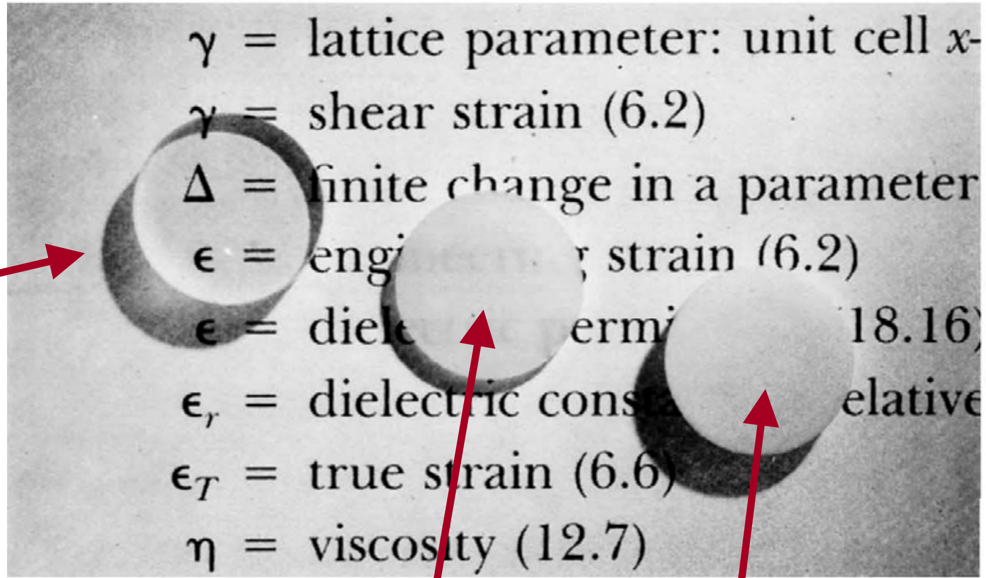
dislocations

Grain boundaries in bubble raft model

Al_2O_3
(Alumina)

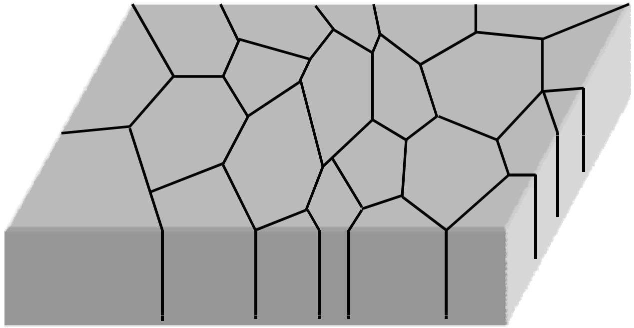
Transparent

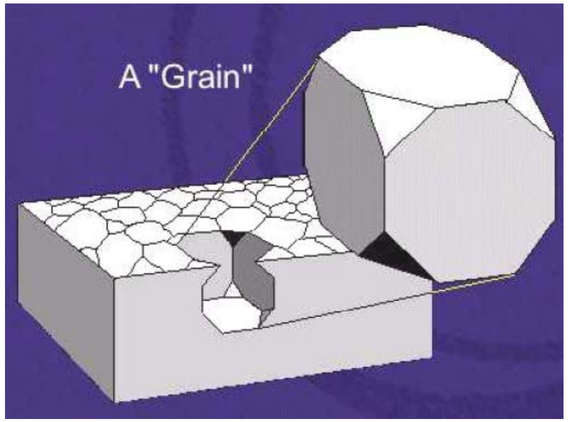
Single crystal



Translucent   Opaque

Small polycrystalline





- Different processing → different structure → different property → different performance

OPTICAL

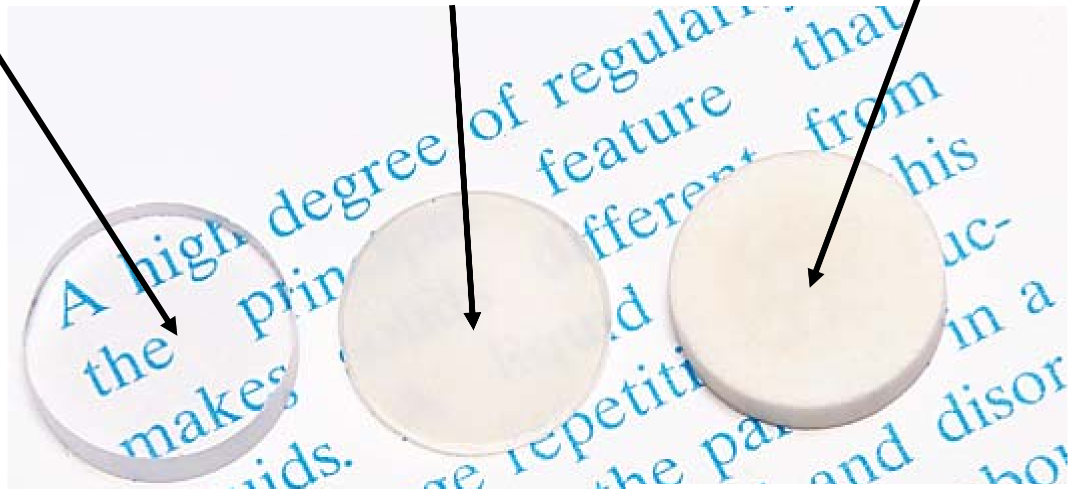
- Transmittance:

  --Aluminum oxide may be transparent, translucent, or opaque depending on the material structure.

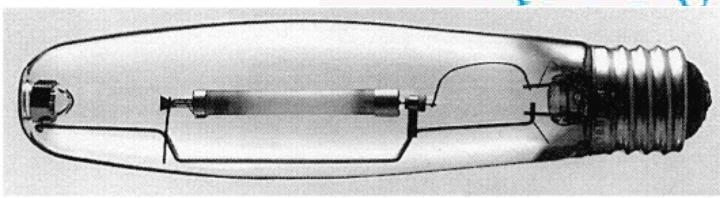
single crystal

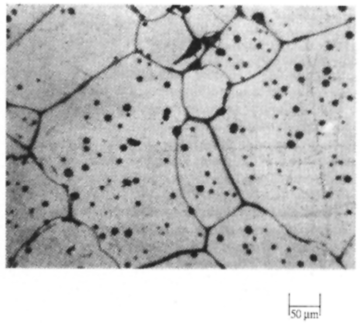
polycrystal: low porosity (Translucent)

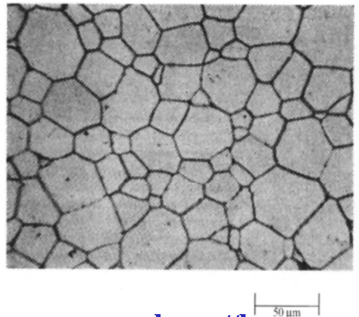
polycrystal: high porosity (Opaque)



Adapted from Fig. 1.2, *Callister 7e.* (Specimen preparation, P.A. Lessing; photo by S. Tanner.)

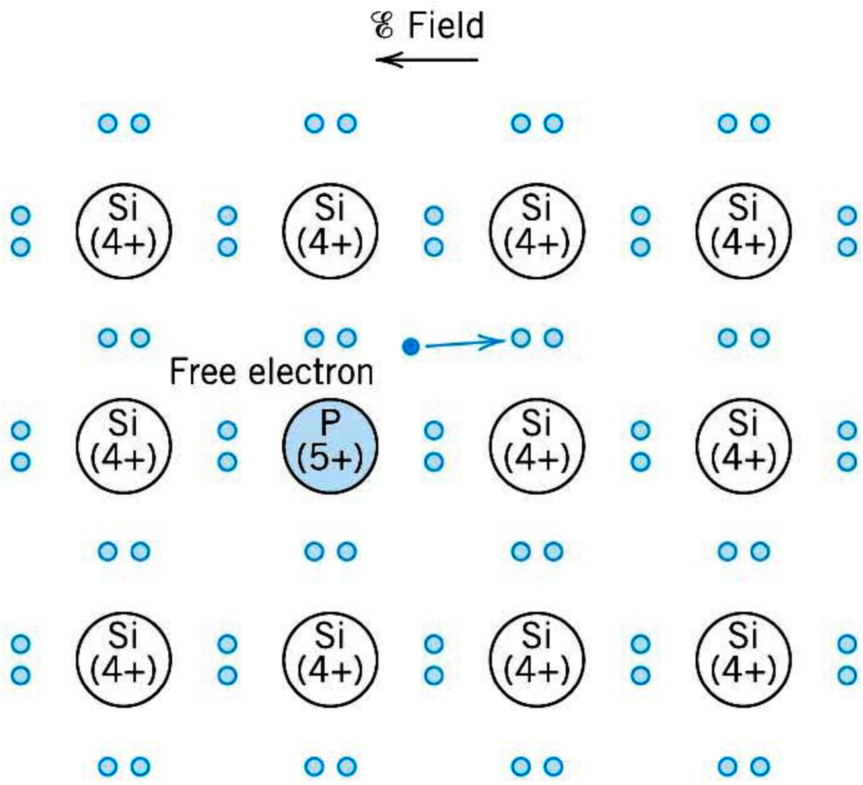




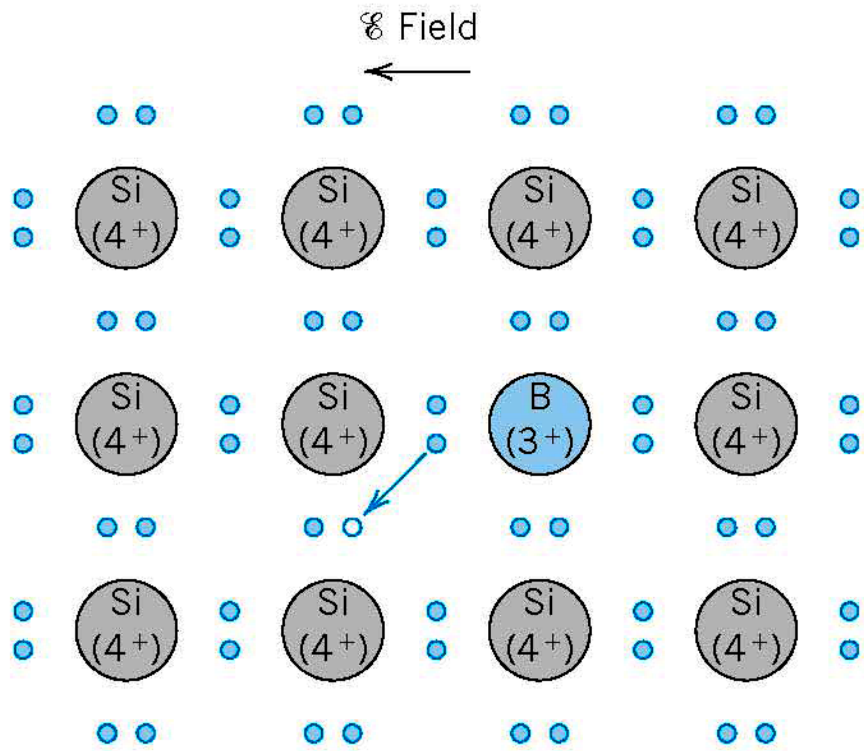


Atomic Structure

n-type

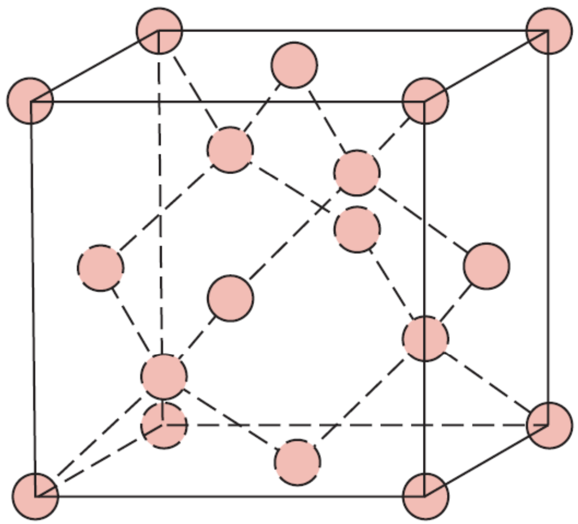


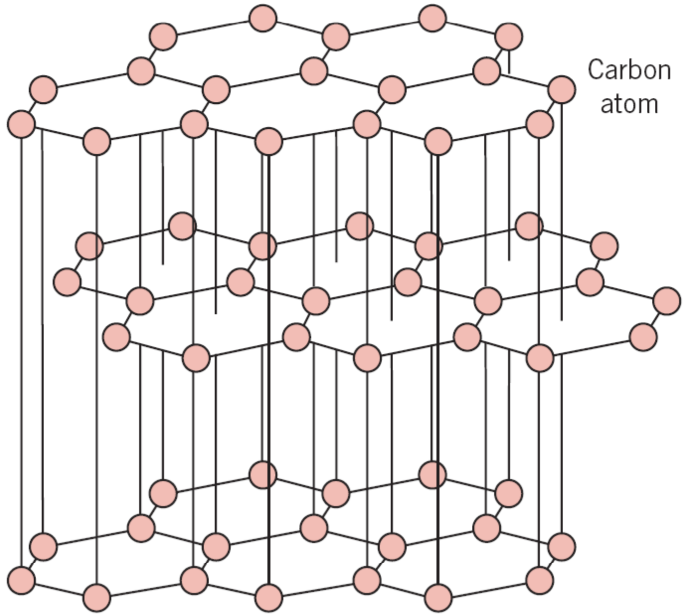
p-type



Crystal Structure

Diamond		Graphite (Carbon; BN)

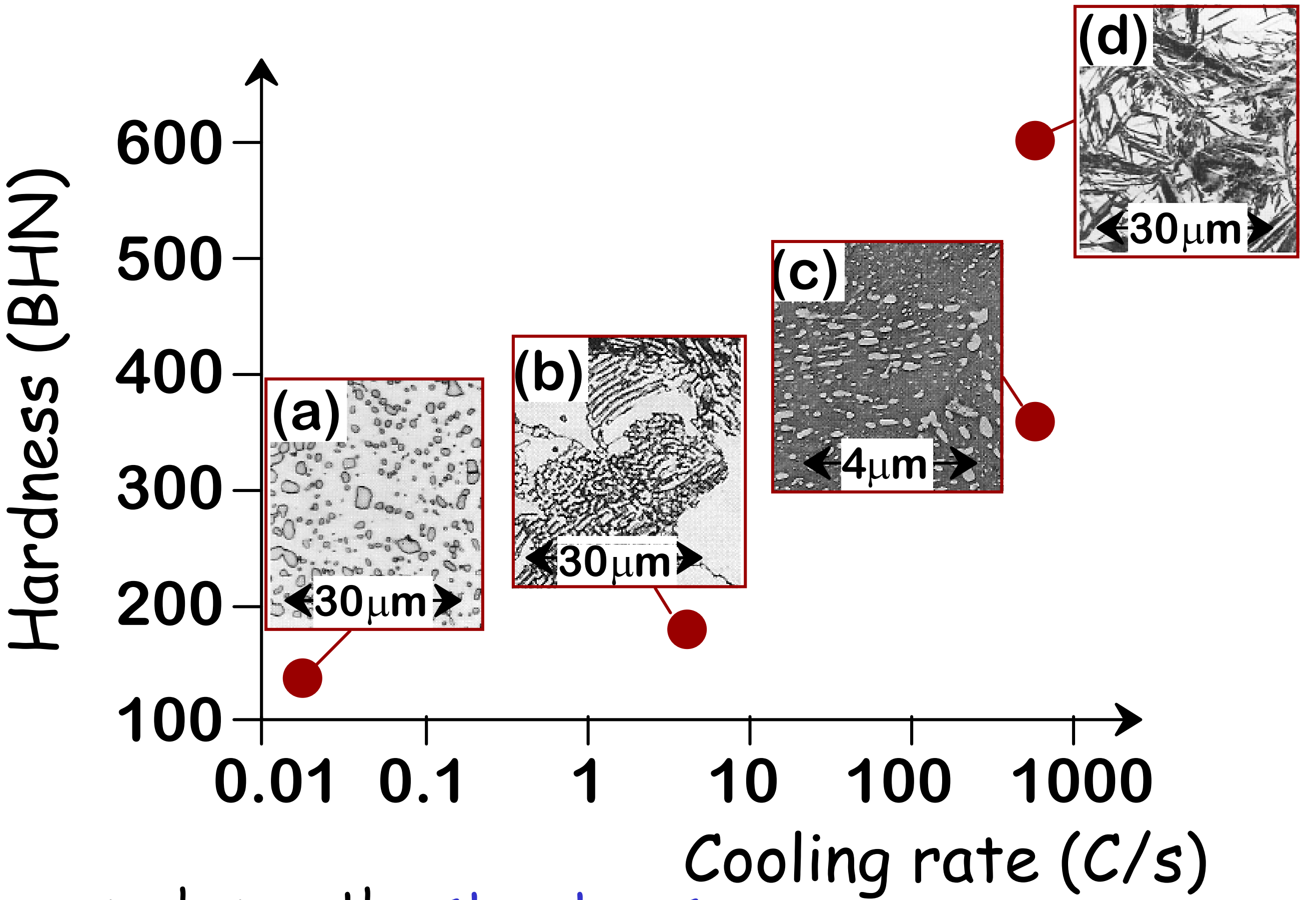




10	Hardness	2
3.5 g/cm^3	Density	2.2 g/cm^3
1.54 Å	Bond length	3.4/1.48 Å
(111)	Cleavage	(001)
cubic	Crystal structure	hexagonal

Structure – Processing - Properties

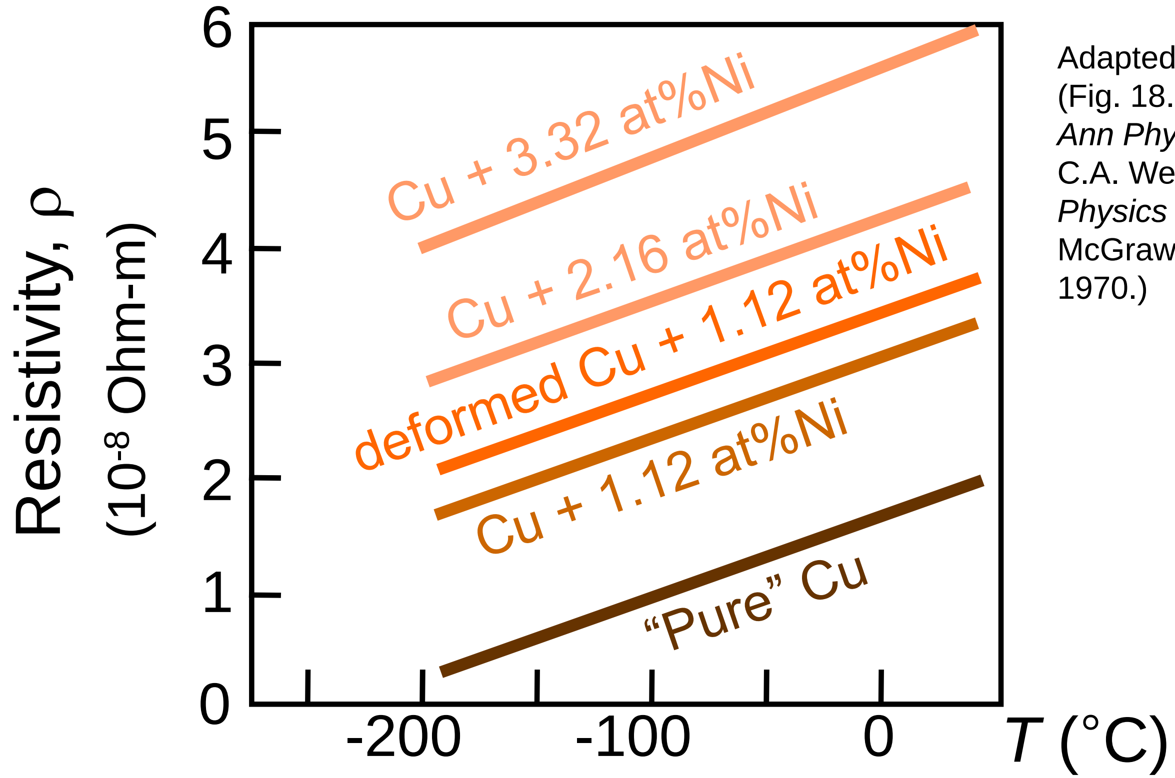
- Properties depend on the structures.
  - ✓ Hardness vs. structure of steel



- Processing can change the structures
  - ✓ Structure vs. cooling rate of steel

Electrical Properties

- Electrical Resistivity of Copper:



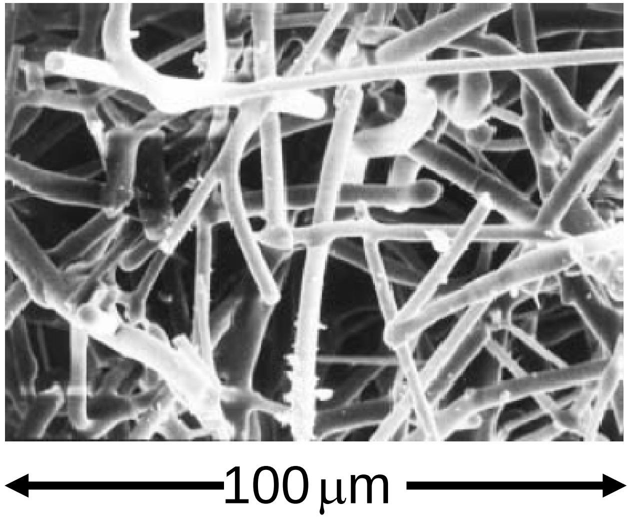
Adapted from Fig. 18.8, *Callister 7e.* (Fig. 18.8 adapted from: J.O. Linde, *Ann Physik* **5**, 219 (1932); and C.A. Wert and R.M. Thomson, *Physics of Solids*, 2nd edition, McGraw-Hill Company, New York, 1970.)

- Adding "impurity" atoms to Cu increases resistivity.
- Deforming Cu increases resistivity.

THERMAL

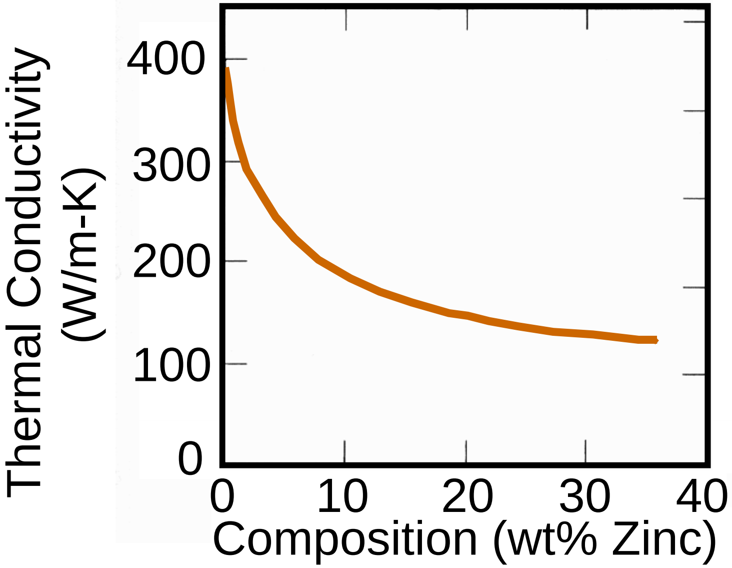
- Space Shuttle Tiles:
  --Silica fiber insulation
  offers low heat conduction.

Adapted from chapter-opening photograph, Chapter 19, *Callister 7e.* (Courtesy of Lockheed Missiles and Space Company, Inc.)



Adapted from Fig. 19.4W, *Callister 6e.* (Courtesy of Lockheed Aerospace Ceramics Systems, Sunnyvale, CA) (Note: "W" denotes fig. is on CD-ROM.)

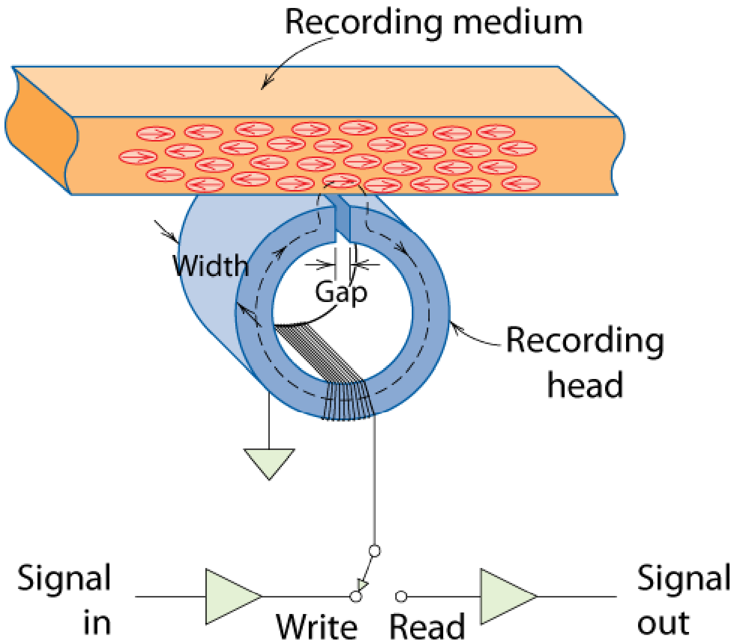
- Thermal Conductivity of Copper:
  --It decreases when
  you add zinc!

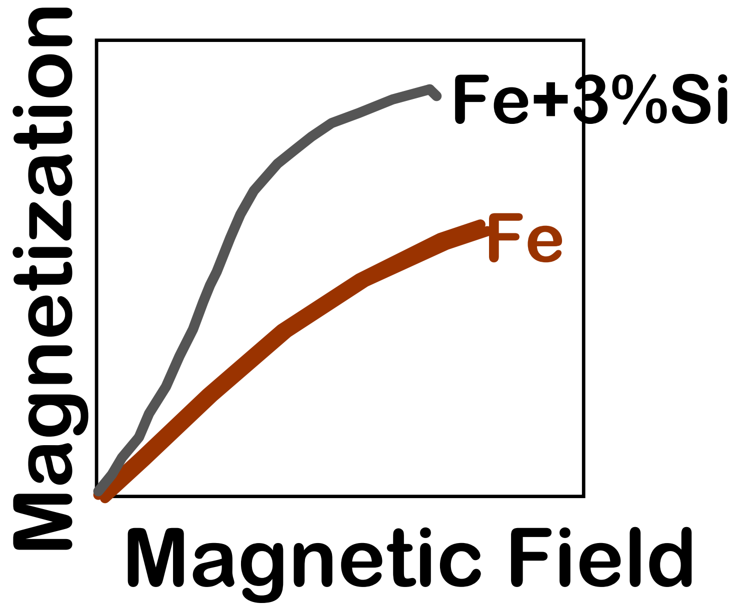


Adapted from Fig. 19.4, *Callister 7e.* (Fig. 19.4 is adapted from *Metals Handbook: Properties and Selection: Nonferrous alloys and Pure Metals*, Vol. 2, 9th ed., H. Baker, (Managing Editor), American Society for Metals, 1979, p. 315.)

MAGNETIC Properties

- Magnetic Storage:
  - ✓ Recording medium is magnetized by recording head

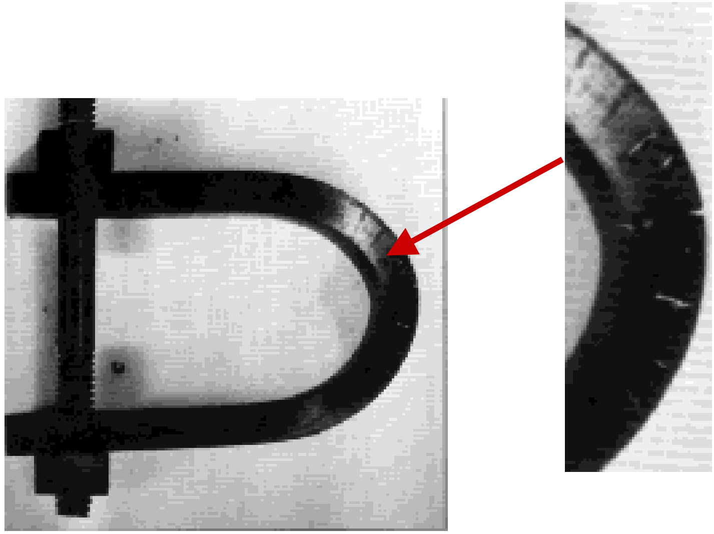




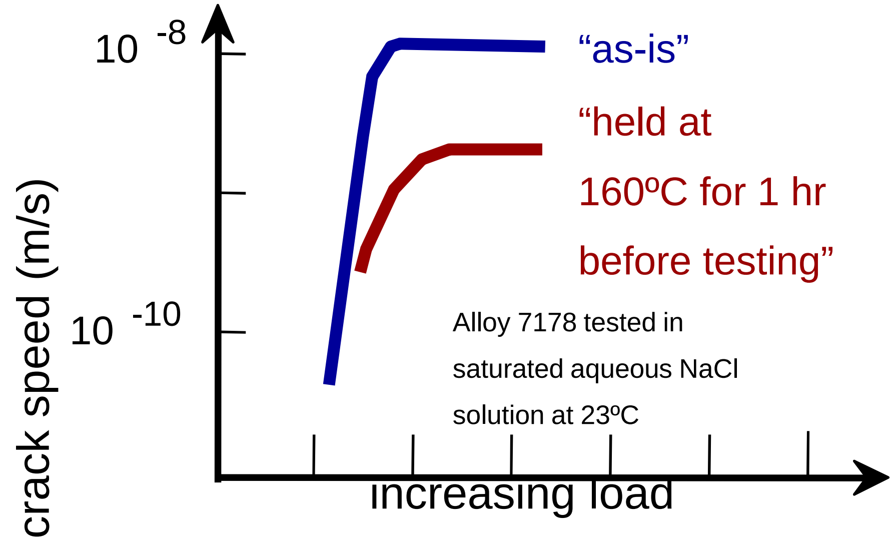
- Magnetic Permeability vs. Composition:
  - ✓ Adding 3 at. % Si makes Fe a better recording medium!

DETERIORATIVE

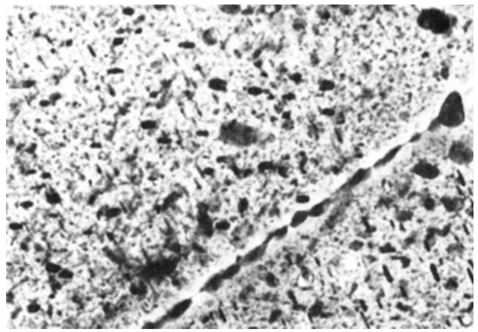
- Stress & Salt water...
  - ✓ causes cracks!



- Heat Treatment
  - ✓ Slows crack speed in salt water!



Material:
7150-T651 Al "alloy"
(Zn-Cu-Mg-Zr)



Materials Classification

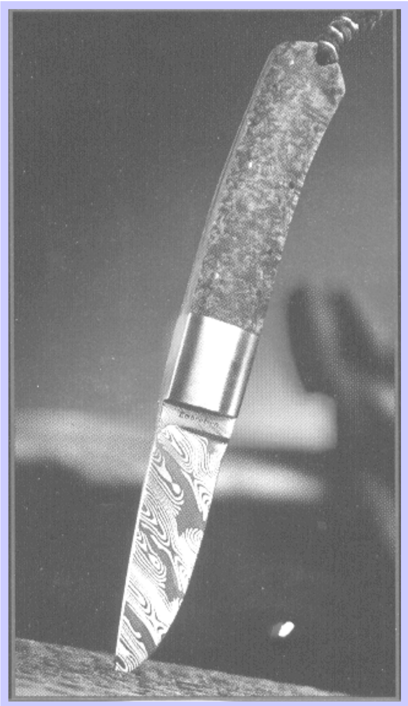
- Metal, ceramics, polymer, composite

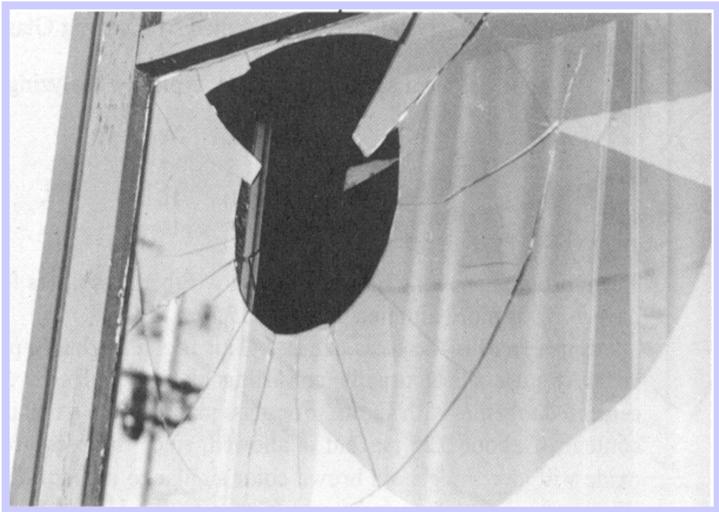
- Chemical
  - ✓ Organic
  - ✓ Inorganic
- Properties
  - ✓ Electronic
  - ✓ Optical
  - ✓ Magnetic
  - ✓ Structural
  - ✓ Biomaterials
- Structure
  - ✓ Single crystal
  - ✓ Polycrystal
  - ✓ Crystallinity
  - ✓ Amorphous

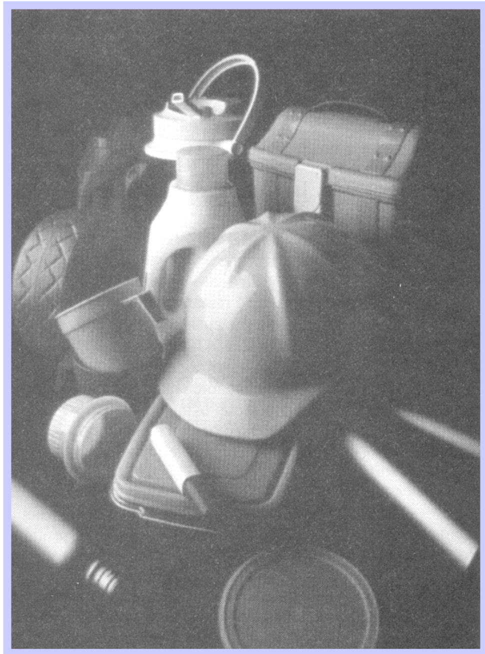
CLASSIFICATION OF MATERIALS

- Three basic groups:

metals *ceramics* *polymers*

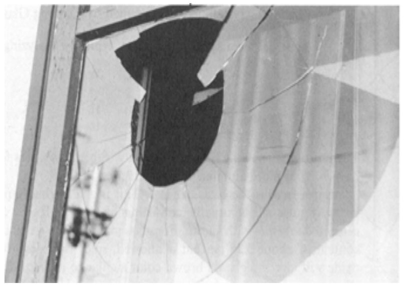






Materials Classification

- Metal
  - ✓ Free electrons
  - ✓ Strong, ductile
  - ✓ Good conductors of electricity & heat
  - ✓ Opaque, reflective
- Ceramic
  - ✓ Ionic/covalent bonding – compounds of metallic & non-metallic elements (oxides, carbides, nitrides, sulfides)
  - ✓ Brittle
  - ✓ Not good conductor of electricity & heat
- Polymer
  - ✓ Covalent bonding → sharing of electrons
  - ✓ Soft (flexible), ductile, low strength, low density
  - ✓ Thermal & electrical insulators
  - ✓ Optically translucent or transparent
  - ✓ Organic compounds (plastic, rubber, etc.)



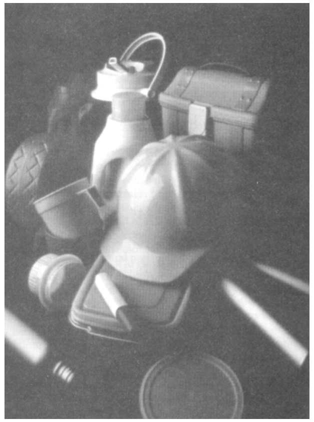


TABLE 1-1 ■ *Representative examples, applications, and properties for each category of materials*

	Examples of Applications	Properties
Metals and Alloys		
Copper	Electrical conductor wire	High electrical conductivity, good formability
Gray cast iron	Automobile engine blocks	Castable, machinable, vibration-damping
Alloy steels	Wrenches, automobile chassis	Significantly strengthened by heat treatment
Ceramics and Glasses		
SiO_2-Na_2O-CaO	Window glass	Optically transparent, thermally insulating
Al_2O_3, MgO, SiO_2	Refractories (i.e., heat-resistant lining of furnaces) for containing molten metal	Thermally insulating, withstand high temperatures, relatively inert to molten metal
Barium titanate	Capacitors for microelectronics	High ability to store charge
Silica	Optical fibers for information technology	Refractive index, low optical losses
Polymers		
Polyethylene	Food packaging	Easily formed into thin, flexible, airtight film
Epoxy	Encapsulation of integrated circuits	Electrically insulating and moisture-resistant
Phenolics	Adhesives for joining plies in plywood	Strong, moisture resistant
Semiconductors		
Silicon	Transistors and integrated circuits	Unique electrical behavior
GaAs	Optoelectronic systems	Converts electrical signals to light, lasers, laser diodes, etc.
Composites		
Graphite-epoxy	Aircraft components	High strength-to-weight ratio
Tungsten carbide-cobalt (WC-Co)	Carbide cutting tools for machining	High hardness, yet good shock resistance
Titanium-clad steel	Reactor vessels	Low cost and high strength of steel, with the corrosion resistance of titanium


Aerospace
C-C composites, SiO_2, Amorphous silicon, Al-alloys, Superalloys, Zerodur™
Structural
Steels, Aluminum alloys, Concrete, Fiberglass, Plastics, Wood
Biomedical
Hydroxyapatite, Titanium alloys, Stainless steels, Shape-memory alloys, Plastics, *PZT*
Smart Materials
PZT, Ni-Ti shape-memory alloys, MR fluids, Polymer gels
Classification of Functional Materials
Electronic Materials
Si, GaAs, Ge, $BaTiO_3$, *PZT*, $YBa_2Cu_3O_{7-x}$, Al, Cu, W, Conducting polymers
Optical Materials
SiO_2, GaAs, Glasses, Al_2O_3, *YAG*, *ITO*
Magnetic Materials
Fe, Fe-Si, NiZn and MnZn ferrites, Co-Pt-Ta-Cr, γ-Fe_2O_3
Energy Technology and Environmental
UO_2, Ni-Cd, ZrO_2, $LiCoO_2$, Amorphous Si:H

Materials 소재

- What is materials science?
- Why should we know about it?

- **Materials drive our society:**
  - ✓ Stone Age
  - ✓ Bronze Age
  - ✓ Iron Age
  - ✓ Now
    - Silicon Age
    - Polymer Age?
    - Carbon Age?

Materials Classification

화학적 분류: 유기재료 (organic)
무기재료(inorganic): 금속, 세라믹

재질적 분류: 금속재료(metal)
세라믹재료(ceramics)
고분자재료(polymer)
복합재료(composite)

용도별 분류: 전자재료(electronic)
광학재료(optical)
구조재료(structural)
생체재료(biomaterials)

구조적 분류: 단결정(single crystal)
다결정(polycrystalline)
결정질(crystallinity)
비정질(amorphous)

Chapter 1 - SUMMARY

- Use the right materials for the right job.
- Understand the correlations between properties, structures, and processing.
- New design opportunities offered by new materials.

- Reading - Chapter 1 of Callister