Introduction to Materials Science and Engineering 2019

Lecture title: Introduction to Materials Science and Engineering

교과목명: 재료공학원리

Course Code (교과목번호): 445.102A Lecture number (강좌번호): 002

Professor: Park, Eun Soo (박은수)

Office (연구실): 33동 313호

Office ☎ (연락처): 02-880-7221

e-mail (전자우편): espark@snu.ac.kr

Class hour(강의시간): Tuesday, Thursday 12:30 – 13: 45

Lecture room (강의실): 33-225 (Classroom: Bldg. 33, Rm 225)

Lecture homepage (강좌관련 홈페이지): *http://etl.snu.ac.kr/*

Office hour(면담시간) : By appointment via email

☐ Textbook and references

Main text: William D. Calister, Jr. "Materials Science and Engineering: An Introduction," , John Wiley & Sons, Inc.

Reference:J. F. Shackelford, "Introduction to Materials Science For Engineerings," Prentice Hall Inc.,

☐ Grade

- Relative grading ((A+B) 70%, (C) 20%, (D-F) 10%)
- Midterm1(25%), Midterm2(25%) Final exam (40 %),
- Homework and Attendance (10 %)
- Note: 1) The weight of each component above could be adjusted up to 5% based on students' performance. 2) Student who retakes this course will have their final scores adjusted downward by 10% in order to ensure fairness with other students.

"2019년 2학기부터 입학 후 두 번째 등록학기에 수강하는 학생과 그 이후에 처음 수강하는 학생은 별도로 평가할 수 있다"

Schedule

week 1 *Introduction*

week 2 *Atomic Structure and Interatomic Bonding* (Chap. 2)

week 3 *Fundamentals of Crystallography* (Chap. 3)

week 4 *The Structure of Crystalline Solids* (Chap. 4)

week 5 *Imperfections in Solids* (Chap. 6)

week 6 *Diffusion* (Chap. 7) *& Mid-term*

week 7 *Mechanical Properties of Metals* (Chap. 8)

week 8 *Dislocations and Strengthening Mechanisms* (Chap. 9)

week 9 *Failure* (Chap. 10)

week 10 *Phase Diagram* (Chap. 11)

week 11 *Phase Transformation* (Chap. 12)

week 12 *Polymer Structures* (Chap. 5)

week 13 *Characteristics, Applications, and Processing of Polymers* (Chap. 15)

week 14 *Functional Polymers* (Chap. 16)

week 15 *Presentation of Team project and Final Exam*

Why do I need to study materials?

1. To graduate ㅜ.ㅜ 
2. Professor Park is known to be generous on the grade.
3. To conserve professor’s job….
4. Not many class I can take….
5. My girl friend is taking this class …
6. I want to develop new materials…..
7. My parents suggested to take this course…..
8. This is the start of my challenge to the universe…

What are Materials?

- **That's easy! Look around.**
- Our clothes are made of materials, our homes are made of materials - mostly manufactured. Glass windows, vinyl siding, metal silverware, ceramic dishes…
- **Most things are made from many different kinds of materials.**

Periodic Table of the Elements

대한화학회
KOREAN CHEMICAL SOCIETY
화학이 지구를 더 푸르게

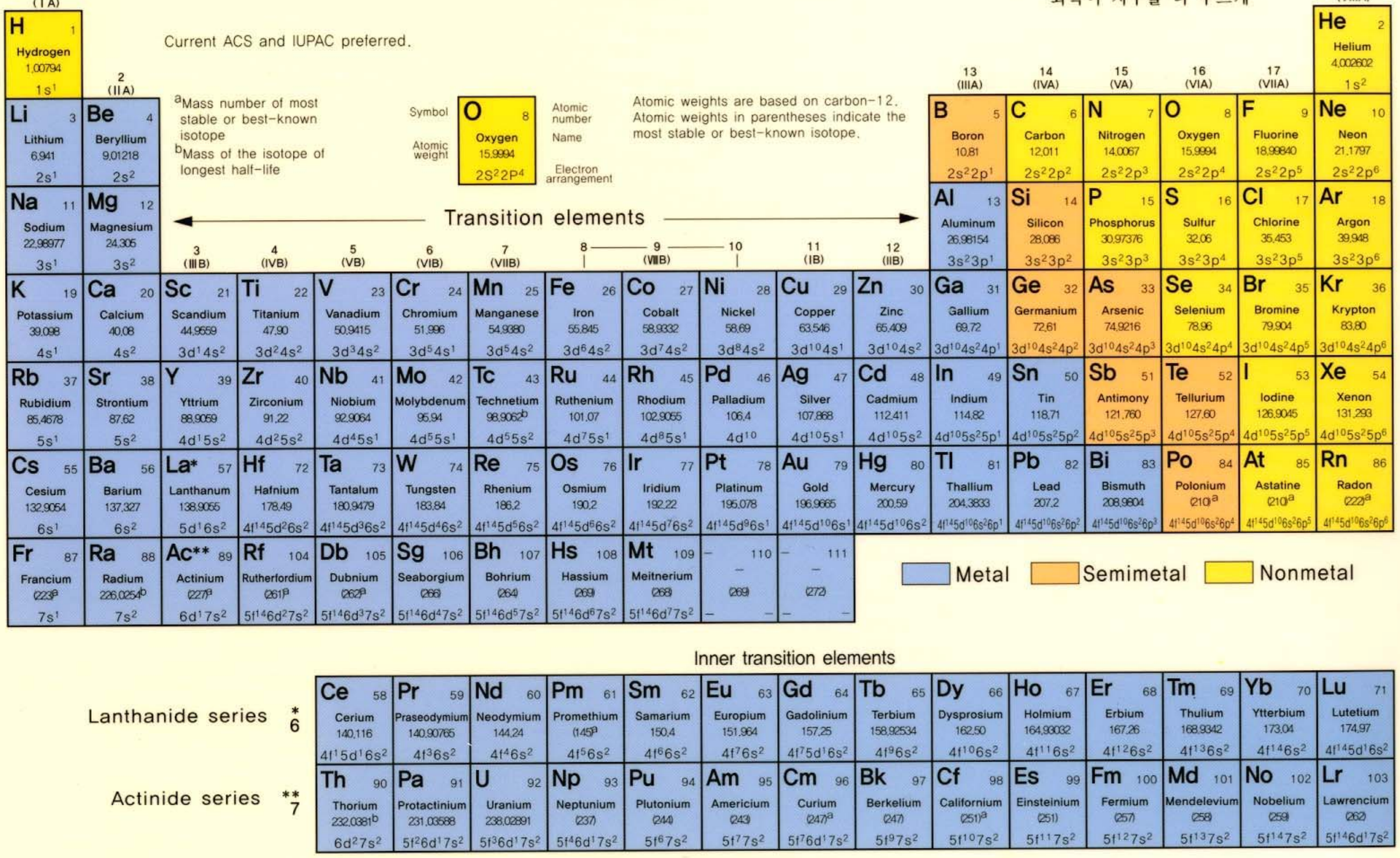
Current ACS and IUPAC preferred.

[a]Mass number of most stable or best-known isotope
[b]Mass of the isotope of longest half-life

Symbol	O 8	Atomic number
Atomic weight	Oxygen 15.9994	Name
	$2S^22P^4$	Electron arrangement

Atomic weights are based on carbon-12. Atomic weights in parentheses indicate the most stable or best-known isotope.

← Transition elements →



Period	Group 1 (IA)	2 (IIA)	3 (IIIB)	4 (IVB)	5 (VB)	6 (VIB)	7 (VIIB)	8	9 (VIIIB)	10	11 (IB)	12 (IIB)	13 (IIIA)	14 (IVA)	15 (VA)	16 (VIA)	17 (VIIA)	18 (VIIIA)
1	**H** 1 Hydrogen 1.00794 $1s^1$																	**He** 2 Helium 4.002602 $1s^2$
2	**Li** 3 Lithium 6.941 $2s^1$	**Be** 4 Beryllium 9.01218 $2s^2$											**B** 5 Boron 10.81 $2s^22p^1$	**C** 6 Carbon 12.011 $2s^22p^2$	**N** 7 Nitrogen 14.0067 $2s^22p^3$	**O** 8 Oxygen 15.9994 $2s^22p^4$	**F** 9 Fluorine 18.99840 $2s^22p^5$	**Ne** 10 Neon 21.1797 $2s^22p^6$
3	**Na** 11 Sodium 22.98977 $3s^1$	**Mg** 12 Magnesium 24.305 $3s^2$											**Al** 13 Aluminum 26.98154 $3s^23p^1$	**Si** 14 Silicon 28.086 $3s^23p^2$	**P** 15 Phosphorus 30.97376 $3s^23p^3$	**S** 16 Sulfur 32.06 $3s^23p^4$	**Cl** 17 Chlorine 35.453 $3s^23p^5$	**Ar** 18 Argon 39.948 $3s^23p^6$
4	**K** 19 Potassium 39.098 $4s^1$	**Ca** 20 Calcium 40.08 $4s^2$	**Sc** 21 Scandium 44.9559 $3d^14s^2$	**Ti** 22 Titanium 47.90 $3d^24s^2$	**V** 23 Vanadium 50.9415 $3d^34s^2$	**Cr** 24 Chromium 51.996 $3d^54s^1$	**Mn** 25 Manganese 54.9380 $3d^54s^2$	**Fe** 26 Iron 55.845 $3d^64s^2$	**Co** 27 Cobalt 58.9332 $3d^74s^2$	**Ni** 28 Nickel 58.69 $3d^84s^2$	**Cu** 29 Copper 63.546 $3d^{10}4s^1$	**Zn** 30 Zinc 65.409 $3d^{10}4s^2$	**Ga** 31 Gallium 69.72 $3d^{10}4s^24p^1$	**Ge** 32 Germanium 72.61 $3d^{10}4s^24p^2$	**As** 33 Arsenic 74.9216 $3d^{10}4s^24p^3$	**Se** 34 Selenium 78.96 $3d^{10}4s^24p^4$	**Br** 35 Bromine 79.904 $3d^{10}4s^24p^5$	**Kr** 36 Krypton 83.80 $3d^{10}4s^24p^6$
5	**Rb** 37 Rubidium 85.4678 $5s^1$	**Sr** 38 Strontium 87.62 $5s^2$	**Y** 39 Yttrium 88.9059 $4d^15s^2$	**Zr** 40 Zirconium 91.22 $4d^25s^2$	**Nb** 41 Niobium 92.9064 $4d^45s^1$	**Mo** 42 Molybdenum 95.94 $4d^55s^1$	**Tc** 43 Technetium 98.9062^b $4d^55s^2$	**Ru** 44 Ruthenium 101.07 $4d^75s^1$	**Rh** 45 Rhodium 102.9055 $4d^85s^1$	**Pd** 46 Palladium 106.4 $4d^{10}$	**Ag** 47 Silver 107.868 $4d^{10}5s^1$	**Cd** 48 Cadmium 112.411 $4d^{10}5s^2$	**In** 49 Indium 114.82 $4d^{10}5s^25p^1$	**Sn** 50 Tin 118.71 $4d^{10}5s^25p^2$	**Sb** 51 Antimony 121.760 $4d^{10}5s^25p^3$	**Te** 52 Tellurium 127.60 $4d^{10}5s^25p^4$	**I** 53 Iodine 126.9045 $4d^{10}5s^25p^5$	**Xe** 54 Xenon 131.293 $4d^{10}5s^25p^6$
6	**Cs** 55 Cesium 132.9054 $6s^1$	**Ba** 56 Barium 137.327 $6s^2$	**La*** 57 Lanthanum 138.9055 $5d^16s^2$	**Hf** 72 Hafnium 178.49 $4f^{14}5d^26s^2$	**Ta** 73 Tantalum 180.9479 $4f^{14}5d^36s^2$	**W** 74 Tungsten 183.84 $4f^{14}5d^46s^2$	**Re** 75 Rhenium 186.2 $4f^{14}5d^56s^2$	**Os** 76 Osmium 190.2 $4f^{14}5d^66s^2$	**Ir** 77 Iridium 192.22 $4f^{14}5d^76s^2$	**Pt** 78 Platinum 195.078 $4f^{14}5d^96s^1$	**Au** 79 Gold 196.9665 $4f^{14}5d^{10}6s^1$	**Hg** 80 Mercury 200.59 $4f^{14}5d^{10}6s^2$	**Tl** 81 Thallium 204.3833 $4f^{14}5d^{10}6s^26p^1$	**Pb** 82 Lead 207.2 $4f^{14}5d^{10}6s^26p^2$	**Bi** 83 Bismuth 208.9804 $4f^{14}5d^{10}6s^26p^3$	**Po** 84 Polonium (210)^a $4f^{14}5d^{10}6s^26p^4$	**At** 85 Astatine (210)^a $4f^{14}5d^{10}6s^26p^5$	**Rn** 86 Radon (222)^a $4f^{14}5d^{10}6s^26p^6$
7	**Fr** 87 Francium (223)^a $7s^1$	**Ra** 88 Radium 226.0254^b $7s^2$	**Ac**** 89 Actinium (227)^a $6d^17s^2$	**Rf** 104 Rutherfordium (261)^a $5f^{14}6d^27s^2$	**Db** 105 Dubnium (262)^a $5f^{14}6d^37s^2$	**Sg** 106 Seaborgium (266) $5f^{14}6d^47s^2$	**Bh** 107 Bohrium (264) $5f^{14}6d^57s^2$	**Hs** 108 Hassium (269) $5f^{14}6d^67s^2$	**Mt** 109 Meitnerium (268) $5f^{14}6d^77s^2$	– 110 – (269) – –	– 111 – (272) – –							

🟦 Metal 🟧 Semimetal 🟨 Nonmetal

Inner transition elements

Lanthanide series *6	**Ce** 58 Cerium 140.116 $4f^15d^16s^2$	**Pr** 59 Praseodymium 140.90765 $4f^36s^2$	**Nd** 60 Neodymium 144.24 $4f^46s^2$	**Pm** 61 Promethium (145)^a $4f^56s^2$	**Sm** 62 Samarium 150.4 $4f^66s^2$	**Eu** 63 Europium 151.964 $4f^76s^2$	**Gd** 64 Gadolinium 157.25 $4f^75d^16s^2$	**Tb** 65 Terbium 158.92534 $4f^96s^2$	**Dy** 66 Dysprosium 162.50 $4f^{10}6s^2$	**Ho** 67 Holmium 164.93032 $4f^{11}6s^2$	**Er** 68 Erbium 167.26 $4f^{12}6s^2$	**Tm** 69 Thulium 168.9342 $4f^{13}6s^2$	**Yb** 70 Ytterbium 173.04 $4f^{14}6s^2$	**Lu** 71 Lutetium 174.97 $4f^{14}5d^16s^2$
Actinide series **7	**Th** 90 Thorium 232.0381^b $6d^27s^2$	**Pa** 91 Protactinium 231.03588 $5f^26d^17s^2$	**U** 92 Uranium 238.02891 $5f^36d^17s^2$	**Np** 93 Neptunium (237) $5f^46d^17s^2$	**Pu** 94 Plutonium (244) $5f^67s^2$	**Am** 95 Americium (243) $5f^77s^2$	**Cm** 96 Curium (247)^a $5f^76d^17s^2$	**Bk** 97 Berkelium (247) $5f^97s^2$	**Cf** 98 Californium (251)^a $5f^{10}7s^2$	**Es** 99 Einsteinium (251) $5f^{11}7s^2$	**Fm** 100 Fermium (257) $5f^{12}7s^2$	**Md** 101 Mendelevium (258) $5f^{13}7s^2$	**No** 102 Nobelium (259) $5f^{14}7s^2$	**Lr** 103 Lawrencium (262) $5f^{14}6d^17s^2$

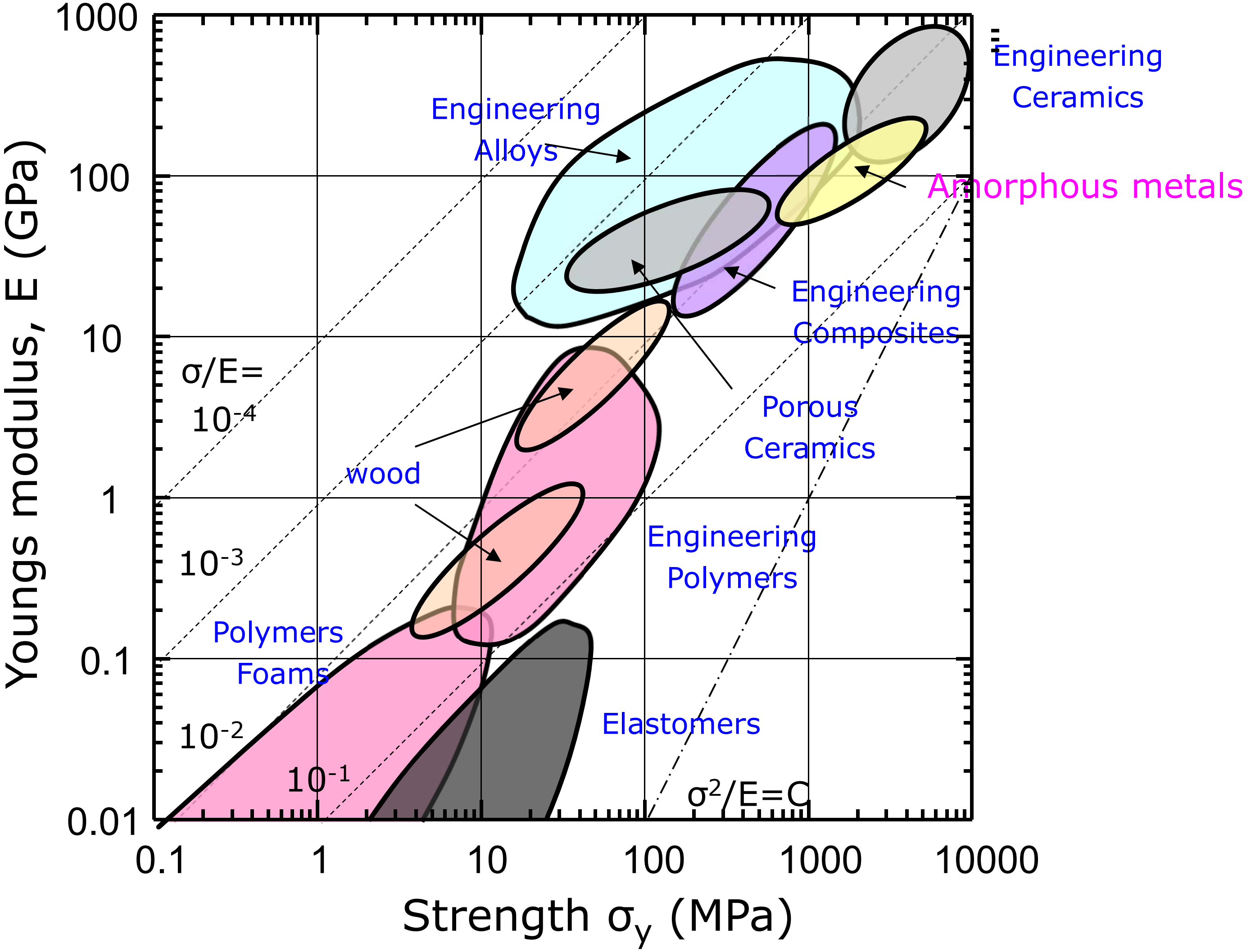
Kinds of Materials

- **Metals:** are materials that are normally combinations of "metallic elements". Metals usually are good conductors of heat and electricity. Also, they are quite strong but malleable and tend to have a lustrous look when polished.
- **Ceramics:** are generally compounds between metallic and nonmetallic elements. Typically they are insulating and resistant to high temperatures and harsh environments.

Kinds of Materials

- **Plastics:** (or polymers) are generally organic compounds based upon carbon and hydrogen. They are very large molecular structures. Usually they are low density and are not stable at high temperatures.
- **Semiconductors:** have electrical properties intermediate between metallic conductors and ceramic insulators. Also, the electrical properties are strongly dependent upon small amounts of impurities.

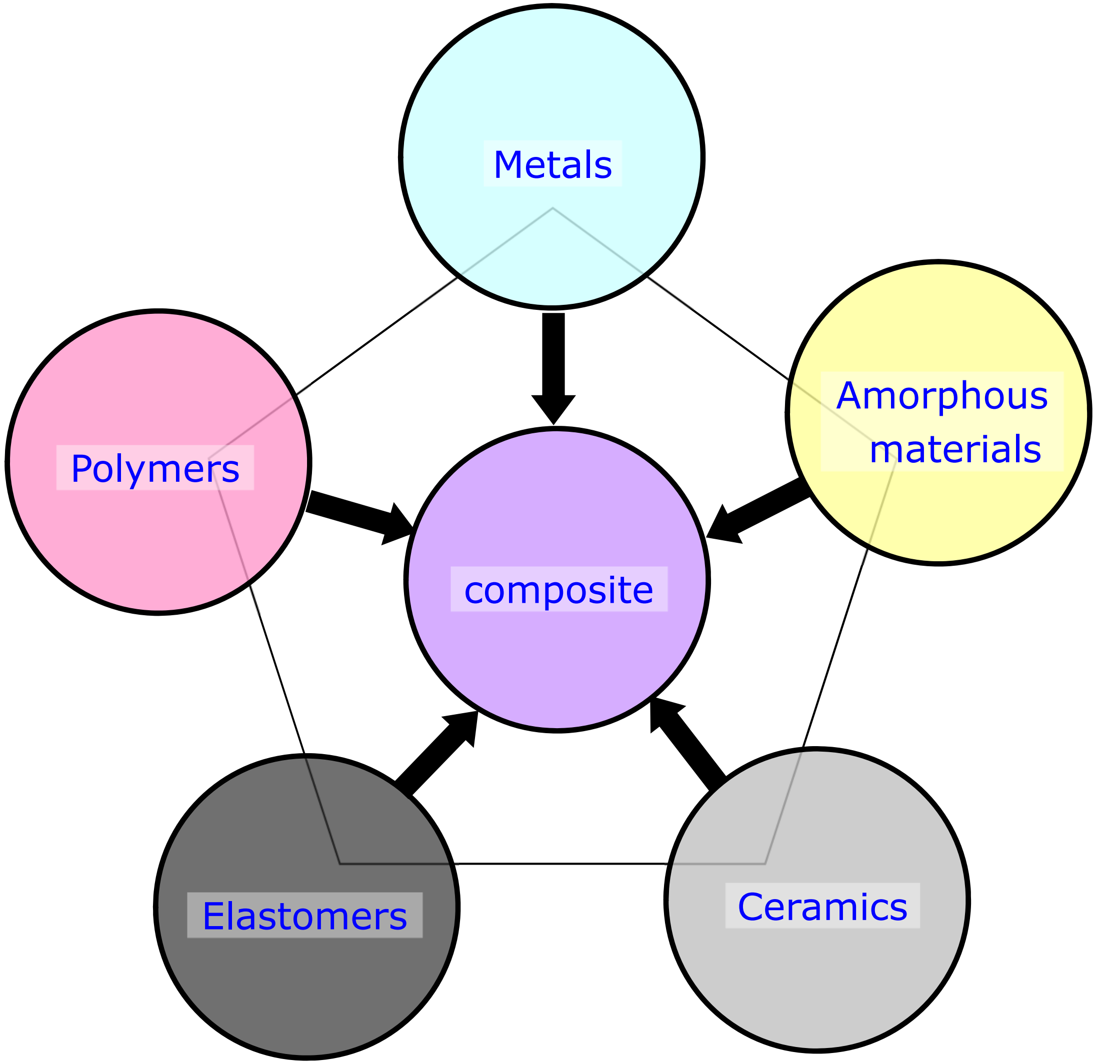
< Ashby map >


Engineering Ceramics
Engineering Alloys
Amorphous metals
Engineering Composites
Porous Ceramics
wood
Engineering Polymers
Polymers Foams
Elastomers
σ/E=
10-4
10-3
10-2
10-1
σ²/E=C
1000
100
10
1
0.1
0.01
0.1
1
10
100
1000
10000
Youngs modulus, E (GPa)
Strength σy (MPa)

Kinds of Materials

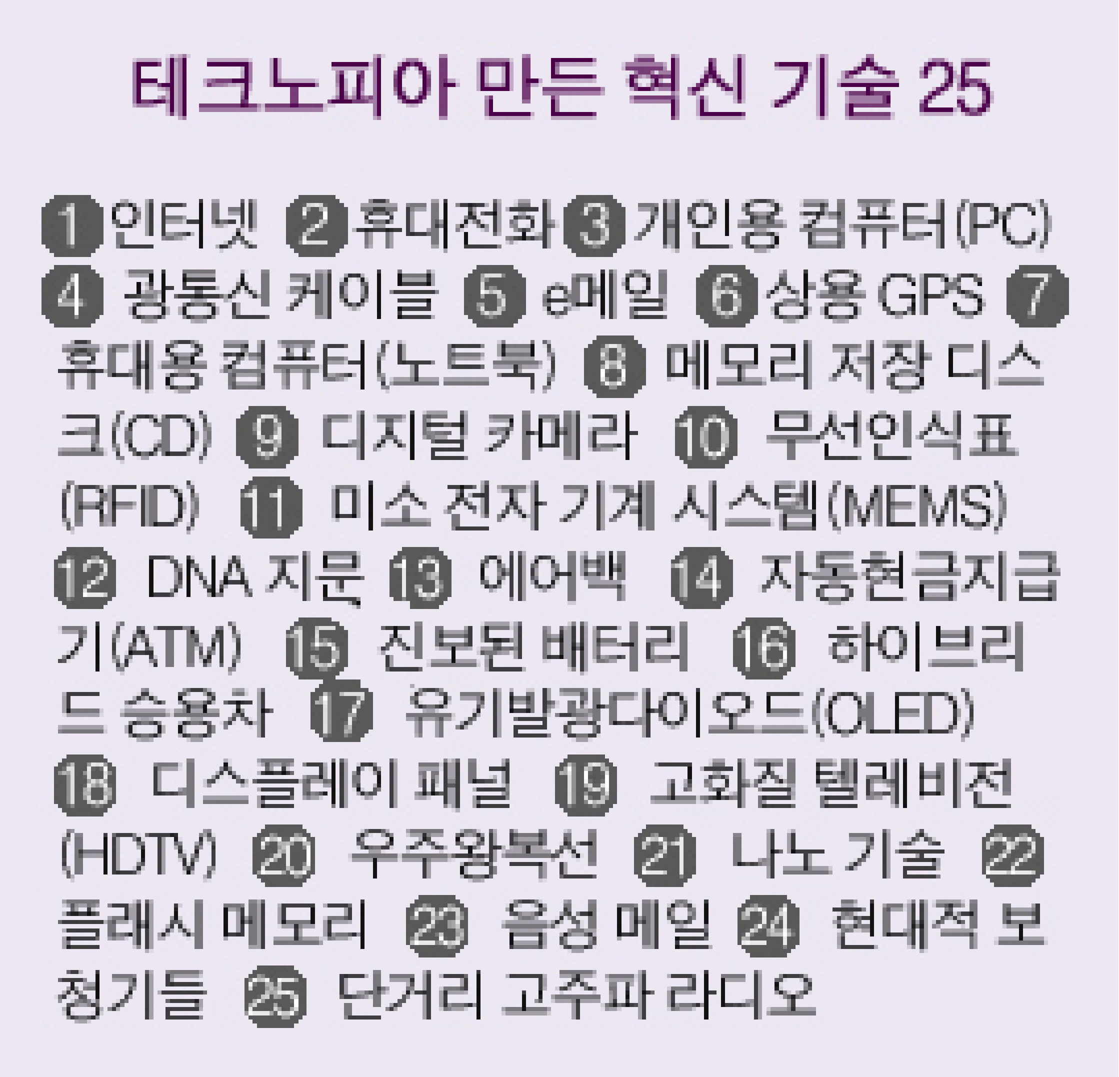
- **Composites:** consist of more than one material type. Fiberglass, a combination of glass and a polymer, is an example. Concrete and plywood are other familiar composites. Many new combinations include ceramic fibers in metal or polymer matrix.

Menu of engineering materials



지난 25년 동안 세상을 바꾼 신기술 25가지

러멜슨-MIT 프로그램

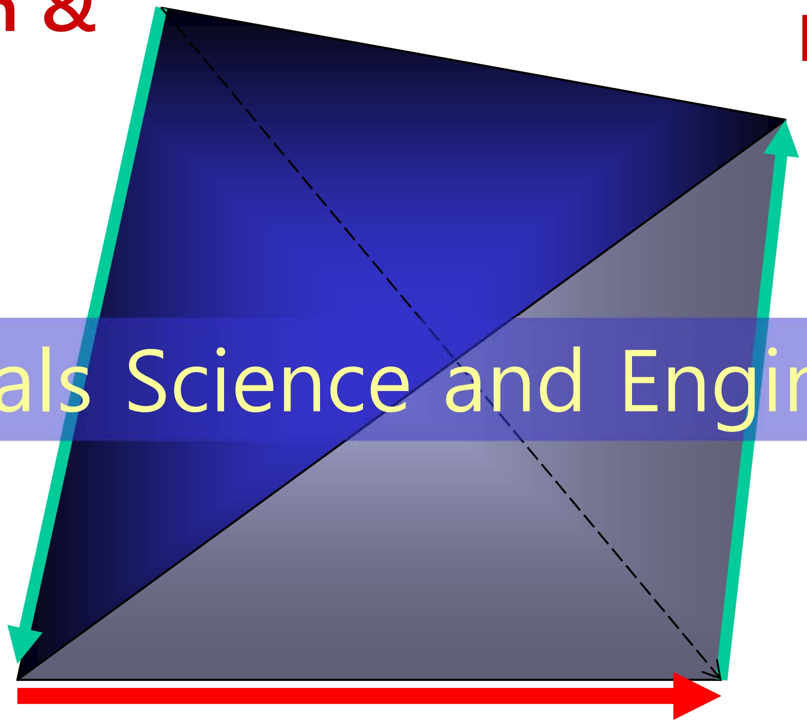


테크노피아 만든 혁신 기술 25

①인터넷 ②휴대전화 ③개인용 컴퓨터(PC) ④ 광통신 케이블 ⑤ e메일 ⑥상용 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

의료 및 의약 분야 기술 제외

Microstructure-Properties Relationships



Alloy design & Processing

Performance

" Materials Science and Engineering"

Microstructure

down to atomic scale

Properties

"Tailor-made Materials Design"

합금설계 + 공정조절 ➡

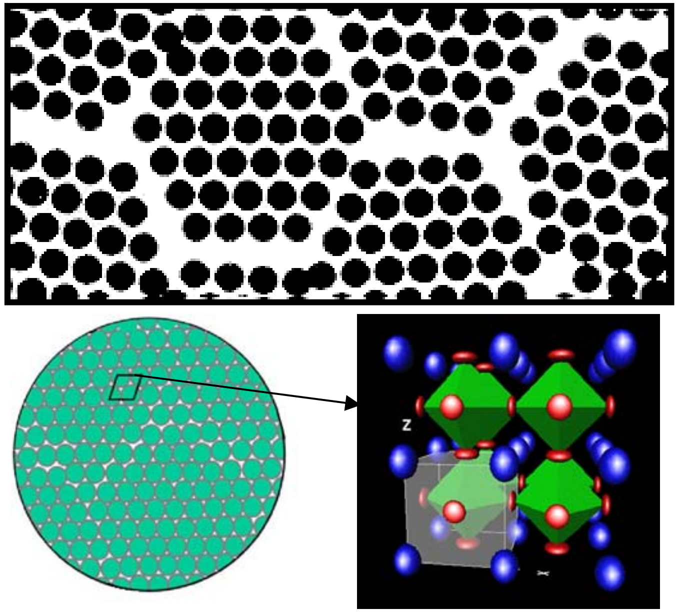
Microstructure Control of Materials

↓

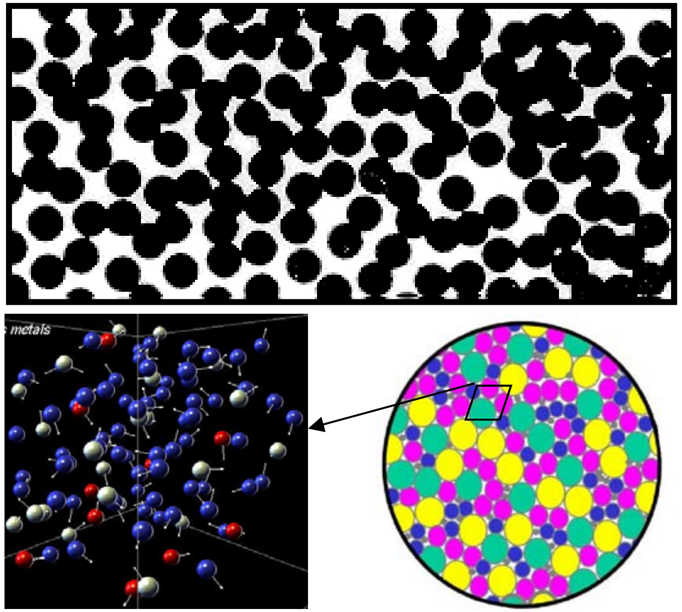
Better Material Properties

Structure *of crystals, liquids and glasses*

Crystals



Liquids, glasses

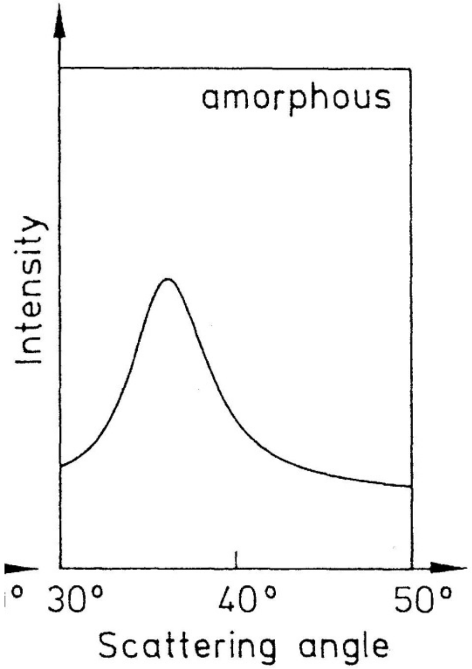


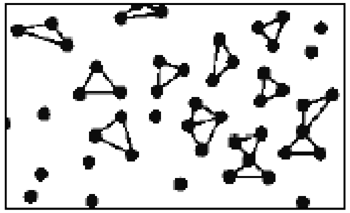
- **periodic**
- **grain boundaries**

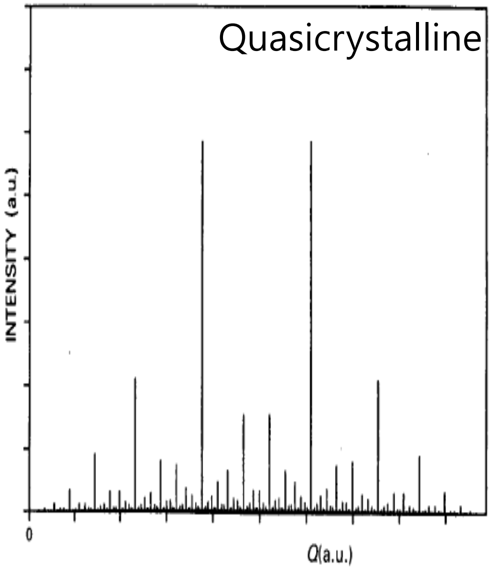
- **amorphous = non-periodic**
- **no grain boundaries**

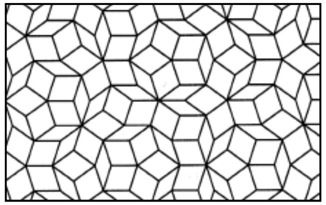
Atomic structure

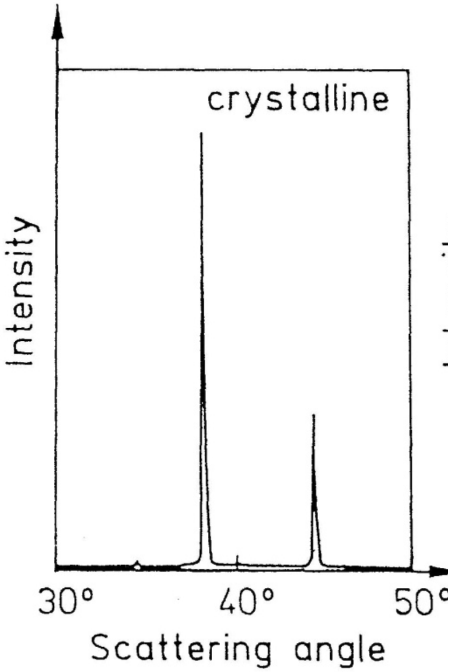
Short-range order ↔ **Periodic order**

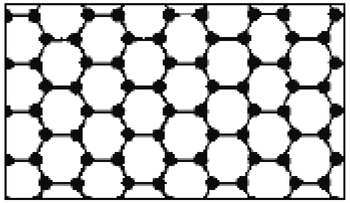












2011 노벨화학상 수상자 대니얼 셰시트먼 박사

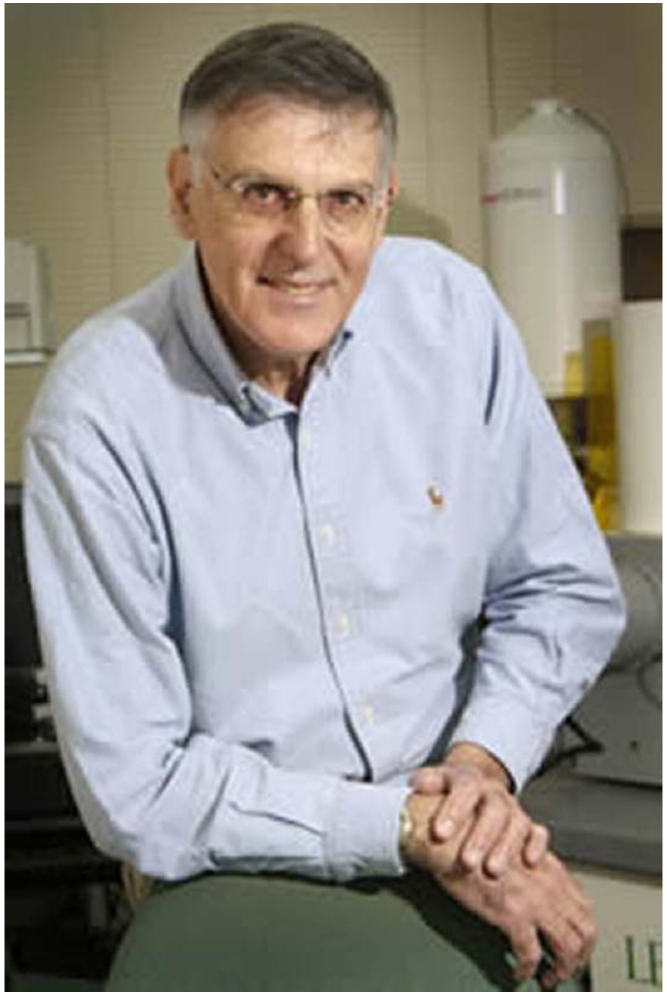
이스라엘 테크니온 공대의 대니얼 셰시트먼 박사(70·사진)가 2011년 노벨 화학상 수상자로 선정됐다.

스웨덴 왕립 과학아카데미는 5일(현지시간) 대니얼 셰시트먼 박사가 준결정(quasicrystal) 발견에 대한 공로를 인정받아 2011년 노벨 화학학상 수상자로 선정했다고 발표했다.

위원회는 "일반적으로 결정(crystal)은 원자가 같은 형태를 반복하면서 이뤄진다"며 "하지만 셰시트먼 박사는 결정 안에 원자들이 반복되지 않는 배열로 존재 할 수 있다는 사실을 발견했다"고 밝혔다.

위원회는 또 "액체와 고체의 중간 상태인 준결정 연구를 통해 고체물질에 대한 이해를 바꿔놨다"고 수상 이유를 밝혔다.

셰시트먼 교수는 지난 1982년 세계 최초로 1982년 4월 특정무늬가 반복되지 않는 배열의 준결정을 발견했다.



2011 노벨 화학상 수상자 대니얼 셰시트먼 박사

What is microstructure?

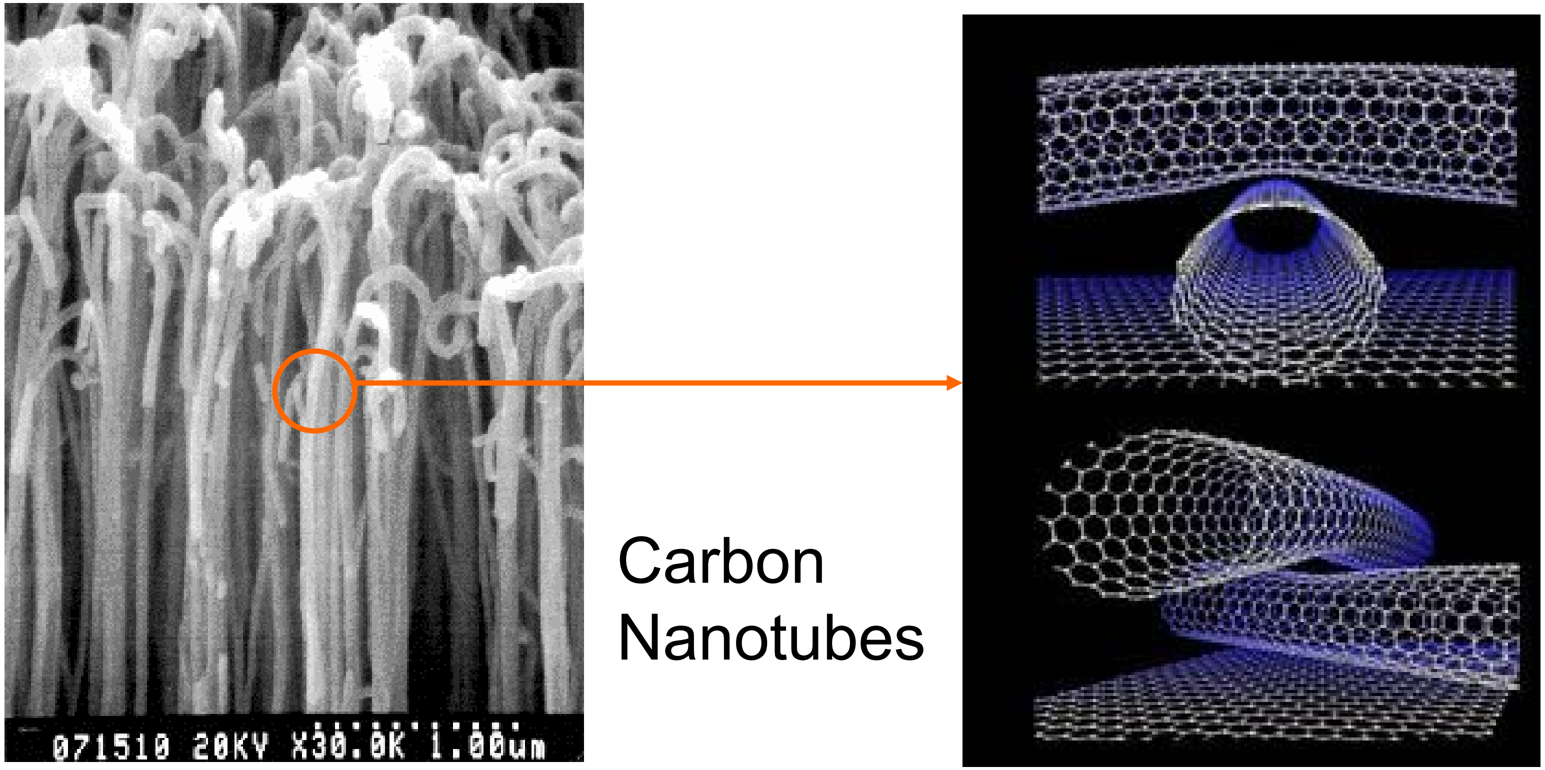
Microstructure originally meant the structure inside a material that could be observed with the aid of a microscope.

In contrast to the crystals that make up materials, which can be approximated as collections of atoms in specific packing arrangements (crystal structure), microstructure is the collection of defects in the materials.

What defects are we interested in?
Interfaces (both grain boundaries and interphase boundaries), which are planar defects,
Dislocations (and other line defects), and
Point defects (such as interstititals and vacancies as well as solute atoms in solution)

미세구조 조절: 1) perfection *vs* imperfection control

Perfect Crystals without Defect



Carbon Nanotubes

High strength, unique magnetic/electrical properties

Perfect Crystal is good in many aspects,
But …

❑ 1) ***Imperfection*** in Metallic Materials ;

Point defect : Vacancies, Impurity atoms

Line defect : Dislocations

Plane defect : Grain Boundaries,
Free Surfaces

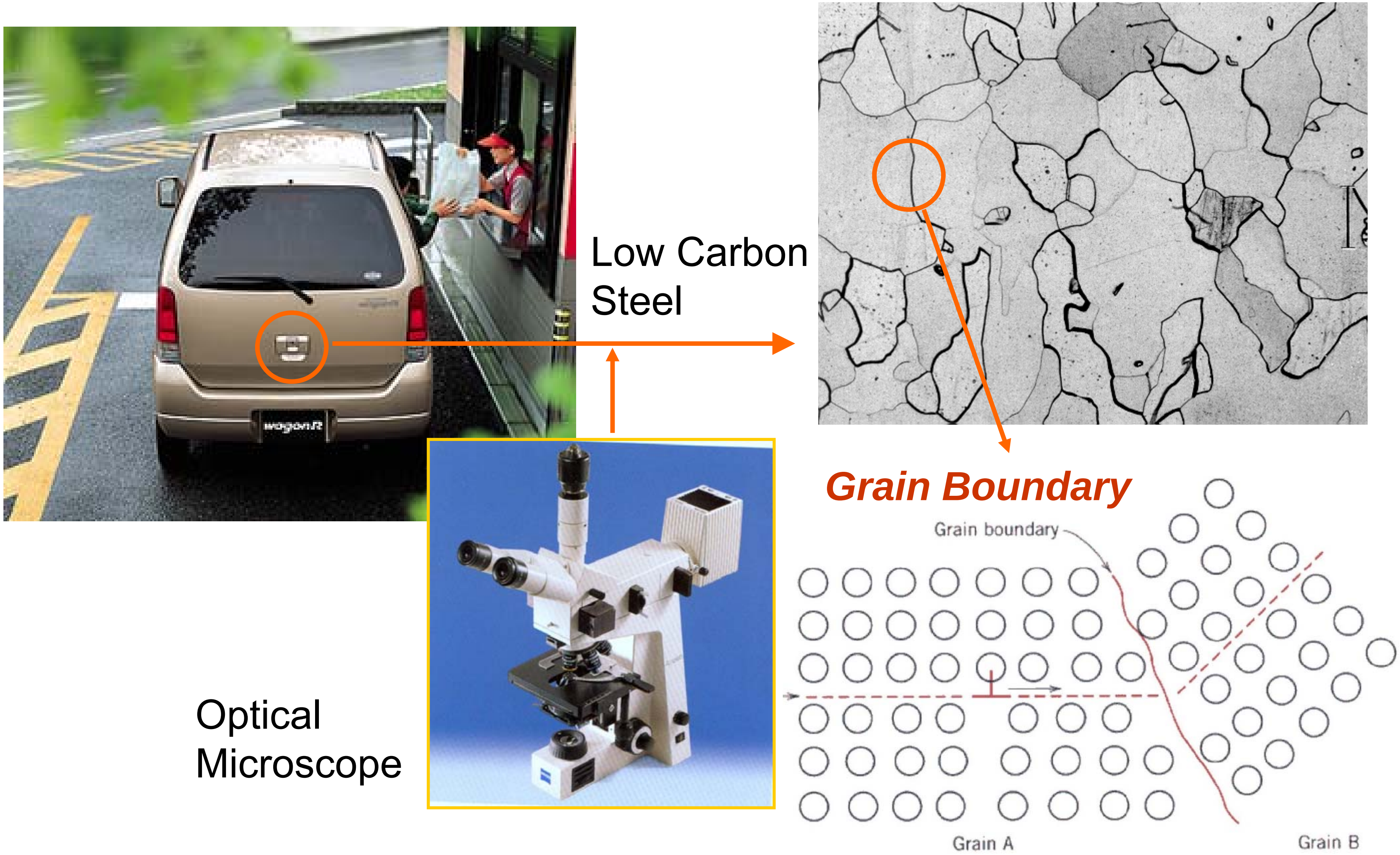
Bulk defect : Voids, Cracks

❑ 2) ***Second Phase Particles*** in Matrix

Mechanical Properties ;
Magnetic properties
Electrical properties
Etc.

1) *Imperfection:* Grain Boundaries

(Planer defect)



Low Carbon Steel

Optical Microscope

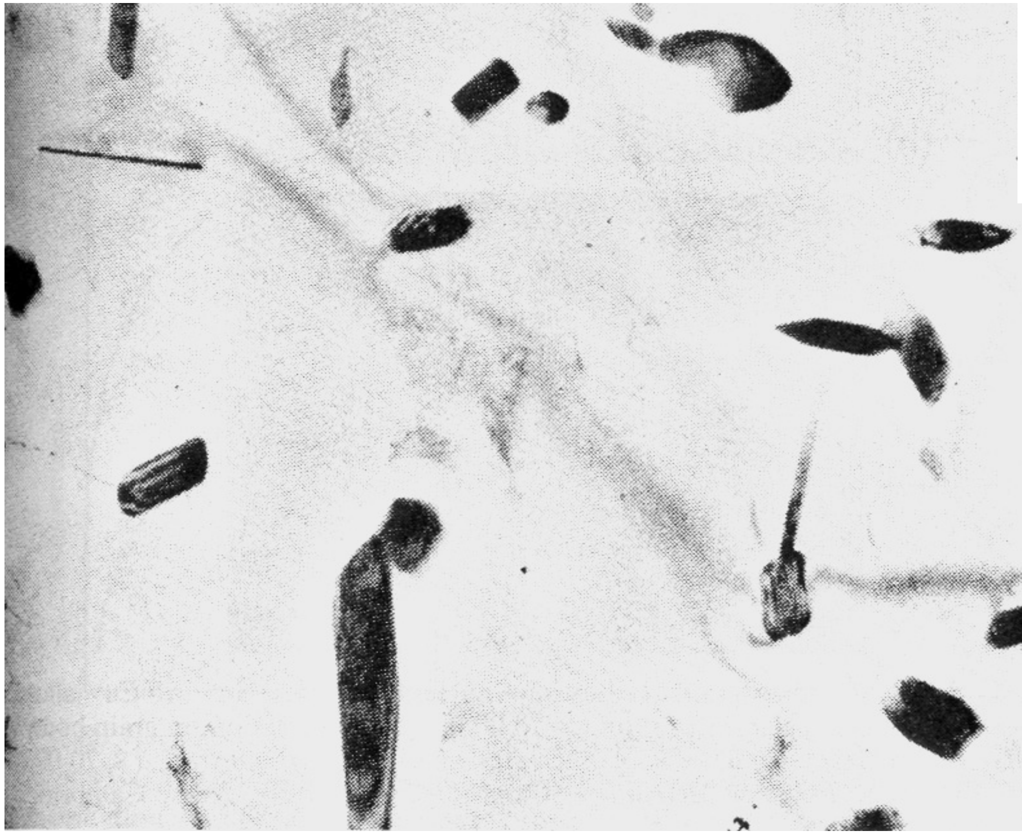
Grain Boundary

1) *Imperfection:* Phase Boundaries

(Planer defect)

JEOL 7500F-1
scanning electron microcsope

θ of Al-Cu alloys (x 8,000) by SEM

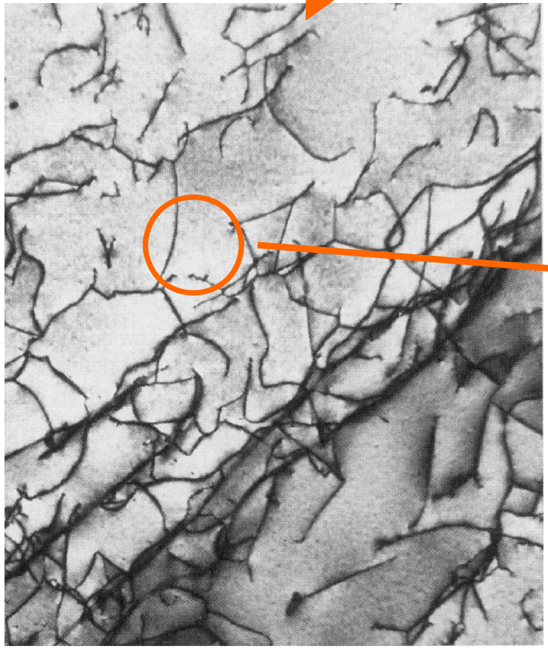


$CuAl_2$: complex body centered tetragonal, incoherent or complex semicoherent

1) *Imperfection:* Dislocations (line defect)

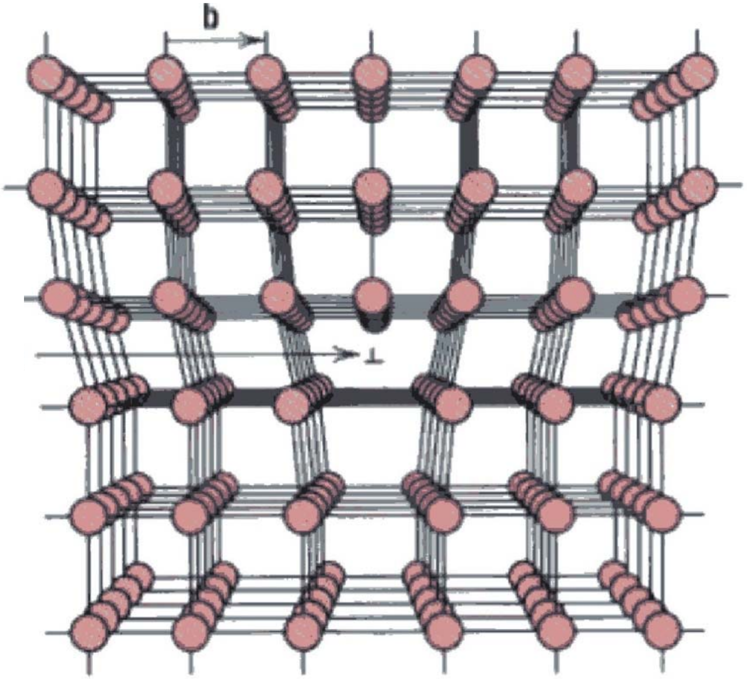
SR-71
with armor of
titanium alloy

It looks perfect.
But….



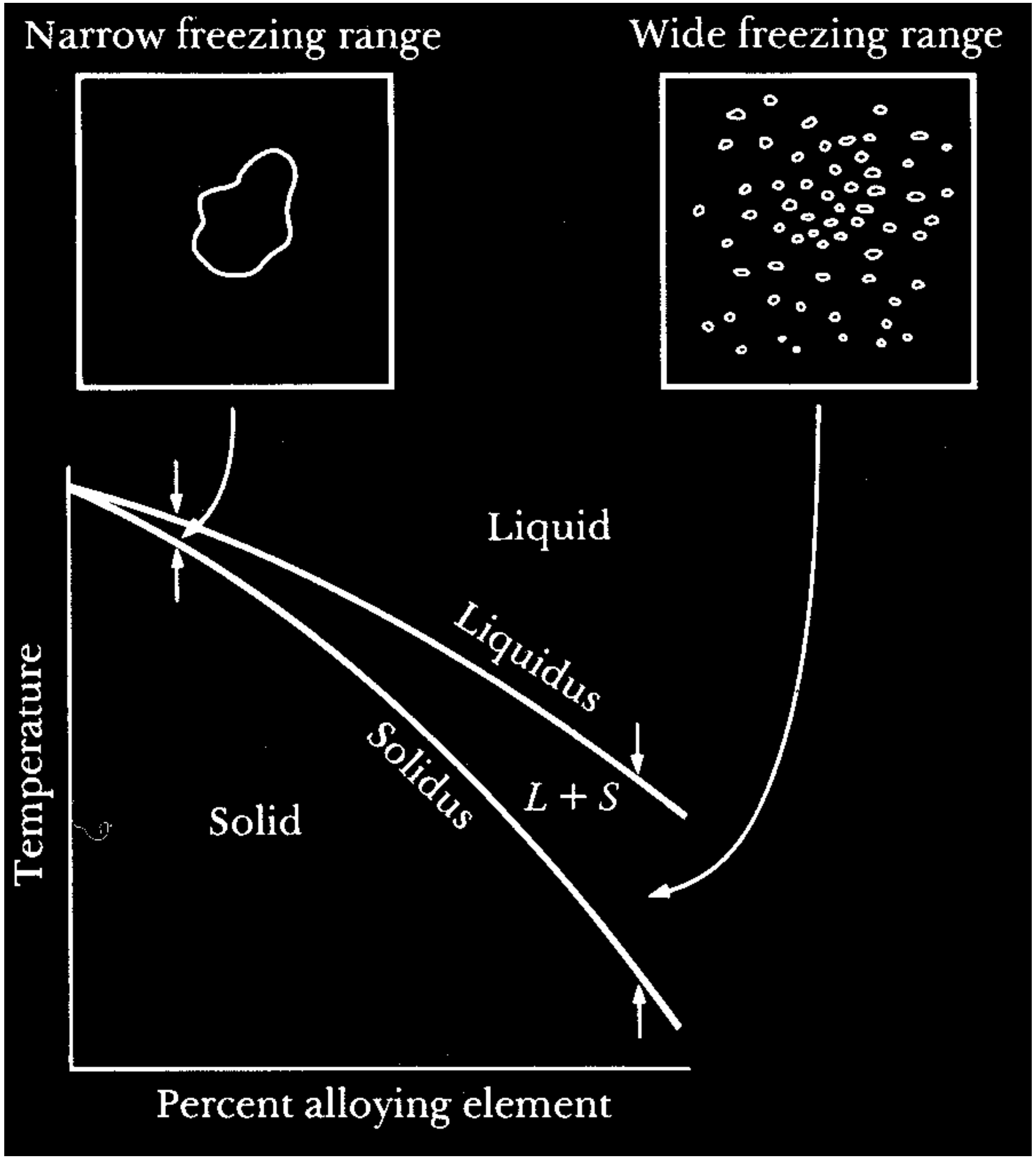
Edge
Dislocation
Line

Burgers vector

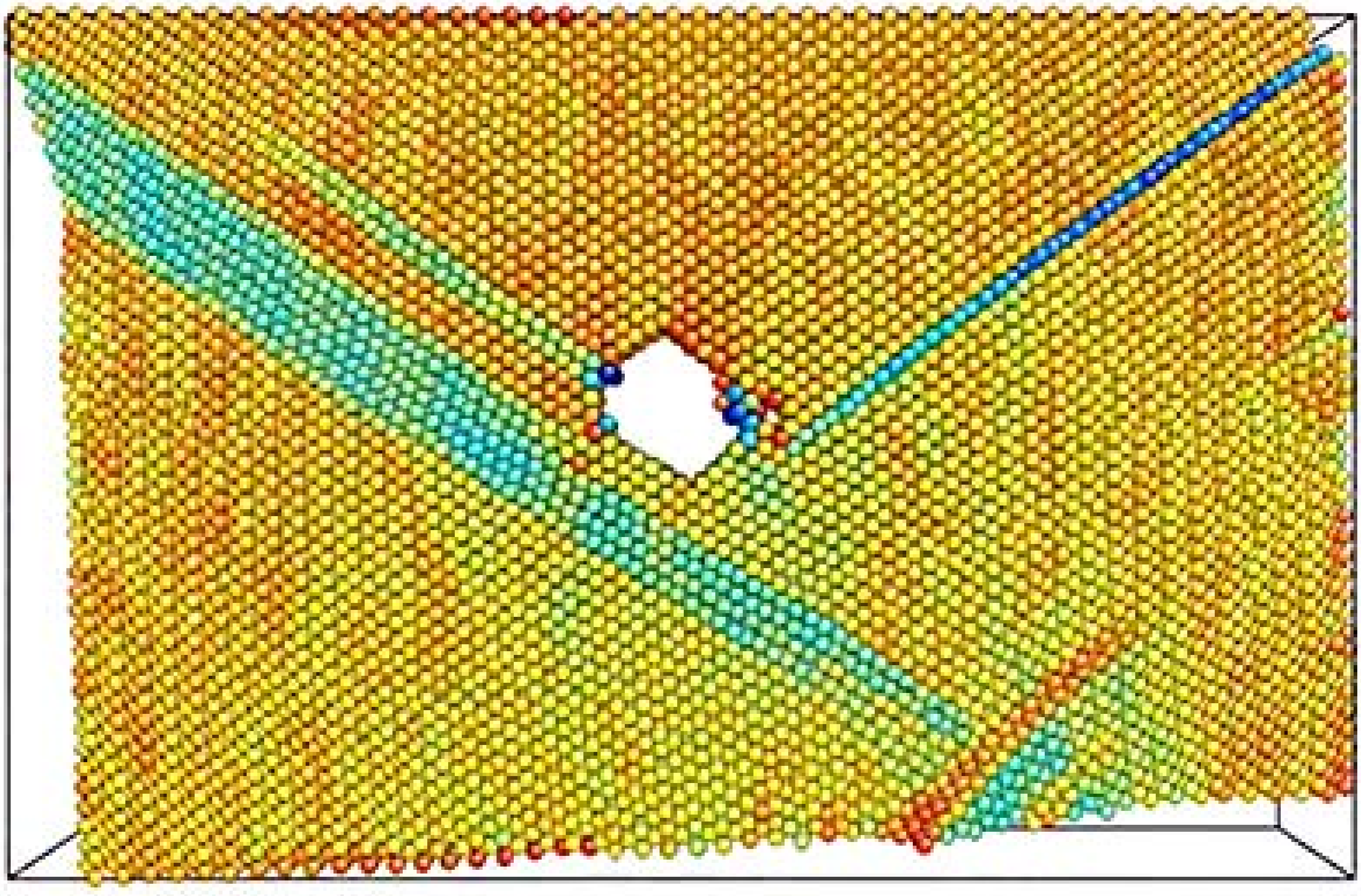


1) *Imperfection:* Voids during solidification

Shrinkage effect

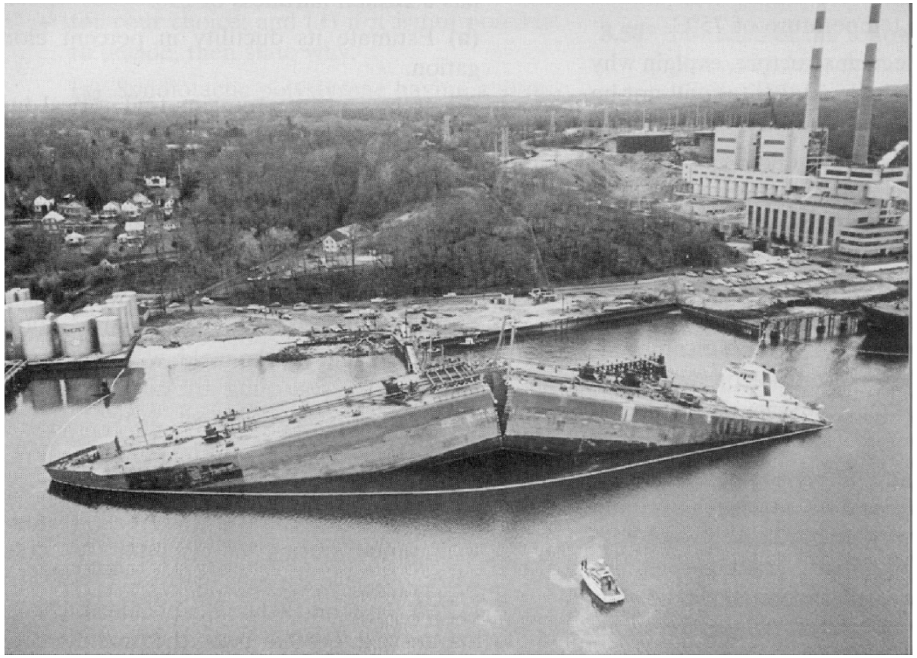


1) *Imperfection:* Voids during deformation



Using of Materials with *Improper Microstructure*

Failures

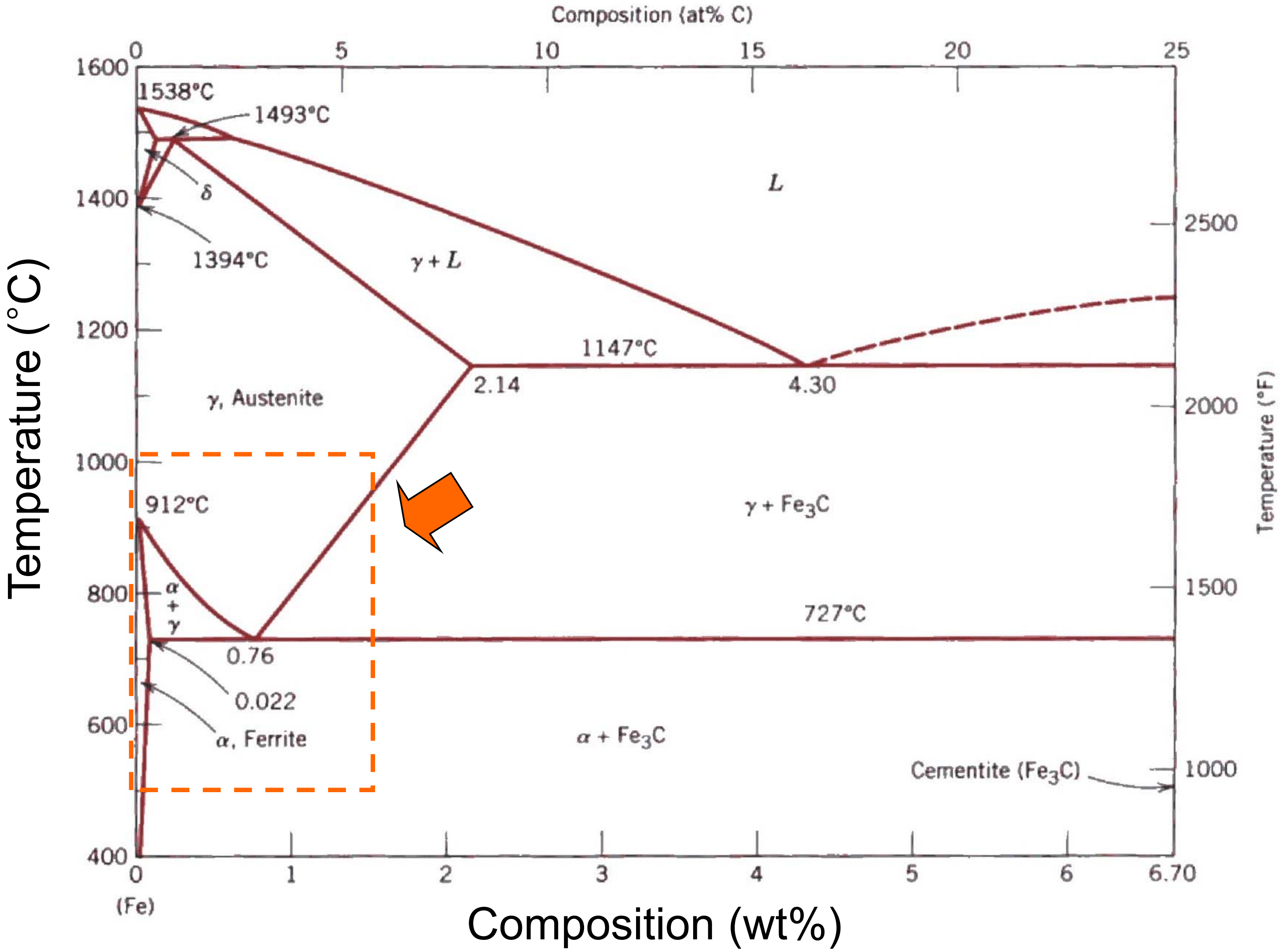


Oil tanker
fractured in a brittle manner

성수대교 붕괴 (1994.10.21)

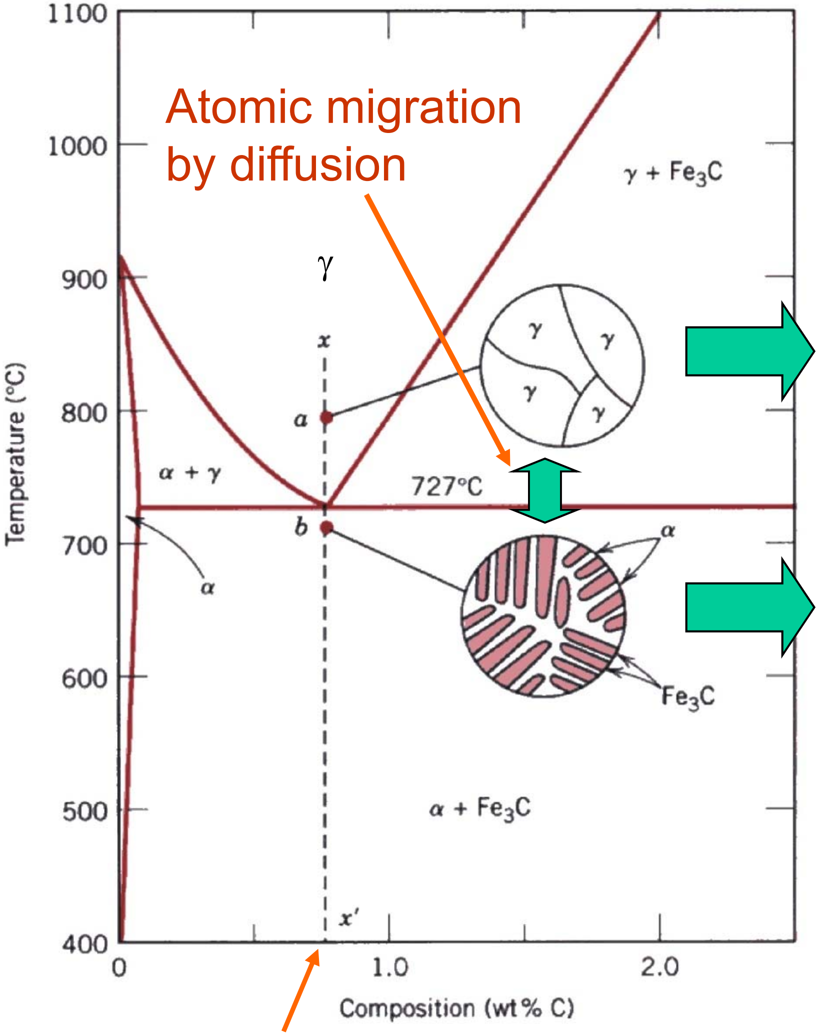
미세구조 조절: 2) Secondary phase control during solidification

Phase Diagram of Iron–Carbon Alloy



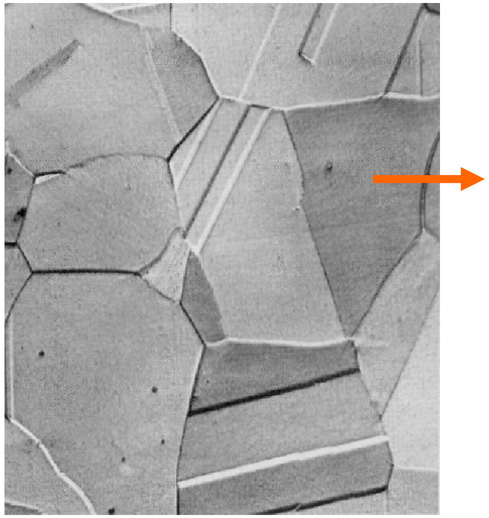
미세구조 조절: 2) Secondary phase control during solidification

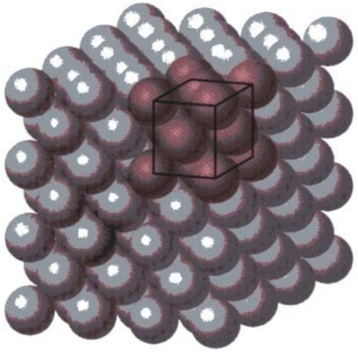
Equilibrium Phases of Iron-Carbon Alloy



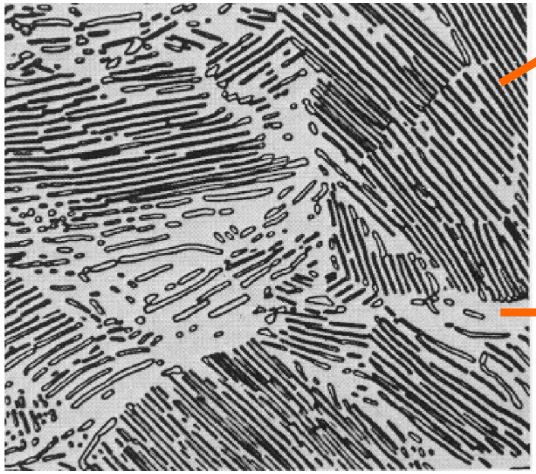
Atomic migration by diffusion

Eutectoid composition

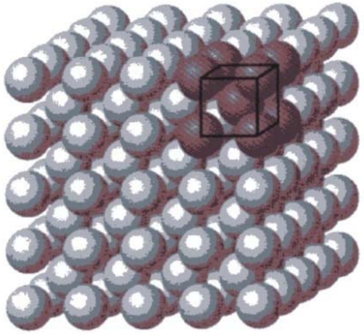




γ phase
(FCC)



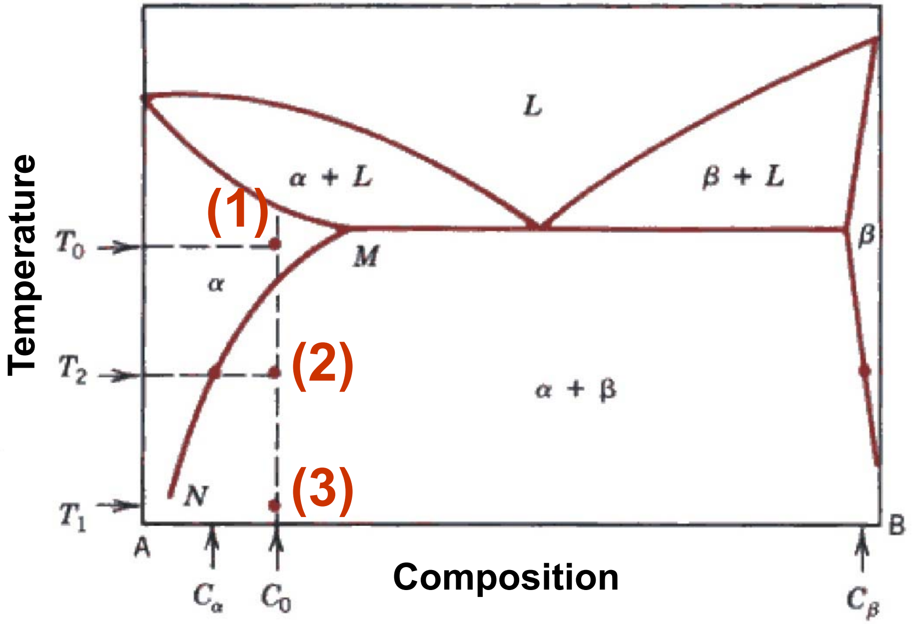
Fe_3C phase

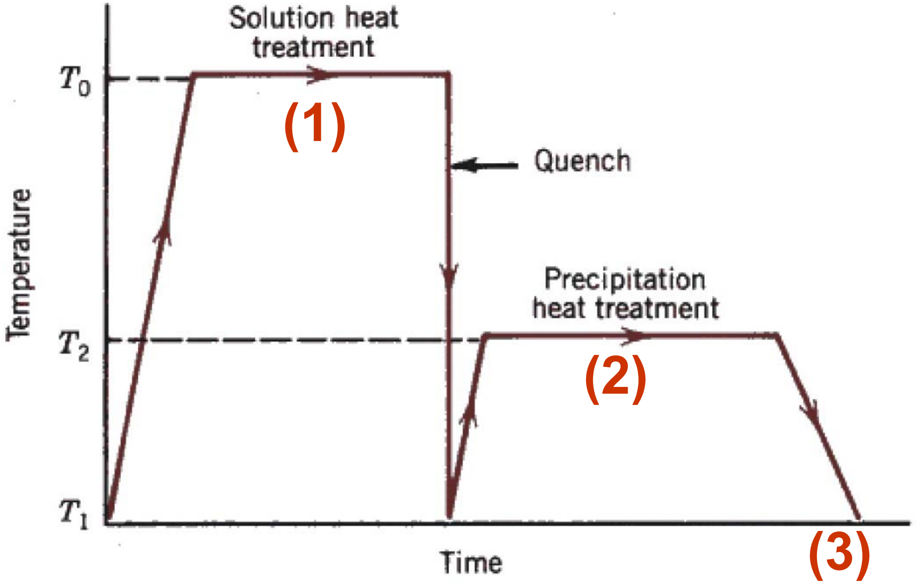


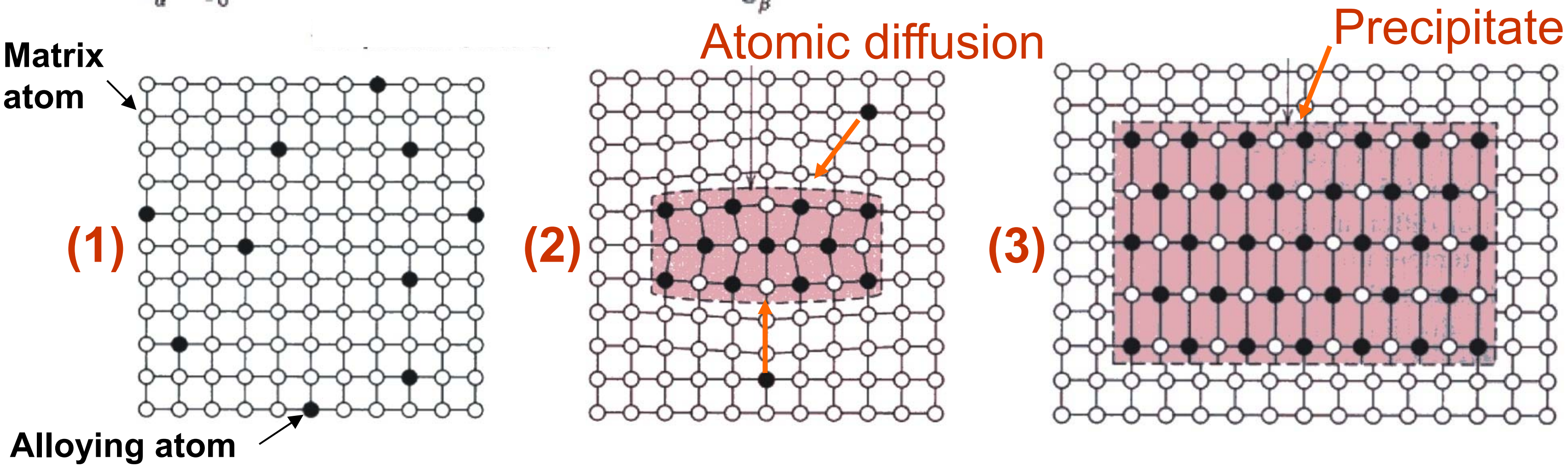
α phase
(BCC)

미세구조 조절: 2) Secondary phase control during annealing

Mechanism of Precipitation

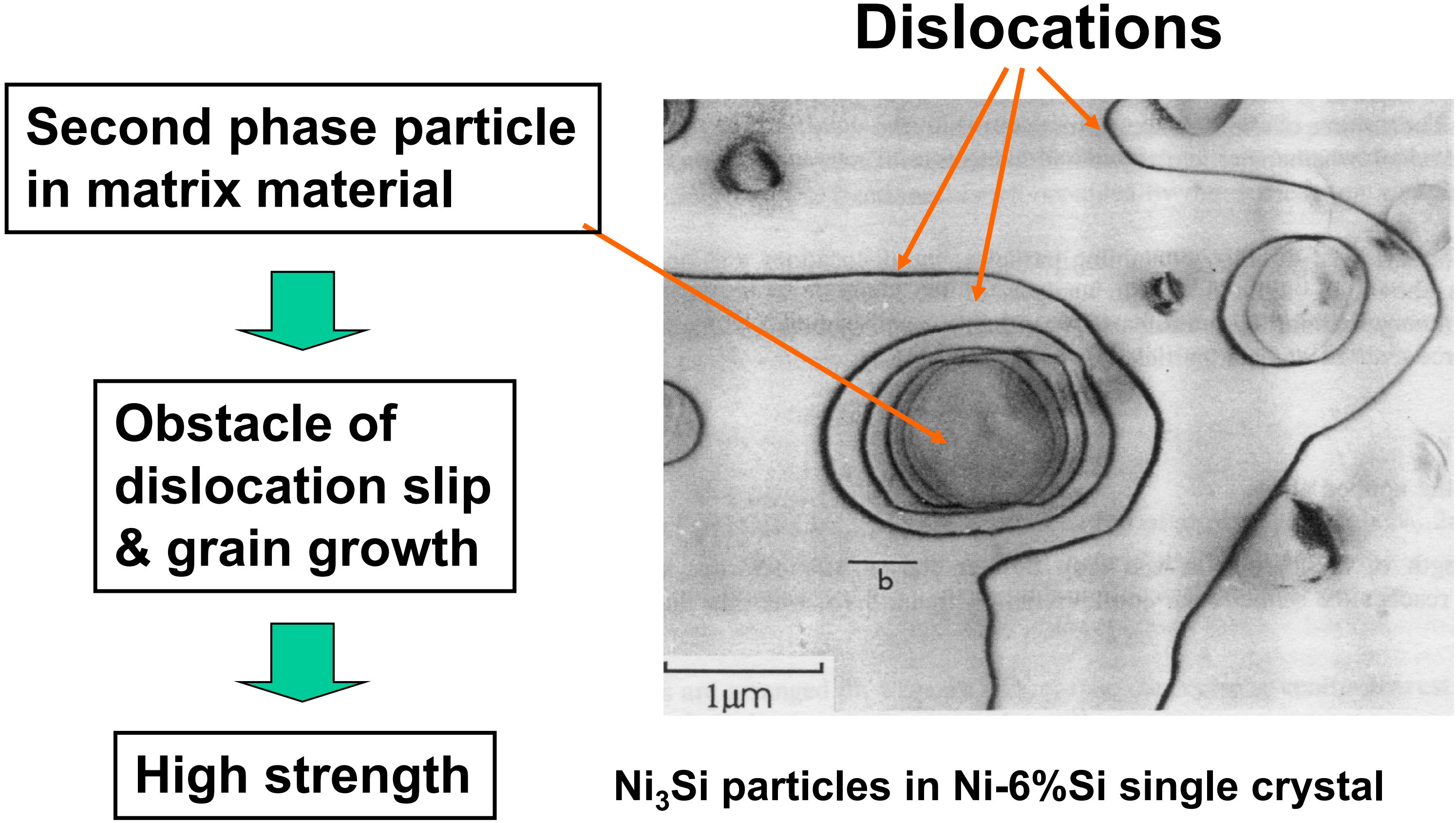






미세구조 조절: 2) Secondary phase control

Effect of Second Phase Particle on Mechanical Property


Second phase particle in matrix material

Obstacle of dislocation slip & grain growth

High strength

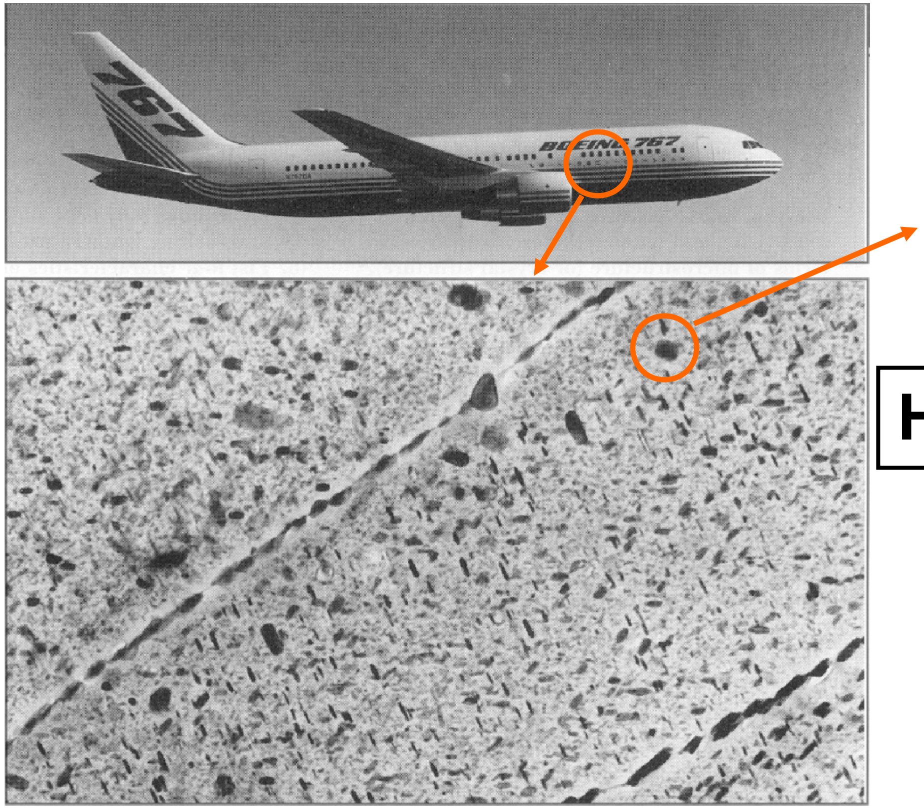
Dislocations

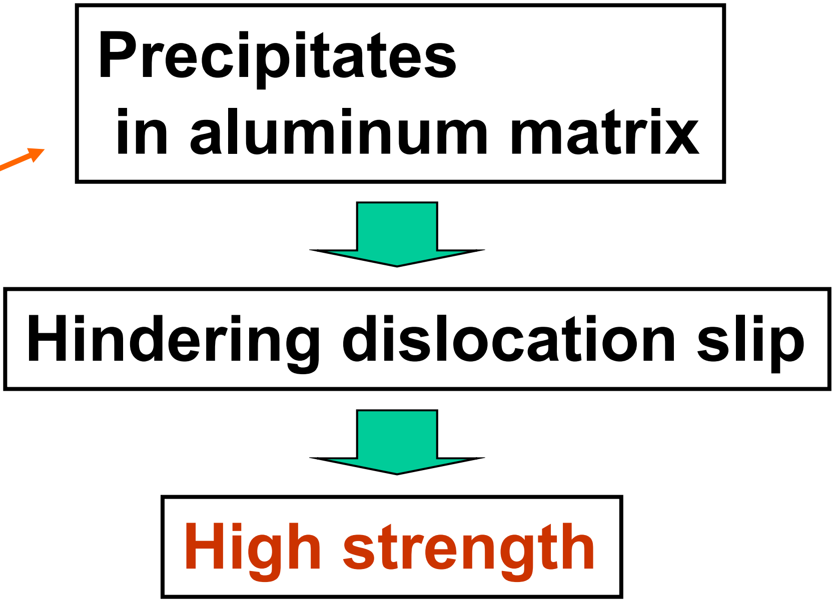
Ni_3Si particles in Ni-6%Si single crystal

미세구조 조절: 2) Secondary phase control

Control of Microstructures by Precipitation Transformation in Aluminum Alloy

Boeing 767 by AA7150 T651 alloy





Precipitates in aluminum matrix

Hindering dislocation slip

High strength

미세구조 조절: 2) Secondary phase control during processing

Control of Microstructures ;

Cold Work_압력을 가해 성형하고 인성을 증가시키는 과정

김홍도 "대장간"

조선시대

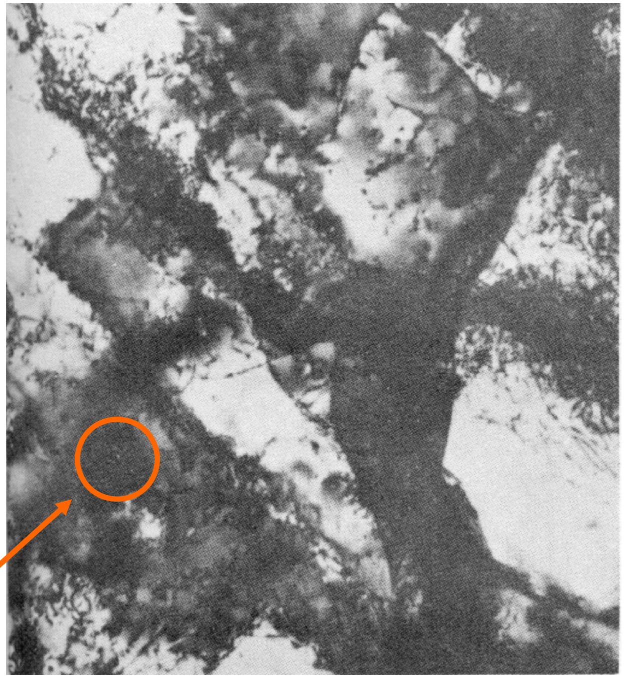
현대의 단조기

Hardening Mechanism by Cold Working

Before cold work

Deformation
or
Cold work

Aluminum alloy

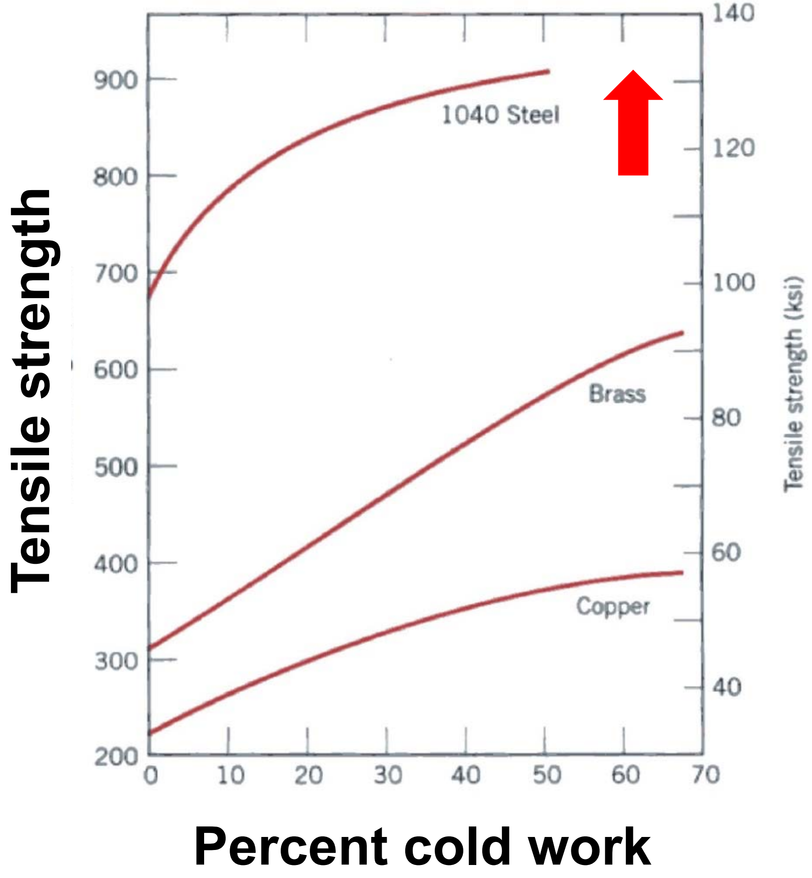


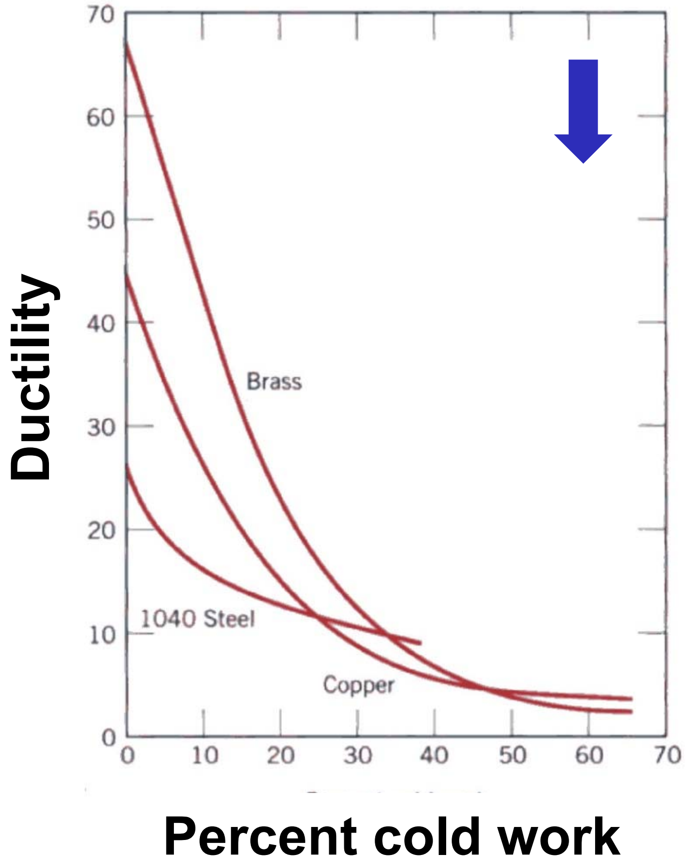
Dislocation tangle

Accumulation of dislocations

미세구조 조절: 2) Secondary phase control during processing

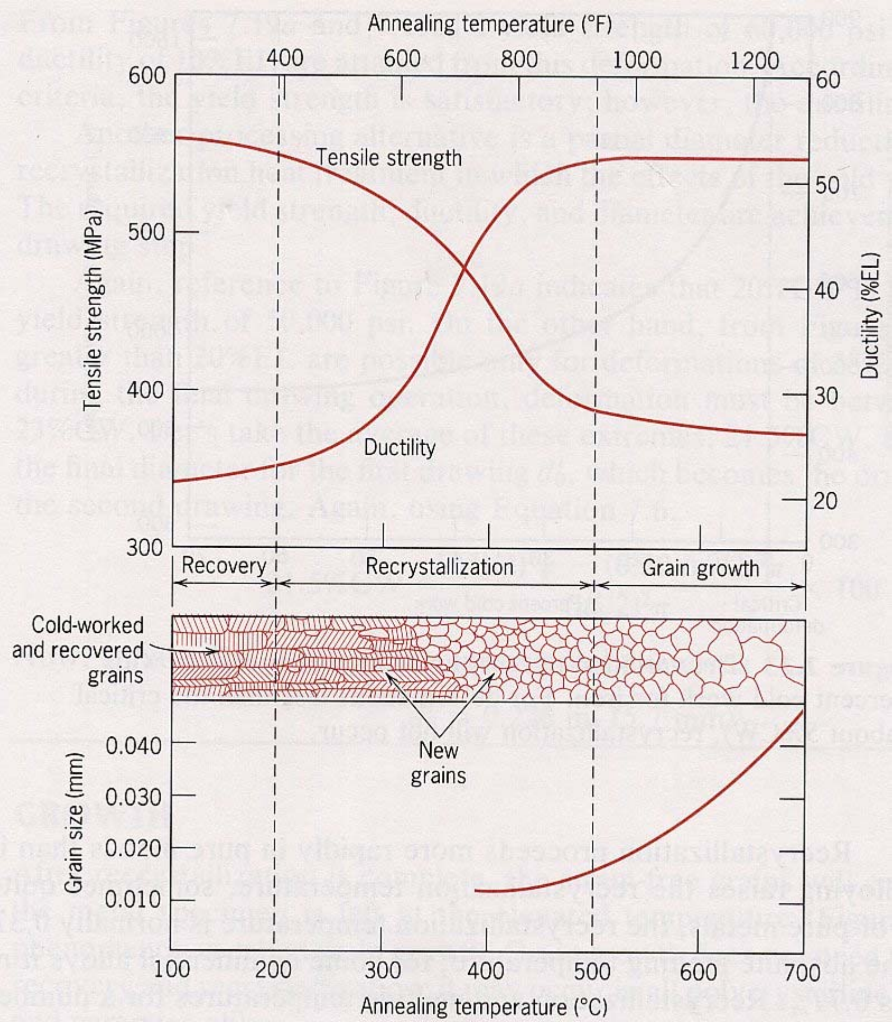
Changes of Strength and Ductility by Cold Working





미세구조 조절: 2) Secondary phase control during processing

Changes of Microstructure & Mechanical Properties during Annealing



Cold working → recovery → recrystallization → grain growth

내부 변형률 에너지 제거 낮은 전위밀도 (변형률이 없는) 결정립

합금설계 + 공정조절 ➡ 특성 최적화

Production and Application of Electrical Steel

Hot rolling - cold rolling – 1st annealing – 2nd annealing

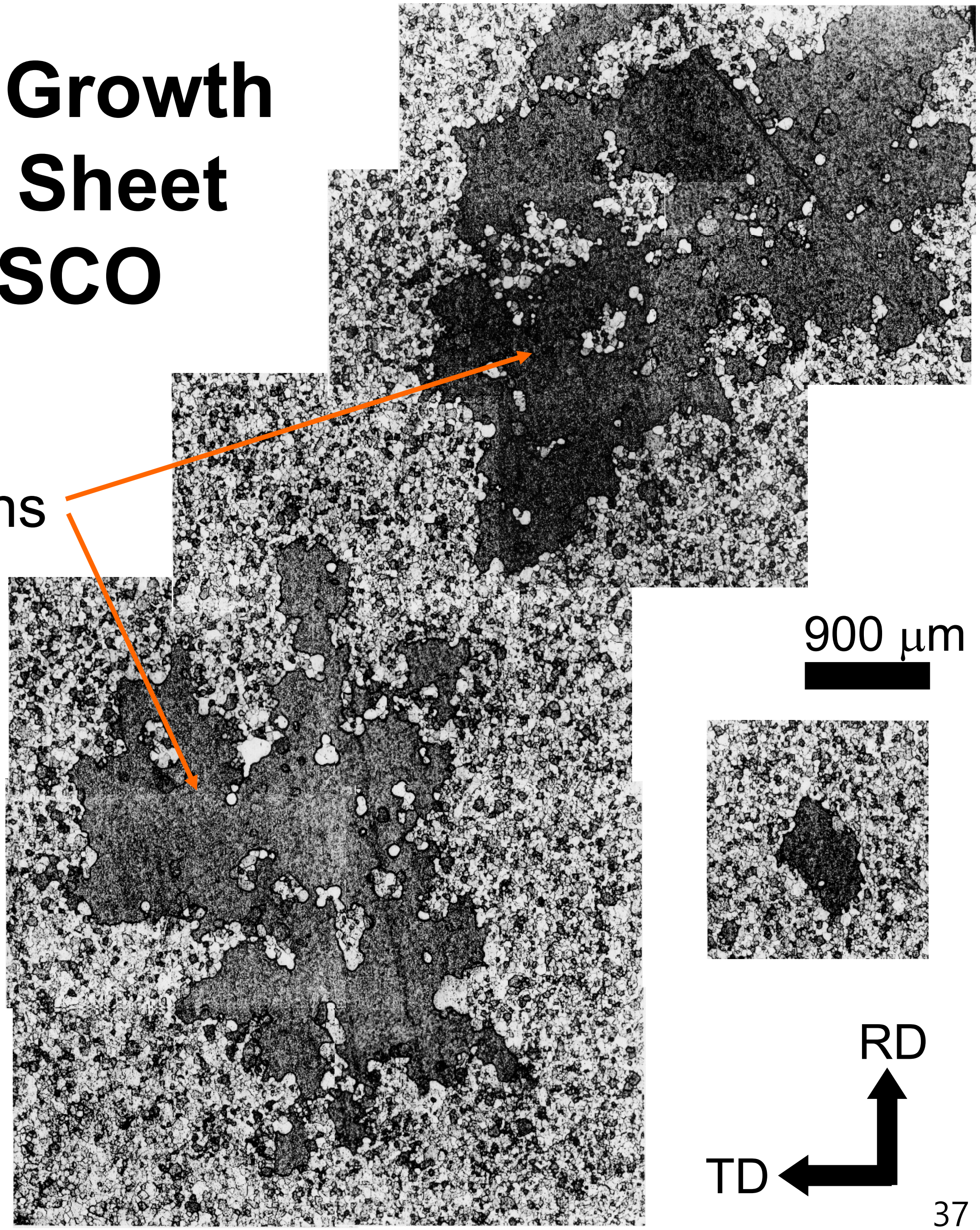
Coils

Stacked transformer core

Transformer
Motor
Etc.

Soft magnetization property

Abnormal Grain Growth In Fe-3%Si Steel Sheet produced by POSCO



Abnormally grown grains
with Goss texture

Control of grain growth

Control of
magnetic property

Important!!!

Understanding **and** ***Controlling***

Phase Transformation of Materials

Phase Transformation

- **Solidification: Liquid → Solid**
- **Phase transformation in Solids**

1) Diffusion-controlled phase transformation ;

Generally long-distance atomic migration

- Precipitation transformation
- Eutectoid transformation ($S \rightarrow S_1 + S_2$)
- etc.

2) Diffusionless transformation ;

Short-distance atomic migration

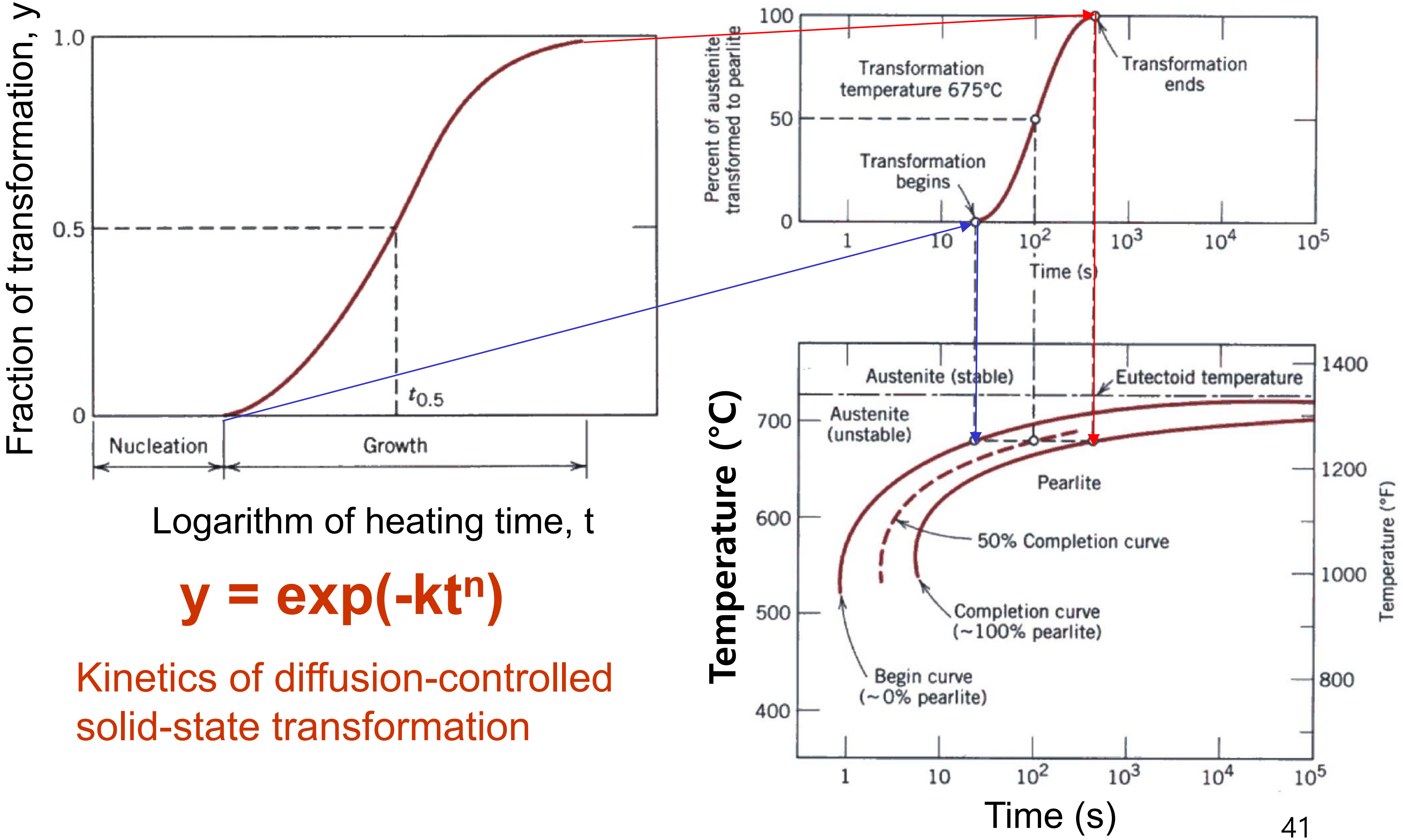
- Martensitic transformation

Diffusion-Controlled Phase Transformation
time dependency

Non-Equilibrium Phases

Need of Controlling
not only *Temperature* & *Composition*
but *Process conditions* (Cooling Rate)

Transformation Kinetics and Isothermal Transformation Diagram



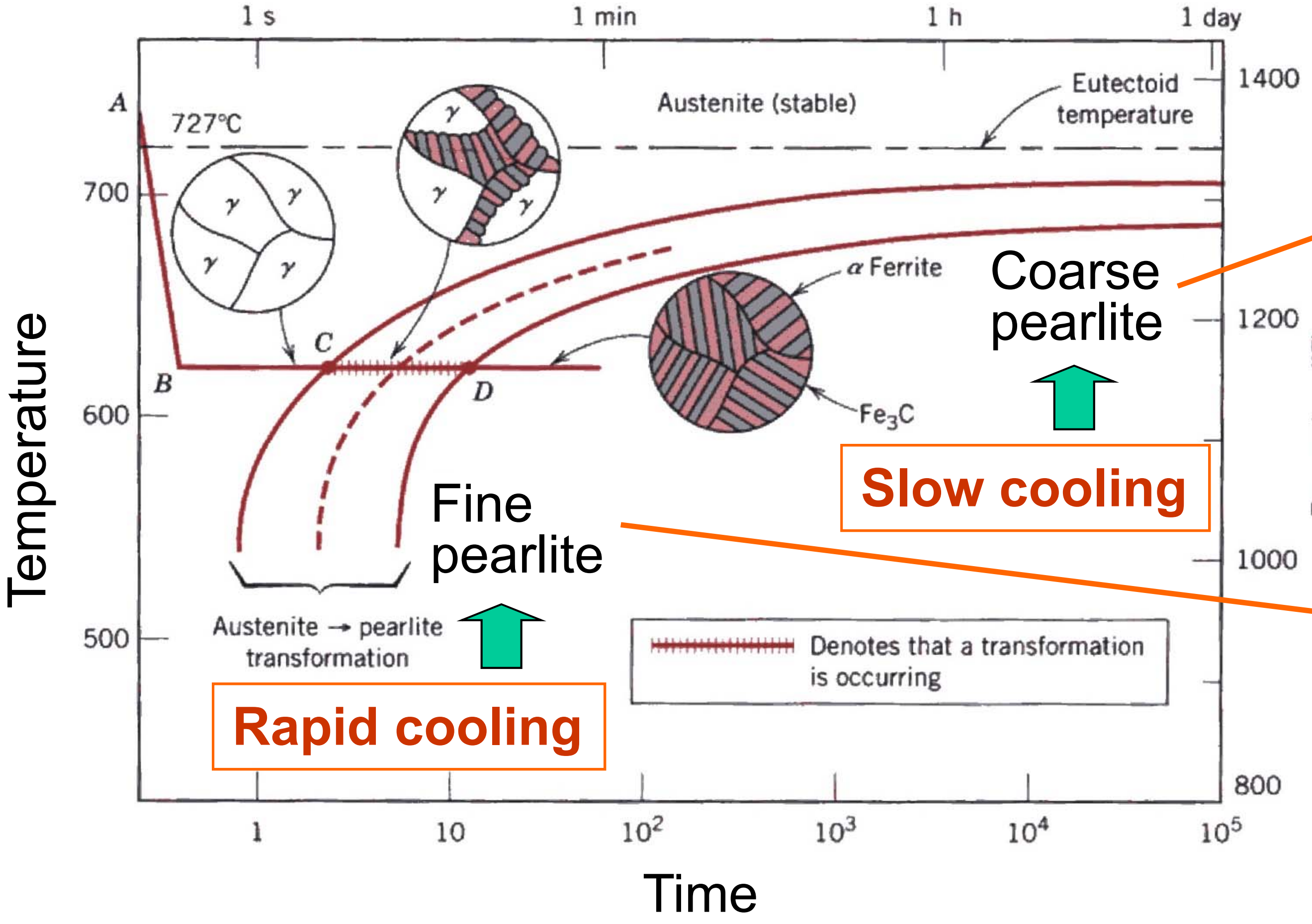
$$y = \exp(-kt^n)$$

Kinetics of diffusion-controlled solid-state transformation

TTT diagram ➡ **Isothermal transformation diagram**

Isothermal Transformation Diagram of a Eutectoid Iron-Carbon Alloy

γ Austenite → α Ferrite + Fe_3C graphite



Coarse pearlite

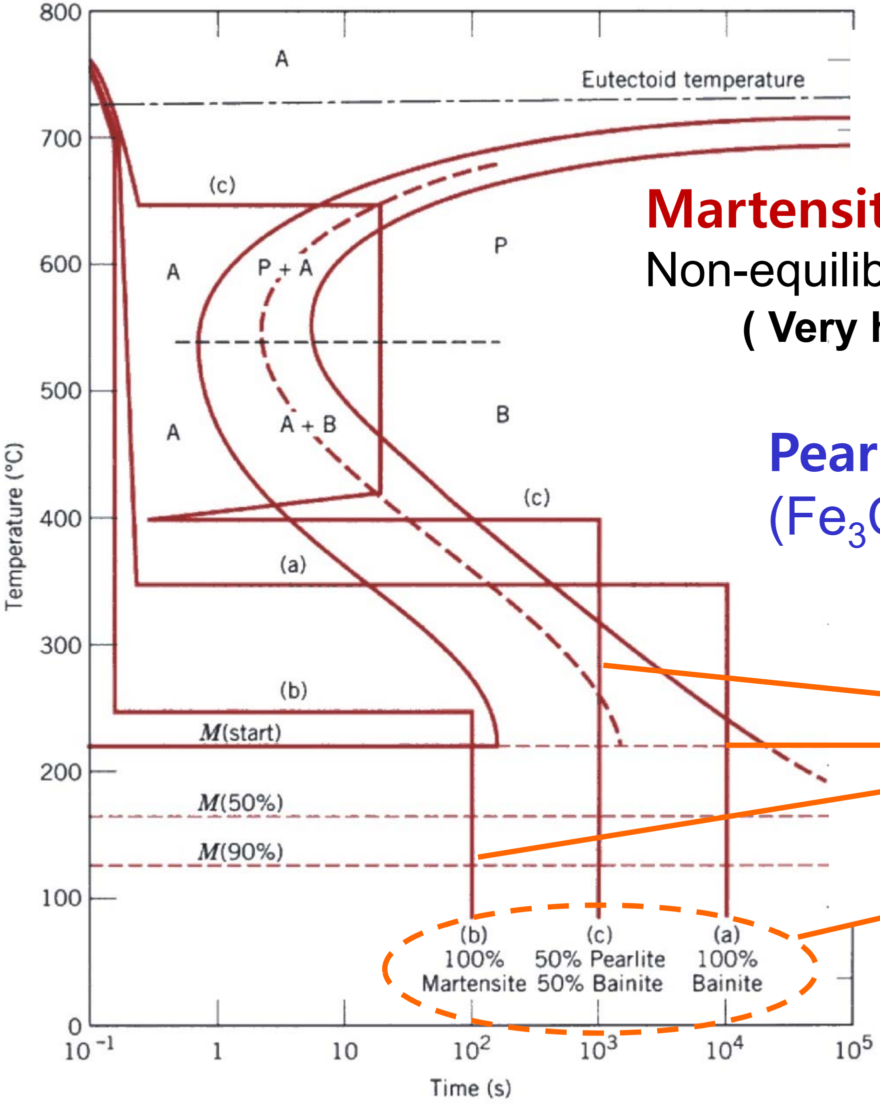
Slow cooling

Fine pearlite

Rapid cooling

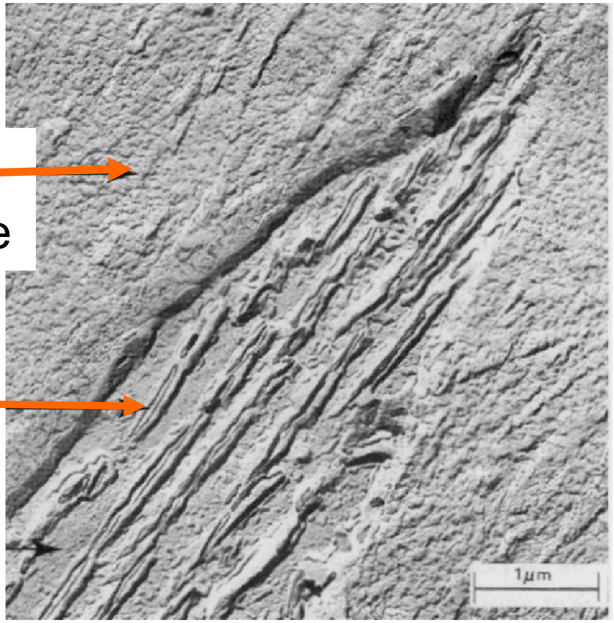
➡ ***Phase Transformation*** **제어을 통한** ***microstructure*****의 조절 가능**

Control of Phases by Heat Treatment



Martensite ;
Non-equilibrium phase
(Very hard)

Pearlite
(Fe_3C+ferrite)



Heat Treatment 공정조절

Phase & Microstructure

Properties of Material

Control of Mechanical Properties by Proper Heat Treatment in Iron-Carbon Alloy

Martensite

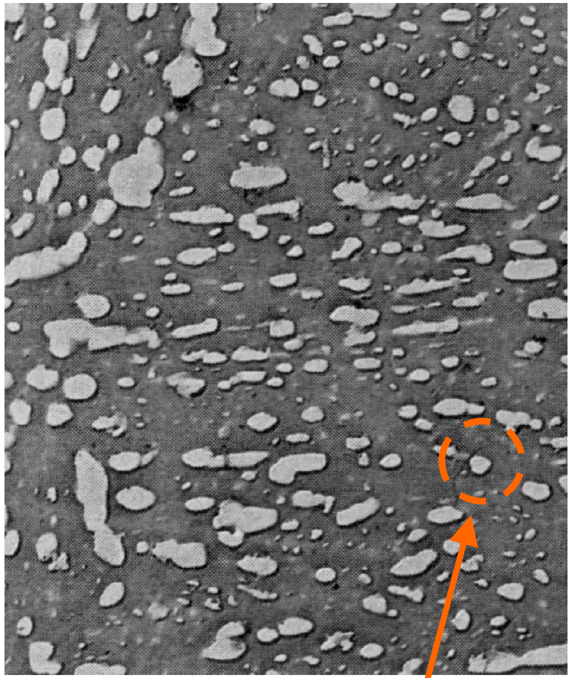
Tip of needle shape grain

Nucleation site of fracture

Brittle

공정조절

Proper heat treatment (tempering)



Tempered martensite

Very small & spherical shape grain

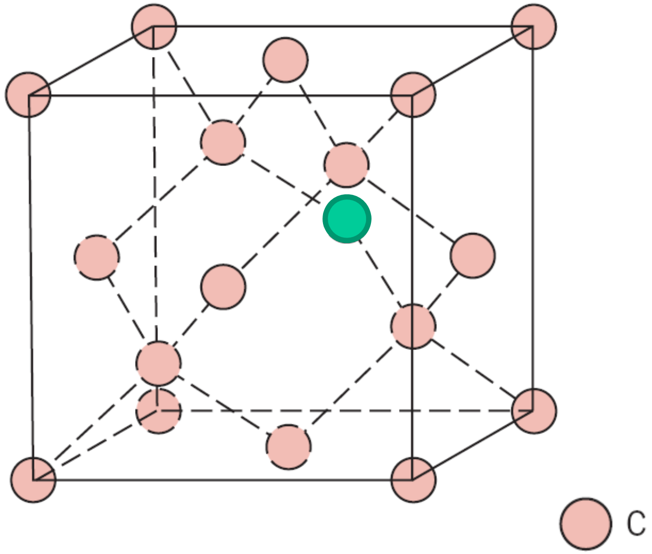
Good strength, ductility, toughness

High performance materials

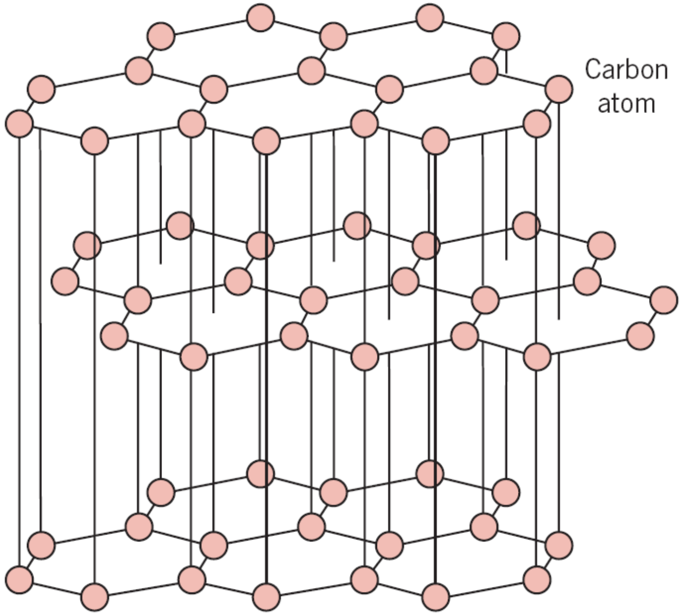
- High/low temperature
- High specific strength (strength/weight)
- High electrical performance
  - High/low dielectric, Ferroelectric, Superconductor
- Nano materials
- Bio-materials
- High performance coatings
- Structural materials
- Optical materials (LED, OLED, Fluorescent)
- Magnetic/Superconducting materials
- Materials are involved in everywhere…. You name it,…

1) Same element, but different structure

diamond



graphite



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

Top 10 most expensive diamonds (1/2)


Allnatt Diamond
101 carat, $ 3M. 20 g


Moussaieff Red Diamond
14 carat, $ 7M. 2.78 g


The Heart of Eternity
14 carat, $ 16 M. 5.5 g


Wittelsbach Diamond
35.6 carat, $ 16.4 M.

The Steinmetz Pink
60 carat, $ 25 M.

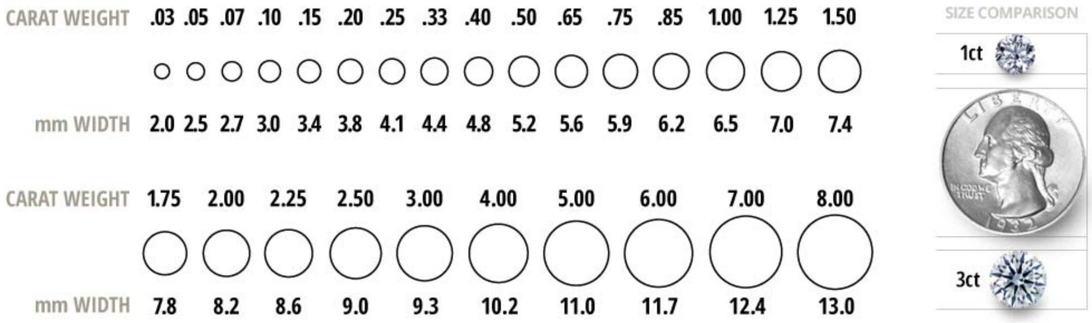

De Beers Centenary Diamond
274 carat, $ 100 M.


The Hope Diamond
45 carat, $ 350 M.


The Cullinan
3100 carat, $ 400 M.

Anything strange? Difference from the typical diamond?

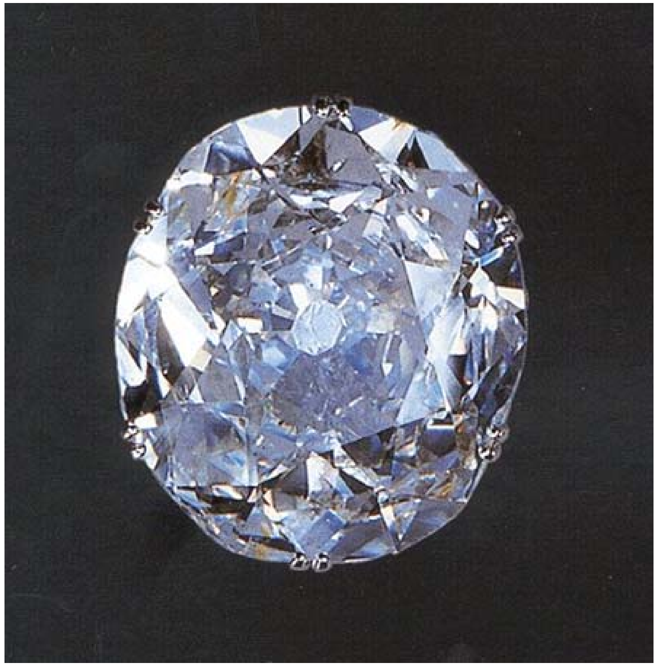
Top 10 most expensive diamonds (2/2)



CARAT WEIGHT	.03	.05	.07	.10	.15	.20	.25	.33	.40	.50	.65	.75	.85	1.00	1.25	1.50
mm WIDTH	2.0	2.5	2.7	3.0	3.4	3.8	4.1	4.4	4.8	5.2	5.6	5.9	6.2	6.5	7.0	7.4

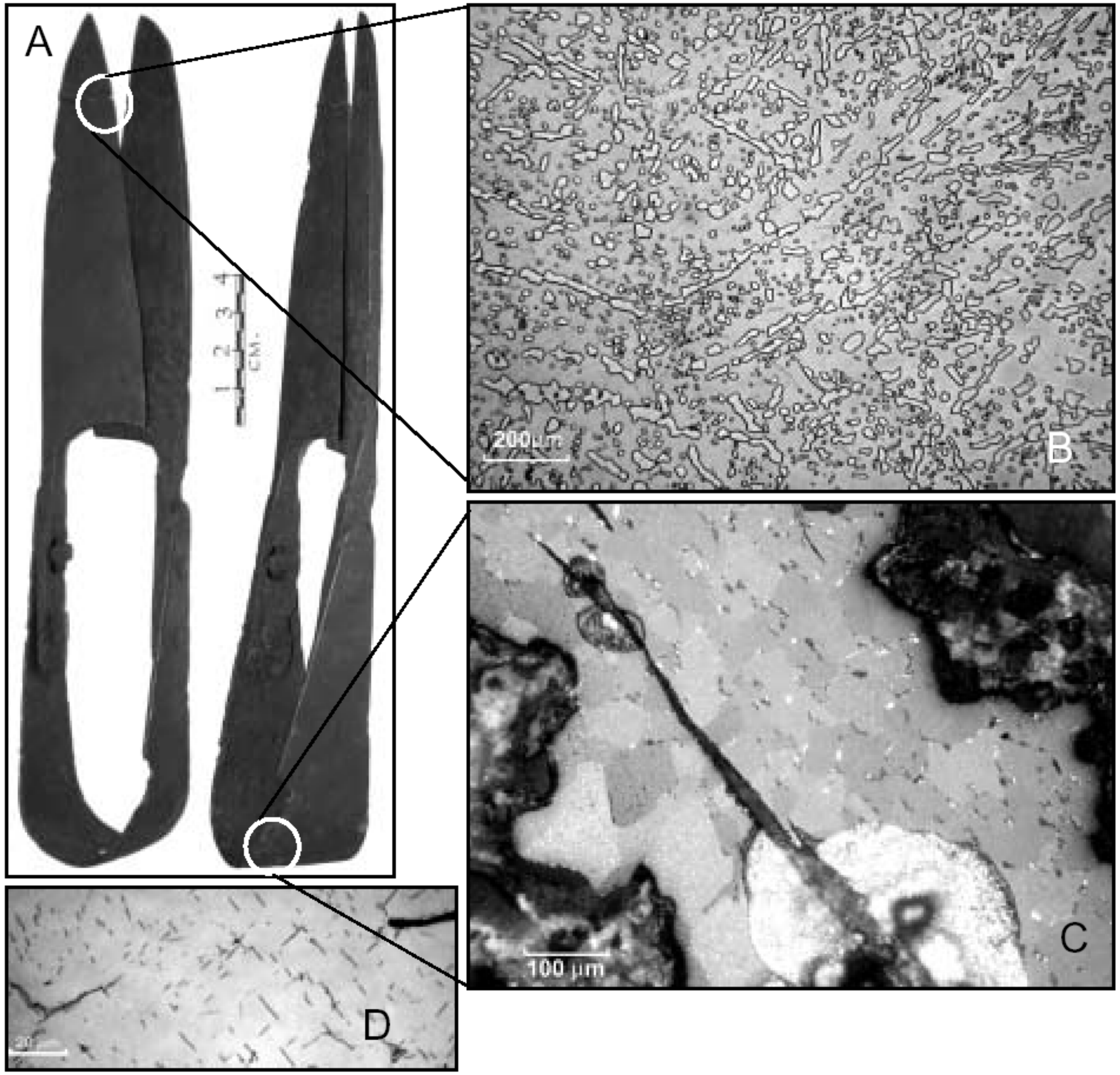
CARAT WEIGHT	1.75	2.00	2.25	2.50	3.00	4.00	5.00	6.00	7.00	8.00
mm WIDTH	7.8	8.2	8.6	9.0	9.3	10.2	11.0	11.7	12.4	13.0

Sancy Diamond
55 carat, $ not estimated.
The great Mughal of India

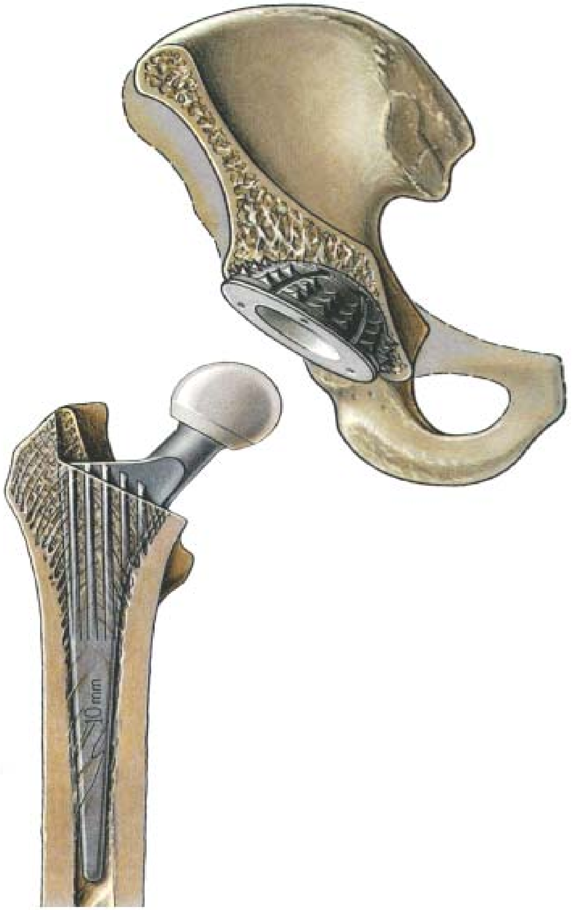


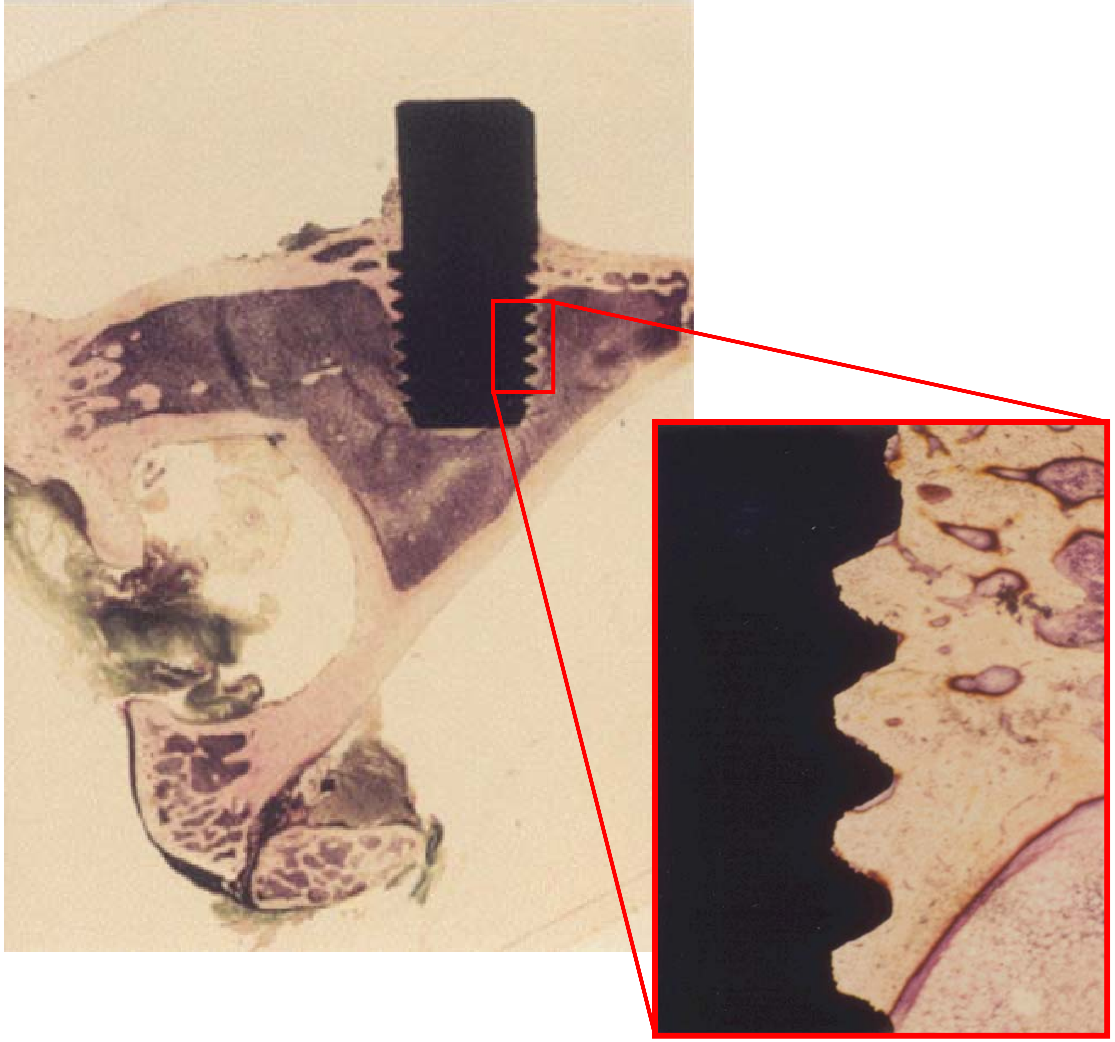
Kohinoor
105 carat, $ not estimated
Purest form of diamond

2) Improvement – Microstructure Control



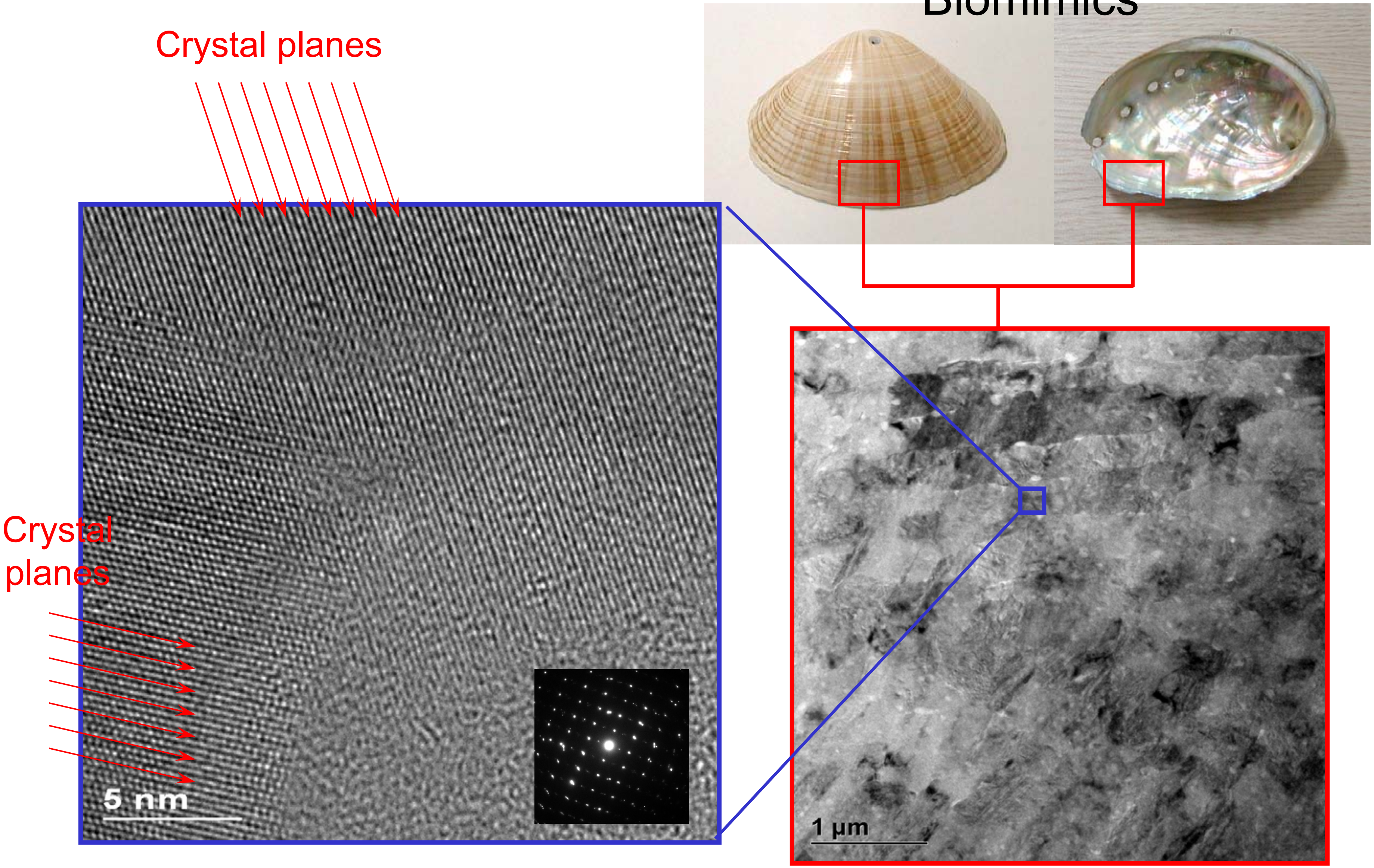
2) Materials for Bio-Medical Application
-Should be failure-proof





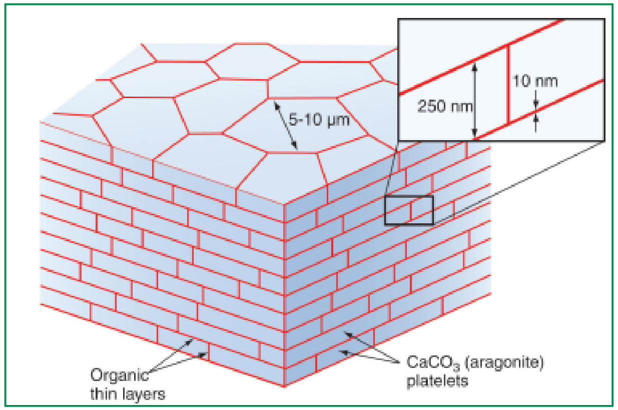
Copying from the Nature

Biomimics


Crystal planes

Crystal planes

Development of ultra-high tough composites



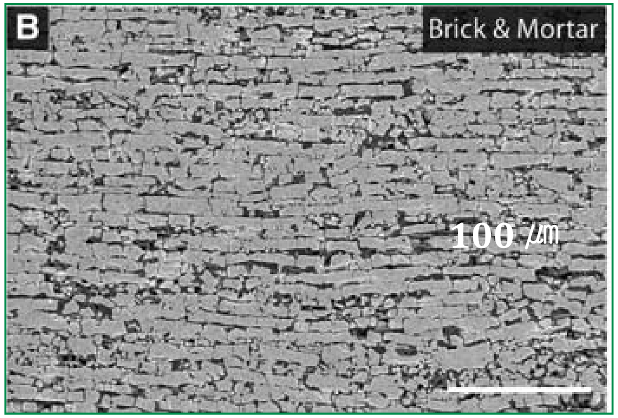
Biological materials

Organic materials / $CaCo_3$

$V_{f.CaCo3}$ ~ 95 vol.%
Thickness δ : < ~ 0.5 ㎛
Wavelength λ < ~ 0.5 ㎛

Bio-inspired materials

*Ceramic Brick & **PMMA mortar***



PMMA / Al_2O_3

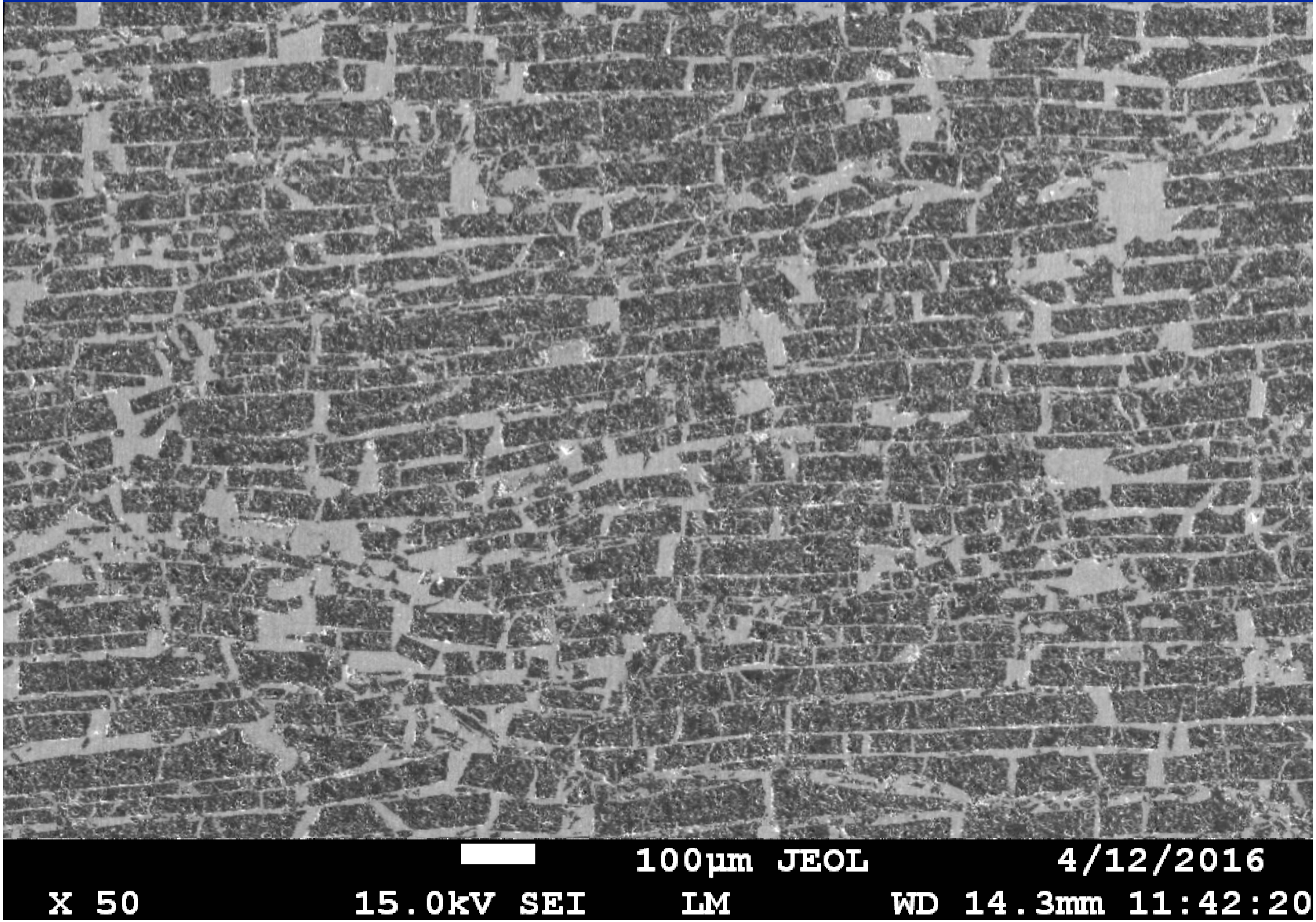
$V_{f.Al2O3}$ ~ 80 vol.%
Thickness δ : < 5 ~ 10 ㎛
Wavelength λ < 11 ~ 12 ㎛

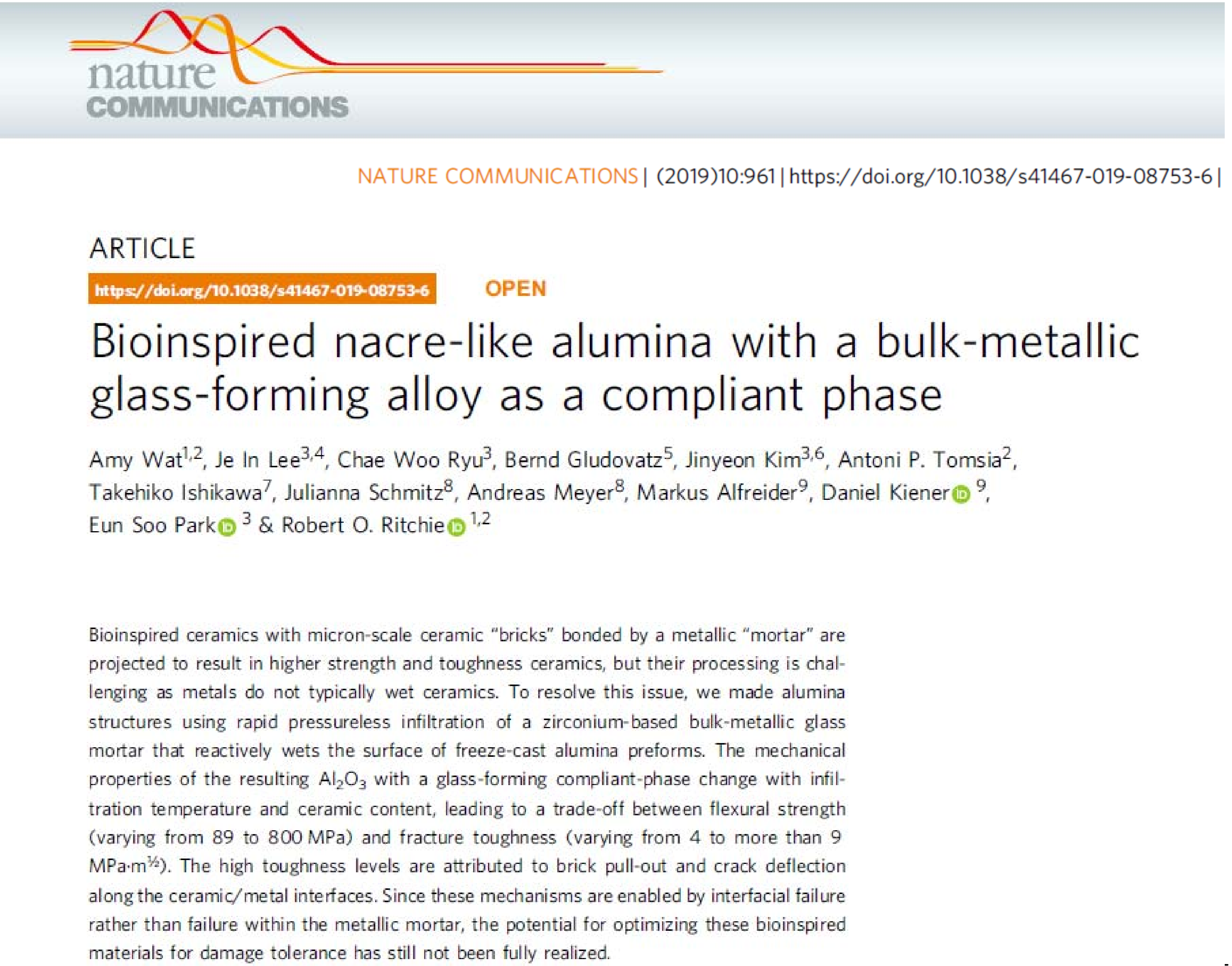
*Ceramic Brick & **Metal mortar***
structure

BMG / Al_2O_3

High strength: > 2 GPa
Large elastic limit: ~ 2 %

Al_2O_3 Ceramic Brick & Zr-BMG mortar composites





nature COMMUNICATIONS

NATURE COMMUNICATIONS | (2019)10:961 | https://doi.org/10.1038/s41467-019-08753-6 |

ARTICLE

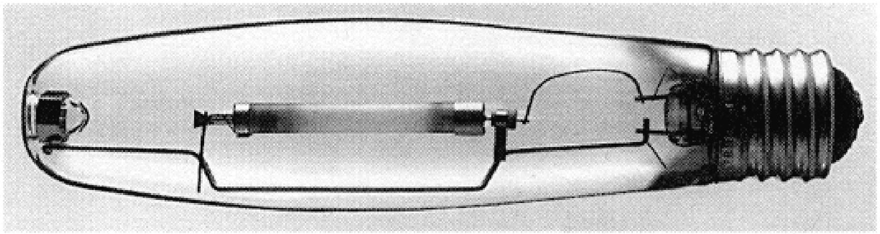
https://doi.org/10.1038/s41467-019-08753-6 OPEN

Bioinspired nacre-like alumina with a bulk-metallic glass-forming alloy as a compliant phase

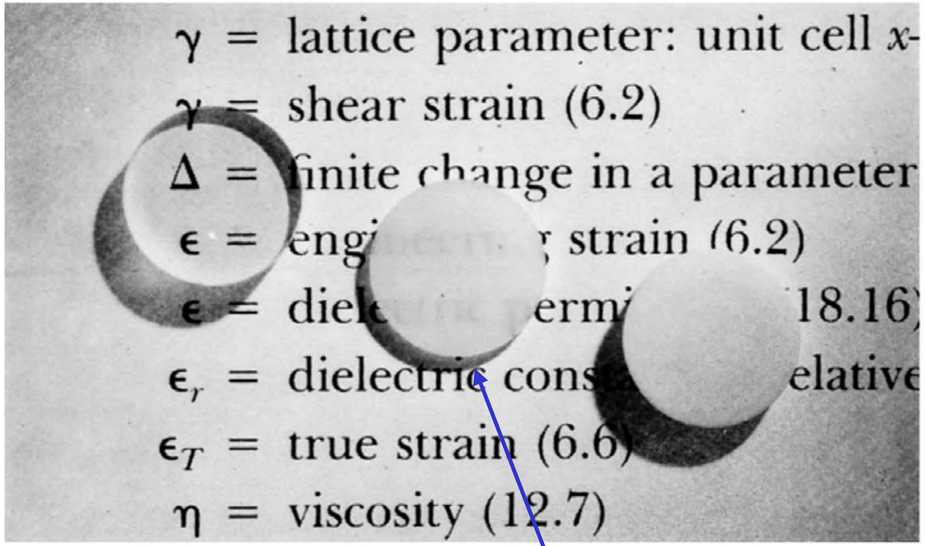
Amy Wat[1,2], Je In Lee[3,4], Chae Woo Ryu[3], Bernd Gludovatz[5], Jinyeon Kim[3,6], Antoni P. Tomsia[2], Takehiko Ishikawa[7], Julianna Schmitz[8], Andreas Meyer[8], Markus Alfreider[9], Daniel Kiener[9], Eun Soo Park[3] & Robert O. Ritchie[1,2]

Bioinspired ceramics with micron-scale ceramic "bricks" bonded by a metallic "mortar" are projected to result in higher strength and toughness ceramics, but their processing is challenging as metals do not typically wet ceramics. To resolve this issue, we made alumina structures using rapid pressureless infiltration of a zirconium-based bulk-metallic glass mortar that reactively wets the surface of freeze-cast alumina preforms. The mechanical properties of the resulting Al_2O_3 with a glass-forming compliant-phase change with infiltration temperature and ceramic content, leading to a trade-off between flexural strength (varying from 89 to 800 MPa) and fracture toughness (varying from 4 to more than 9 MPa·m^{½}). The high toughness levels are attributed to brick pull-out and crack deflection along the ceramic/metal interfaces. Since these mechanisms are enabled by interfacial failure rather than failure within the metallic mortar, the potential for optimizing these bioinspired materials for damage tolerance has still not been fully realized.

2) Microstructure of optical fiber

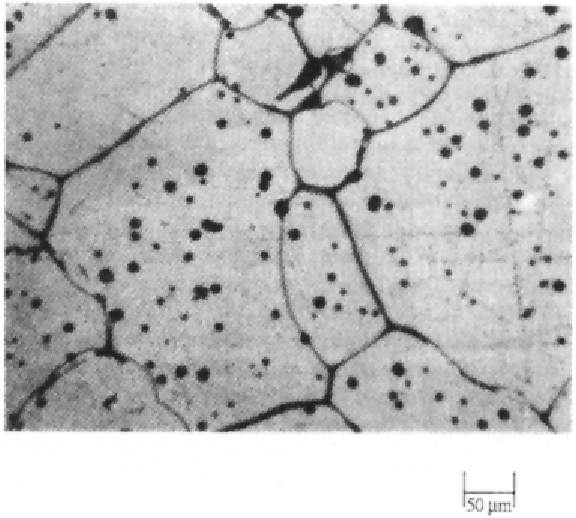


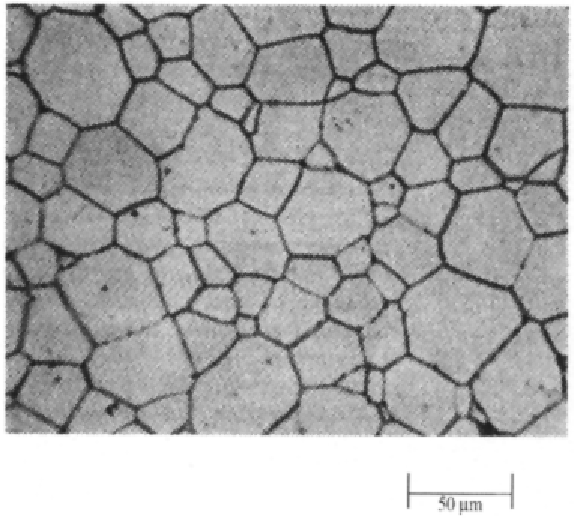
high temp
sodium vapor lamp
Al_2O_3



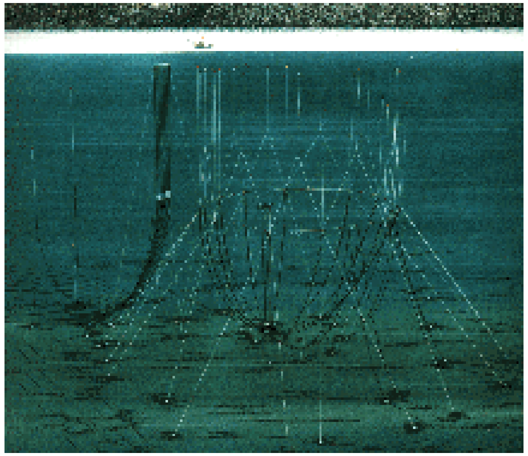
opaque

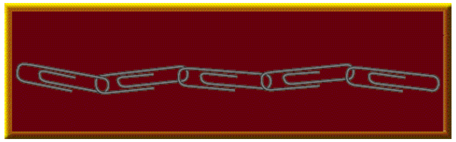
translucent



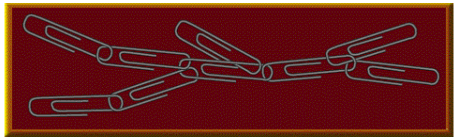


2) Improvement : Lighter and Stronger

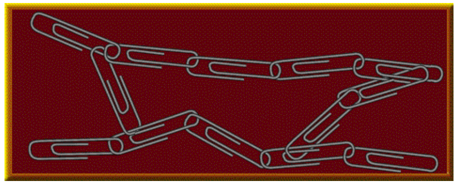




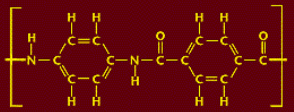
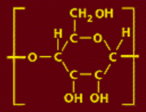
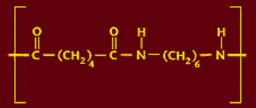
Linear polymer : Microwaveable food containers, Dacron carpets and Kevlar ropes



Branched polymers : flexible shampoo bottles and milk jugs



Cross-linked polymers : Car tires and bowling balls

Common Name	Chemical Formula of the Monomer	Breaking Strength (grams / denier)
Kevlar		20-30
Rayon		1-2
Nylon-66	 $\left[-\overset{O}{\overset{\Vert}{C}}-(CH_2)_4-\overset{O}{\overset{\Vert}{C}}-\overset{H}{\overset{\vert}{N}}-(CH_2)_6-\overset{H}{\overset{\vert}{N}}-\right]$	3-10
Nomex		4-5.5

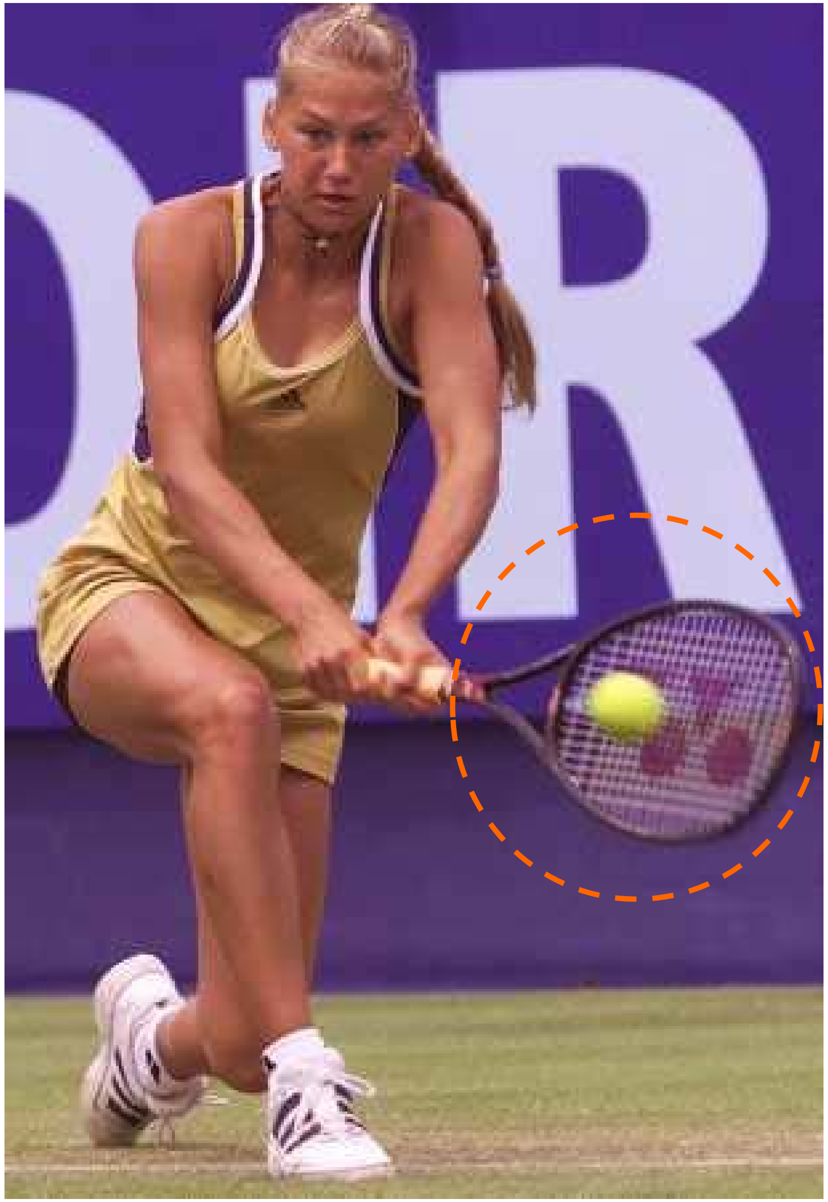
3) Improvement : Phase transformation

Boeing 777

이륙 전 (47 °C)

이륙 후 지상 10000m 높이
외부 온도 영하 38°C

> 섭씨 80도 이상의 온도 차이에서도 안정된 날개



Look !!

Not Anna,
But Racket

Moment of Impact

If the racket is weak
or Its head is small,
…

Anna cannot win alone.
A good racket is needed.

Anna Kournikova

4) Improvement : Composite & Design

a.**Tennis Racket**

Stronger and lower density material → **Bigger head** → **More comfortable to play**

1700's

1970's

today

b. **Fighters ;**

Most strong, light, and tough Materials

F-22 Raptor

2000's Titanium alloy + Carbon fiber Composites

FW-190

1940's Aluminum alloy

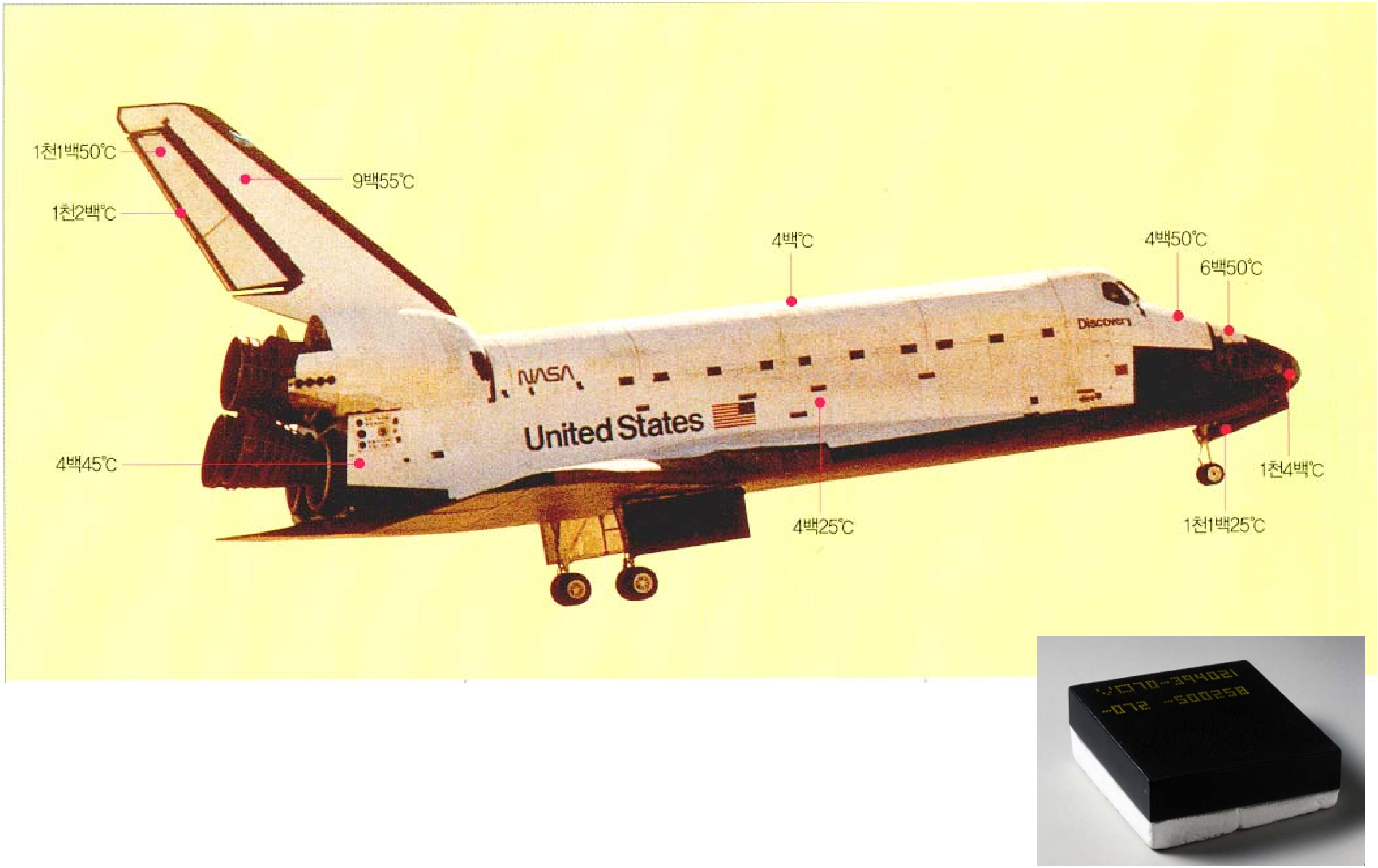
Voker Dr I

1910's wood, canvas

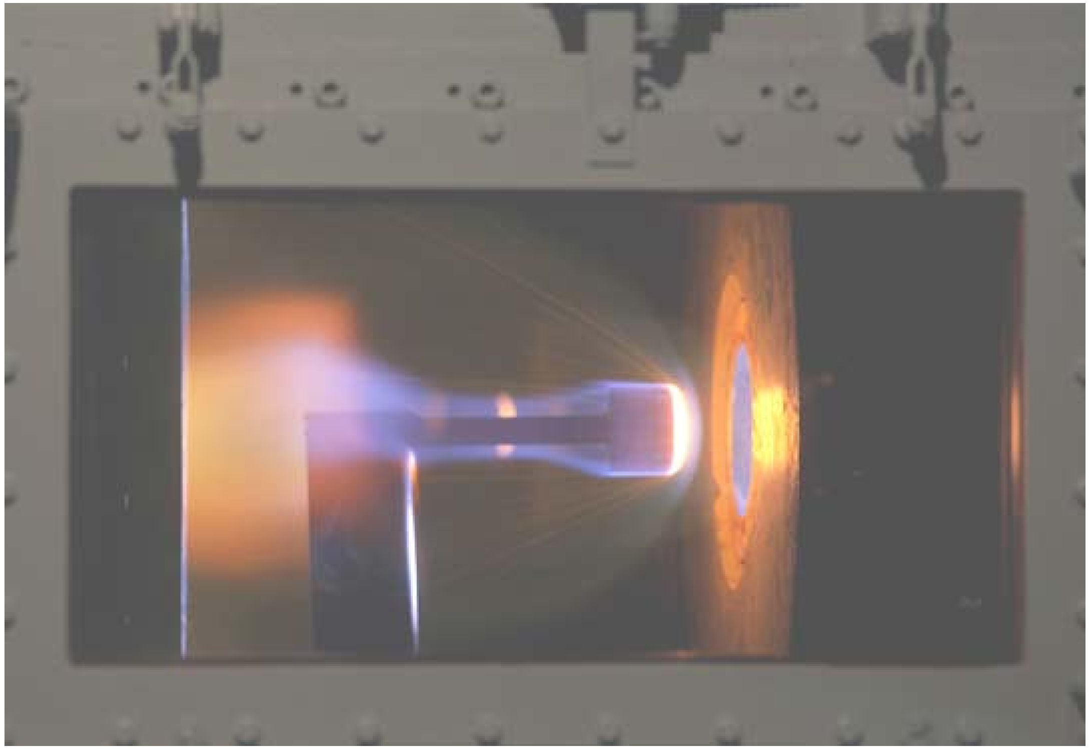
F-14 Tomcat

1970's Steel + Titanium alloy

c. Space Shuttle



c-i) 내열 재료



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

Credits - NASA

c-ii) Other forms of materials

Porous and Cellular Materials

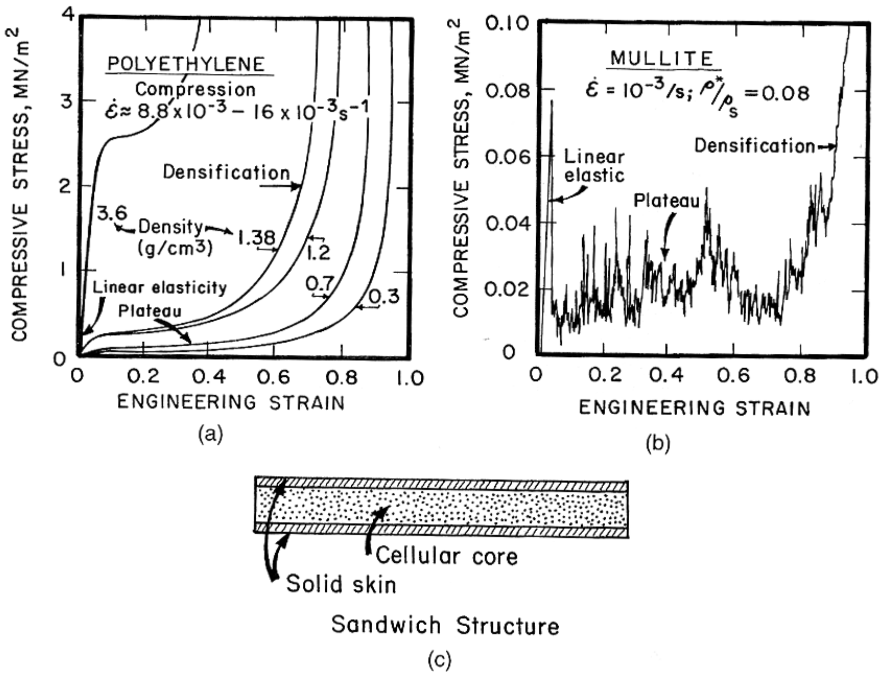
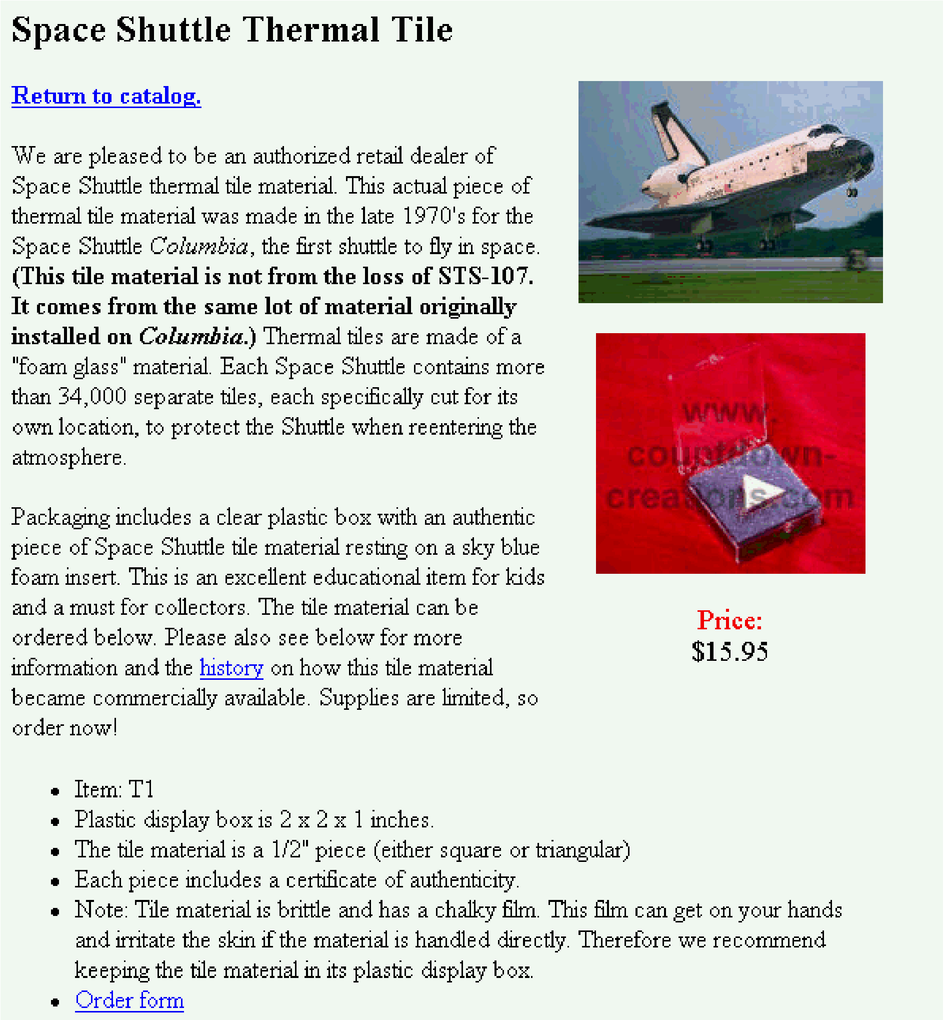


Figure 1.31 Compressive stress–strain curves for foams. (a) Polyethylene with different initial densities. (b) Mullite with relative density $P^*/Ps = 0.08$ (adapted from L. J. Gibson and M. F. Ashby, *Cellular Solids: Structure and Properties* (Oxford, UK: Pergamon Press 1988), pp. 124, 125). (c) Schematic of a sandwich structure.



Space Shuttle Thermal Tile

Return to catalog.

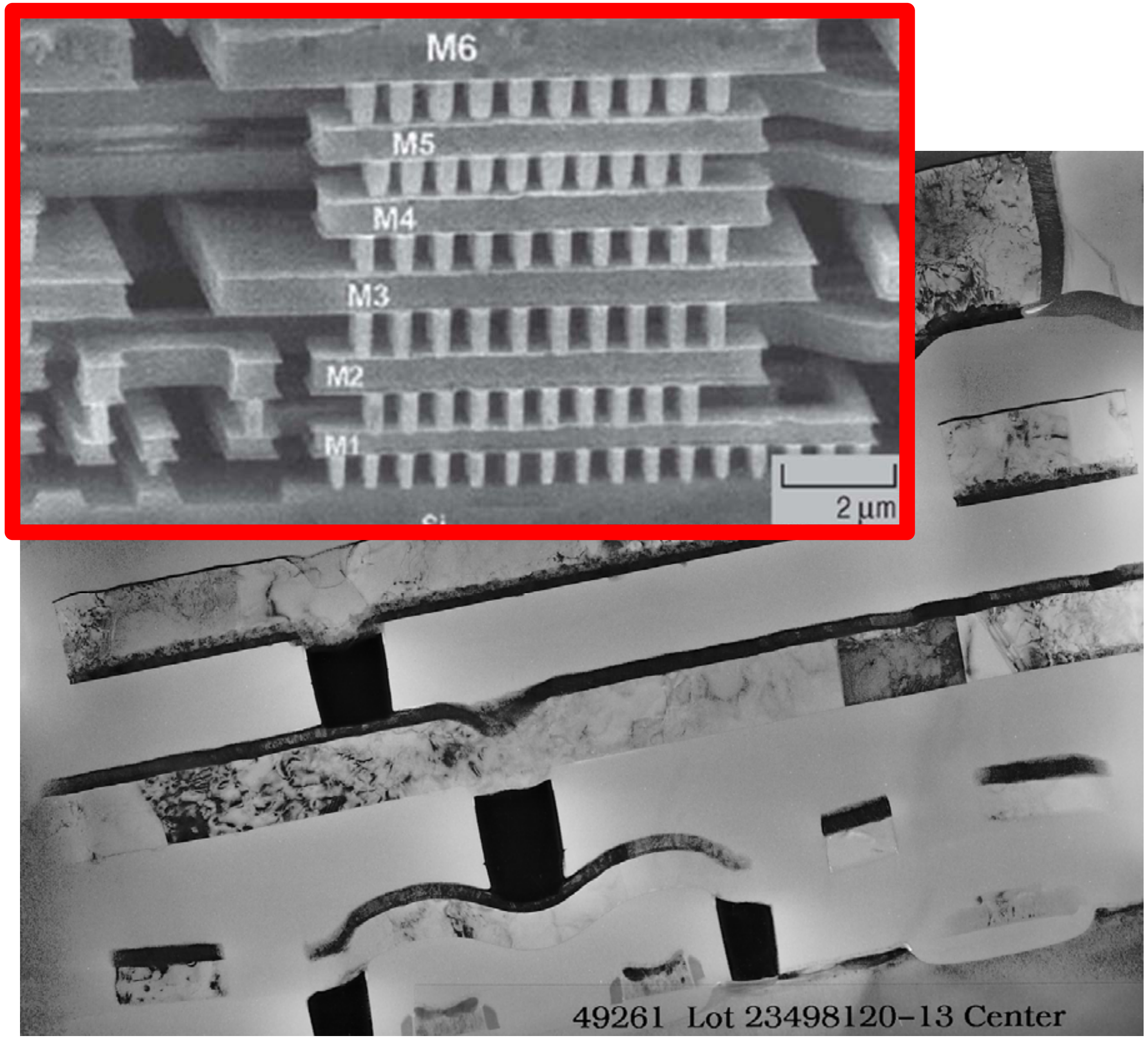
We are pleased to be an authorized retail dealer of Space Shuttle thermal tile material. This actual piece of thermal tile material was made in the late 1970's for the Space Shuttle *Columbia*, the first shuttle to fly in space. **(This tile material is not from the loss of STS-107. It comes from the same lot of material originally installed on *Columbia*.)** Thermal tiles are made of a "foam glass" material. Each Space Shuttle contains more than 34,000 separate tiles, each specifically cut for its own location, to protect the Shuttle when reentering the atmosphere.

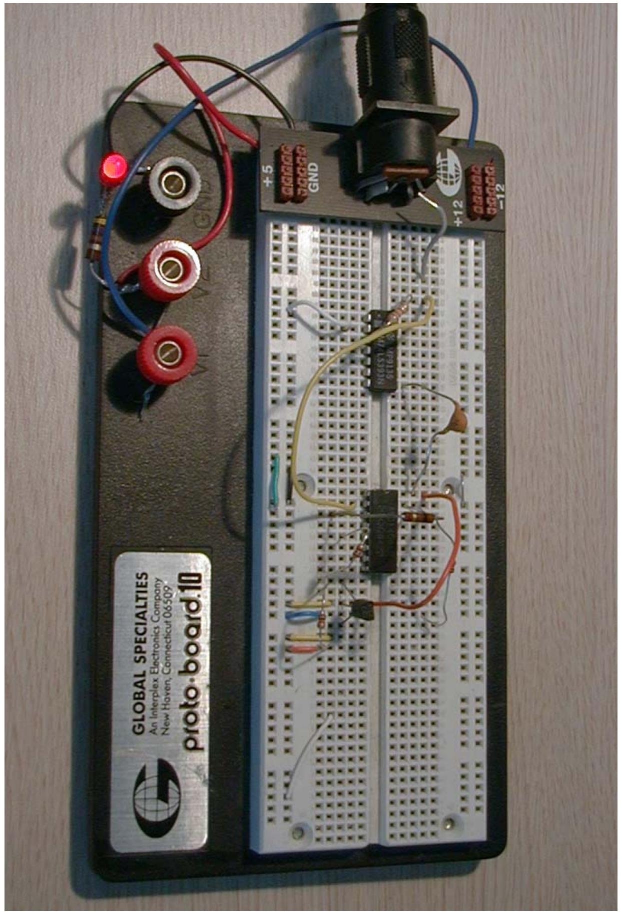
Packaging includes a clear plastic box with an authentic piece of Space Shuttle tile material resting on a sky blue foam insert. This is an excellent educational item for kids and a must for collectors. The tile material can be ordered below. Please also see below for more information and the history on how this tile material became commercially available. Supplies are limited, so order now!

Price:
$15.95

- Item: T1
- Plastic display box is 2 x 2 x 1 inches.
- The tile material is a 1/2" piece (either square or triangular)
- Each piece includes a certificate of authenticity.
- Note: Tile material is brittle and has a chalky film. This film can get on your hands and irritate the skin if the material is handled directly. Therefore we recommend keeping the tile material in its plastic display box.
- Order form

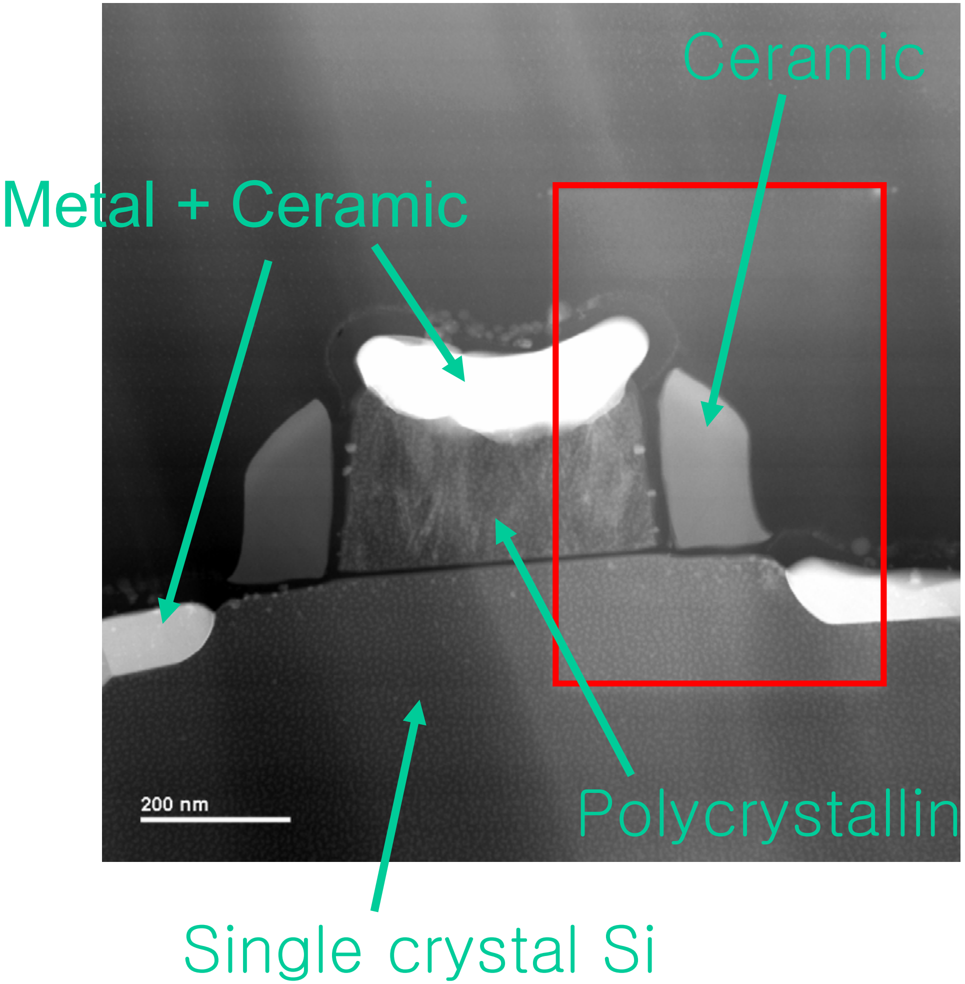
d) Combination of Materials



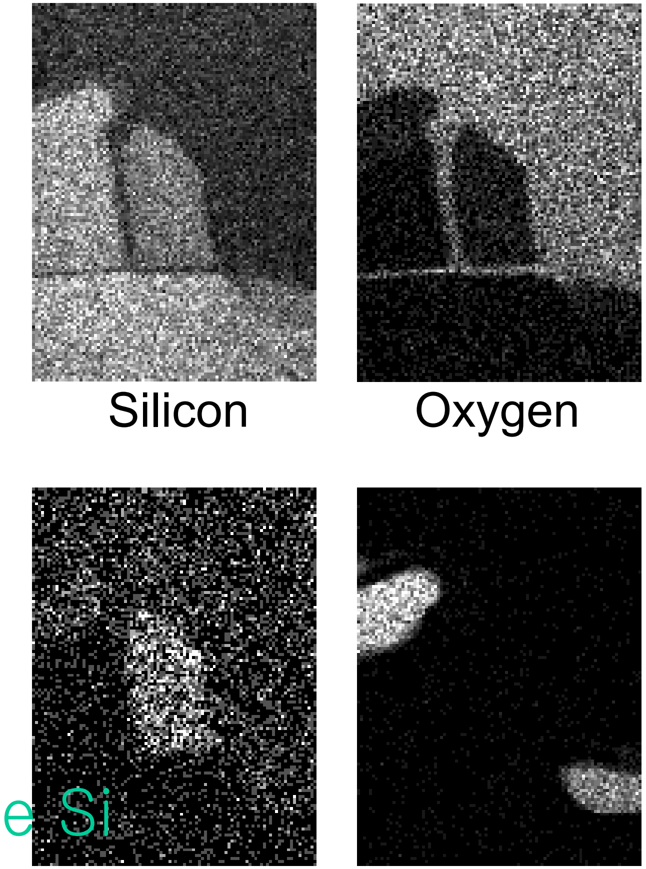


Detailed view of transistor

ADF image



EDS mapping


Silicon

Oxygen

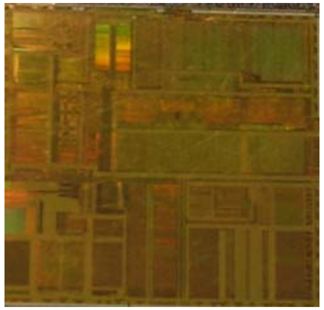
Nitrogen

Titanium

Moore's Law

"The number of transistors incorporated in a chip will approximately double every ~~24~~ 18 months"

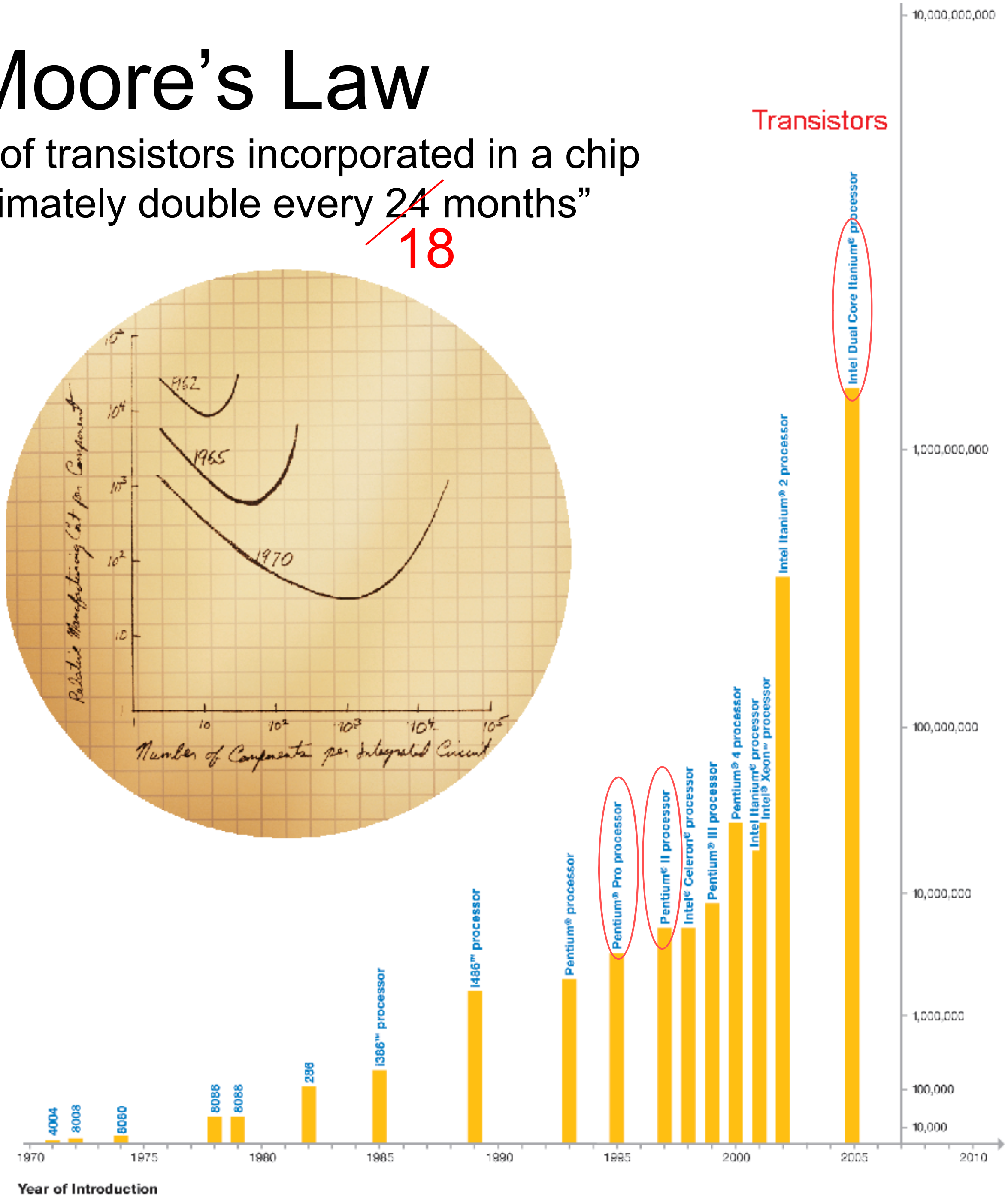
10 mm



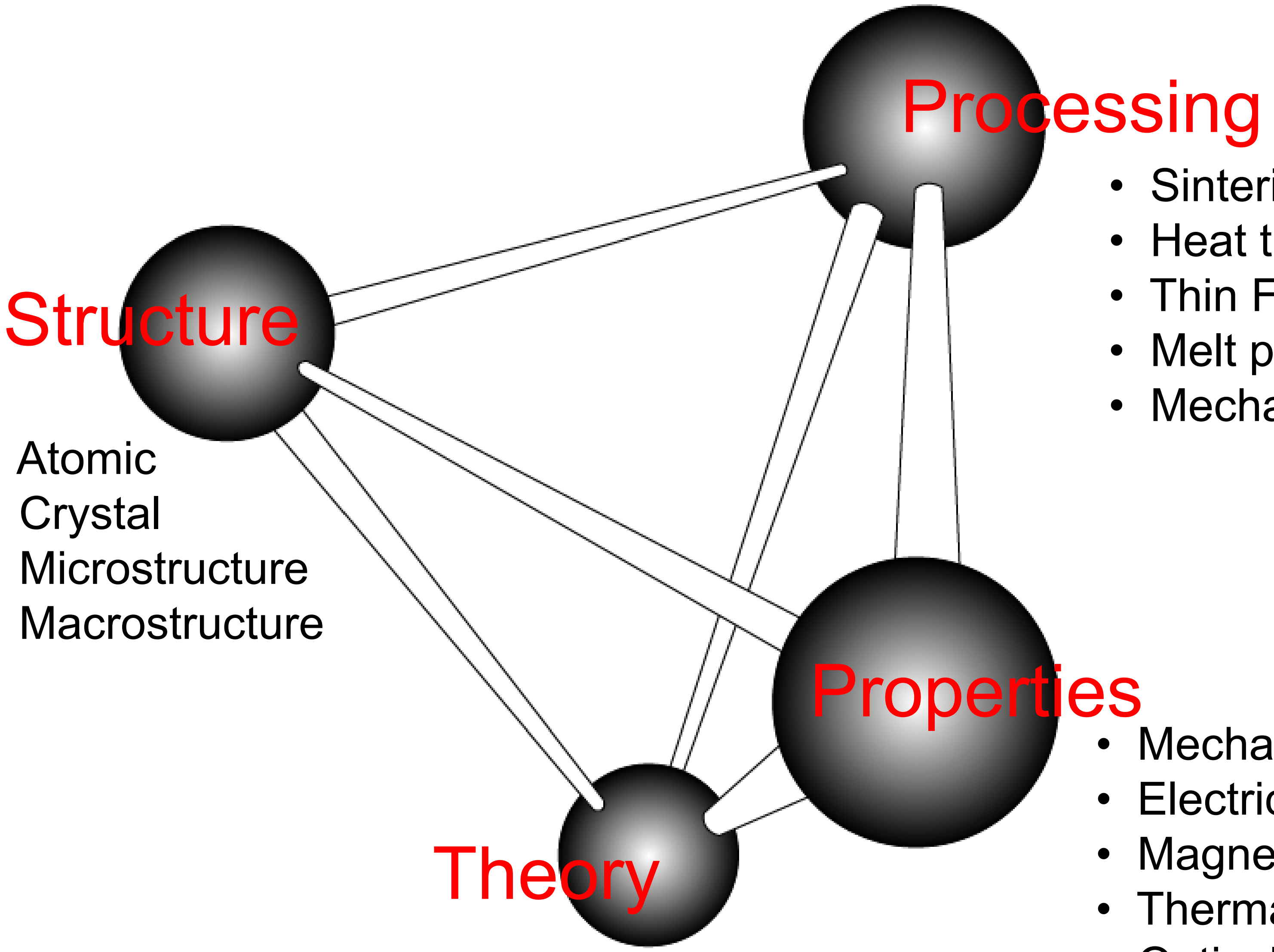
Pentium, 0.8 μm line width

Pentium, 0.5 μm line width

Pentium II, 0.25 μm line width



Materials Science and Engineering



Processing

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

Structure

- Atomic
- Crystal
- Microstructure
- Macrostructure

Properties

- Mechanical
- Electrical
- Magnetic
- Thermal
- Optical

Theory