Microstructure Mechanics

Polymers: Structure and Properties

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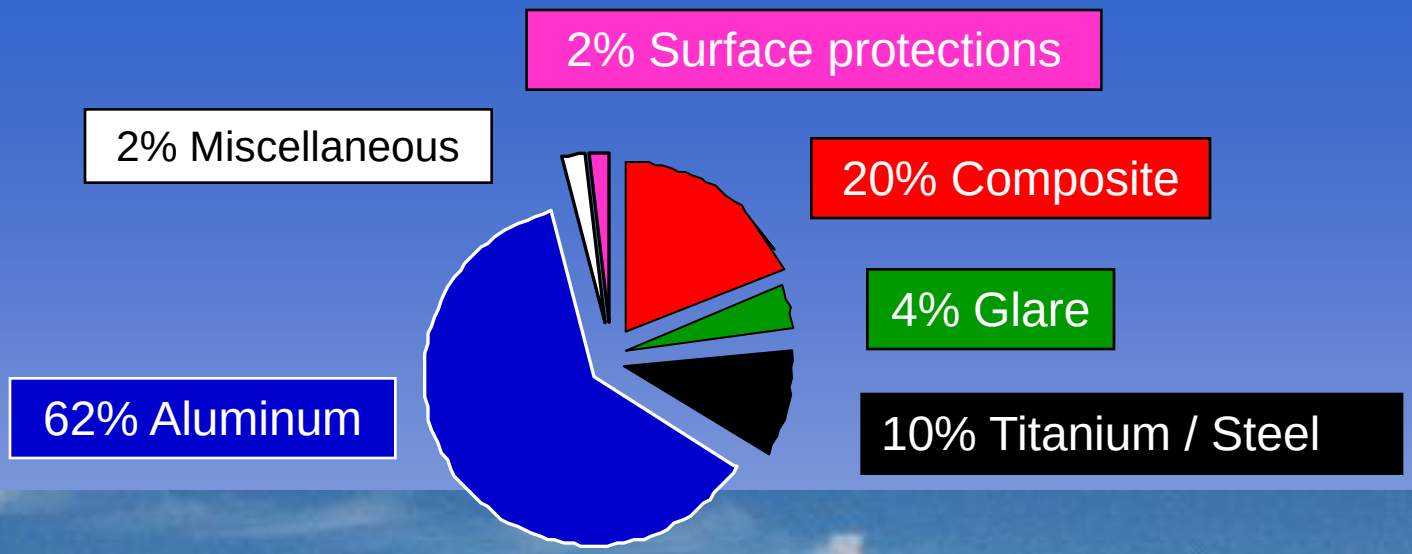
Class 2011

New materials for key technologies: Aero-space

Titanium
Aluminium
Magnesium
Nickel
Steels
Intermetallics

Technology Status A380 – Material Distribution

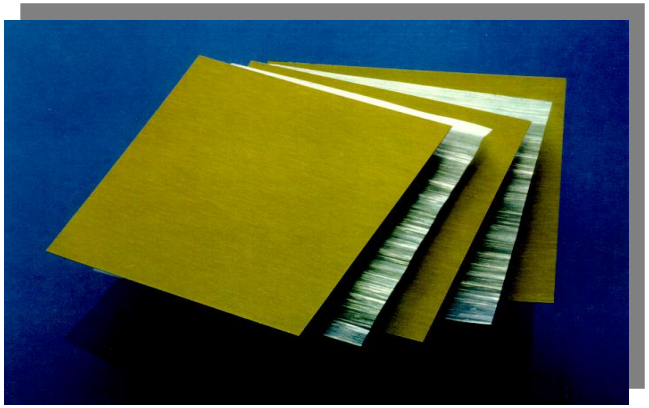
Fly



AIRBUS

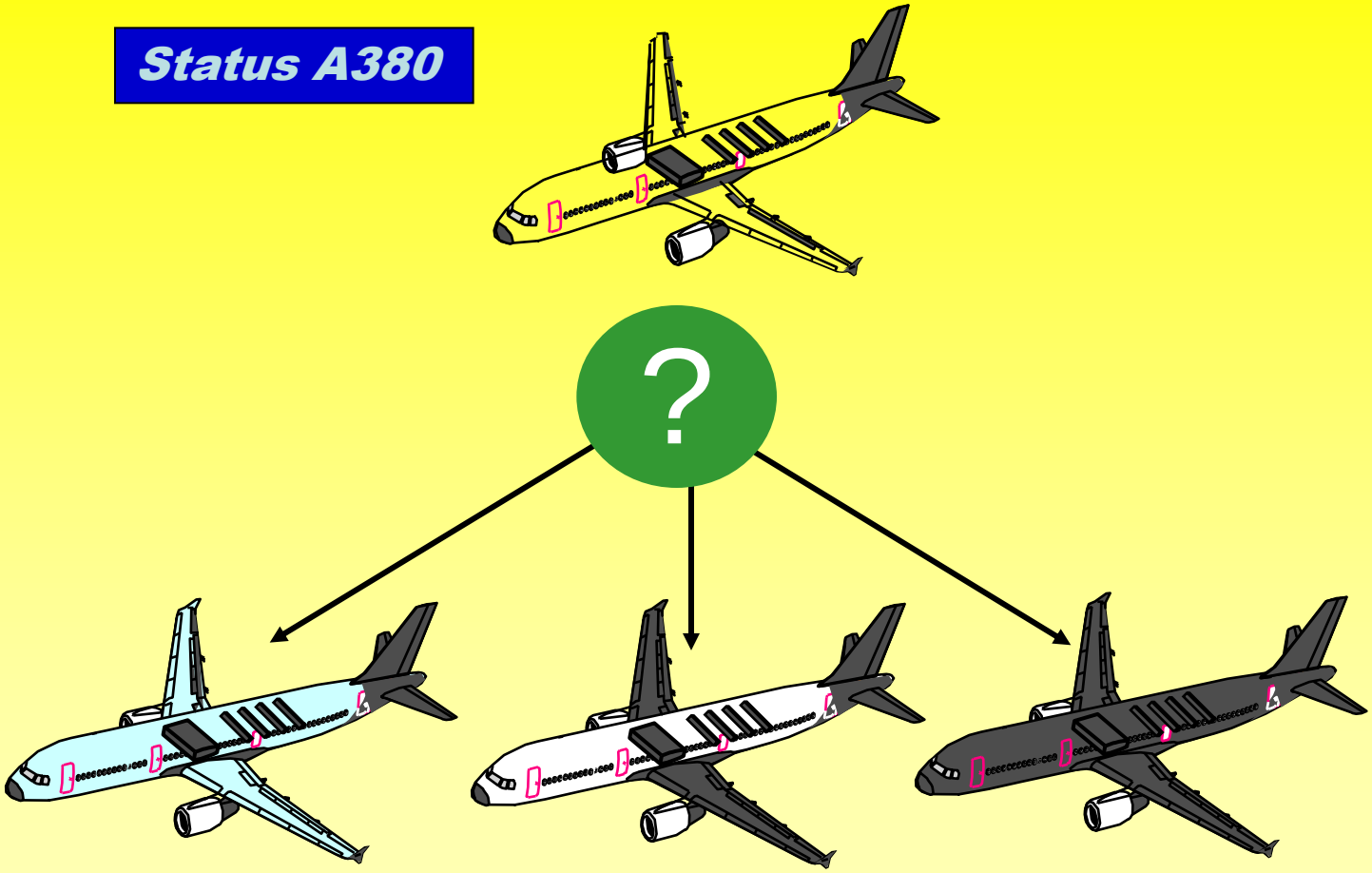
Technology Status A380 – Material Distribution

- **Advanced Alloys**
  - *New initiative of metal industry*
  - *Improved DT, density, stiffness*
- **Premium Casting**
  - *Industrial attractive*
  - *Competition (High Speed Milling, etc.)*
- **Advanced Welding**
  - *Laser Beam Welding*
  - *Friction Stir Welding*
  - *Damage tolerance*
- **Fiber Metal Laminates**
- **Metal Laminates**



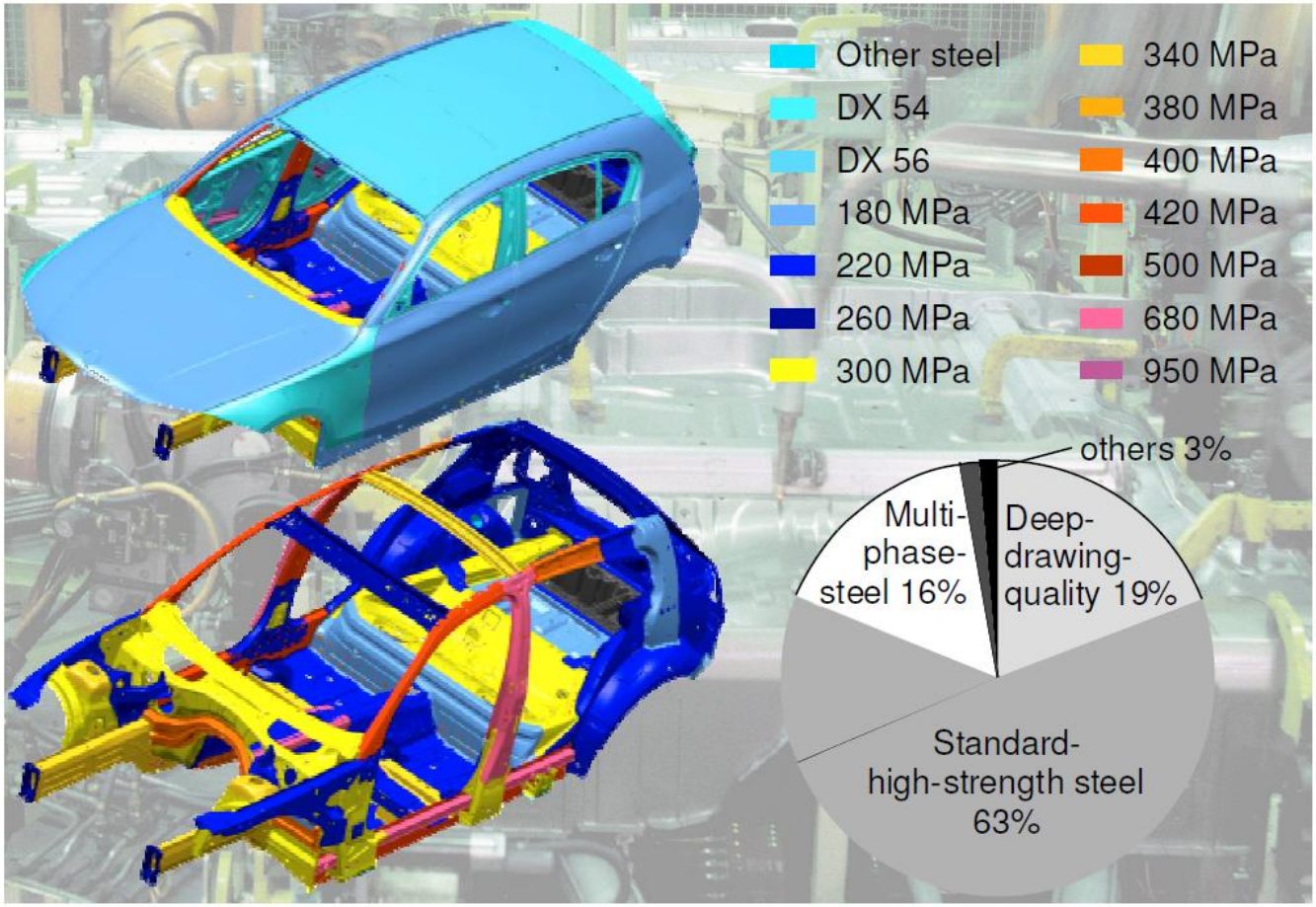
- Improved Stiffness
- Improved hot-wet shear
- Material Optimised Hybrid
- Cost reduction
- Design rules
  - *Fiber dominated*
  - *Bonded Metal laminate*

Technology Status A380 – Material Distribution



Status: A380 – Advanced . Advanced Metal-Technologies in Fuselage and Wing	***Status: Composite Wing . Advanced Metal-Technologies in Fuselage***	***Status: Full Composite***

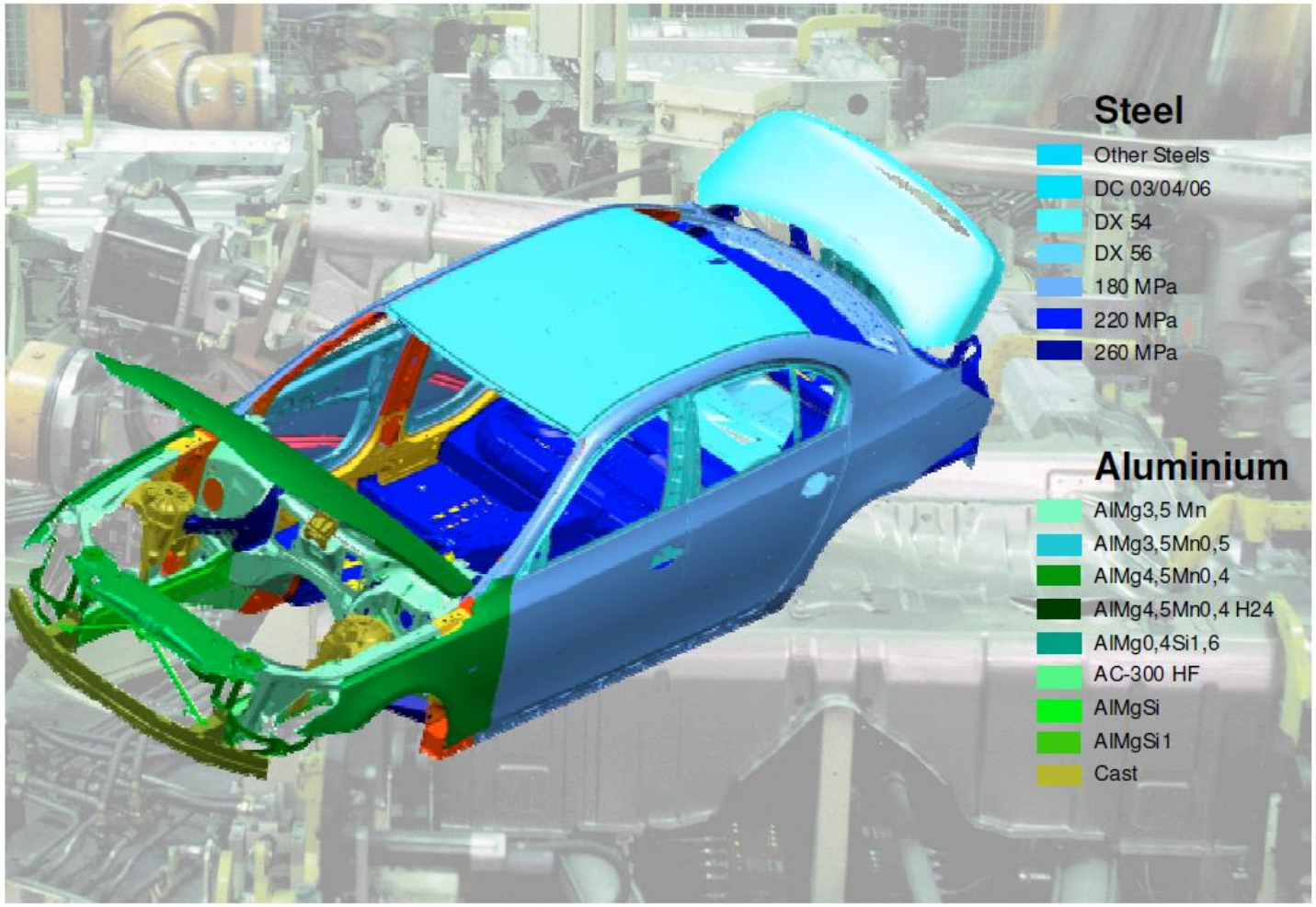
Car Body Structure.
High Strength Steel.
BMW 1 Series.



Car Body Structure.

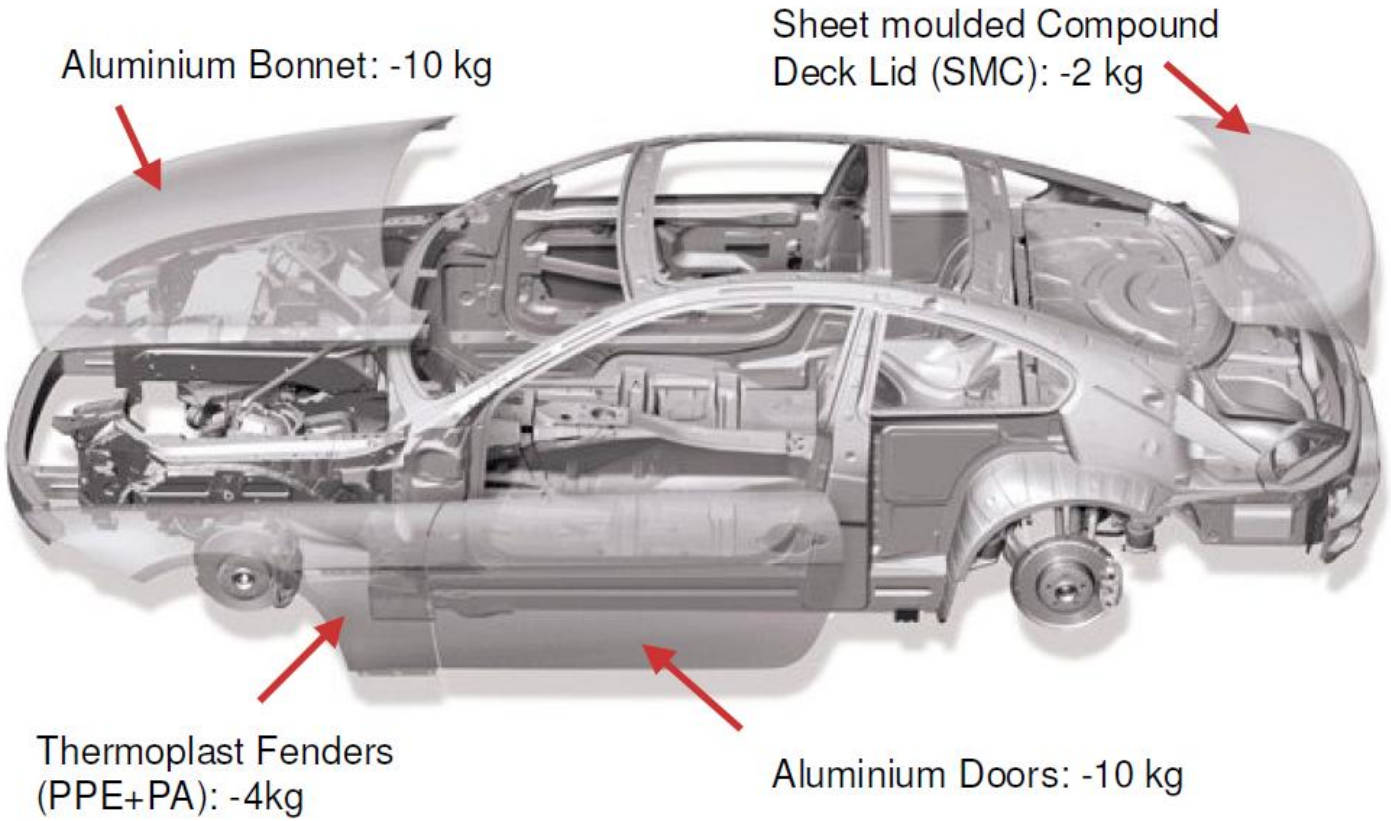
Aluminium Front End / Steel passenger Cab.

BMW 5 Series.



Car Body Shell.

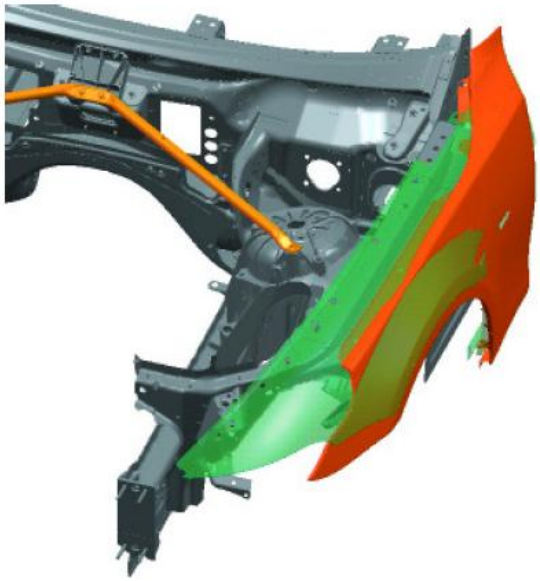
Materials for the BMW 6 Series.
Weight savings compared to Steel

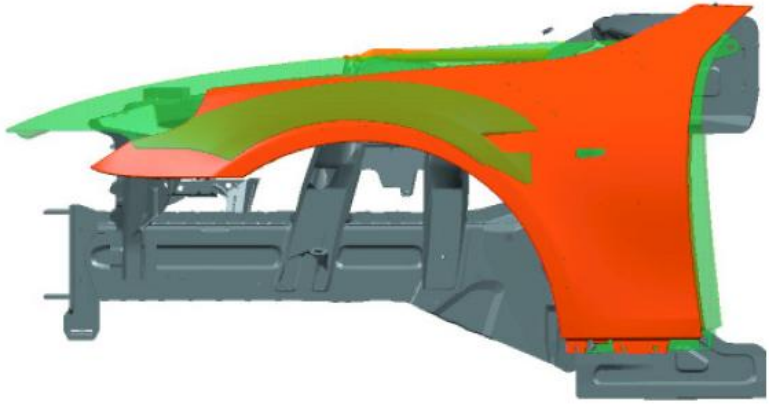


Car Body Shell.

Aluminium and Steel.

Car Body Shell.
Aluminium and Thermoplastic.

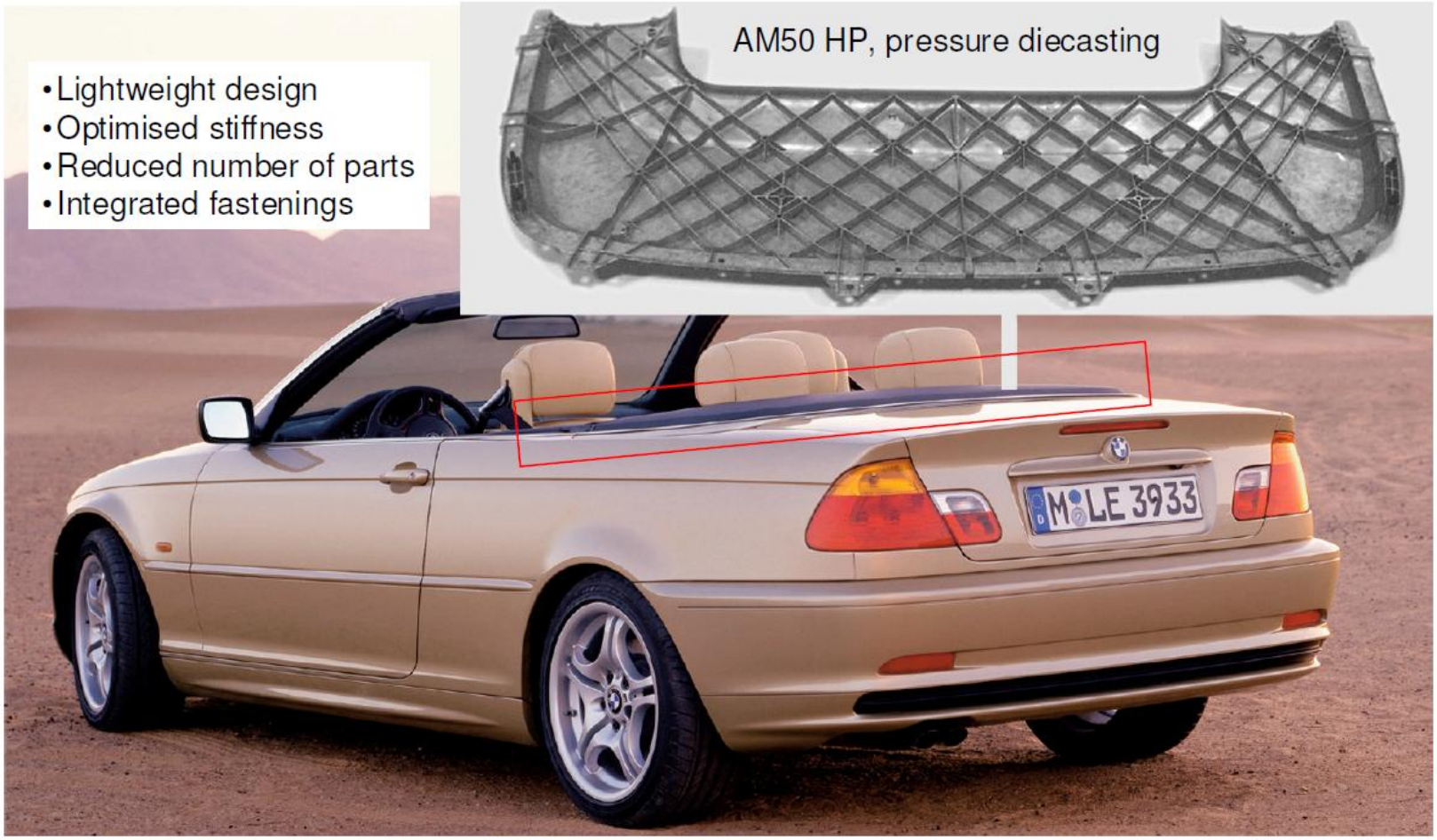




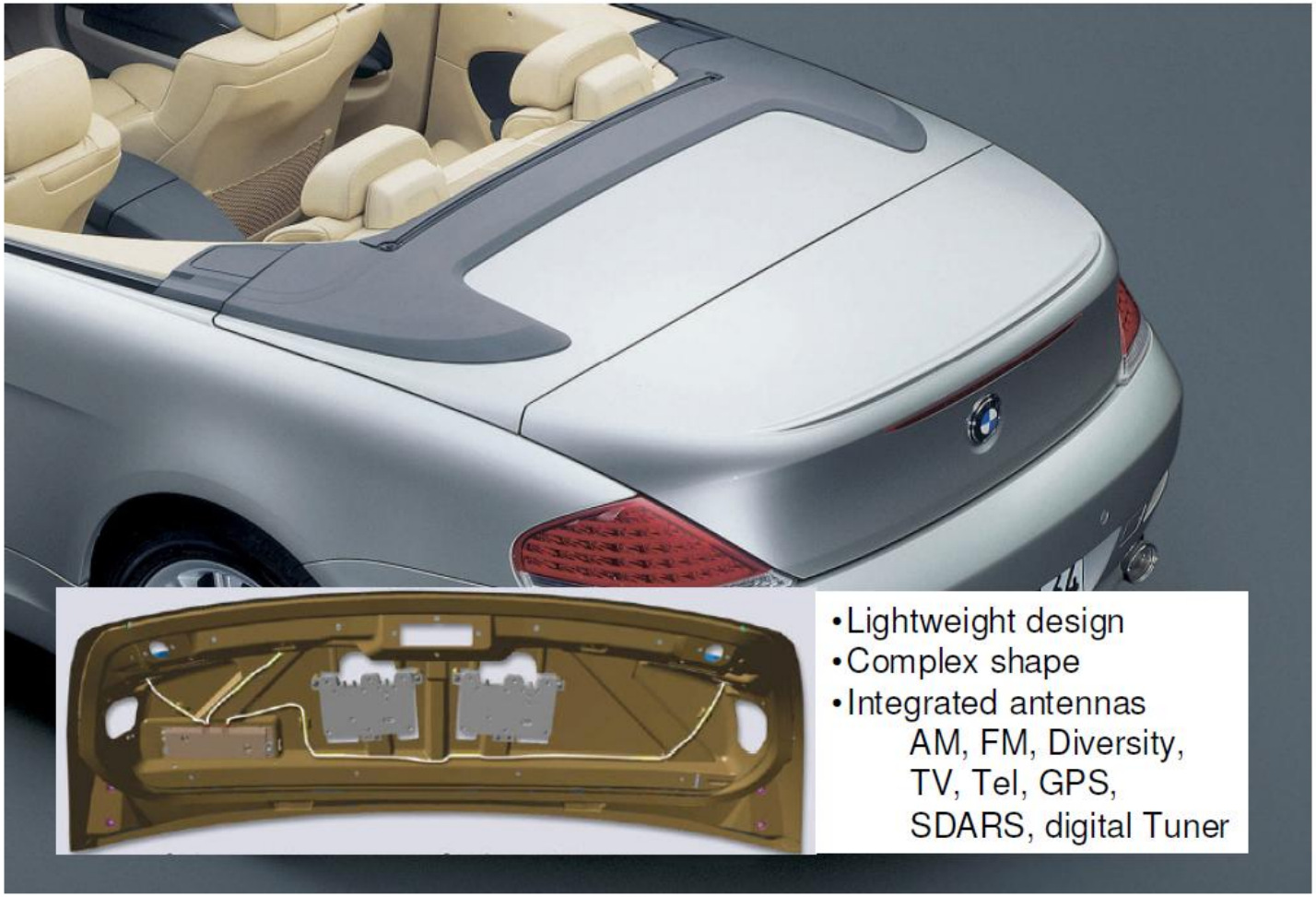
BMW 5 Series (Aluminium)

BMW 6 Series (Thermoplastics)

Car Body Shell.
Cast Magnesium.
BMW 3 Series Convertible.



Car Body Shell.
Sheet Moulded Compound (SMC).
Deck Lid BMW 6 Series.



New materials for key technologies: automotive mobility

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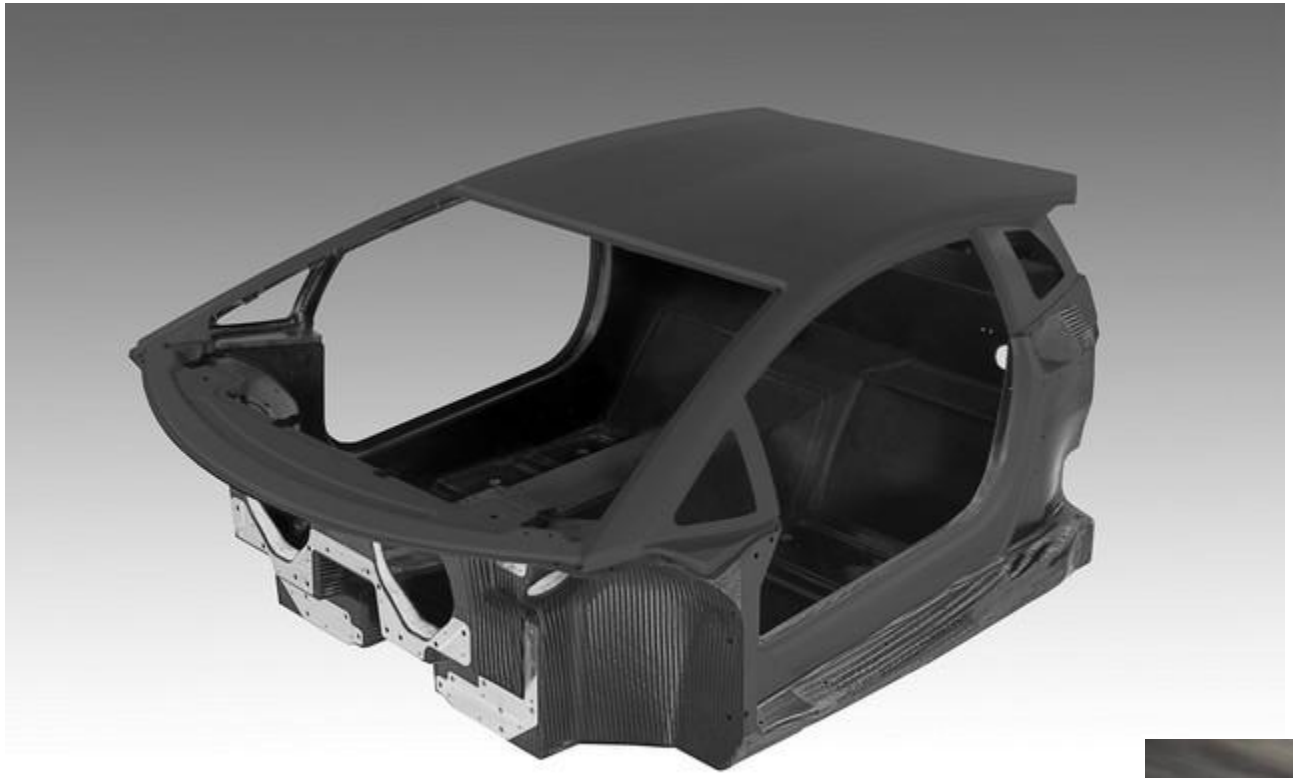
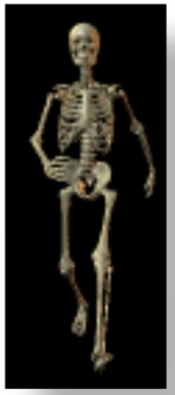
New materials for key technologies: automotive mobility

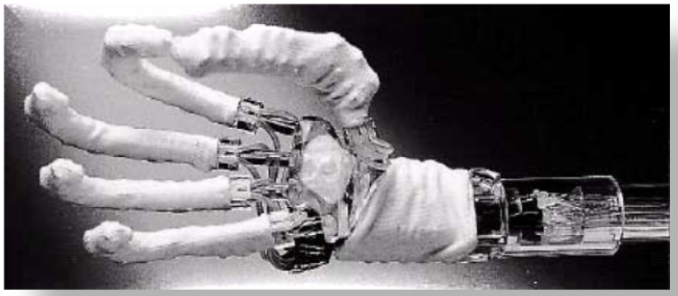


New materials for key technologies: Green energy

New materials for key technologies: Health

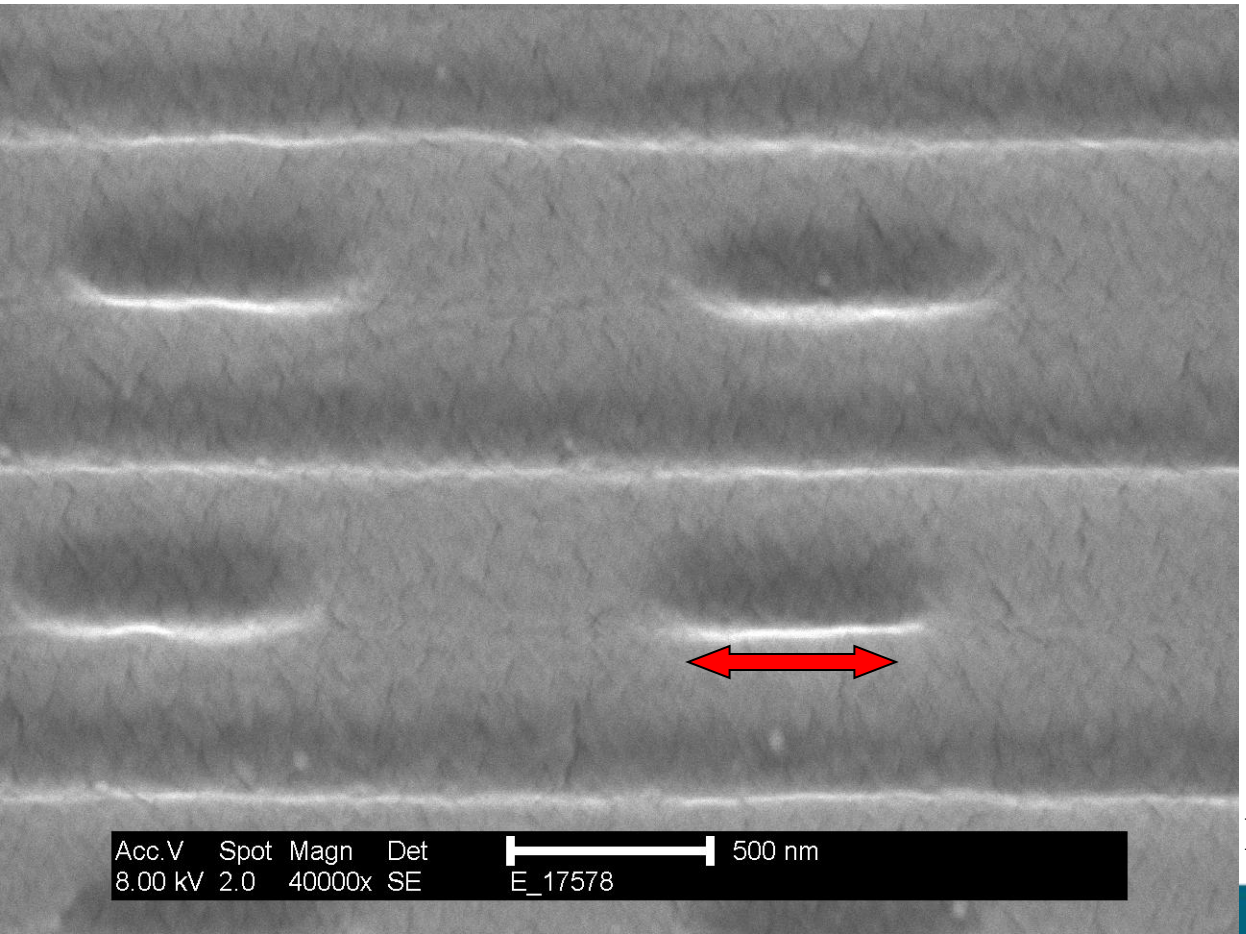
TITANIUM
MAGNESIUM
POYLMERS
BONE

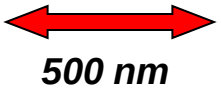




Polycarbonate (PC) and the PC/Ni interface

Grooves and address pits of a die cast sample of polycarbonate for a high storage density (**blue laser**) optical disc



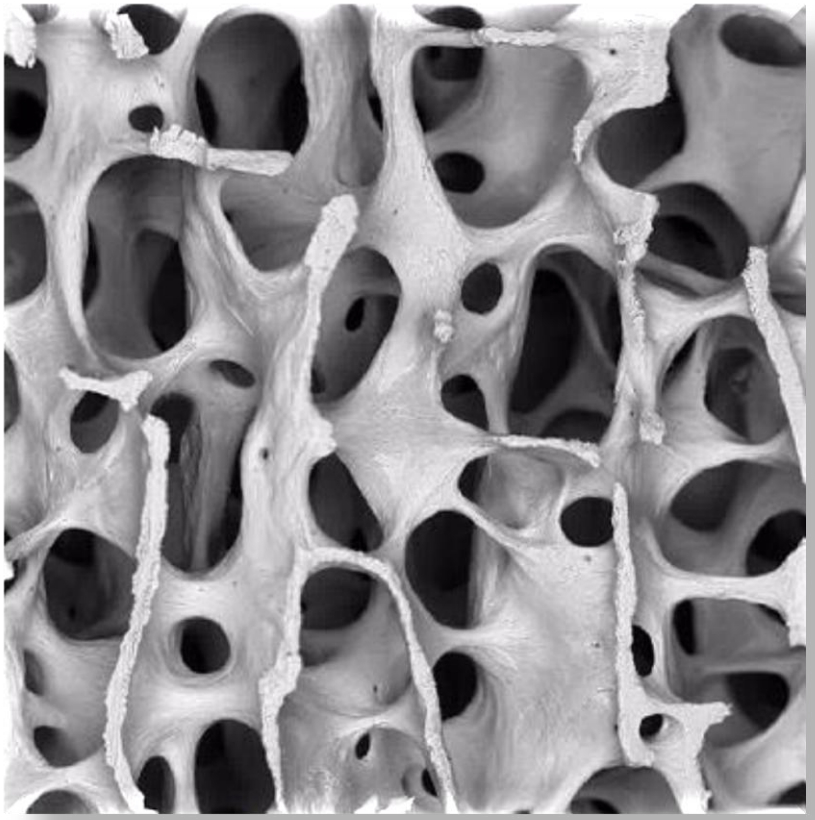


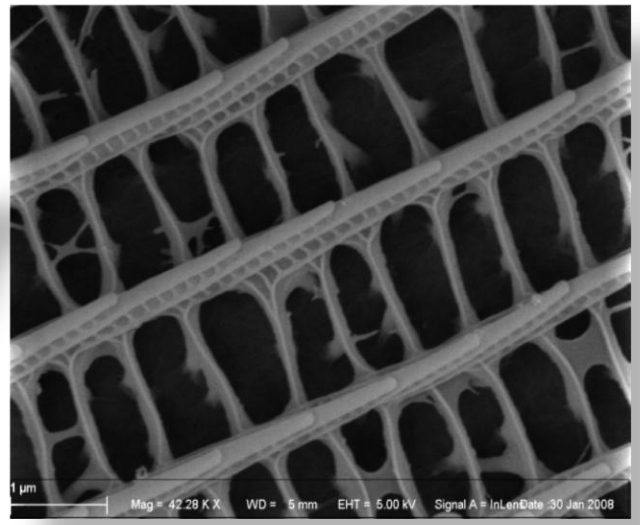
Bayer Materials

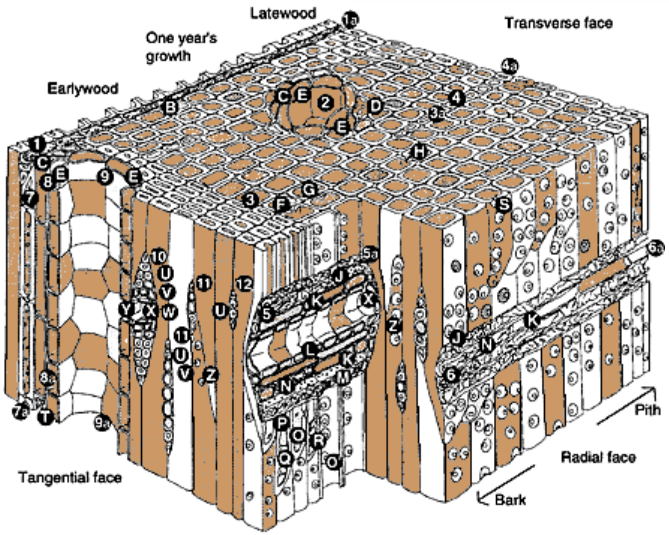
New polymer materials

Self-healing materials,polymer batteries, flexible electronics, electronic polymers, organic light emittig diodes (OLED), regenerative biomaterials, organic solar cells, drug delivery materials, materials science of food (organics), soft matter in medicine……

Natural materials



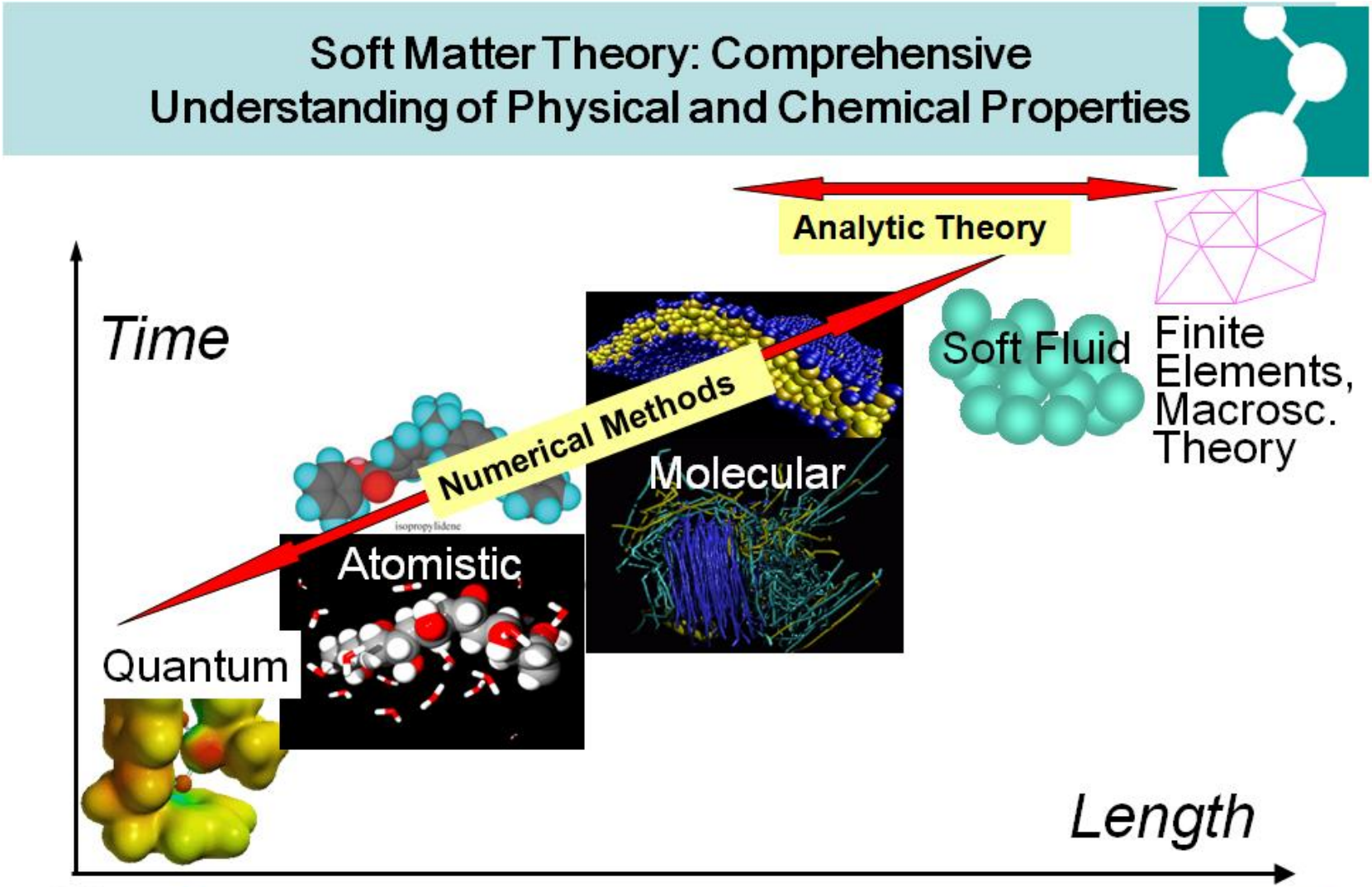




Overview

- Polymers
- Biological Materials

Theory of polymers (slide with courtesy from Prof. Kurt Kremer)

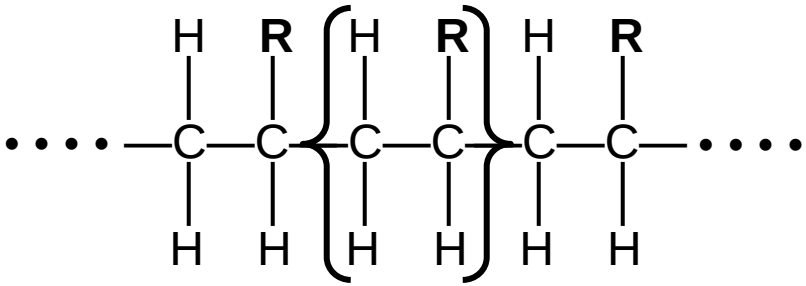


Local Chemical Properties ⇔ Scaling Behavior of Nanostructures
Energy Dominance ⇔ Entropy Dominance of Properties

Structure of polymers

- Macromolecule that is formed by linking of repeating units through covalent bonds in the main backbone
- Properties are determined by
  - molecular weight
  - length
  - backbone structure
  - side chains
  - crystallinity
- Resulting macromolecules have huge molecular weights

Types of polymers



Structure	Source-Based Name	Application
R = -H	Polyethylene	Plastic
R = $-CH_3$	Polypropylene	Rope
R = -Cl	Poly(vinyl chloride)	"Vinyl"
X = -H, R = $-C_2H_5$	Poly(ethyl acrylate)	Latex paints
X = $-CH_3$, R = $-CH_3$	Poly(methyl methacrylate)	Plastic
R = -H	Polybutadiene	Tires
R = $-CH_3$	Polyisoprene	Tires
X = -F, R = -F	Polytetrafluoroethylene	Teflon®

Monomer arrangement in copolymers

Monomers within a copolymer may be organized along the backbone in a variety of ways.

•**Alternating copolymers** possess regularly alternating monomer residues

•**Periodic copolymers** have monomer residue types arranged in a repeating sequence: $[A_nB_m...]$ m being different from n .

•**Statistical copolymers** have monomer residues arranged according to a known statistical rule. A statistical copolymer in which the probability of finding a particular type of monomer residue at an particular point in the chain is independent of the types of surrounding monomer residue may be referred to as a truly **random copolymer**

•**Block copolymers** have two or more homopolymer subunits linked by covalent bonds (4). Polymers with two or three blocks of two distinct chemical species (e.g., A and B) are called diblock copolymers and triblock copolymers, respectively. Polymers with three blocks, each of a different chemical species (e.g., A, B, and C) are termed triblock terpolymers.

Durability of polymer composites

Polymer composites change with time and most significant factors are

- Elevated temperatures
- Fire
- Moisture
- Adverse chemical environments
- Natural weathering when exposed to sun's ultra-violet radiation

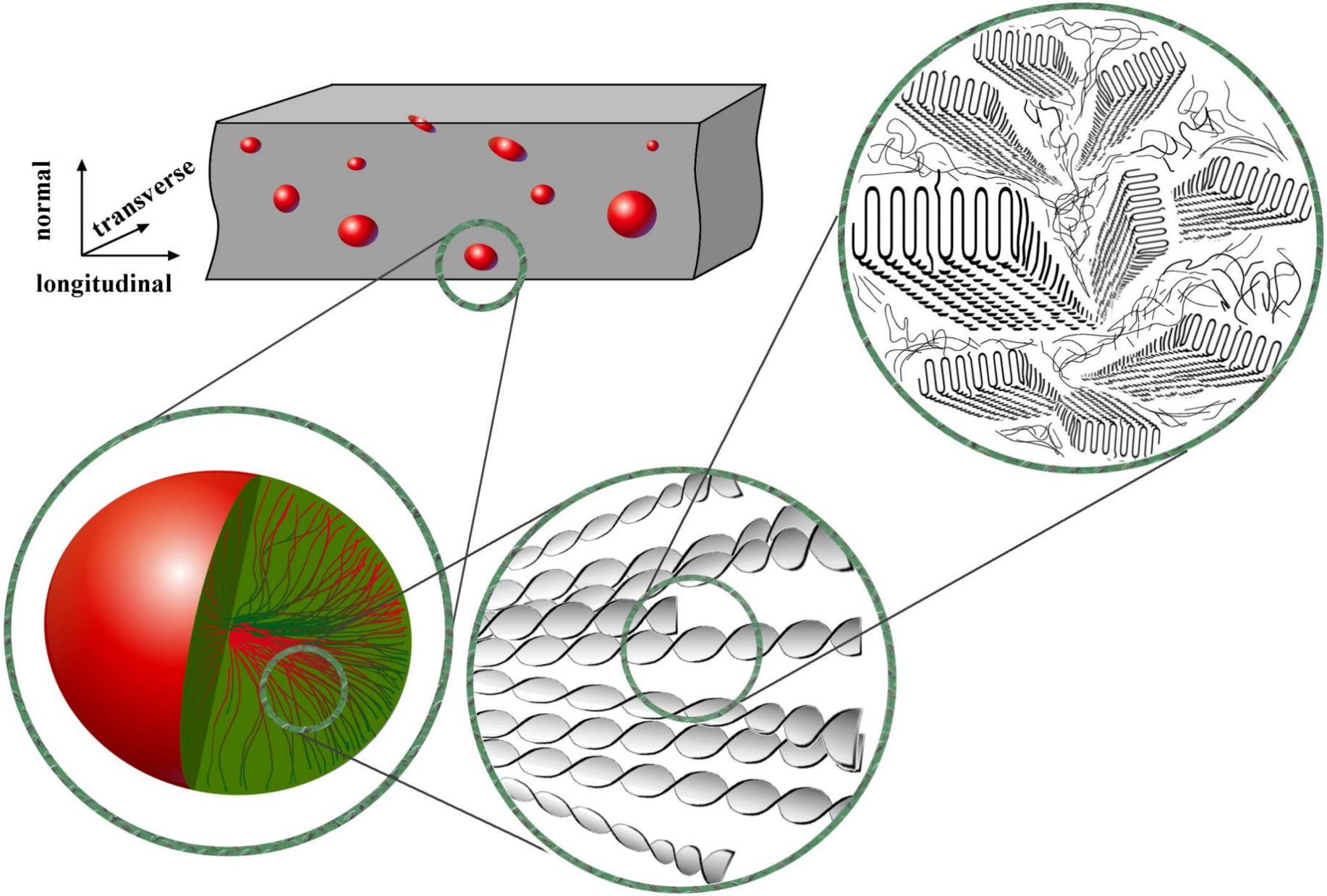
Polymer composites: mechanical properties

MATERİAL	Relative density	Diameter thickness ratio (microns)	Length (mm)	E (GPa)	Tens. Str. (MPa)	Failure strain (%)	Volume in composite (%)
Mortar matrix	1.8-2.0	300-5000	-	10-30	1-10	0.01-0.05	85-97
Concrete matrix	1.8-2.4	10000-20000	-	20-40	1-4	0.01-0.02	97-99.5
Asbestos	2.55	0.02-30	5-40	164	200-1800	2-3	5-15
Carbon	1.16-1.95	7-18	3-cont.	30-390	600-2700	0.5-2.4	3-5
Glass	2.7	12.5	10-50	70	600-2500	3.6	3-7
Polyethylene							
HDPE filament	0.96	900	3-5	5	200	-	2-4
High modulus	0.96	20-50	Cont.	10-30	> 400	> 4	5-10
Polypropylene (Monofilament)	0.91	20-100	5-20	4	-	-	0.1-0.2
Polyvinyl alcohol (PVA)	1-3	3-8	2-6	12-40	700-1500	-	2-3
Steel	7.86	100-600	10-60	200	700-2000	3-5	0.3-2.0

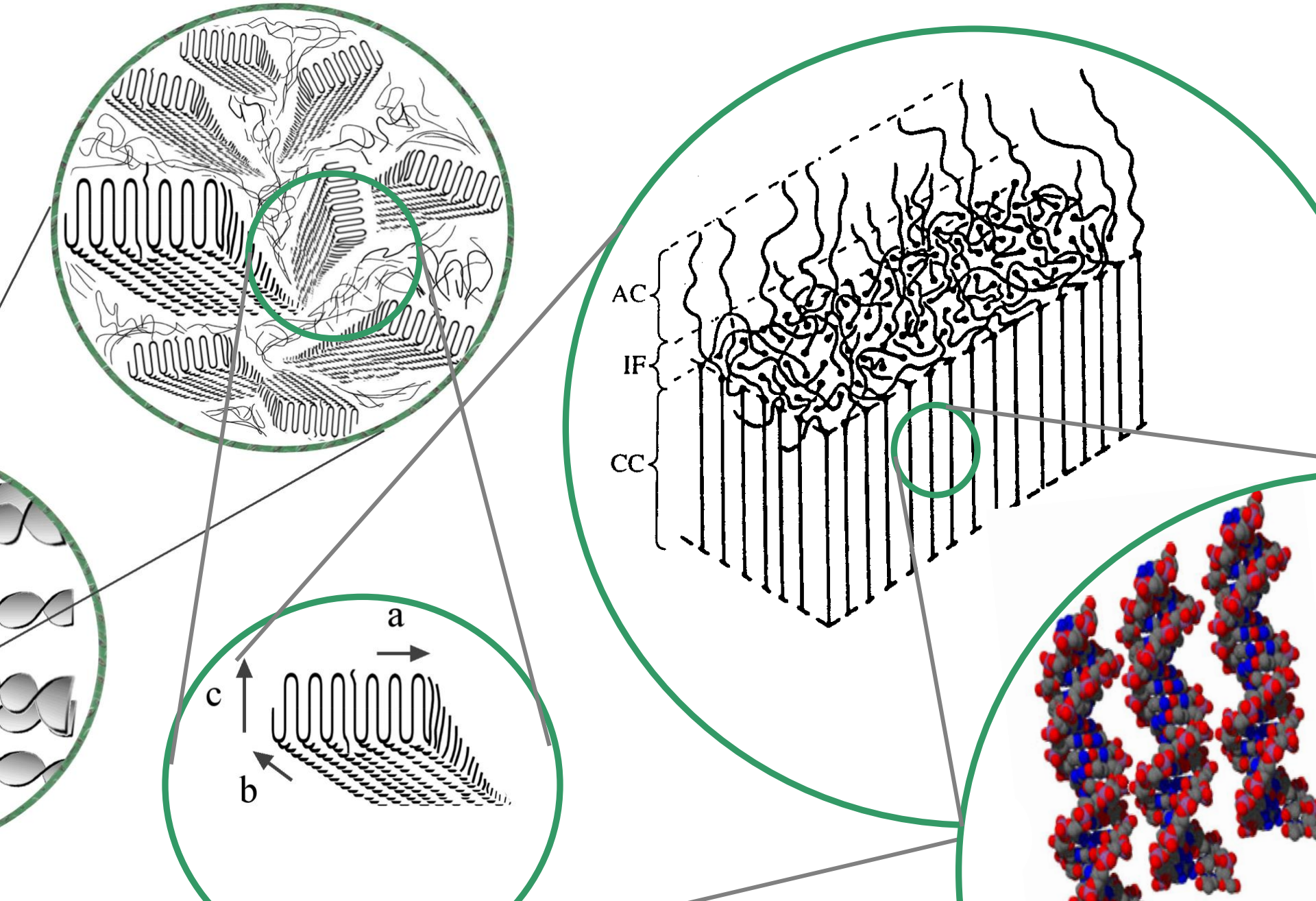
Performance is controlled by

- **vol. fraction of fibers**
- **properties of fibers and matrix**
- **bond between the two**

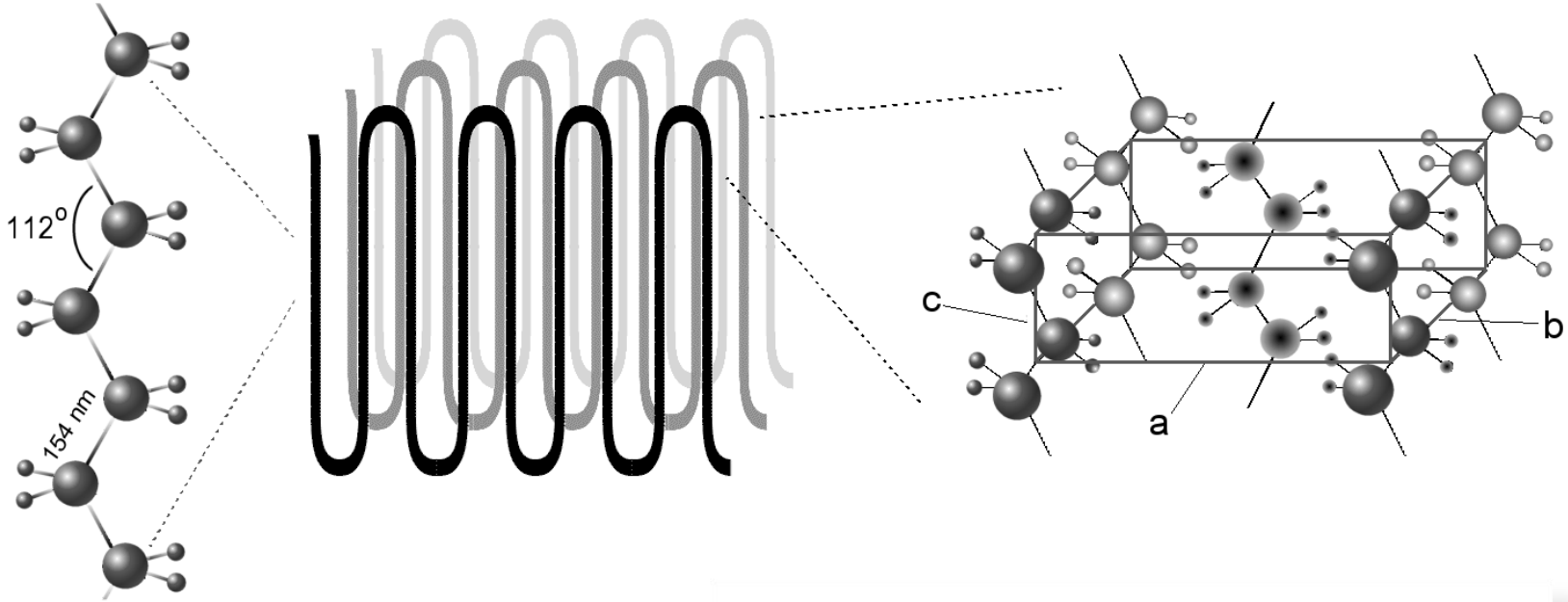
Structure, scales, partially crystalline polymers



Structure, scales, partially crystalline polymers

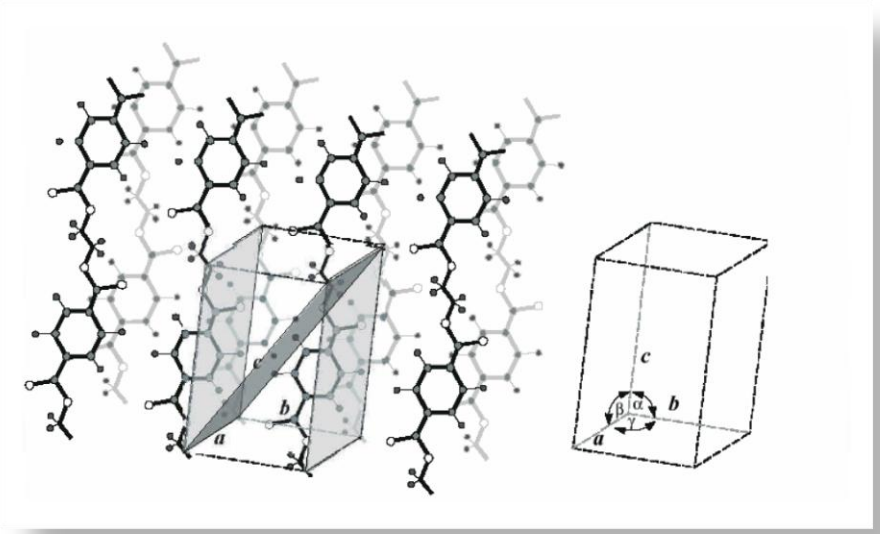


Structure, scales, partially crystalline polymers

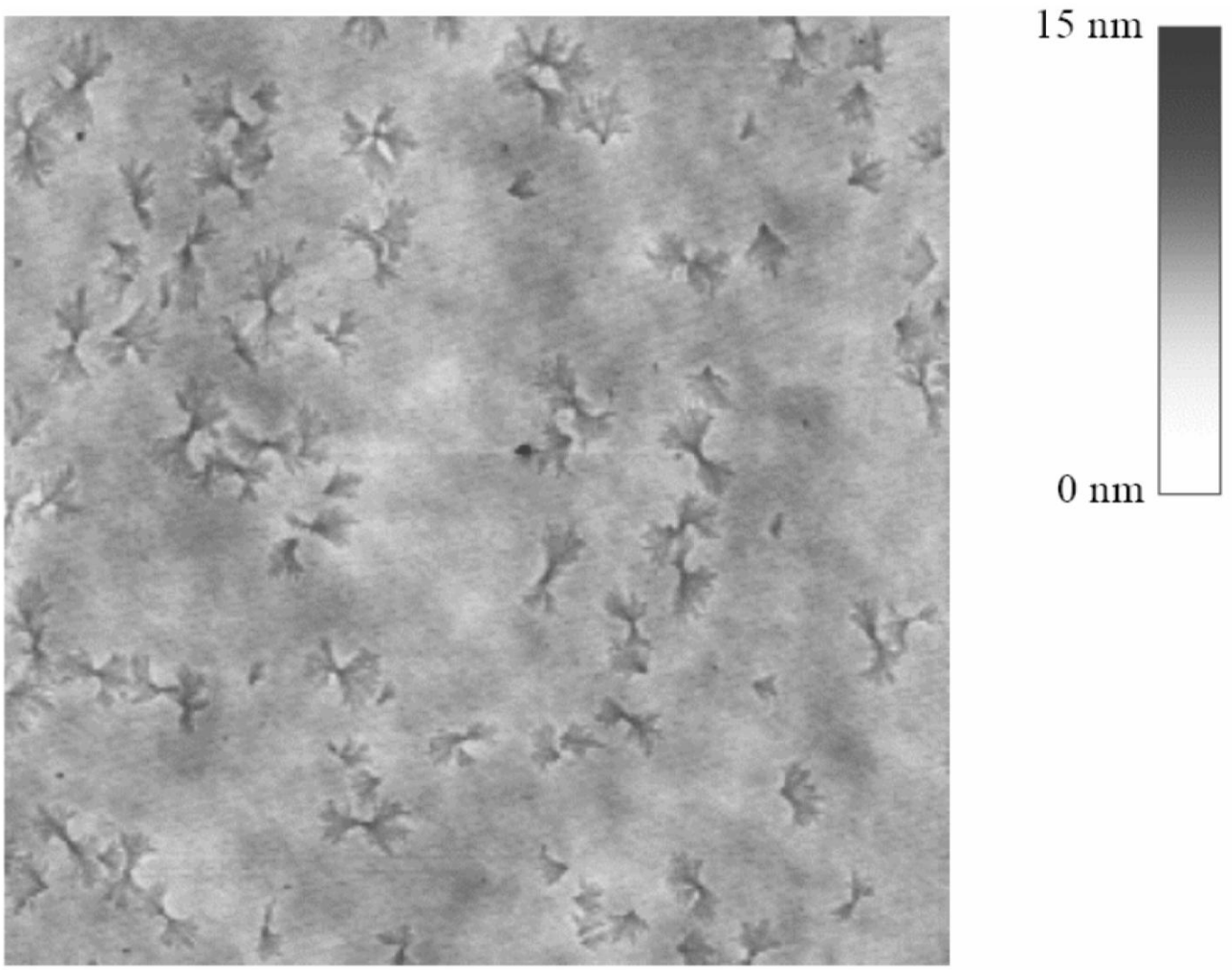


The crystalline unit cell for PET (a = 4.56 Å, b = 5.94 Å, c = 10.75 Å; α = 98.5°, β = 118°, γ = 112°),

M Durell (2002)

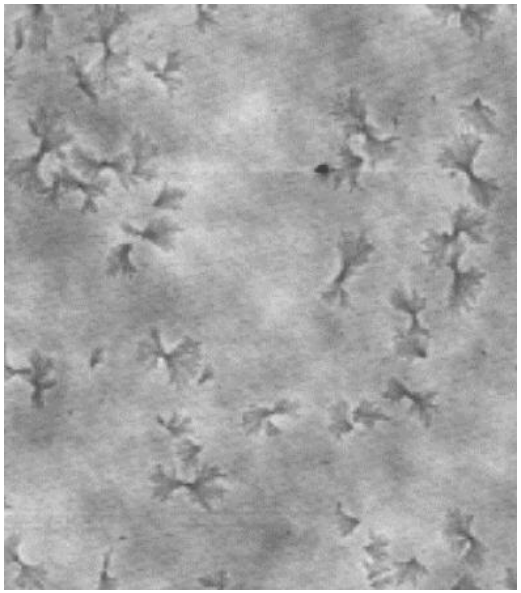


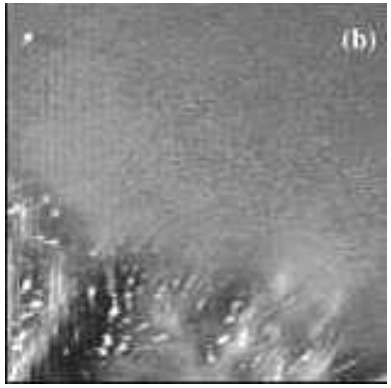
Polymer structure: spherulite growth

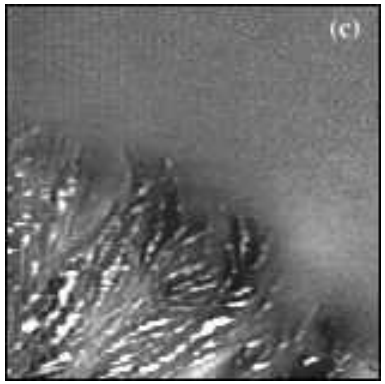


PET / AFM: M Durell, J E Macdonald, D Trolley, Europhysics Letters (2002)

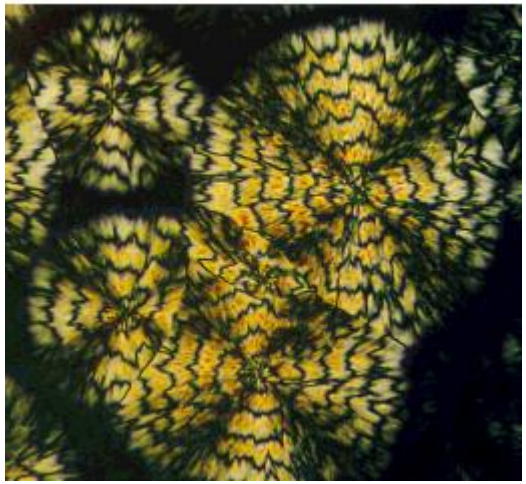
Polymer structure: spherulite growth







1 micron square, AFM



1 millimeter square, OM

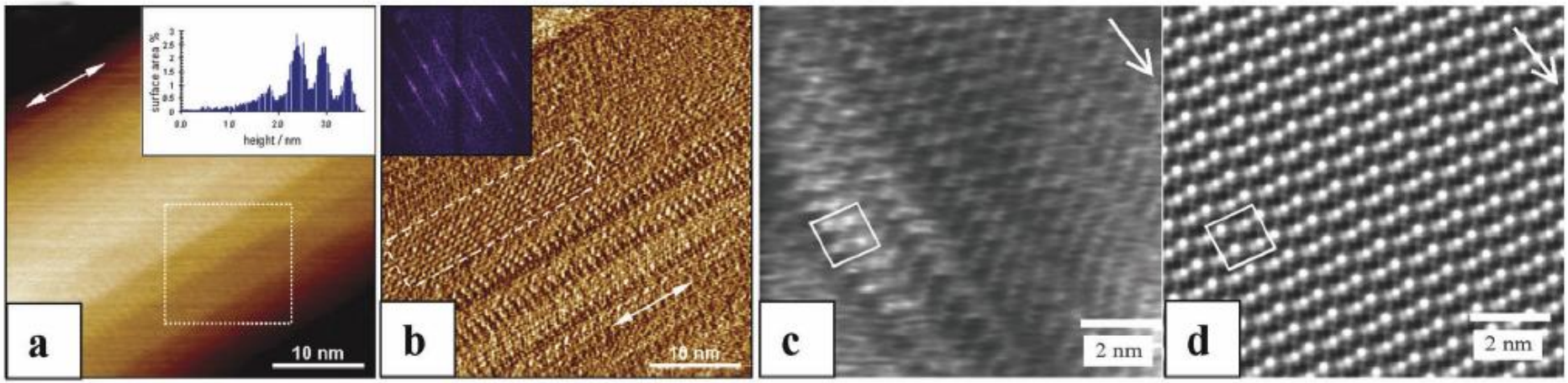
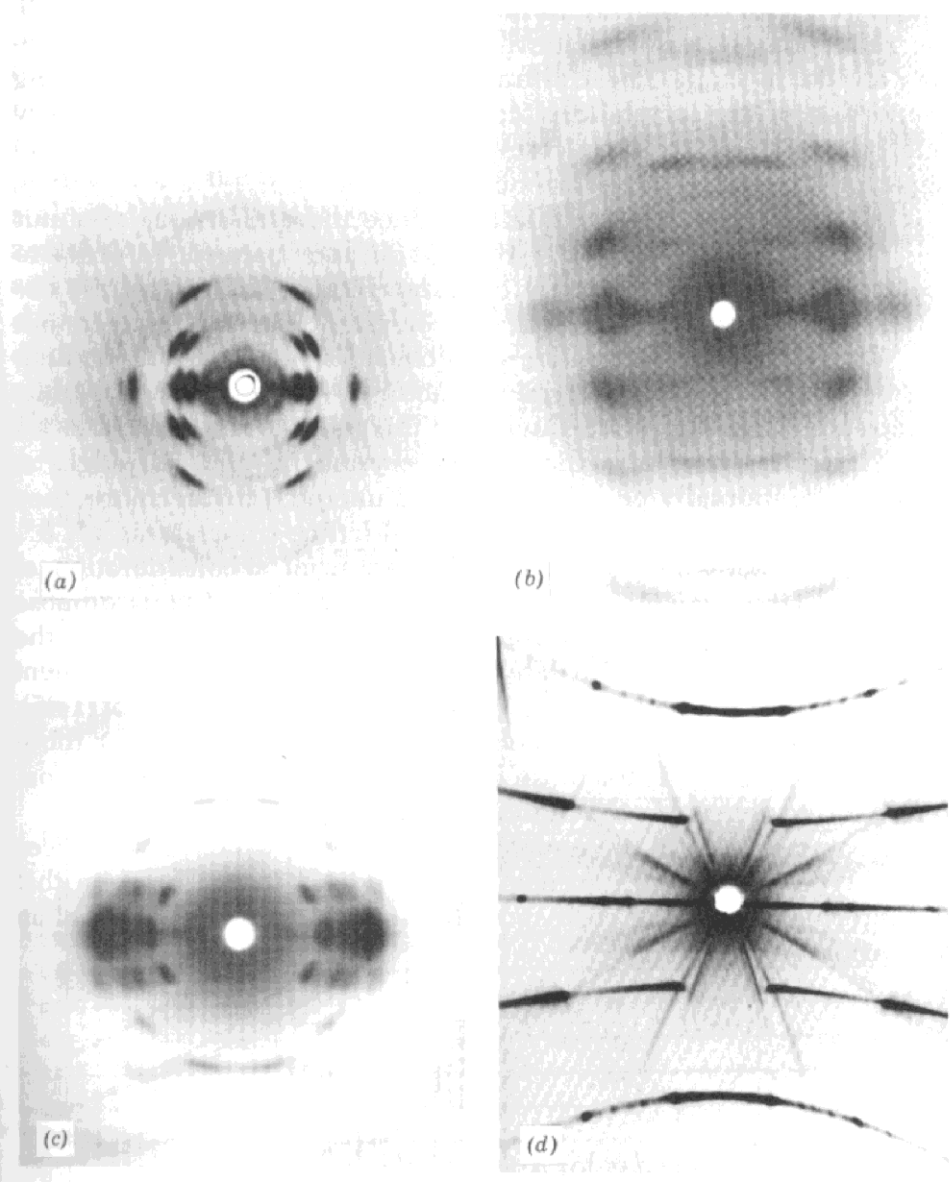
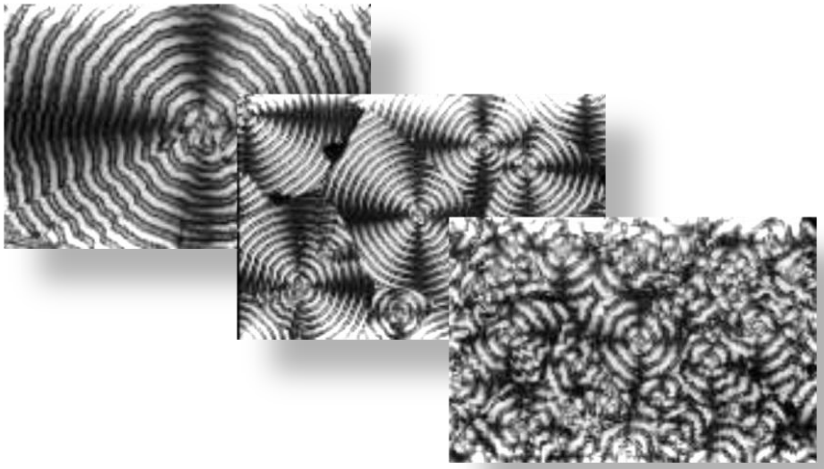


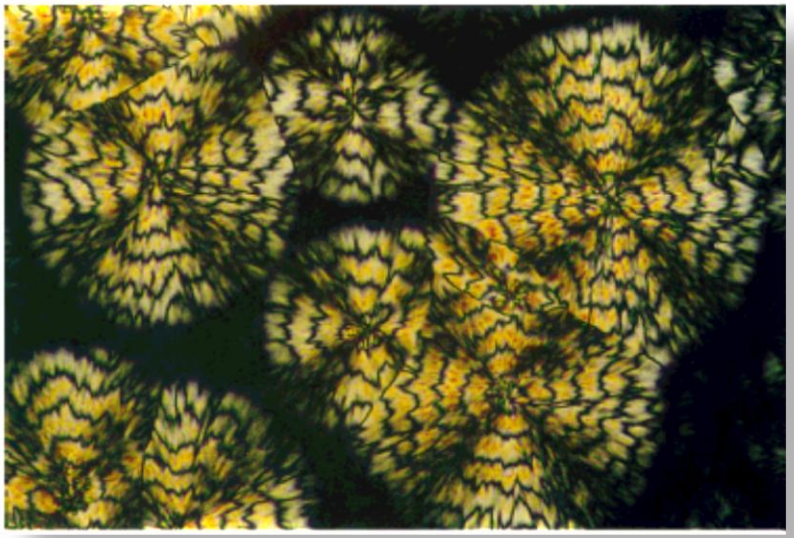
Fig. 2 AFM contact mode images. Cellulose molecules in micro-fibril crystal: (a) topographic image; and (b) error-signal image. Polybutene-1 molecules: (c) topographic image; and (d) simulated AFM image based on crystallographic data.

M. Miles, M. Antognozzi, H. Haschke, J. Hobbs, A. Humphris, T. McMaster
H.H. Wills Physics Laboratory, University of Bristol, Materials Today, Feb. 2003

Polymer structure: spherulite growth



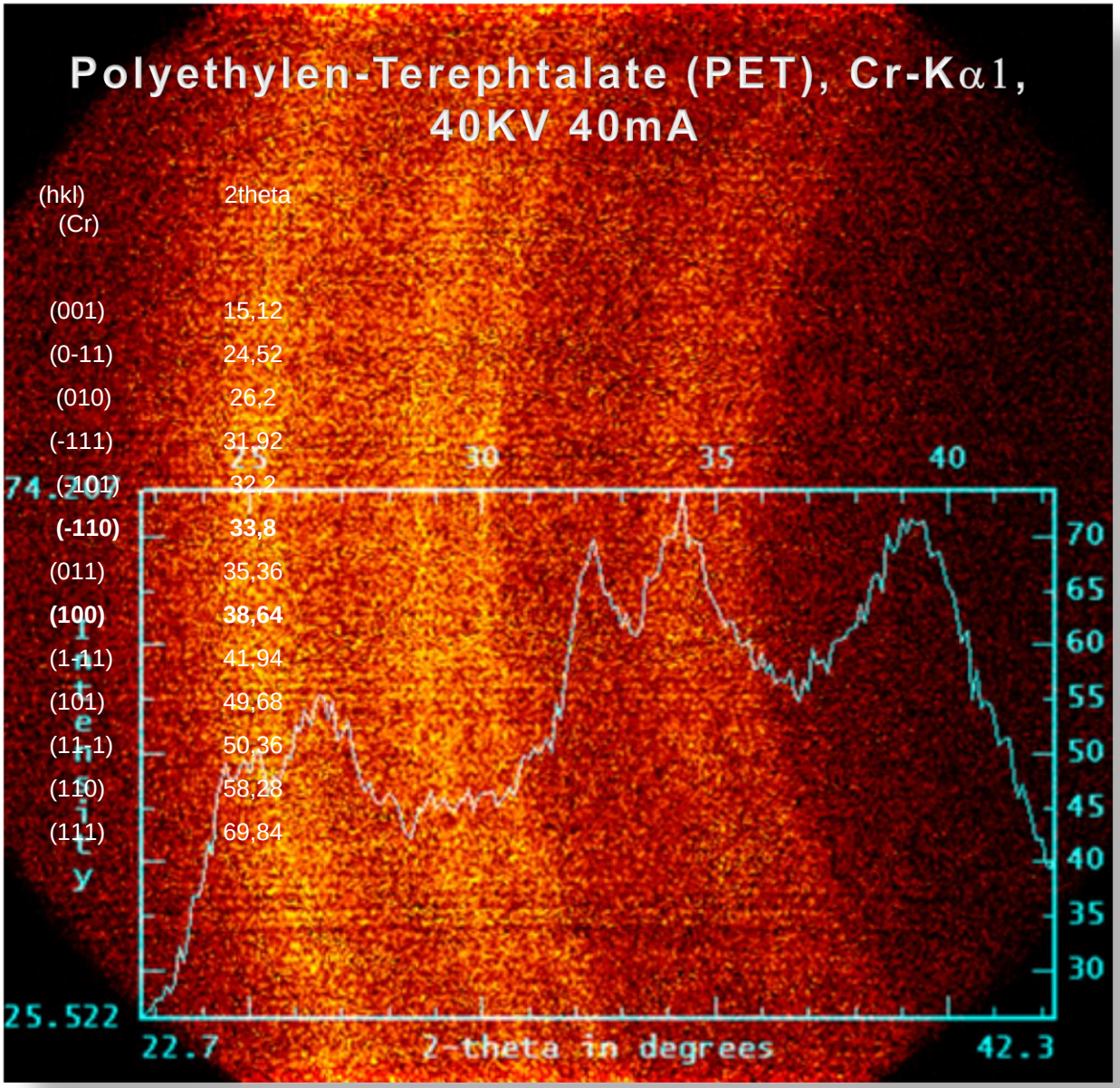


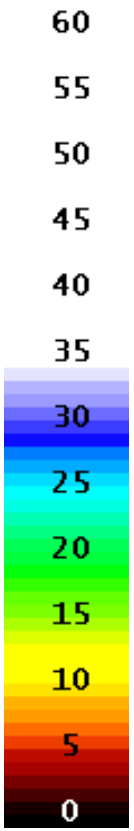


1 millimeter square, OM

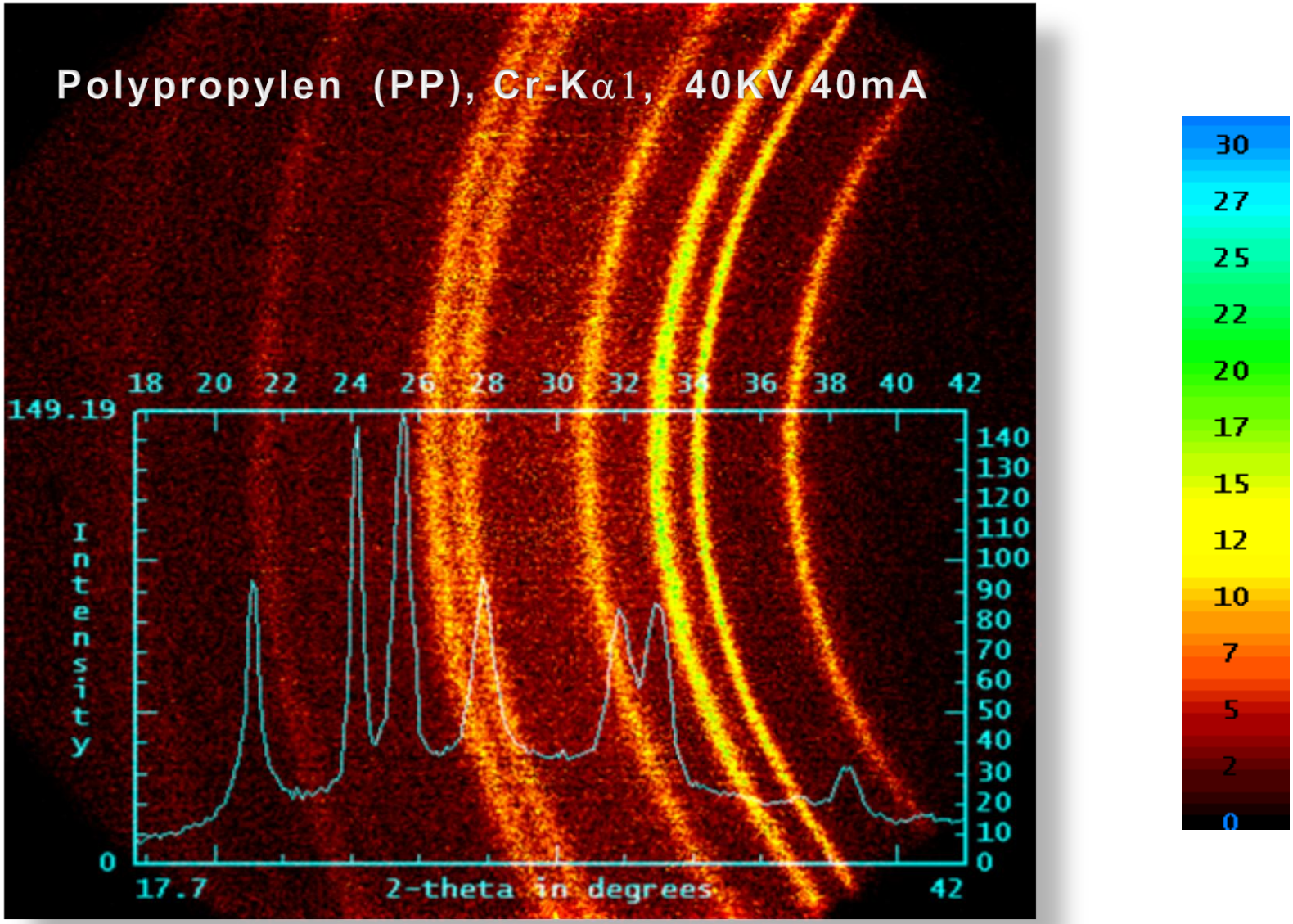
Bamford, Nature 173 (1954) p. 27; Astbury, Endeavor 1(1942) p. 70

Polymer structure: PET: XRD

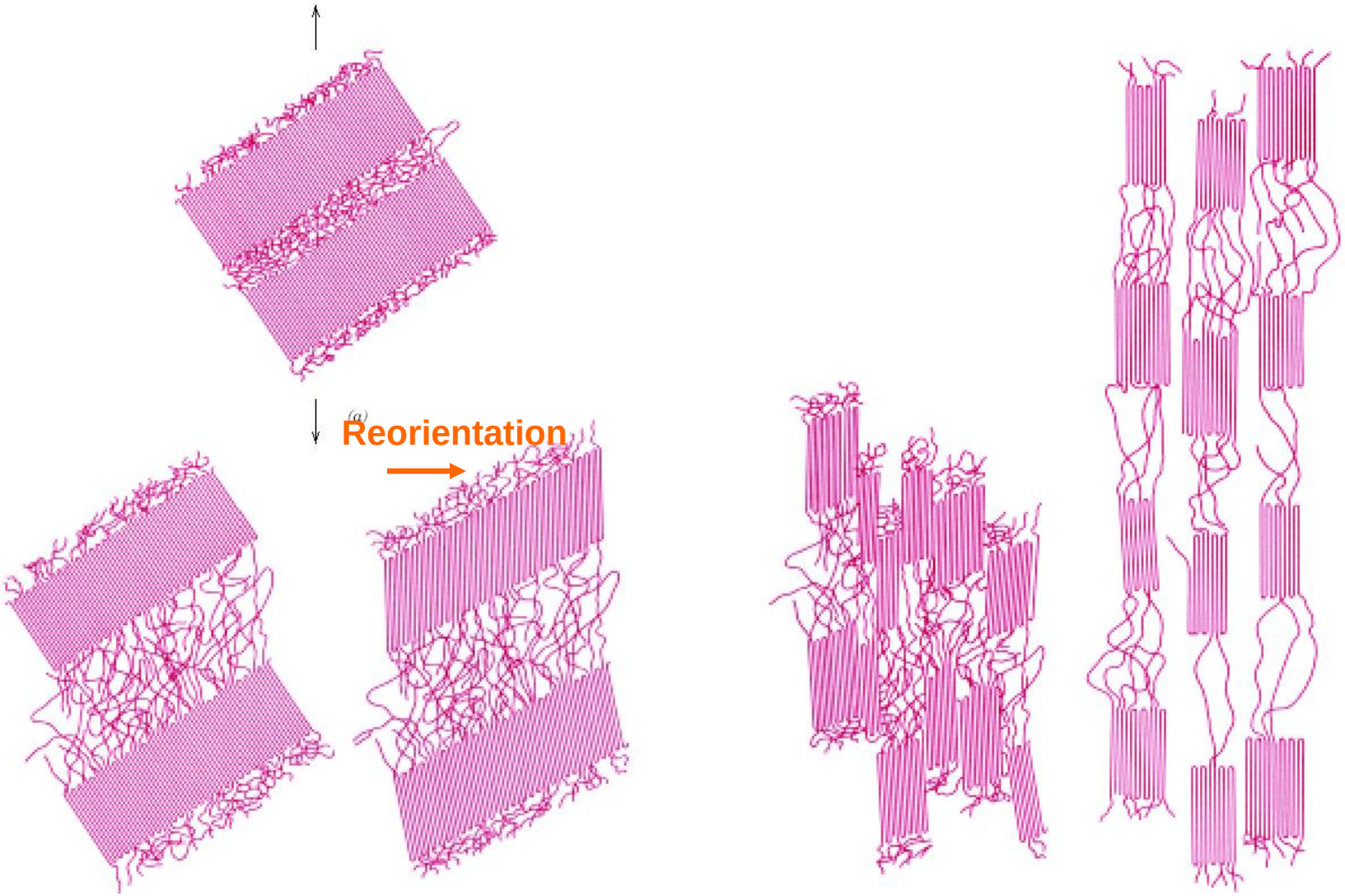




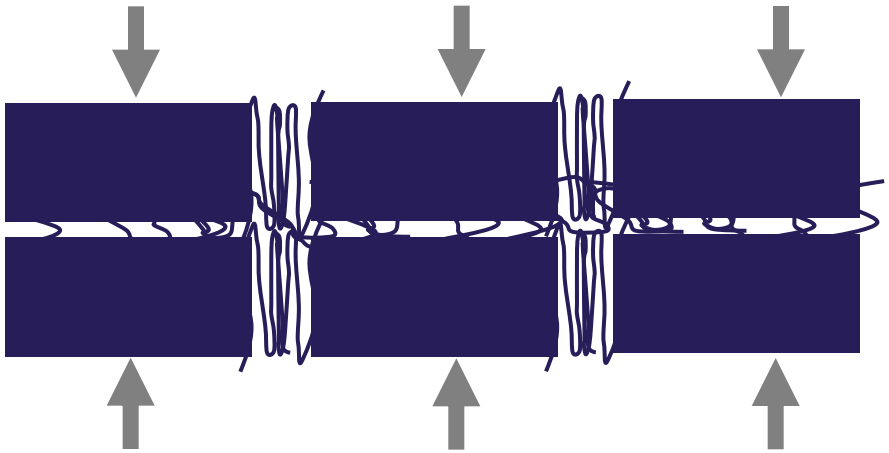
Polymer structure: PP: XRD



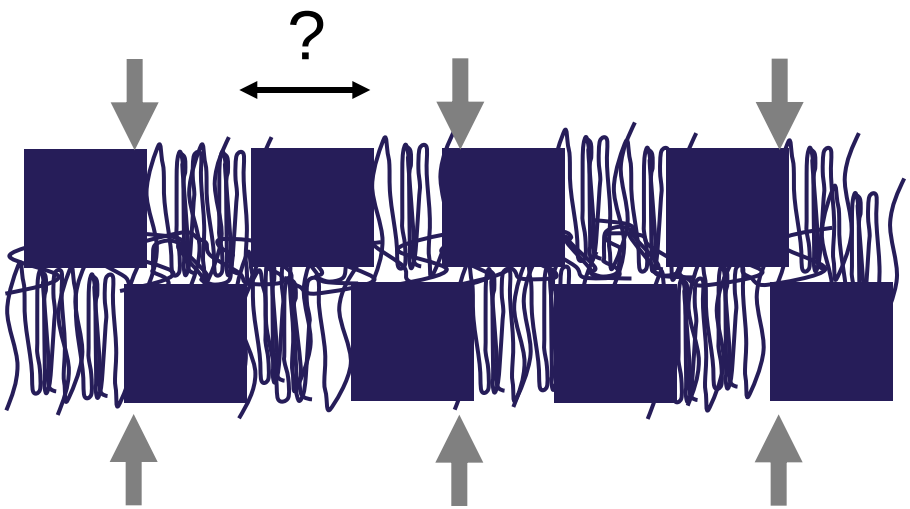
Polymer structure: deformation



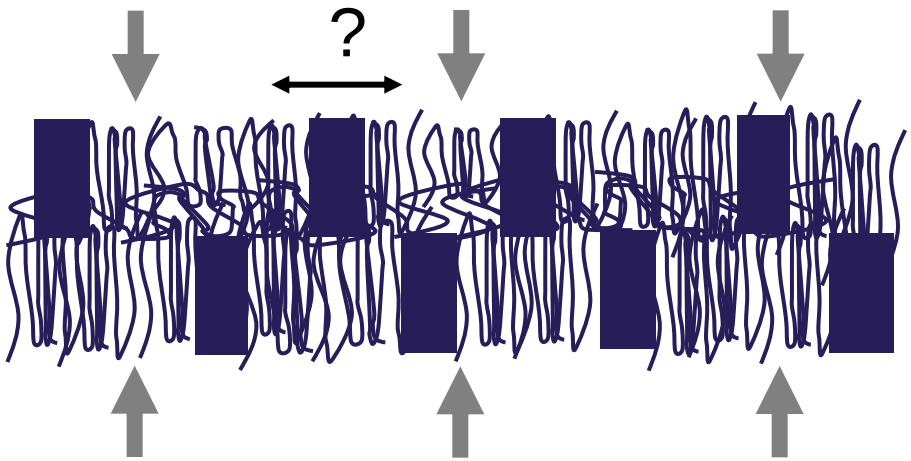
Polymer structure: deformation and decrystallization



orientation-dependence of decrystallization



$-\sigma_{11}$



tensorial nature of polymer deformation

$-\sigma_{11}$