Bachelor and Masters of Materials Science at ETH Zurich

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Teaching at the Department of Materials

- What is a Materials Scientist?
- Educational Goals
- Curriculum Structure

What is a Materials Scientist?

The materials engineer/scientist distinguishes himself/herself by **bridging scales for an atomistic understanding** of macroscopic materials characteristics, and by combining the thus gained understanding of the function of materials with a feeling for the **integrational possibilities** in technologically relevant systems in order to use it **creatively** and **critically** for the benefit of mankind.

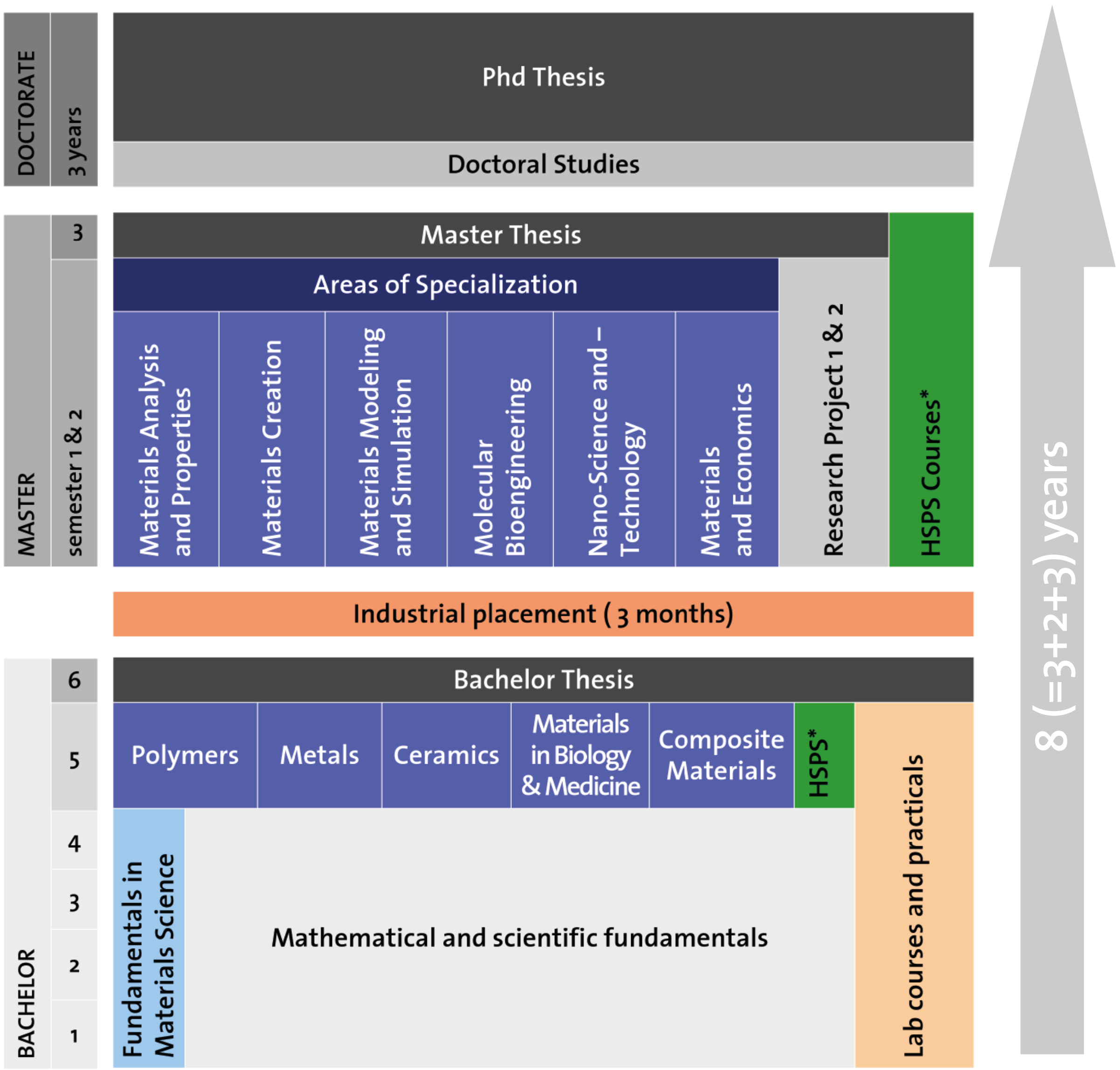
Educational Goals

During their studies the students should acquire basic competences which enables **continued learning, intellectual growth and creative usage of knowledge**.

The students acquire ***solid expertise*** *in*

- **scientific principles and methodology**,
- **fundamental disciplines** such as mathematics, physics, chemistry, biology … (»Join the fundamental and broad courses for the specialists, given by the specialists«)
- **core subjects** such as thermodynamics, statistical mechanics and quantum mechanics
- **understanding** structure/property or structure/behavior **connections and relationships** between processing, structure, properties and performance
- **computational** methods and materials modeling
- materials for **micro- and information-technology**
- **technologies/applications for the future** (nanomaterials, polymers and biomaterials, surface science and materials, semiconductor science …)
- **participating** in research projects and presenting scientific findings
- **management** and entrepreneurship as well as **teamwork**, presentation, sales …

Curriculum Structure - 1



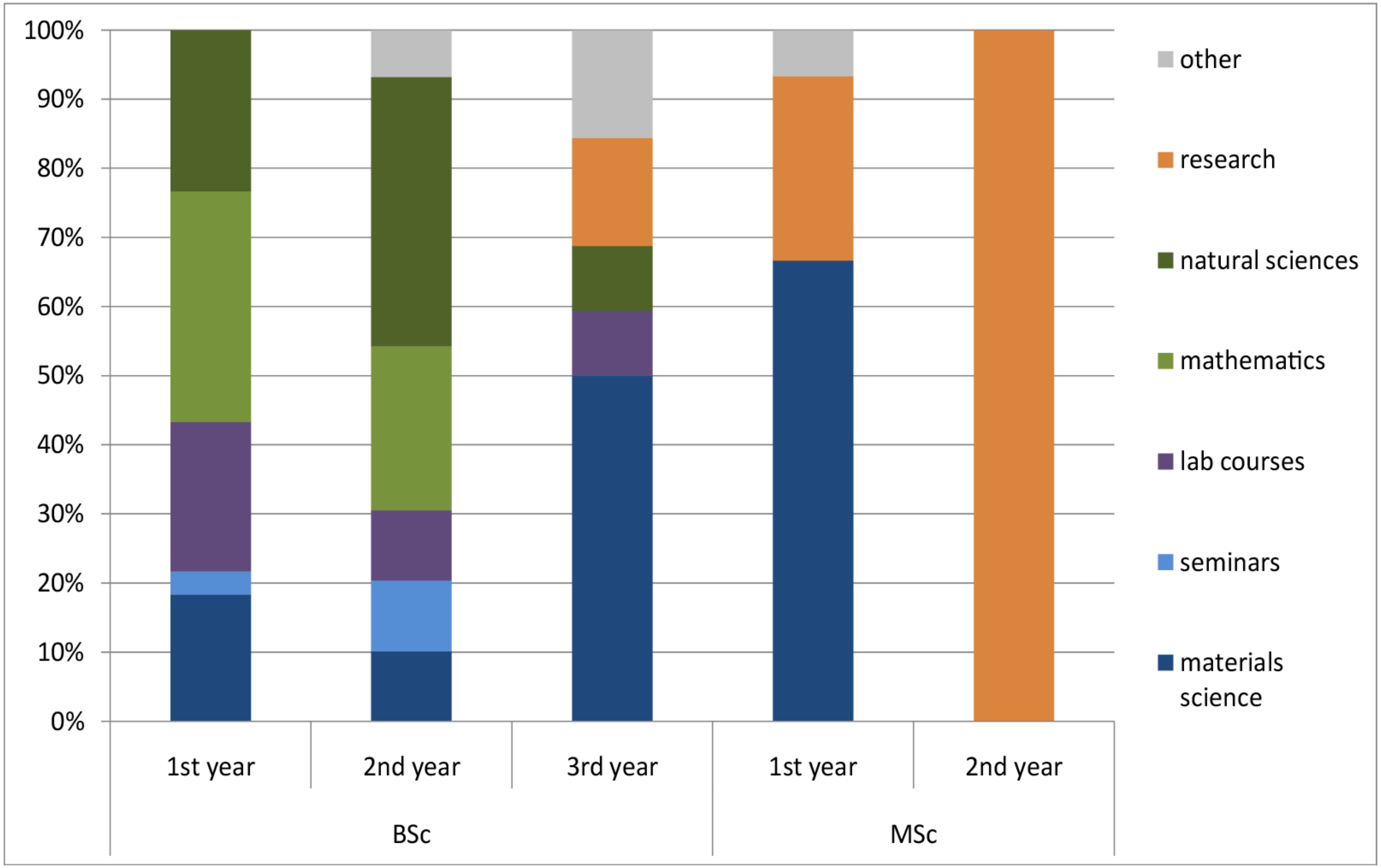
*HSPS: mandatory courses in humanities, social & political science

DMATL

Curriculum Structure - 2

Bachelor and Master Programme Materials Science

Teaching Contents

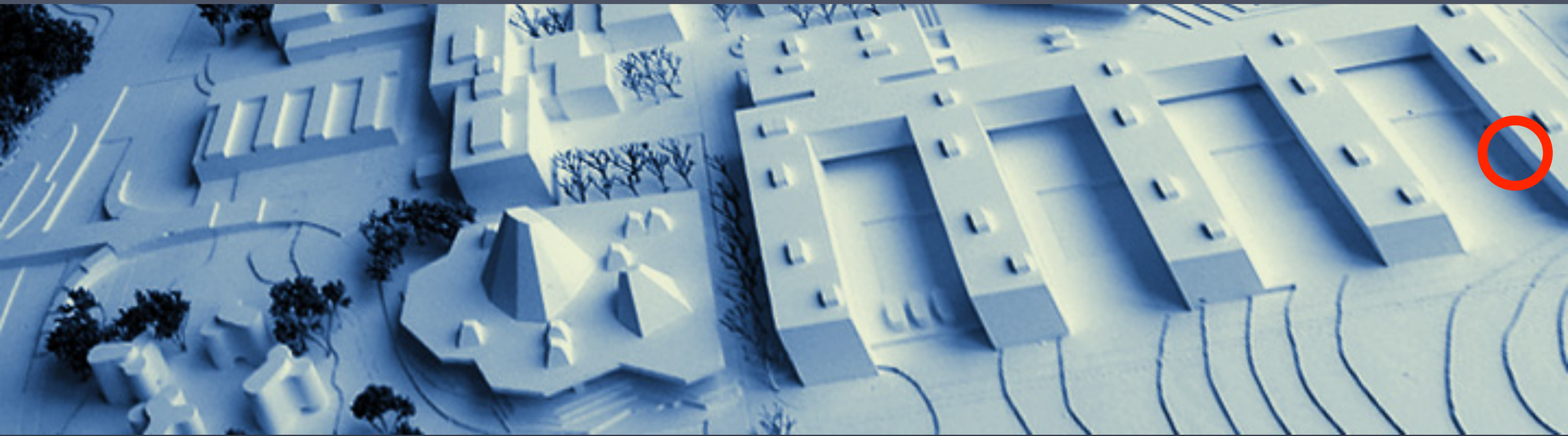


Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

laboratory for nanometallurgy

Materialwissenschaft an der Nanometerskala: Phänomene und Herausforderungen

Ralph Spolenak



Fallstudien zu Materialeigenschaften in kleinen Dimensionen

- Definition einer Längenskala: Was ist klein?
- Fallstudie I: Mikroelektronik (Physik/Mechanik)
- Fallstudie II: Farbgebung (Physik/Chemie)
- Fallstudie III: Geckohaftung (Biologie/Mechanik)

DC Kollektion

DC Kollektion

Handy Kollektion

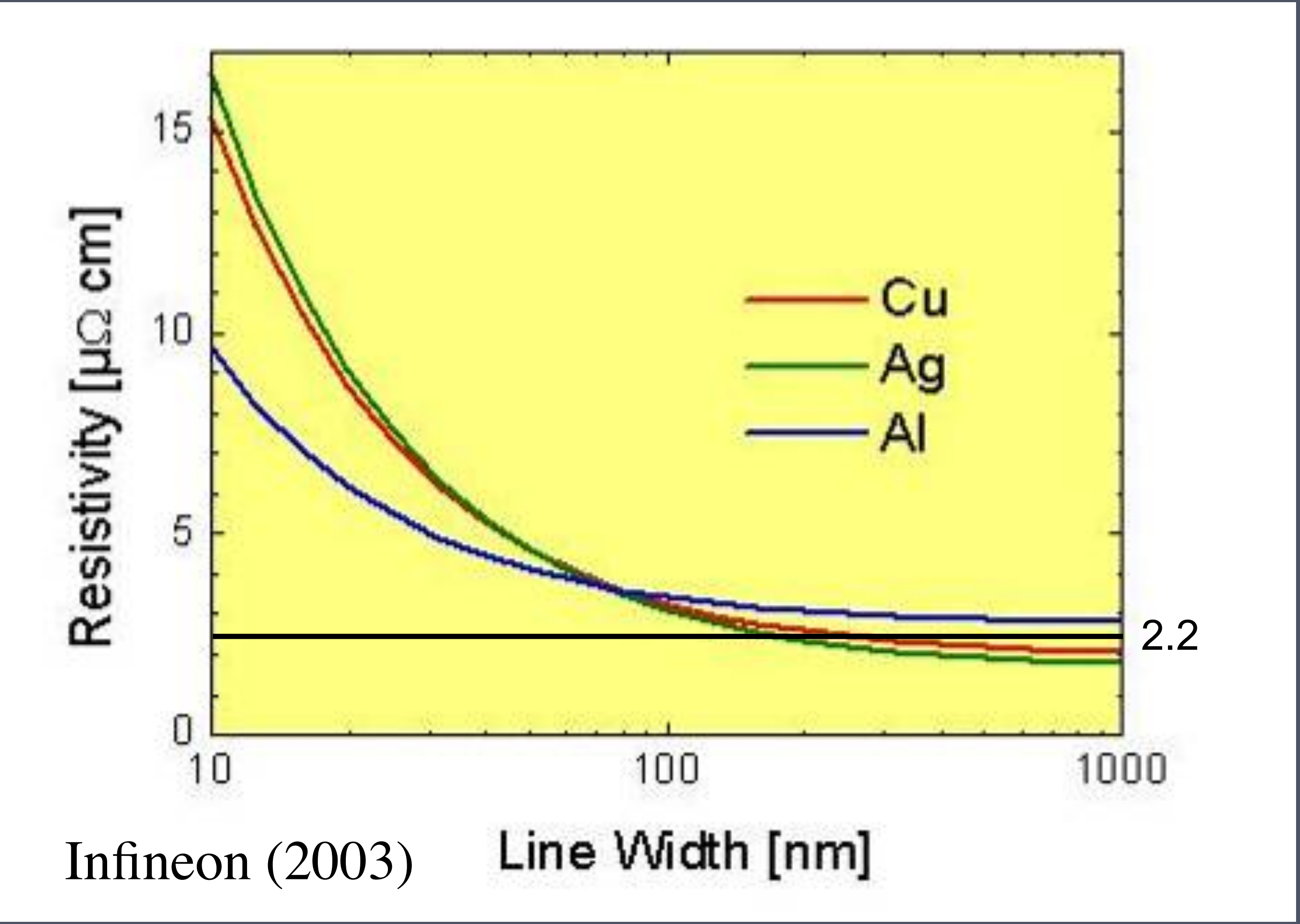
Was ist klein? Definition einer Längenskala

- Auto: Parklücke (5 m), Körpergrösse (2 m)
- Handy: Mund-Ohr Abstand (10 cm)
- Versetzungen (1µm)
- Freie Weglänge von Elektronen (100 nm)
- Atome (0.1 nm)

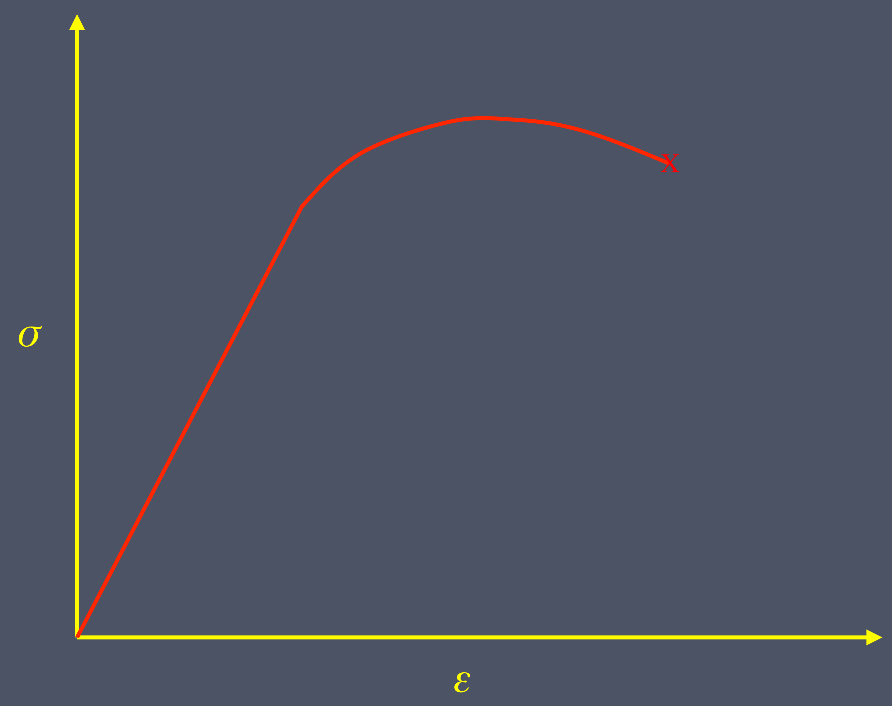
Moore`s Law: Beispiele aus der Mikroelektronik

Die Integrationsdichte von Siliziumchips verdoppelt sich alle 2 Jahre.

Spezifischer Widerstand

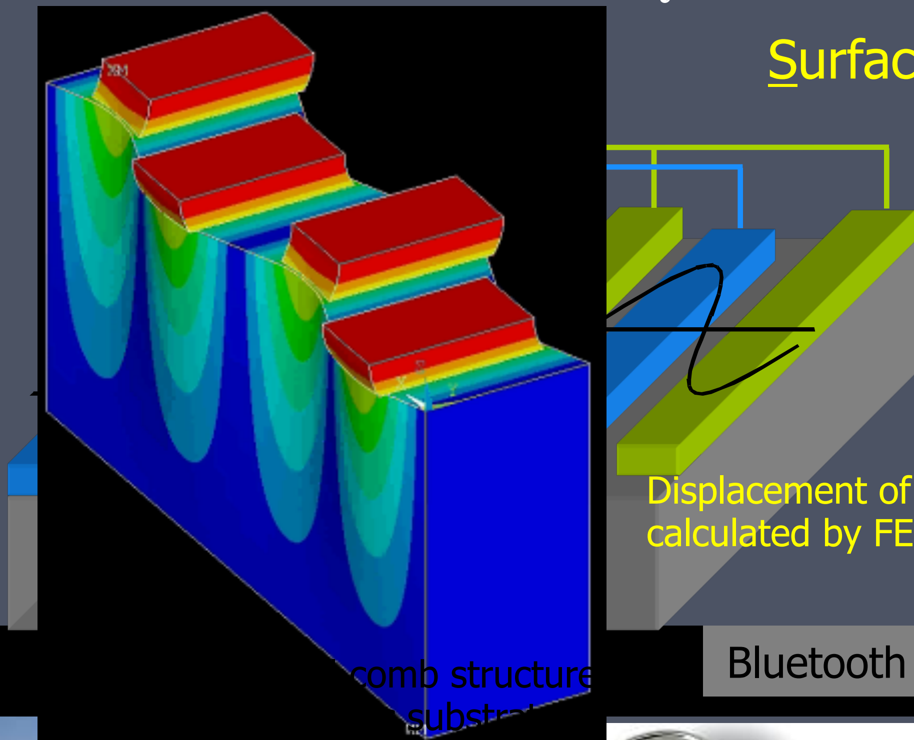


Spannungs-Dehnungskurve

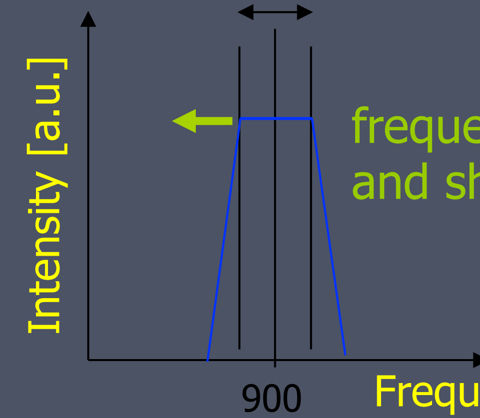


Device reliability for mobile communication applications

Surface Acoustic Wave (SAW) frequency filters :



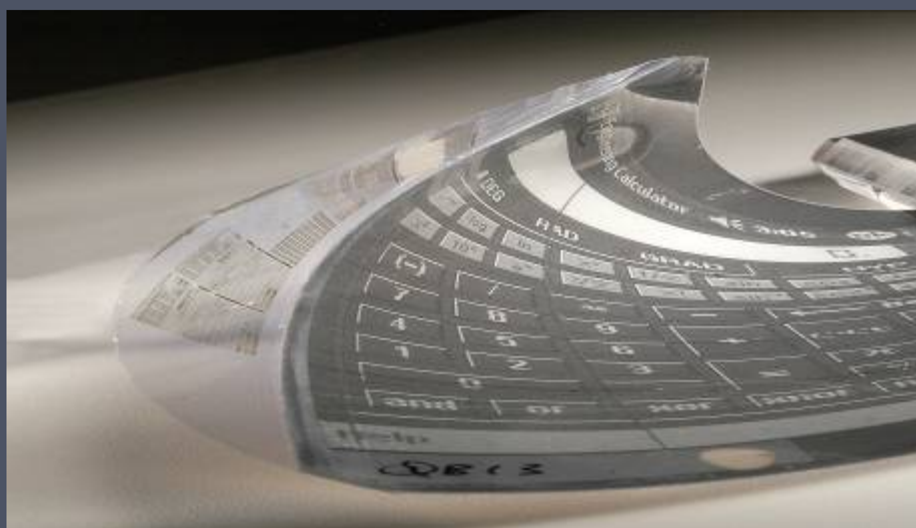
Displacement of electrodes calculated by FEM



frequency shift and short circuit

Bluetooth | Cellular phones | Wireless LAN

“Tragbare” Elektronik

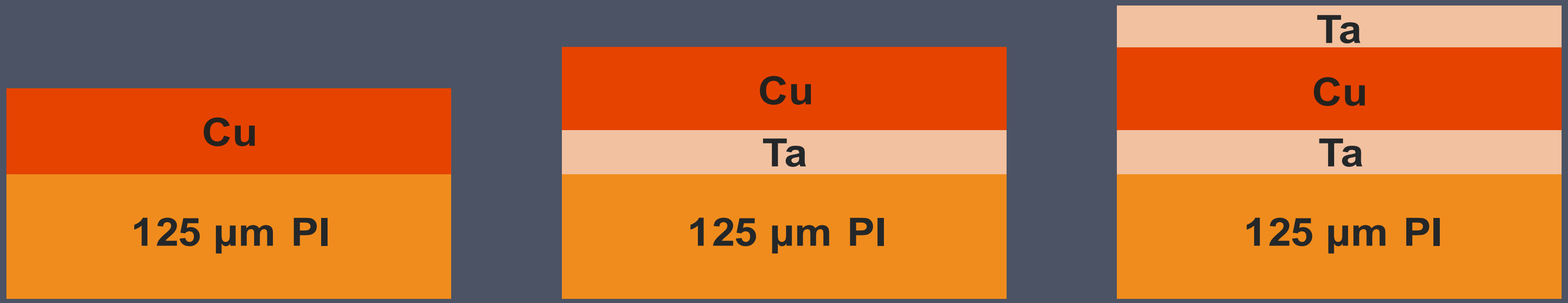


Source: Polymervision

Source: Infineon

Hohe Dehnungen werden vorausgesetzt!

Polycrystalline Ta/Cu film systems



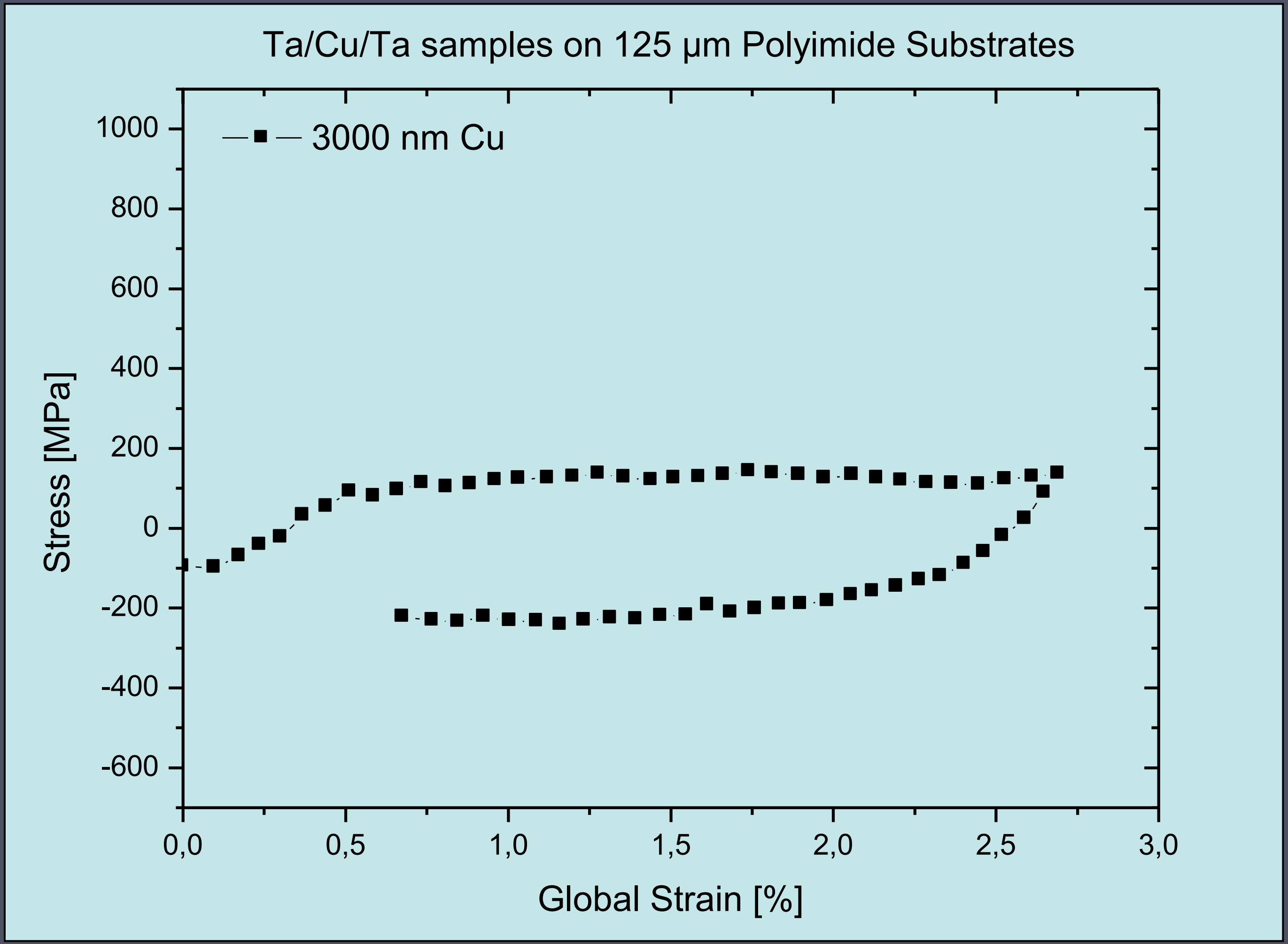
Cu thickness between 20 nm and 3000 nm.

Ta thickness always 10 nm.

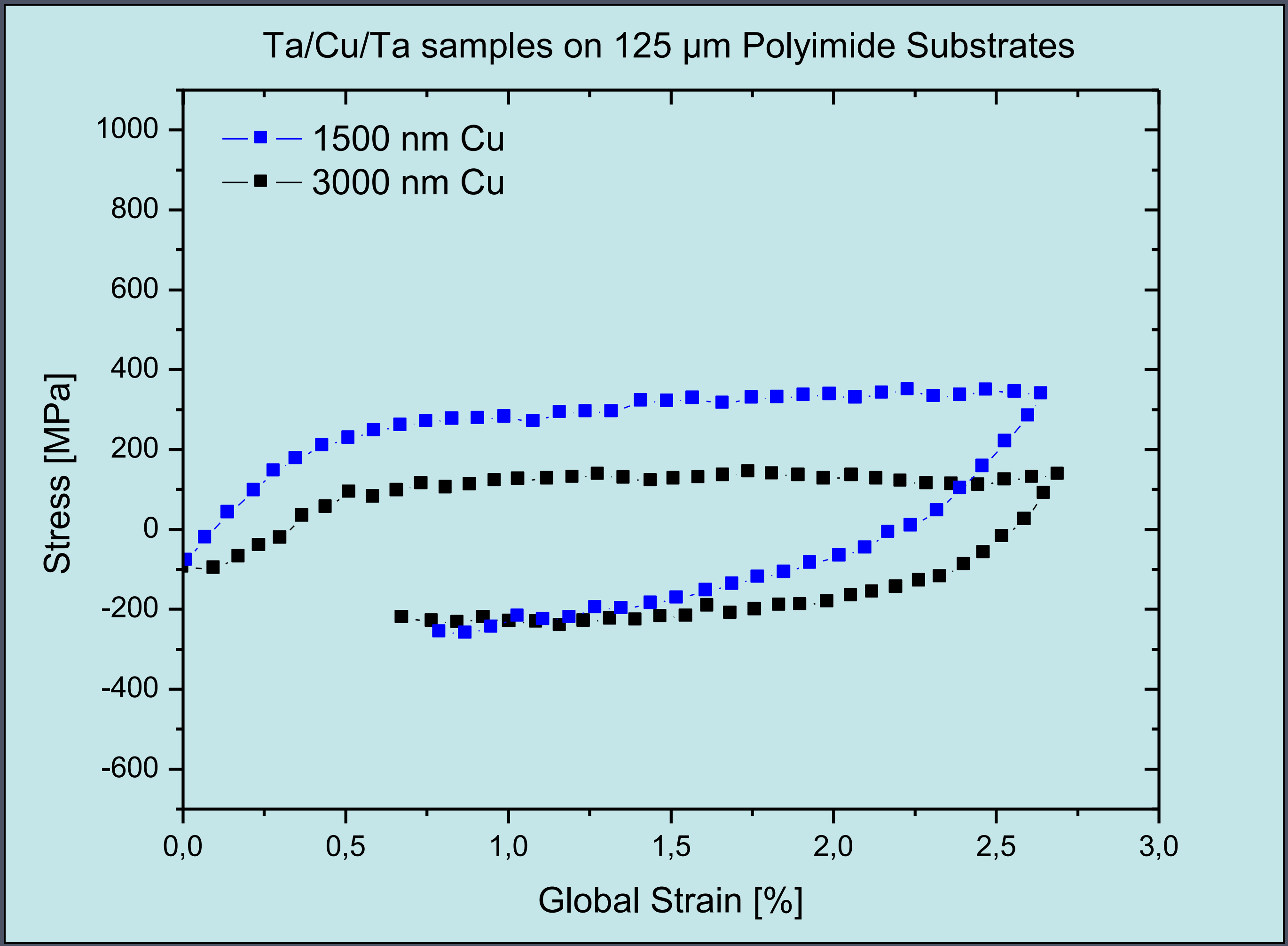
Ta layers enhance the texture and adhesion of the Cu film and act as diffusion barriers.

How do the Ta layers influence the deformation behavior?

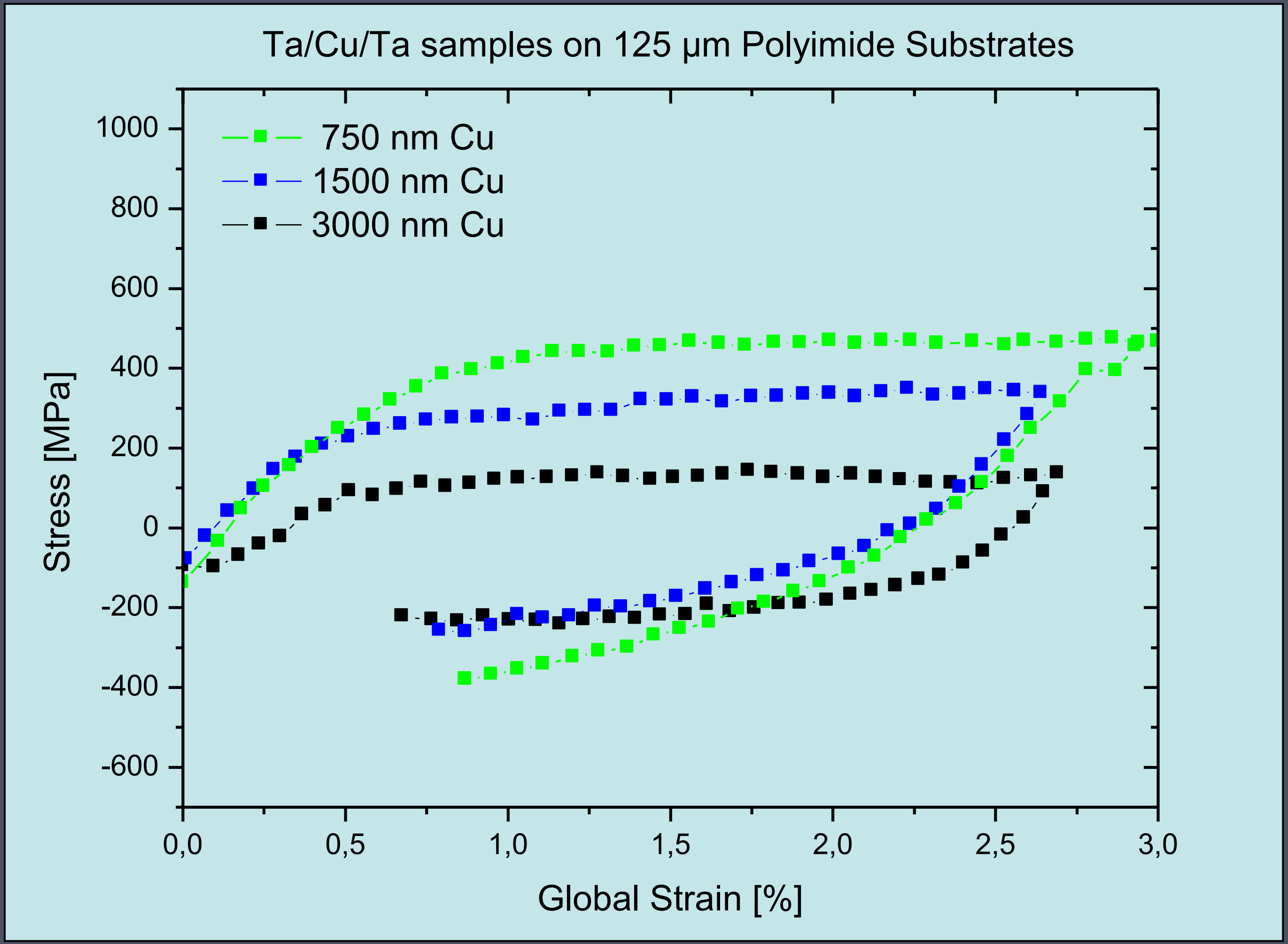
Stress-strain-curves



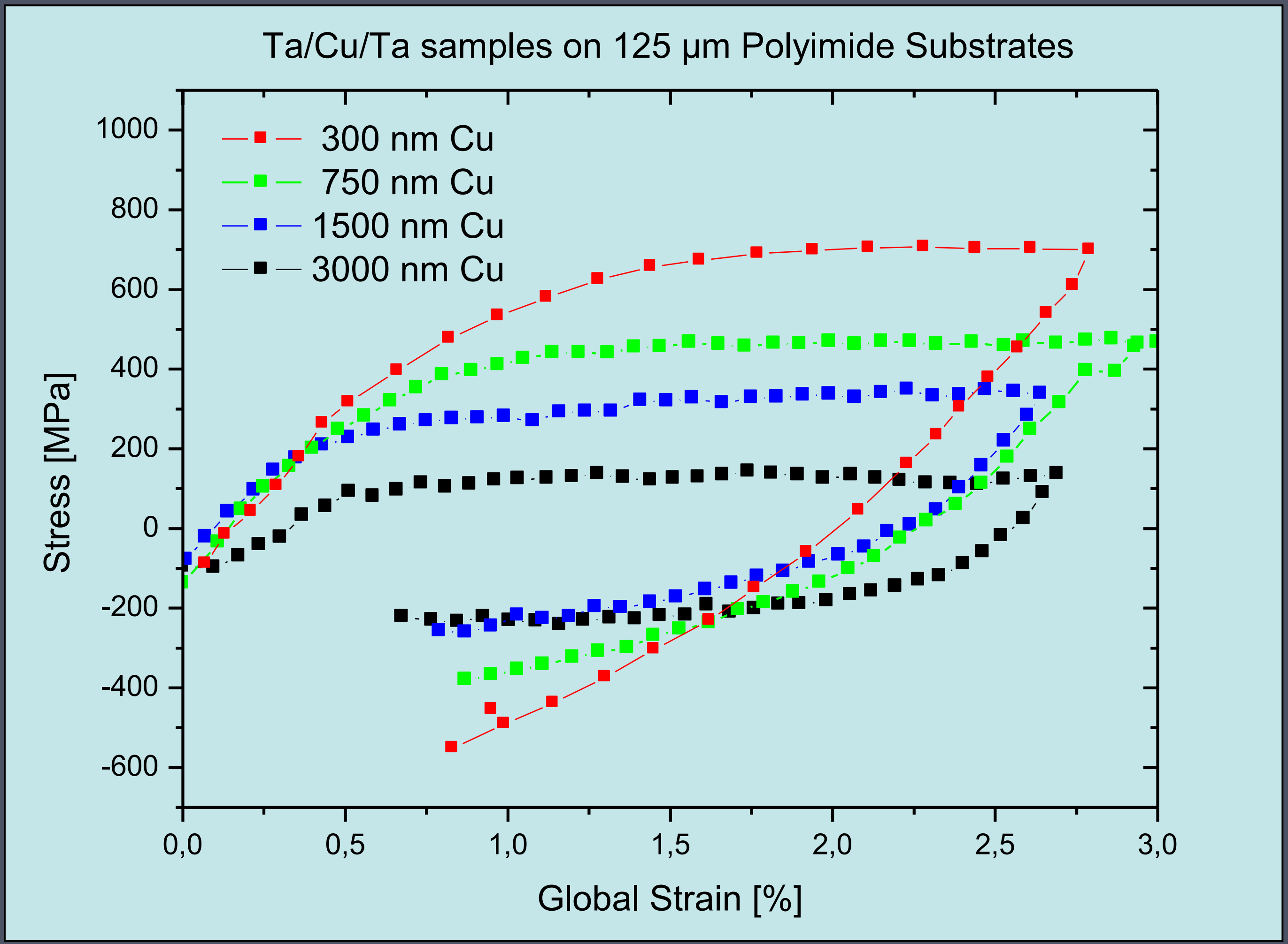
Stress-strain-curves



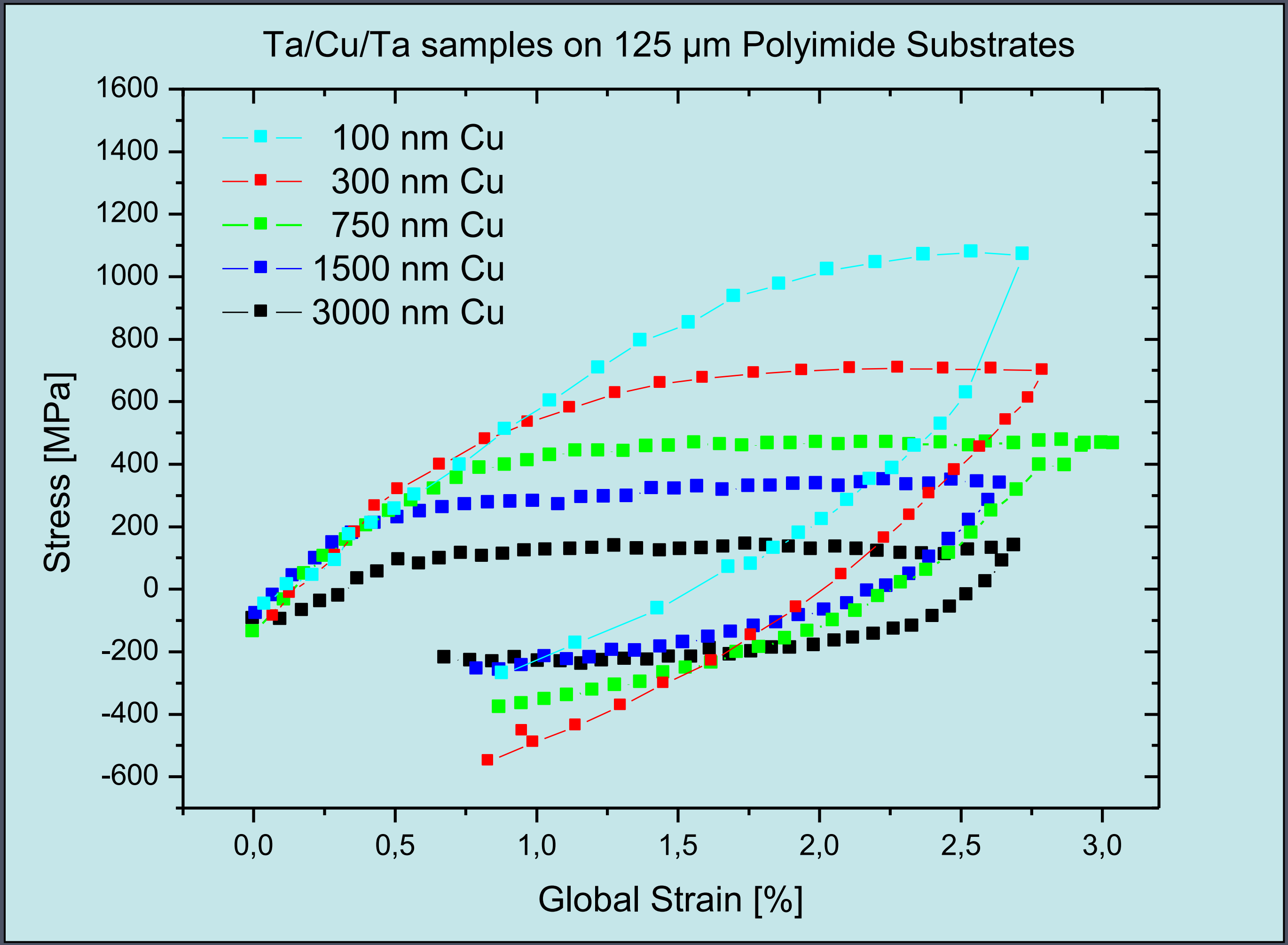
Stress-strain-curves



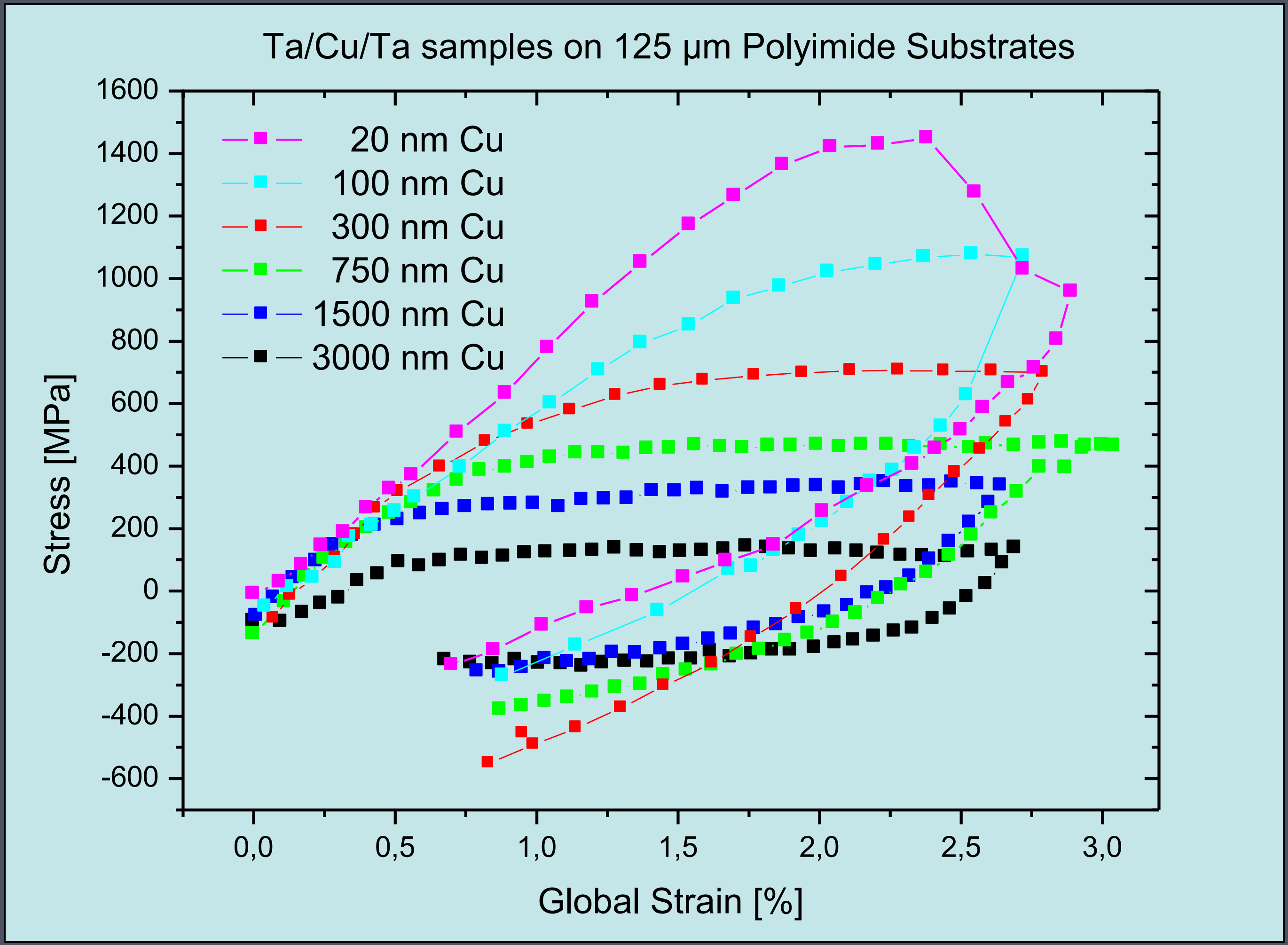
Stress-strain-curves



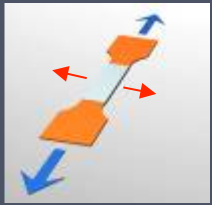
Stress-strain-curves

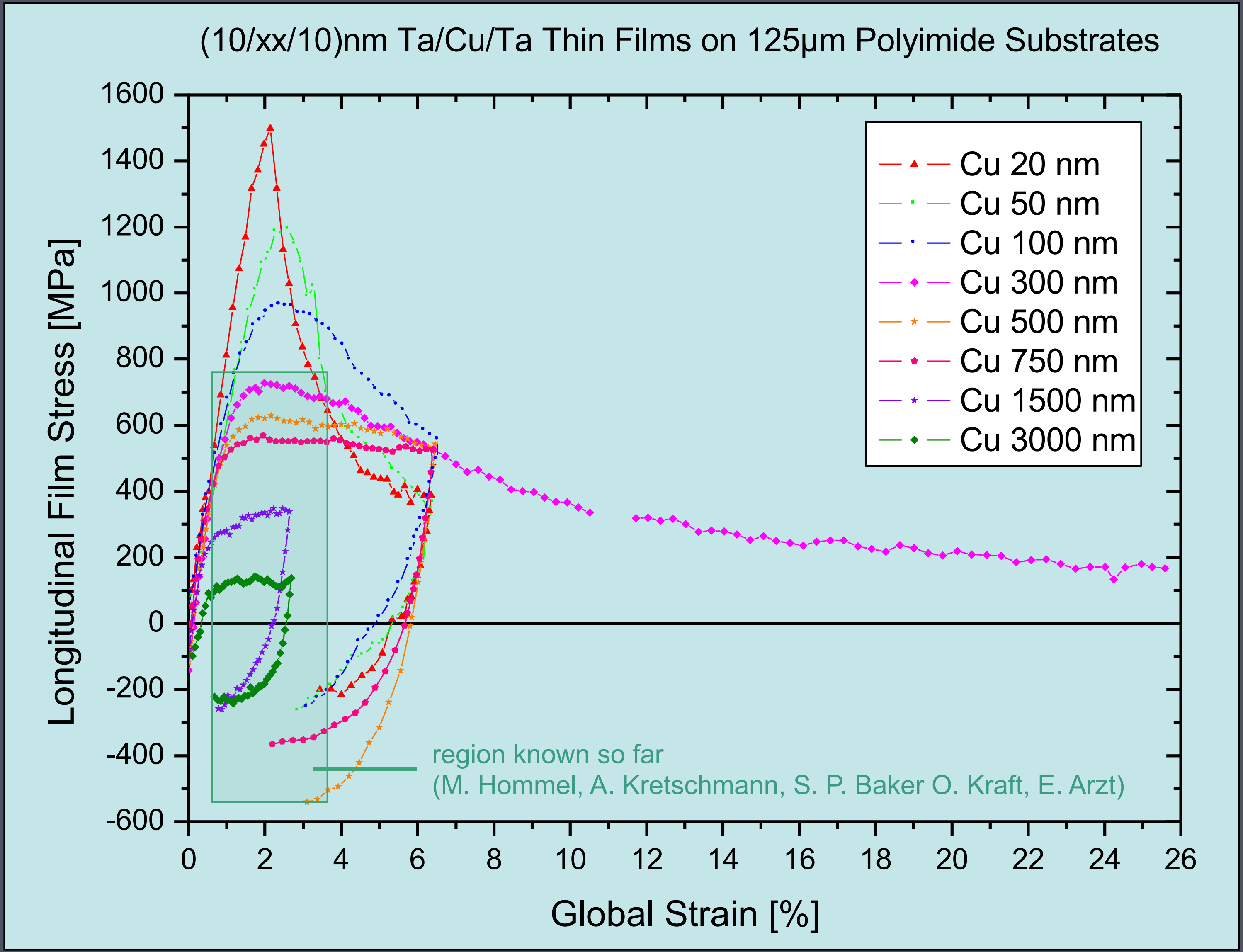


Stress-strain-curves

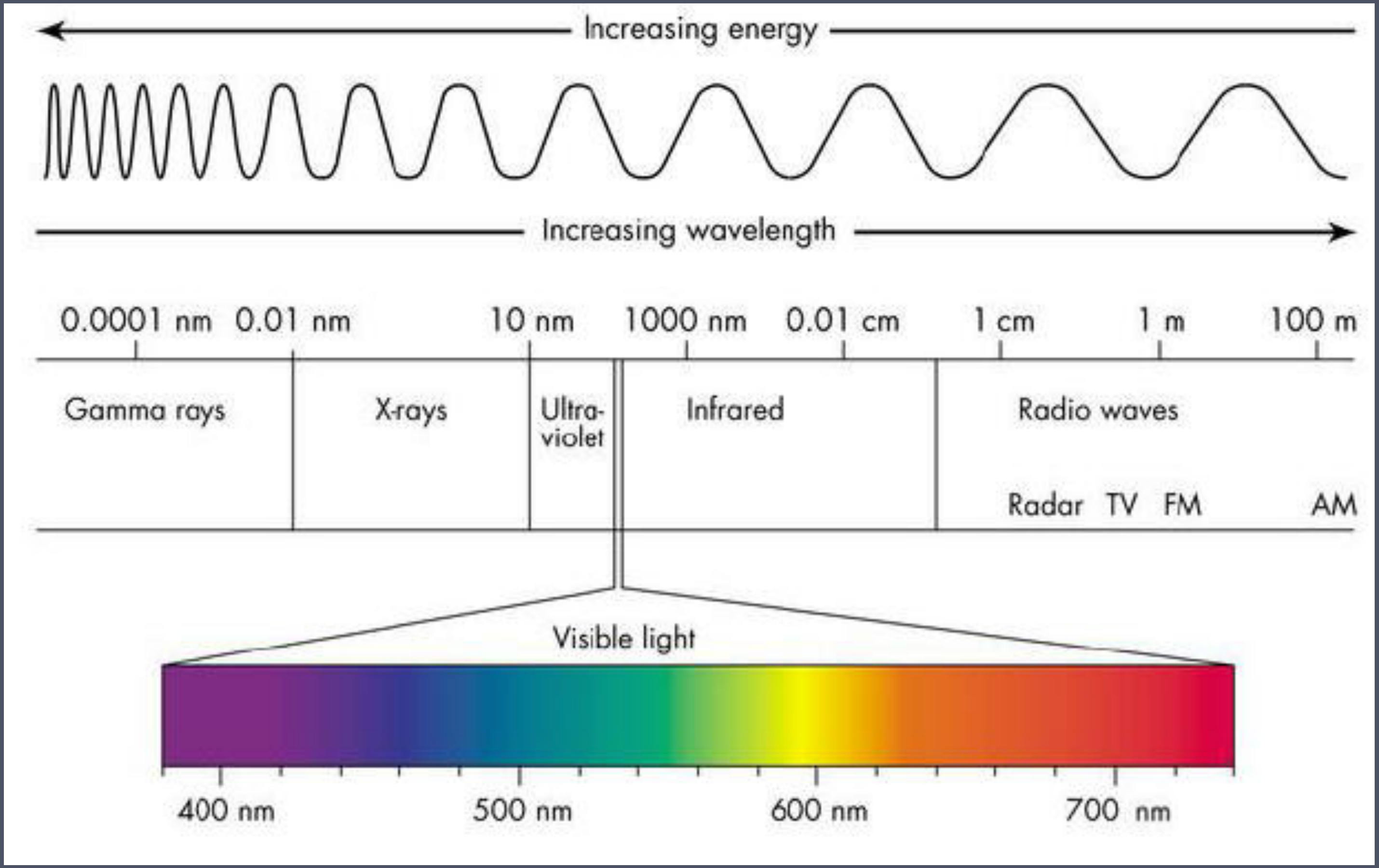


Cu Films on Polyimide Substrates





Electromagnetic Waves



Courtesy of Dr. Nick Bühler

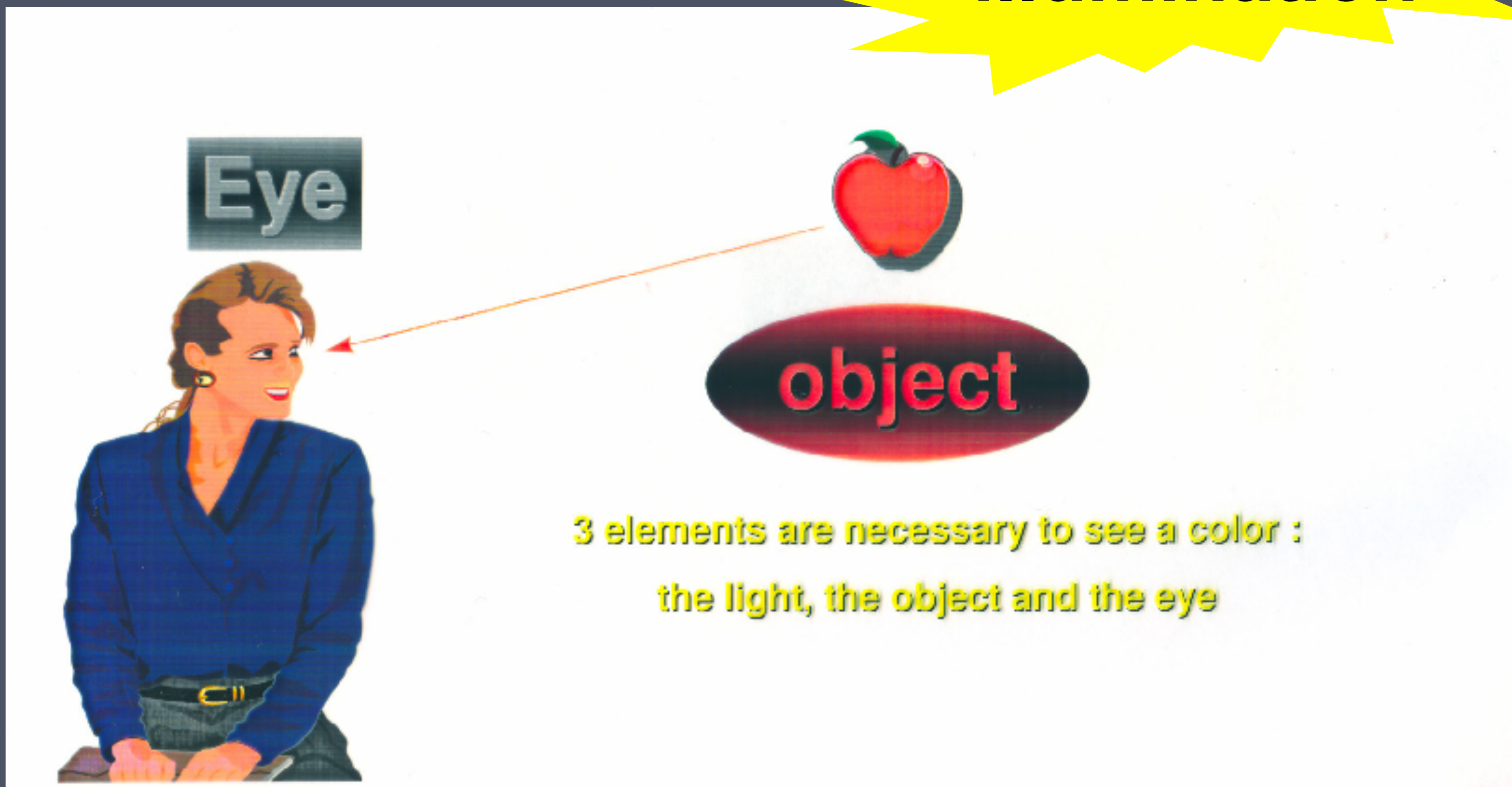
Visible Light

White light = sum of all colors

Courtesy of Dr. Nick Bühler

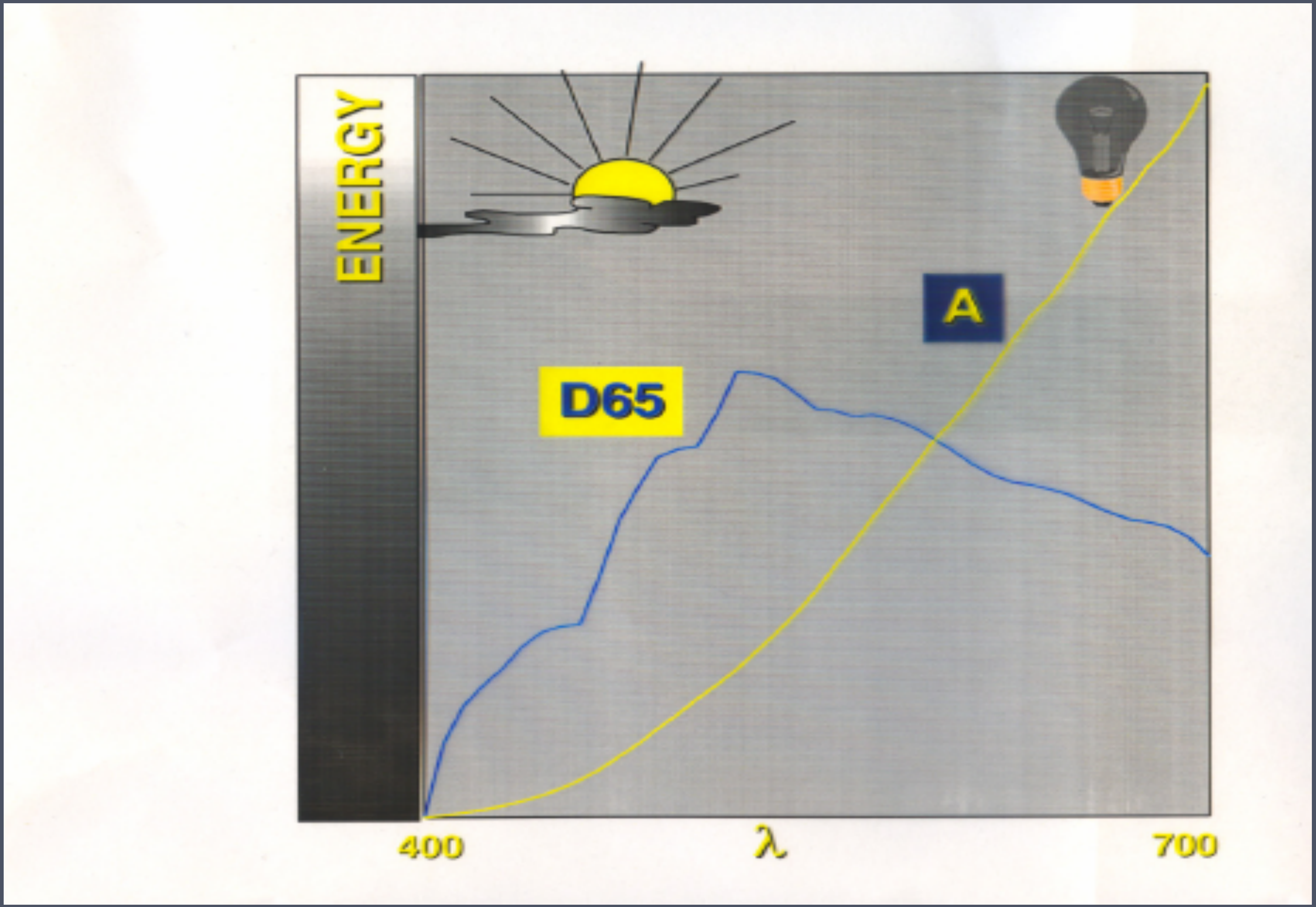
The elements which are necessary to see a color

illumination



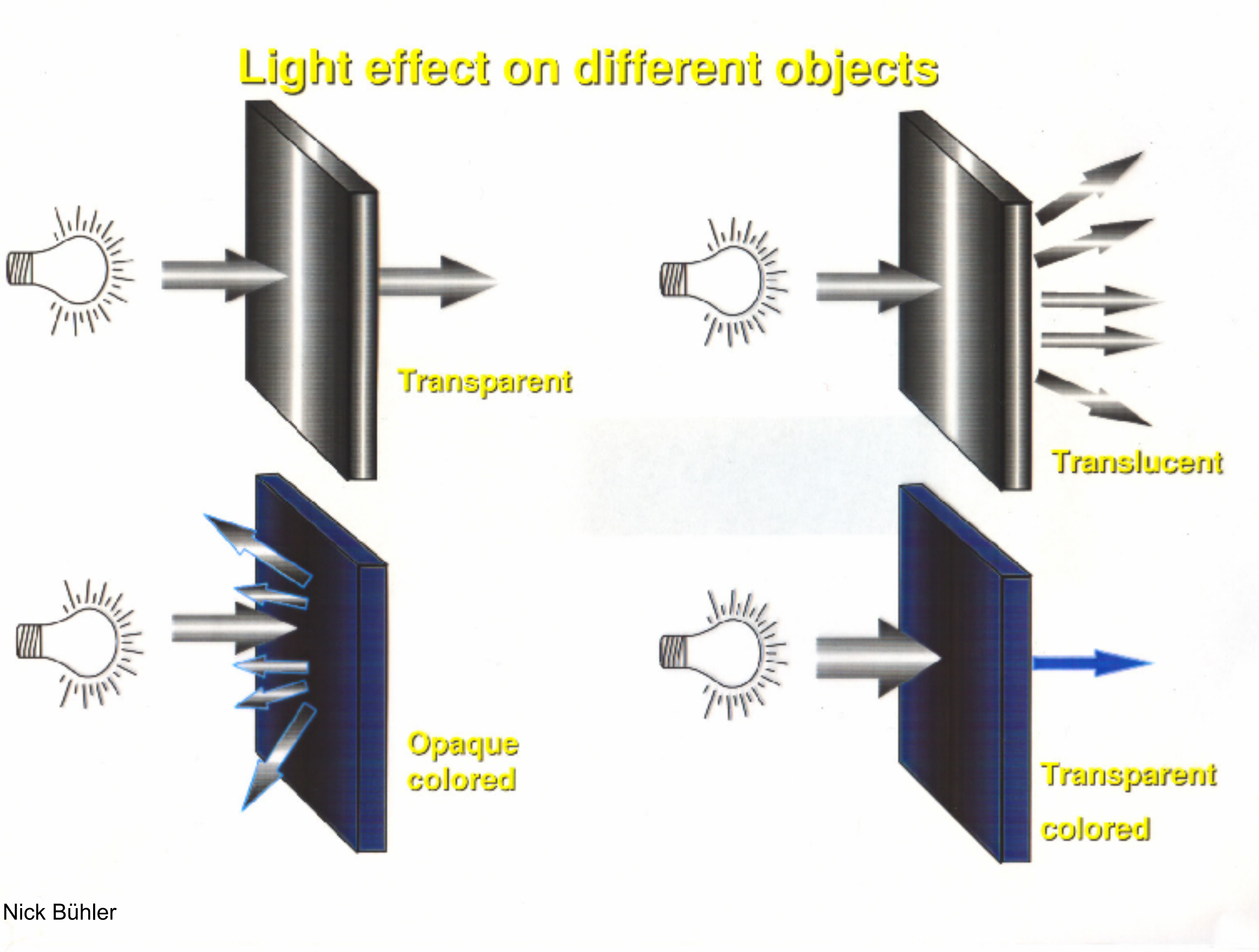
Courtesy of Dr. Nick Bühler

Spectral energy distribution of standard illuminants (sun, halogen light)



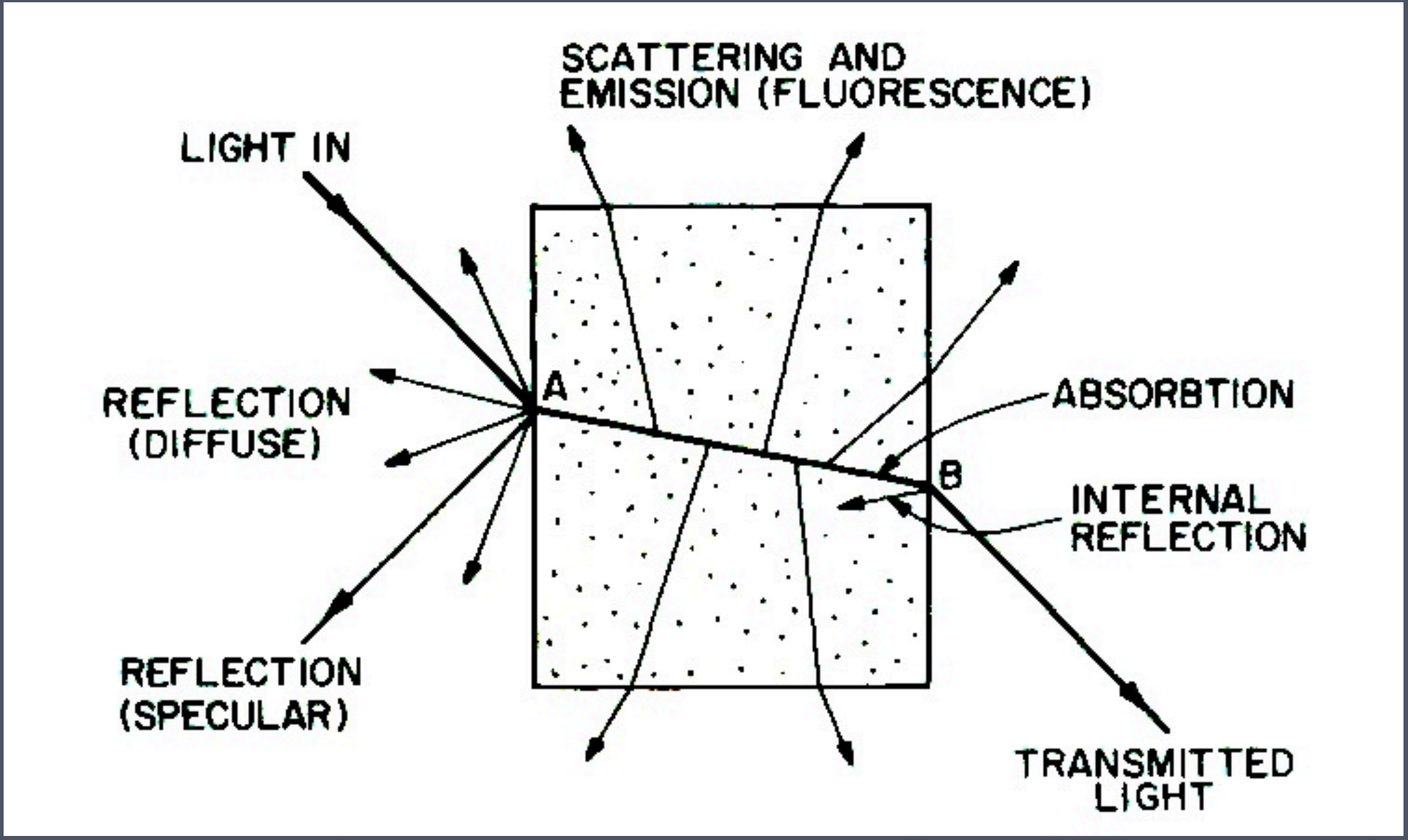
Courtesy of Dr. Nick Bühler

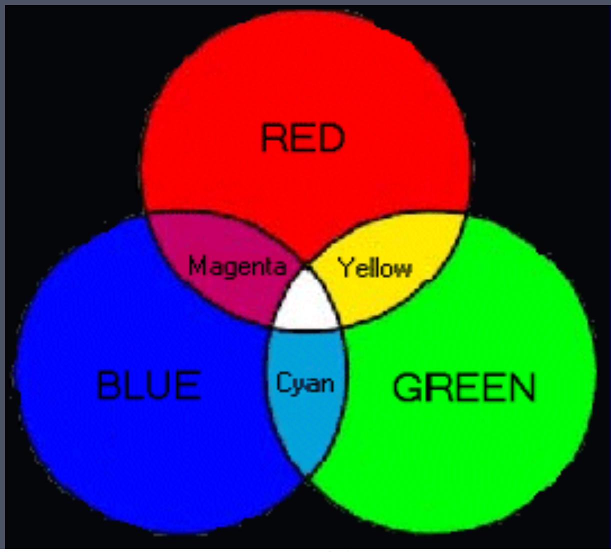
When light shines on an object

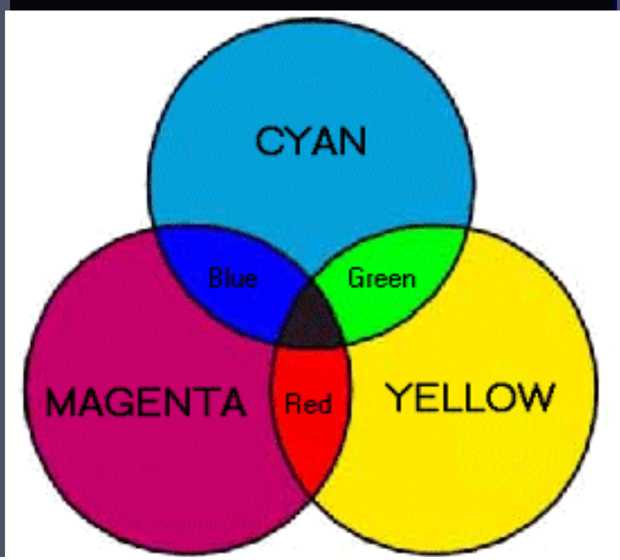


Courtesy of Dr. Nick Bühler

Adventures of a beam of light through a material



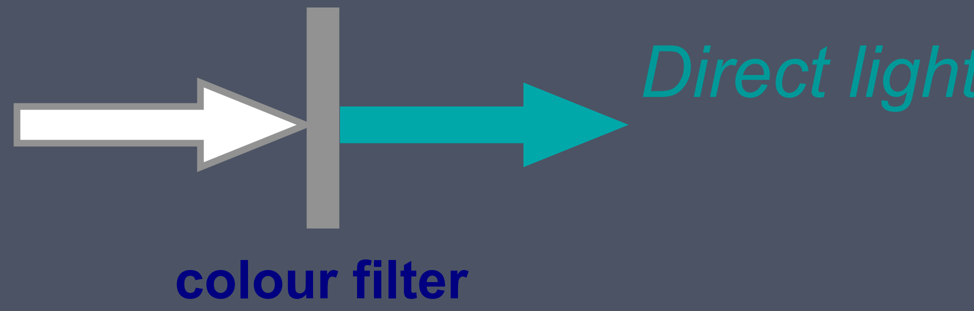




Courtesy of Dr. René Schneider
Ciba Speciality Chemicals, Basel

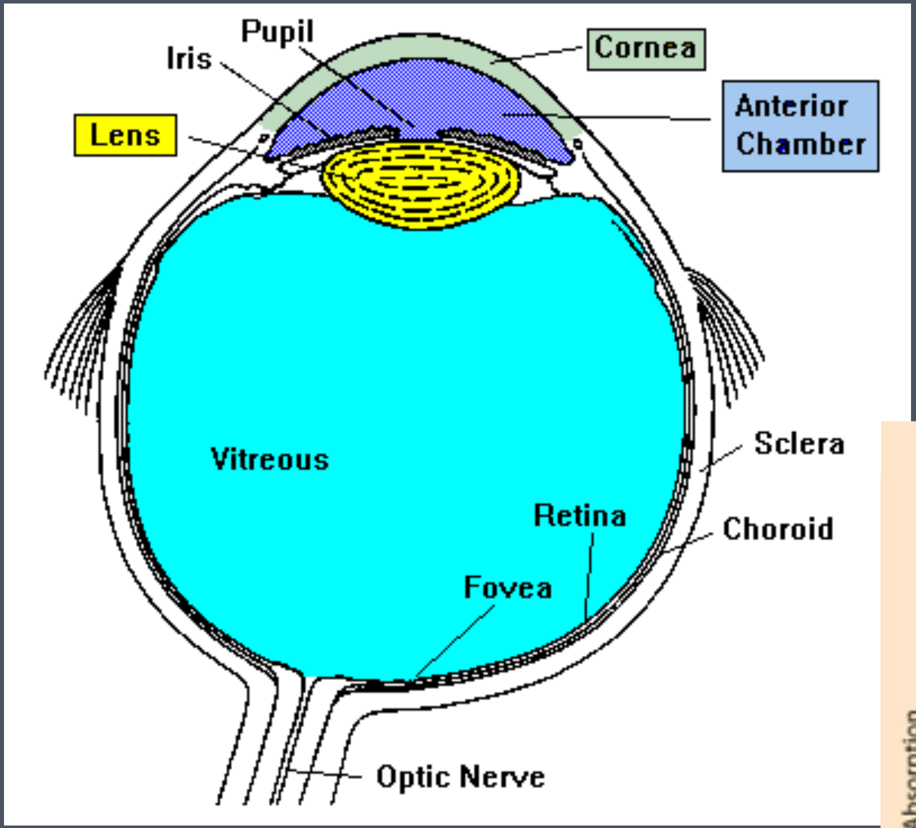
Primary Colours:

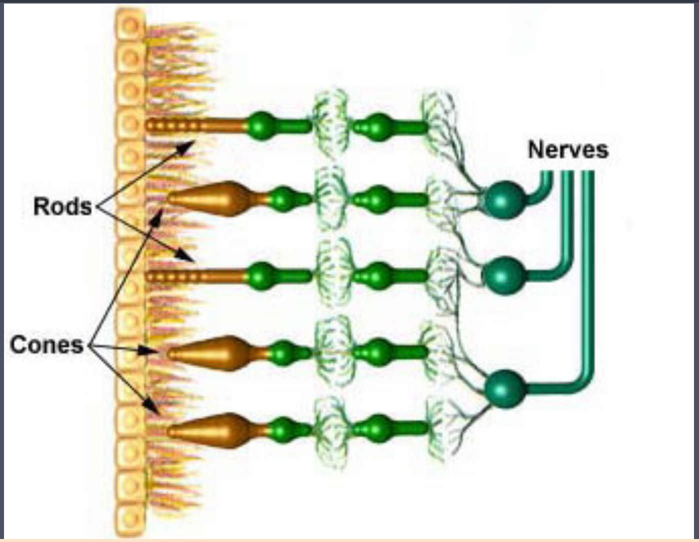
- **ADDITIVE COLOURS**

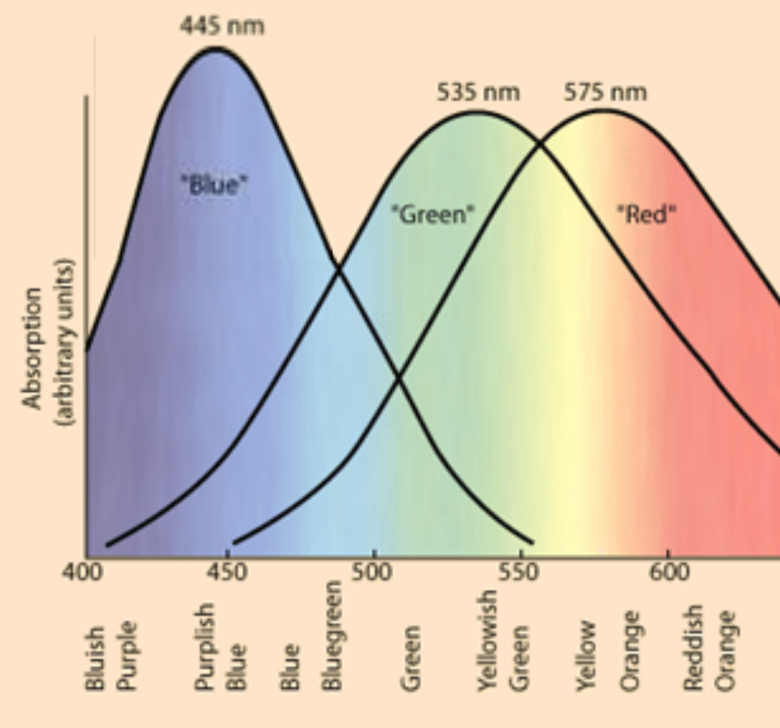


- **SUBTRACTIVE COLOURS**

Human Eye







40 red
20 green
1 blue

Courtesy of Dr. René Schneider
Ciba Speciality Chemicals, Basel

15 causes of color (Kurt Nassau, 1987)

Vibrations and simple excitations

1. Incandescence: flames, lamps, carbon arc, limelight
2. Gas excitations: vapor lamps, lightning, auroras, some lasers
3. Vibrations and rotations: water, ice, iodine, blue gas flame

Transitions involving ligand-field effects

4. Transition-metal compounds: turquoise, malachite, chrome green, copper patina, Thenard's blue, some fluorescence, lasers, and phosphors
5. Transition-metal impurities: ruby, emerald, aquamarine, red iron ore, some fluorescence and lasers

Transitions between molecular orbitals

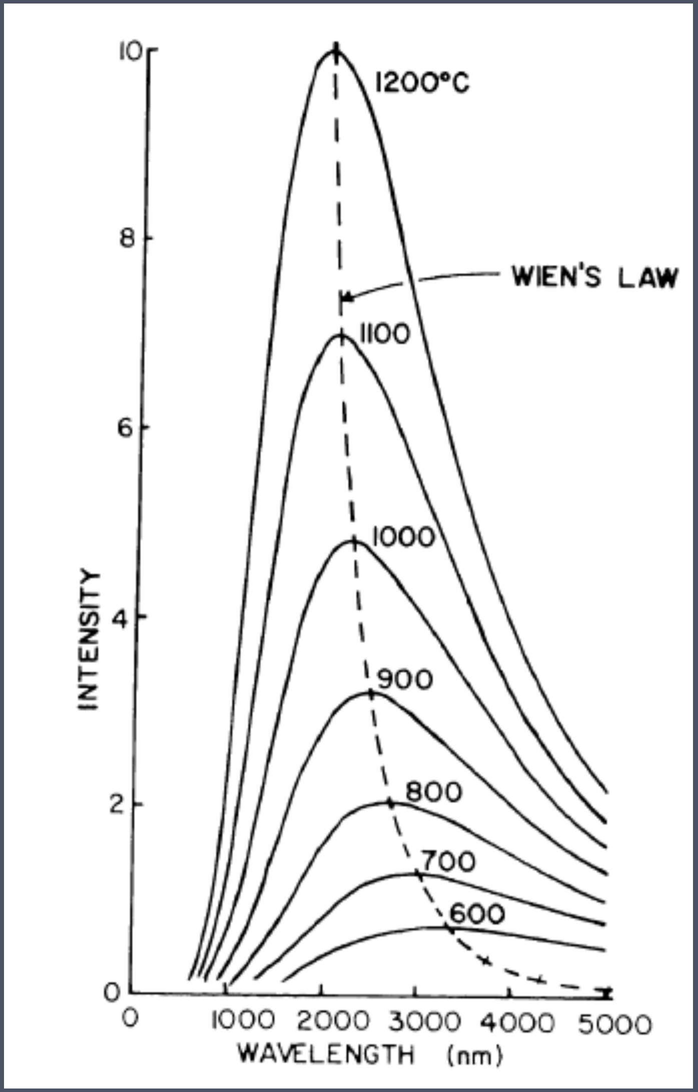
6. Organic compounds: most dyes, most biological colorations, some fluorescence and lasers
7. Charge transfer: blue sapphire, magnetite, lapis lazuli, ultramarine, Prussian blue

Transitions involving energy bands

8. Metals: copper, silver, gold, iron, brass, “ruby” glass
9. Pure semiconductors: silicon, galena, cinnabar, vermillion, cadmium orange, diamond
10. Doped semiconductors: blue and yellow diamond, light-emitting diodes, some lasers and phosphors
11. Color centers; amethyst, smoky quartz, desert “amethyst” glass, some fluorescence and lasers

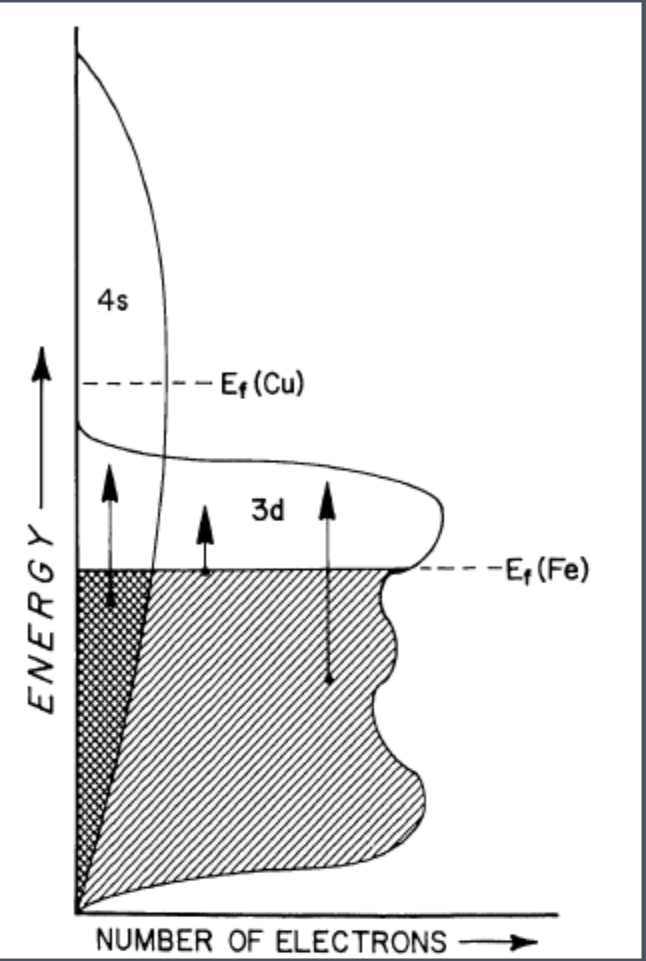
Geometrical and physical optics

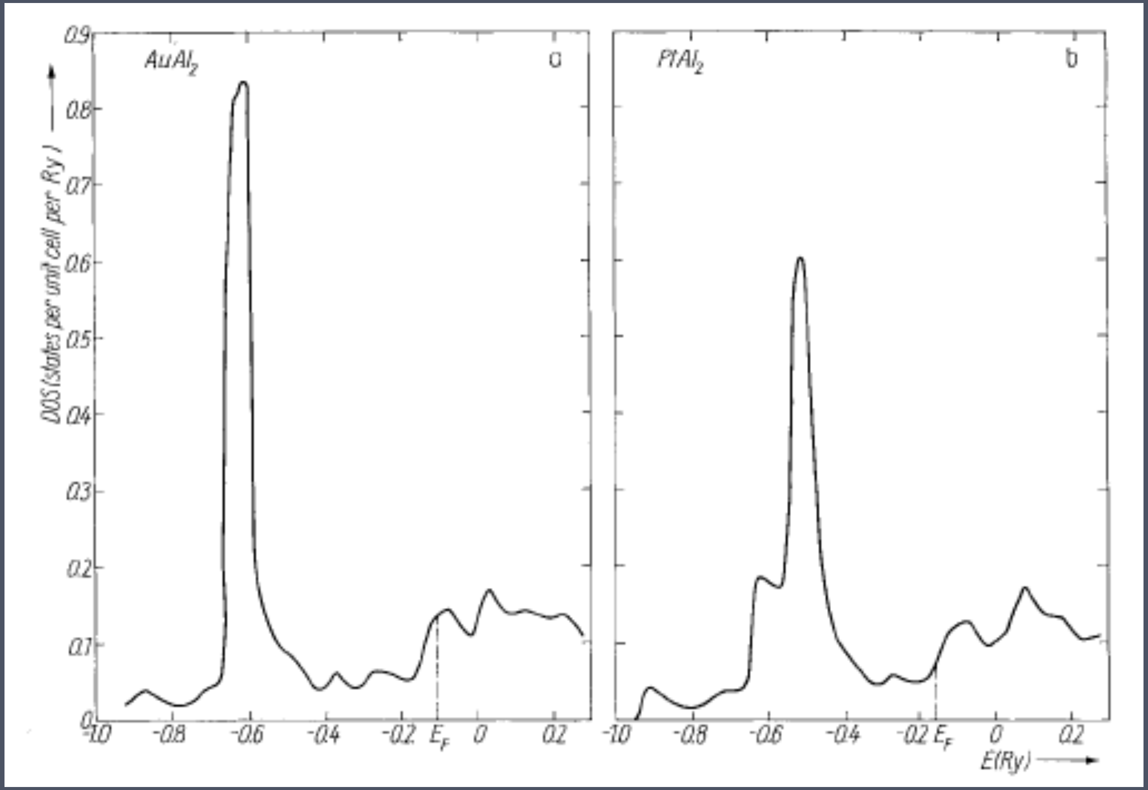
12. Dispersive refraction: rainbows, halos, sun dogs, green flash of sun, “fire” in gemstones, prism spectrum
13. Scattering: blue sky, red sunset, blue moon, moonstone, blue eyes, skin, butterflies, bird feathers and some other biological colors, Raman scattering
14. Interference: oil slick on water, soap bubbles, coating on camera lenses, some biological colors
15. Diffraction: aureole, glory, diffraction gratings, opal, some biological colors, most liquid crystals

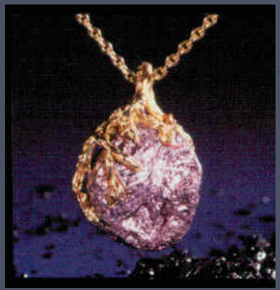


The following figures are taken from: K. Nassau, Color Research and application, Vol. 12, 1, 1987

Transitions involving energy bands



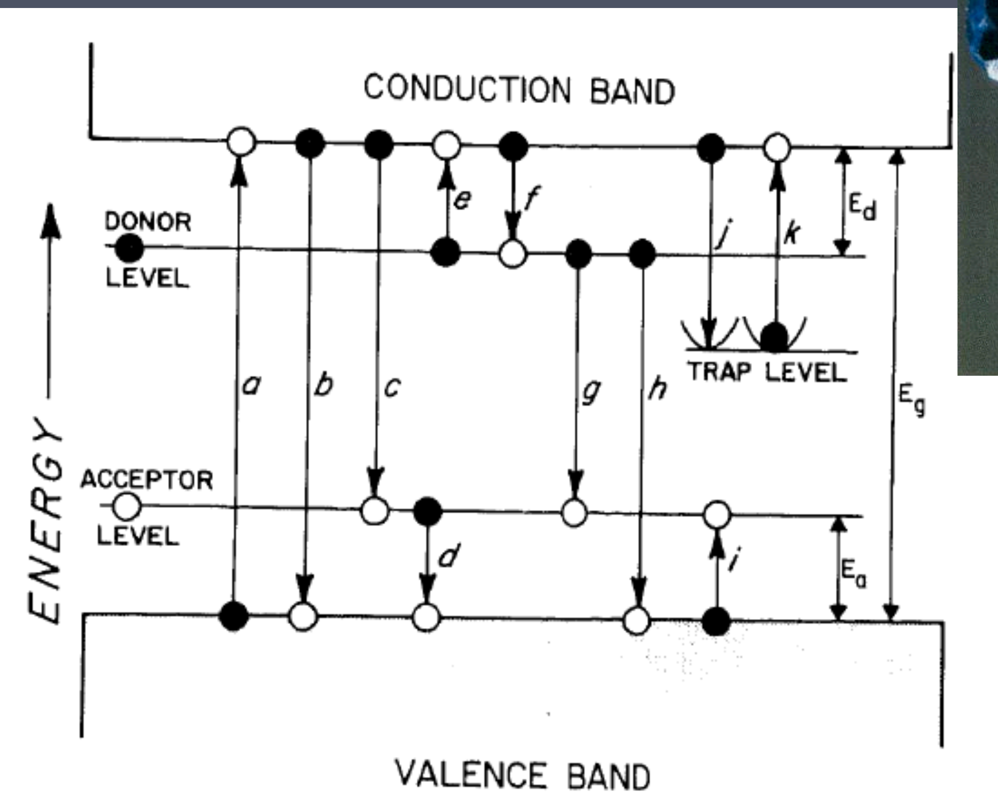


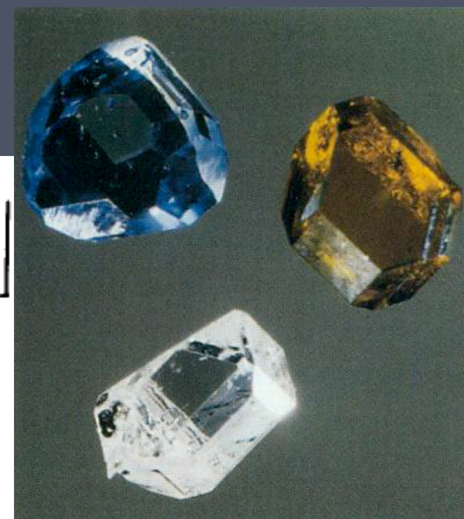


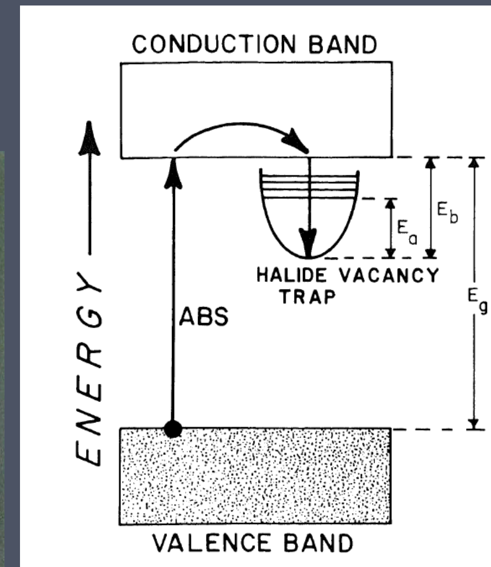
From Corti, *Special colours of gold*, 2006

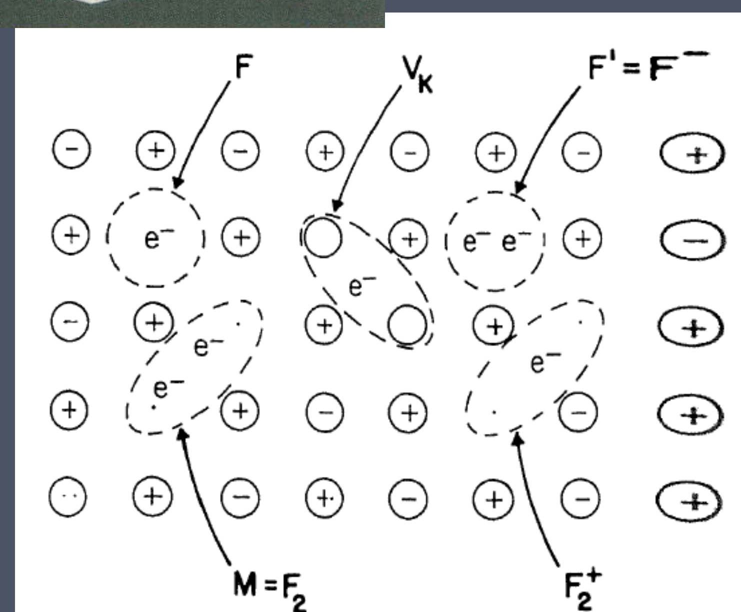
From Supansomboon, *Purple glory, 2008*

States and traps in the band gap









Col

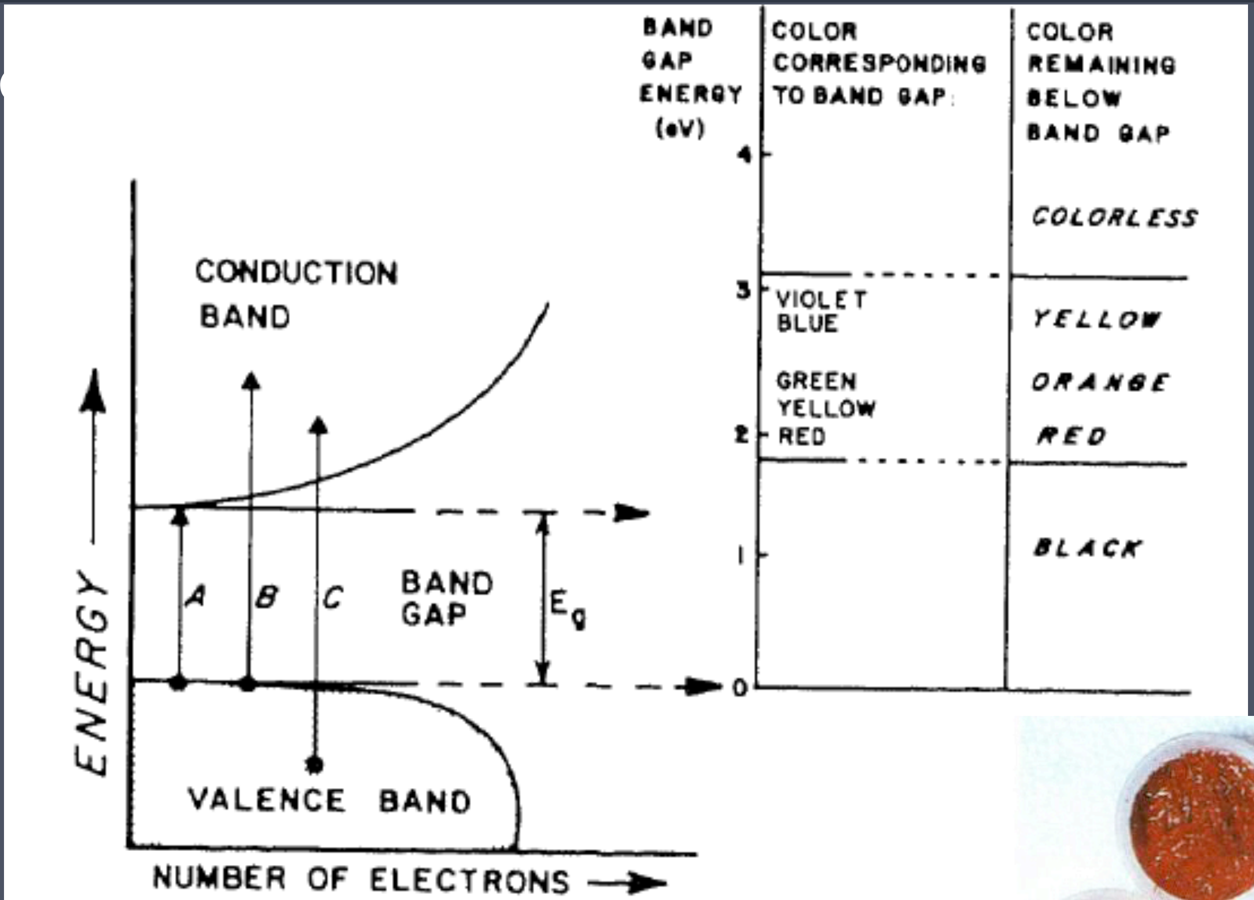
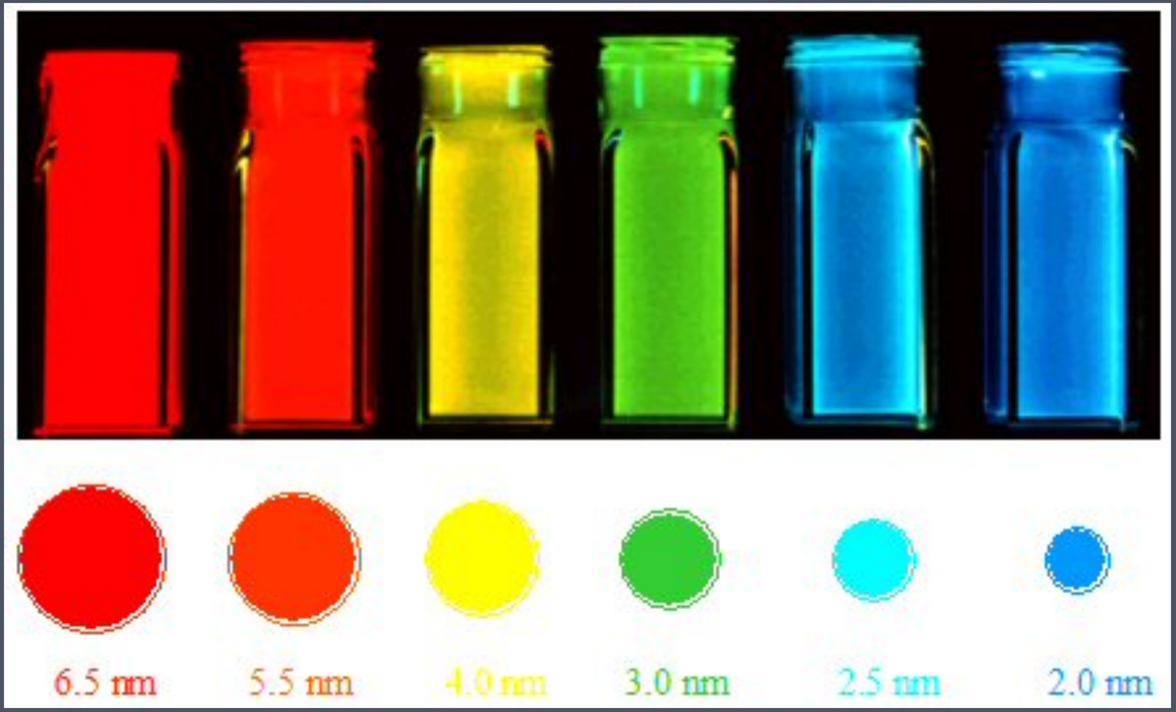


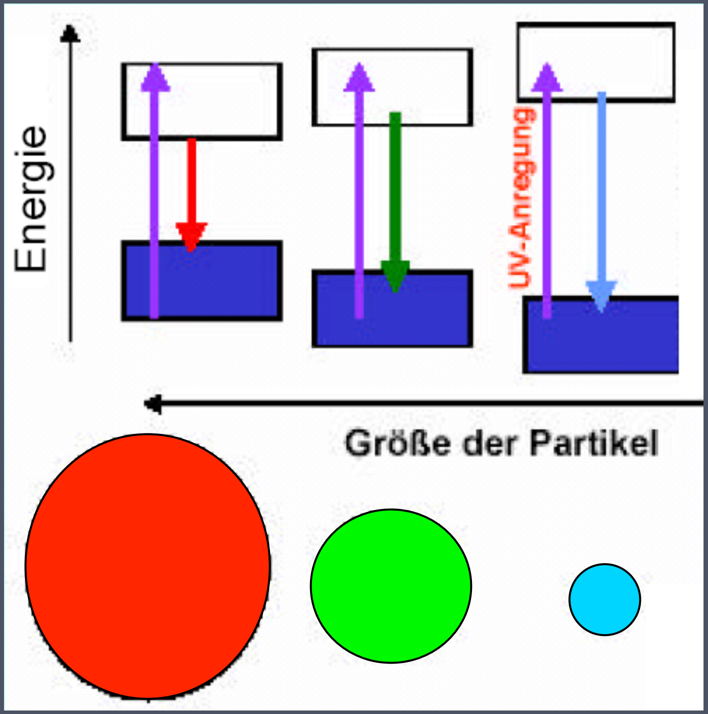
TABLE II. Color of some band-gap semiconductors.

Substance	Mineral name	Pigment name	Band gap, eV	Color
C	Diamond	—	5.4	Colorless
ZnO	Zincite	Zinc white	3.0	Colorless
CdS	Greenockite	Cadmium yellow	2.6	Yellow
$CdS_{1-x}Se_x$	—	Cadmium orange	2.3	Orange
HgS	Cinnabar	Vermillion	2.0	Red
HgS	Metacinnabar	—	1.6	Black
Si	—	—	1.1	Black
PbS	Galena	—	0.4	Black

Warum „Nano“? Grössenabhängige Eigenschaften!

CdSe Quantenpunkte





Die Eigenschaften eines Materials können verändert werden, indem die Grösse der Nanopartikel variiert wird - und nicht die Zusammensetzung!

Bandlücke zwischen Valenz- und Leitungsband wird grössenabhängig!

Was ist klein an Beispielen der Tierwelt

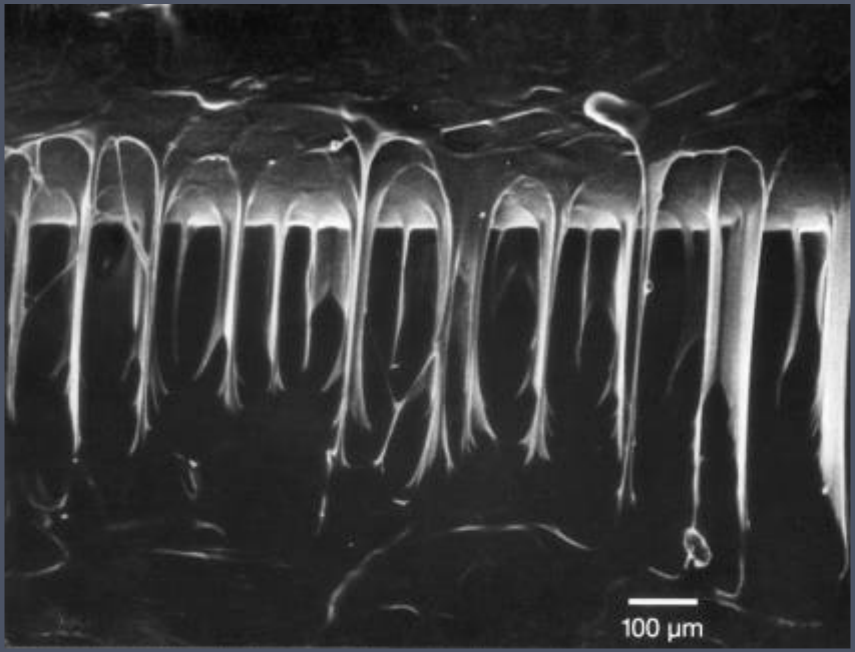
S. Gorb, MPI Stuttgart

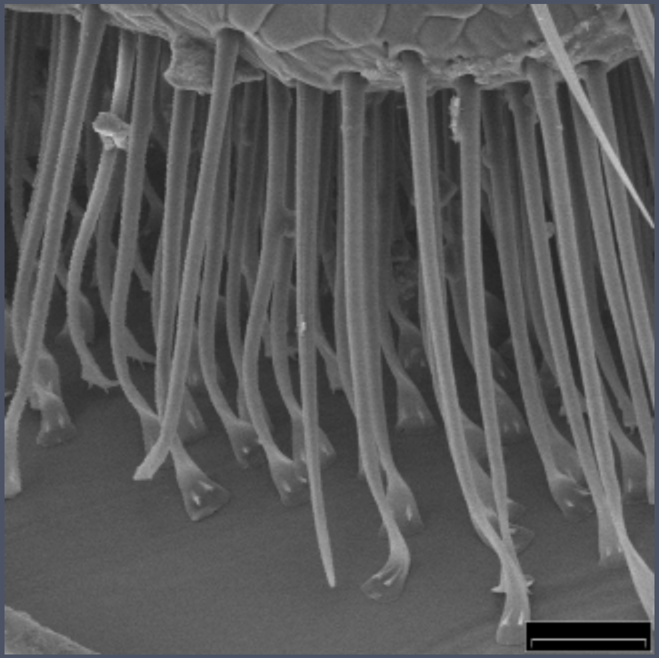
Analogie zur Technologie

K. Lewtas, ExxonMobil Chemical Europe

?

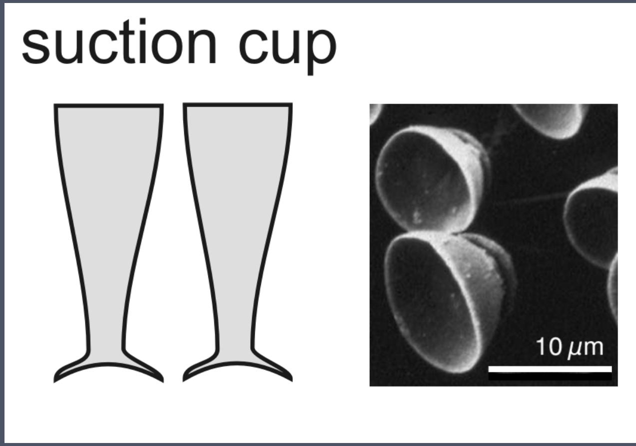
S. Gorb, MPI Stuttgart





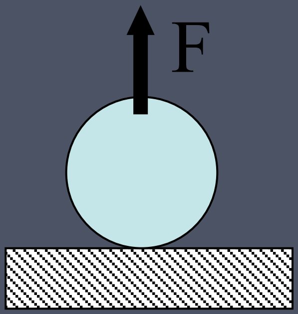
20 µm

Warum haftet ein Gecko?



- Saugnäpfe
- van der Waals Kräfte

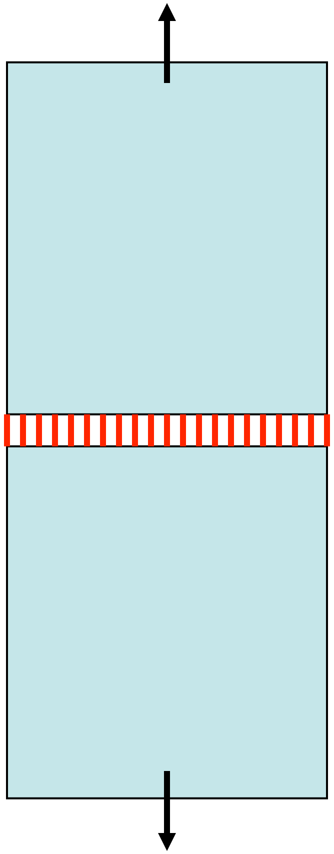
$$F = \frac{3}{2} R\pi\gamma$$



- durch Feuchtigkeit (Kapillarkräfte)

$$F = 2\pi R\gamma_L\left(\cos\theta_1 + \cos\theta_2\right)$$

van der Waals bonds are strong if.....



estimate „pull-off strength“:

$$\sigma_C = \frac{\gamma}{s} \approx \frac{10^{-2}}{10^{-10}} Nm^{-2} = 100\, MPa$$

pull-off force for A=1 cm²: $F_C = \sigma_C A \approx 10^4\, N$

Scaling of contact elements

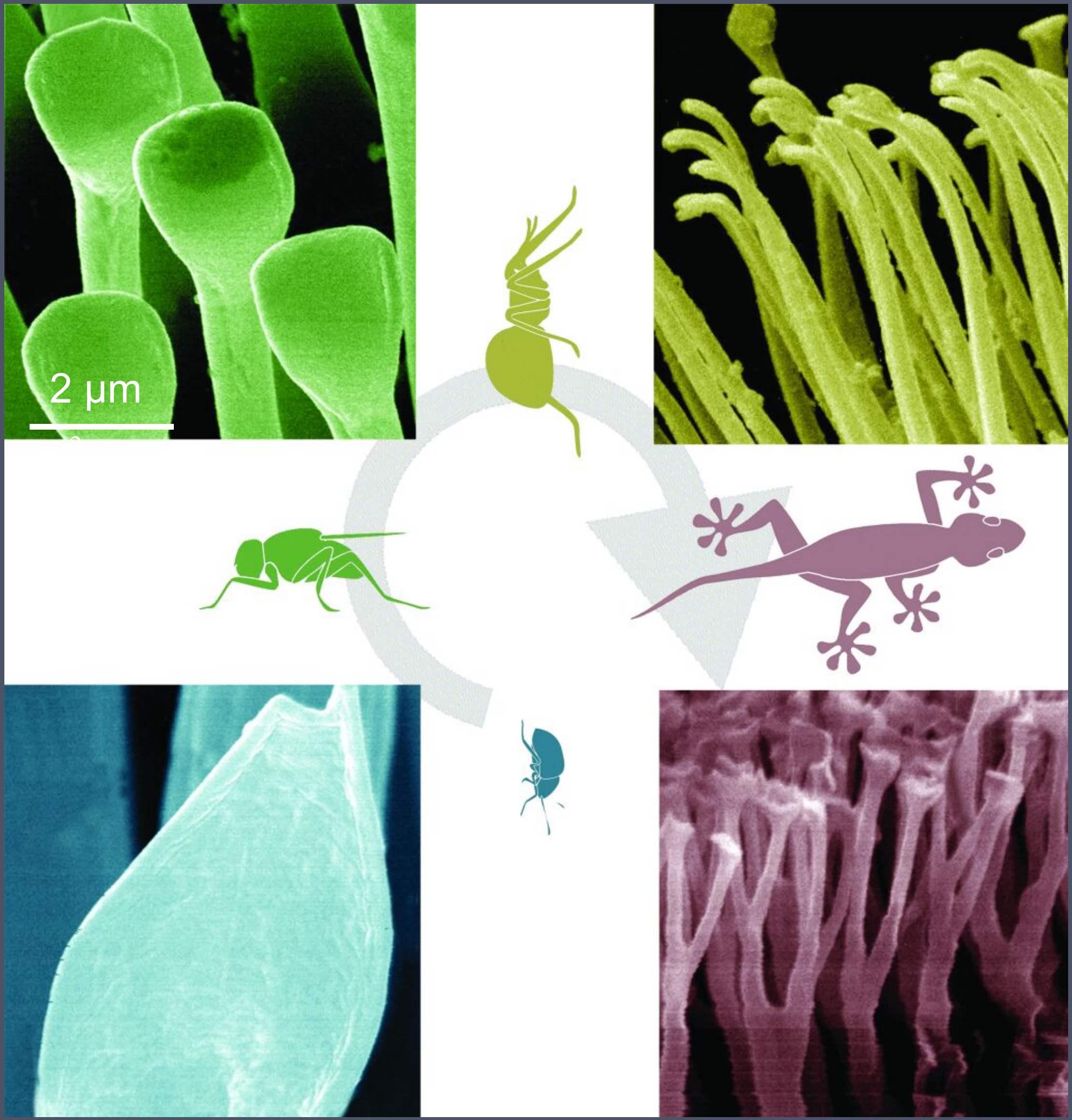
$$F_C(n) = \sqrt{n}\, F_C$$

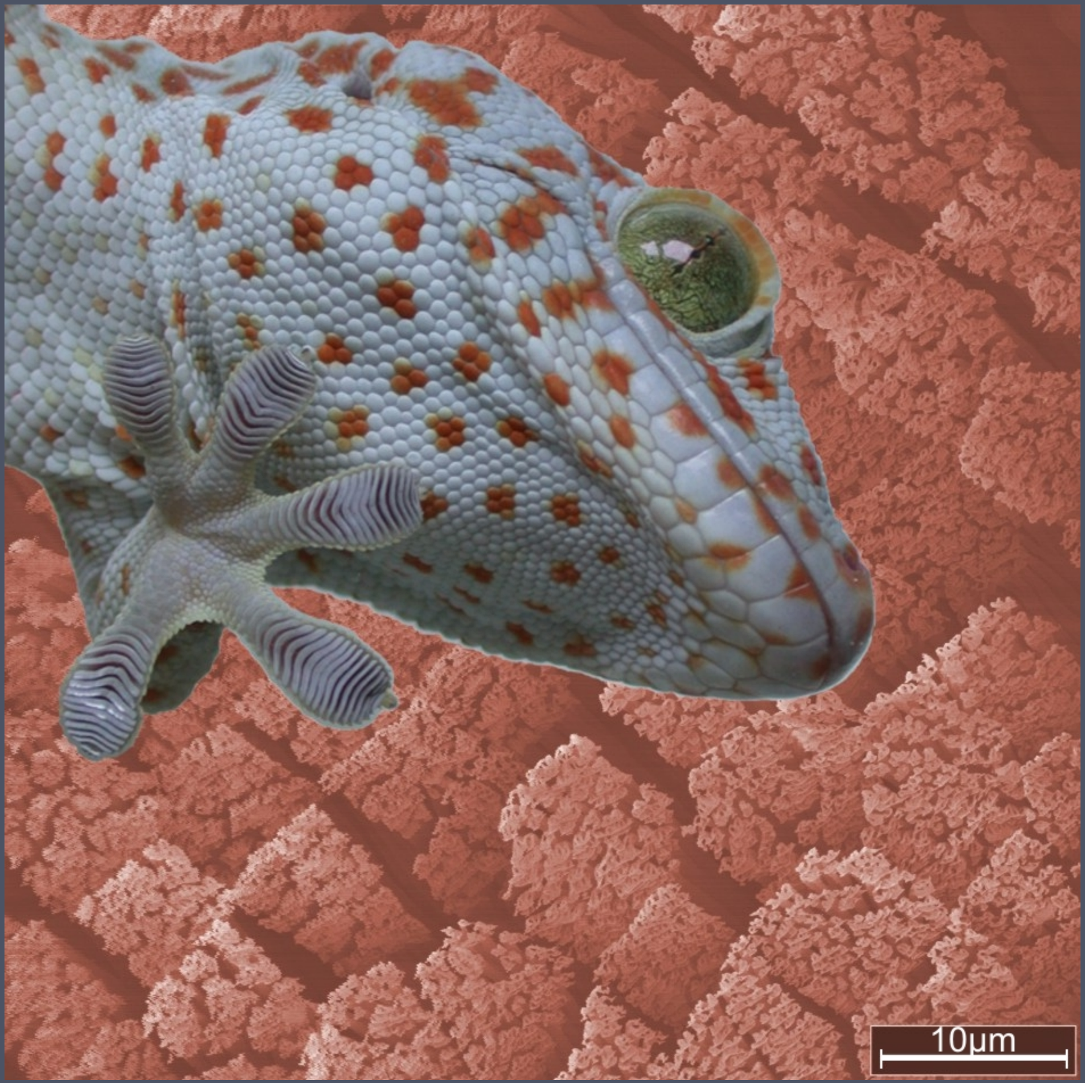
$$assume:\ F_C(n) \propto m\ (mass)$$

$$\sqrt{n}\, m^{1/3} \propto m$$

$$\frac{n}{area} \propto \frac{n}{m^{2/3}} \propto m^{2/3}$$

self-similar scaling





courtesy of S. Gorb

Schlussfolgerungen

- Kleiner ist nicht immer besser (aber oft;)).
- Längenskalen brauchen Bezugspunkte.
- Metalle verhalten sich wie Keramiken, wenn man sie klein genug macht.
- Viele, aber nicht alle Materialeigenschaften sind grössenabhängig.
- In diesen Fällen liegt die optimale Längenskala bei ein paar Hundert Nanometern.
- Bruchmechanik ist das Bindeglied zwischen Geckohaftung und Materialversagen.