Metallic Implants In Biomedical Engineering

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Implants

- substitution of damaged mechanical and physical functions of the
- human body
- temporary implants and long-term implants
- direct contact with human tissue

  ➡ Choice of the right material is very important

Used materials:

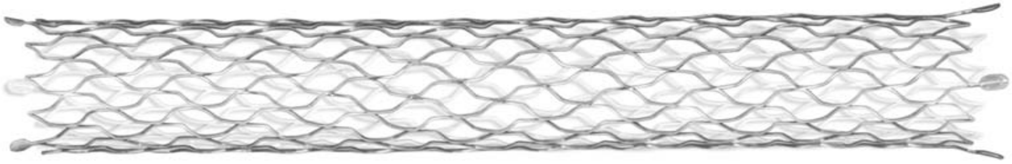
- polymers
- metals
- ceramics

Metallic Implants

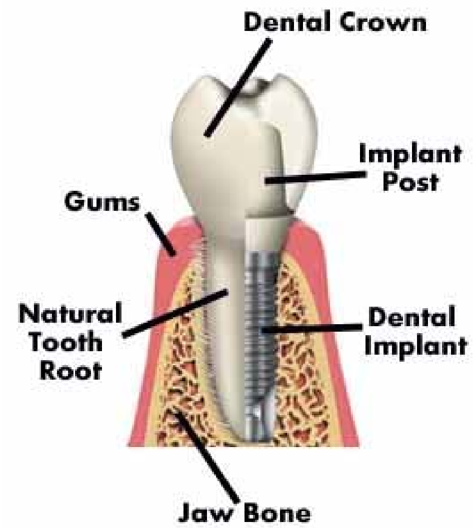
Main applications for metallic implants

- Osteosynthesis and joint replacement
- dental surgery
- vascular surgery

[1] Screws, nails and plates for bone fractures



[2] Stent



[3] Dental implant

[1] http://www.beverlyhillsperio.com/dental-implants.html
[2] http://www.opti-med.de/nc/produkte/details/p-kategorie/vaskulaere-interventionen/subkategorie/stents/p-produkt/sinus-repo-visual-6f/
[3] http://www.beverlyhillsperio.com/dental-implants.html

Demands On Metallic Implants

- **Mechanical strength:** guarantee of steady load transmission between implant and body tissue, similar stiffness of implant to the bone.
- **Biocompatibility:** no damage of body tissue by the implant or primary corrosion products and abrasion particles.
- **Corrosive stability** (in many cases), for some applications absorbable metals are necessary
- **Haemocompatibility** (for implants in contact with blood): behaviour of material surfaces to blood

➡ **metals used in medical engineering** for non-absorbable implants:

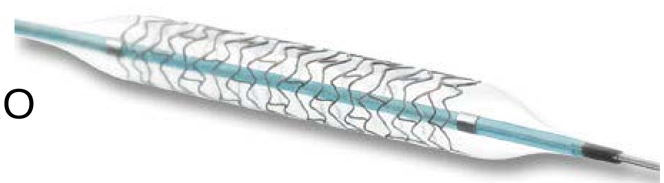
- stainless steel

- cobalt alloys

- Ti and Ti-alloys

Biocompatible Metals

- **Stainless steel 316L:** Cr 17–20 wt.%, Ni 12–14 wt.%, Mo 2–4 wt.%
  Application: plates, screws
- **CoCr-Alloys:** Cr < 27 wt.%, Mo 5-7 wt.%, Ni < 1%
  Application: joint replacement, cardiac valves, stents
- **Ti, Ti-Alloys** TiAl6V4 and TiAl6Nb7
  Application: dental implants, hip joint endoprothesis



[4] CoCr-Stent PRO Kinetic, Biotronik

[5] Ti-hip joint endoprosthesis

[4] http://www.biotronik.de/de/de/884#
[5] http://www.euromed.de

Titanisation of Polymersurfaces

- Formation of TiO_2
- Excellence **adsorption of proteins** on implant-surface

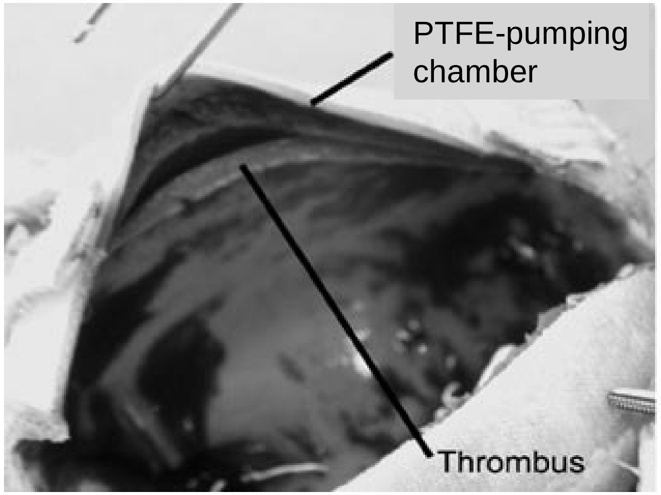
  ➡ higher **cell vitality** than on uncoated polymers

  ➡ **integration of implant** in human tissue

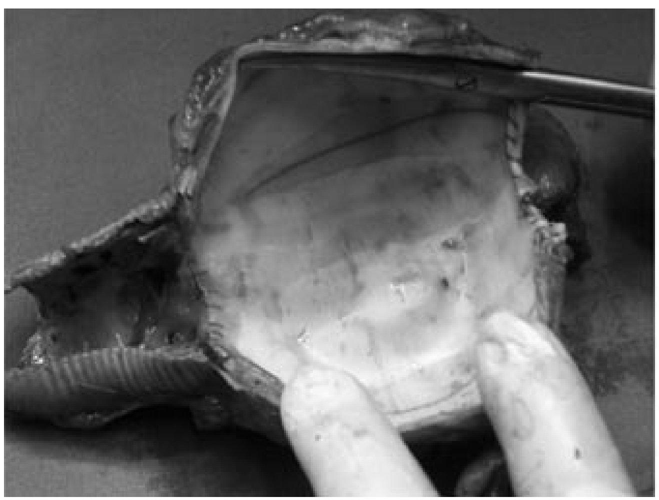
- Ti-coated surfaces act **anti-thrombogenic**

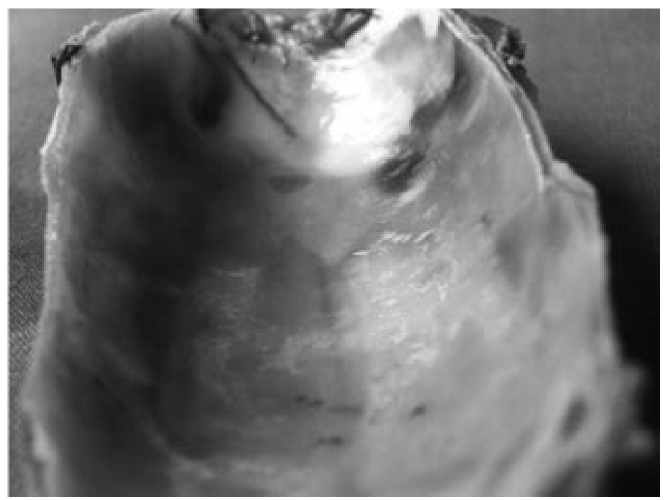
Applications: vascular implants, artificial hearts

Ti-coated Biomechanical Heart (BMH)



PTFE-pumping chamber of a BMH after an implantation time of 8 weeks. Inner surface completely covered by a thrombus.





Ti-coated PTFE-pumping chamber of BMH after an implantation time of 6,5 month. Inner surface is thinly covered with endothelial tissue.

[6] E. Wintermantel. Medizintechnik – Life Science Engineering. Springer-Verlag, 2009.

Bioabsorbable Implants

Applications:

- sutures
- Plates, screws
- Stents

Advantages:

- Avoidance of a second surgery
- No negative impact on the issue caused by mechanical long-term loading

Disadvantage:

Today mainly implants made from polymers (PLA, PGA)

➡ limited mechanical properties and inflammatory response

➡ **Solution: metallic bioabsorbable implants**
(iron, magnesium, zinc)

Magnesium as Implant-material

Why magnesium?

- **Hypothrombogenic** properties and **tissue tolerance**
- **Mechanical properties**
- Important **trace-element** in the human body

But **pure magnesium is too corrosive** as implant-material

➡ Usage of magnesium alloys

➡ Coatings

Magnesium Alloys in Implantology

Assortment of used **alloys**: AZ91, WE43, MgCa0.8

- **Al:** improvement of corrosion behaviour ($Mg_{17}Al_{12}$, Mg_2Al_3)
- **Ca:** for higher creep resistance
- **Mn:** catcher of iron and reduction of corrosive activity of residual Fe-impurities
- **Y, Nd, Zn:** improvement in mechanical strength
- **Zr:** grain refinement

[7] MgCa0.8 bone screws

[7] N. Erdmann et al. Acta Biomaterialia 7 (2011) 1421–1428

Magnesium Alloy Stent

- Composition of WE43 [8]

Element	Ratio [wt.%]
Yttrium	3.7 – 4.3
Rare Earth Elements	2.4 – 4.4
thereof Neodym	2.0 – 2.5
Zirconium	0.4 min
Magnesium	Balance

- Lifetime of a WE43 stent is 2 months in human body [9]
- Assumed Lifetime > 4 months

➡ coatings for improved corrosion behaviour

[8] Magnesium Elektron. Elektron WE43 Wrought Alloy – Datasheet: 478.
[9] J.A. Ormiston et al. Bioabsorbable Coronary Stents. Contemporary Reviews in Interventional Cardiology 2 (2009) 255 - 260.

Coatings

- **Polymer-Coating:**
  - → no bare metal implant
  - → negative properties of a polymer implant, only as drug-eluting system useful [10]

- **Metallic Coating:**
  - ➢ electrochemical methods
  - ➢ Physical and Chemical Vapour Deposition (PVD, CVD)

Problem: in many cases no sufficient adhesion

→ **Thermal Treatment**

[10] R. Erbel et al. Herz 32 (2007) 308 – 19.

Aim of thermal treatment:

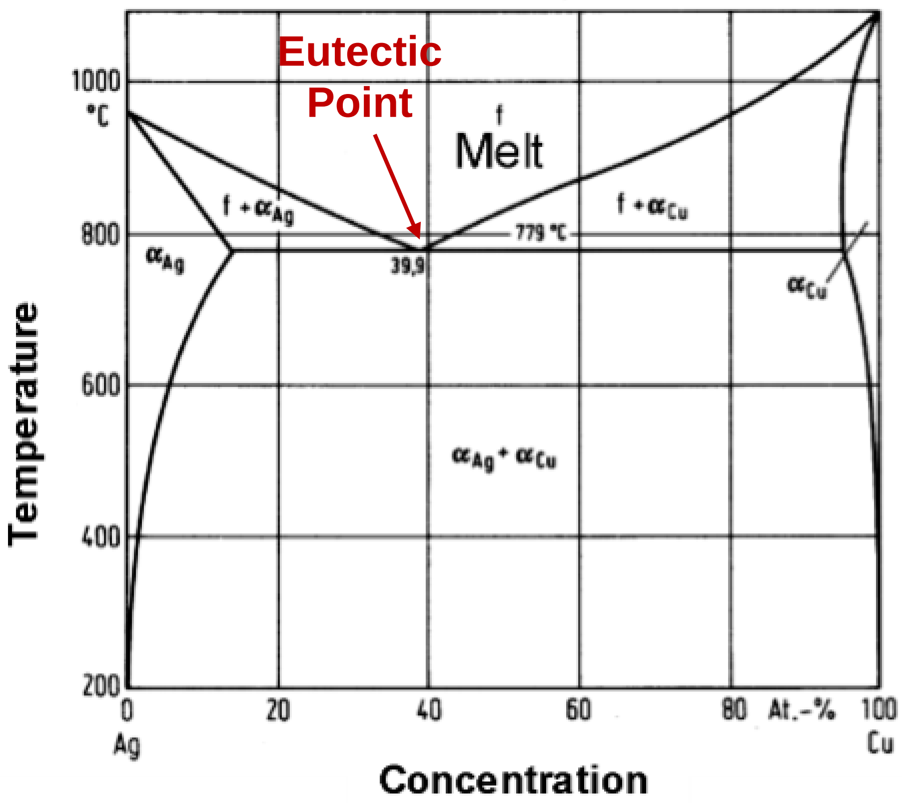
- good coating adhesion
- only alloying in the contact region

➡ **utilisation of eutectic systems**

Eutectic system:

melting point of the binary system of two substances has a lower temperature than the melting points of the pure substances.

Eutectic Phase Diagram

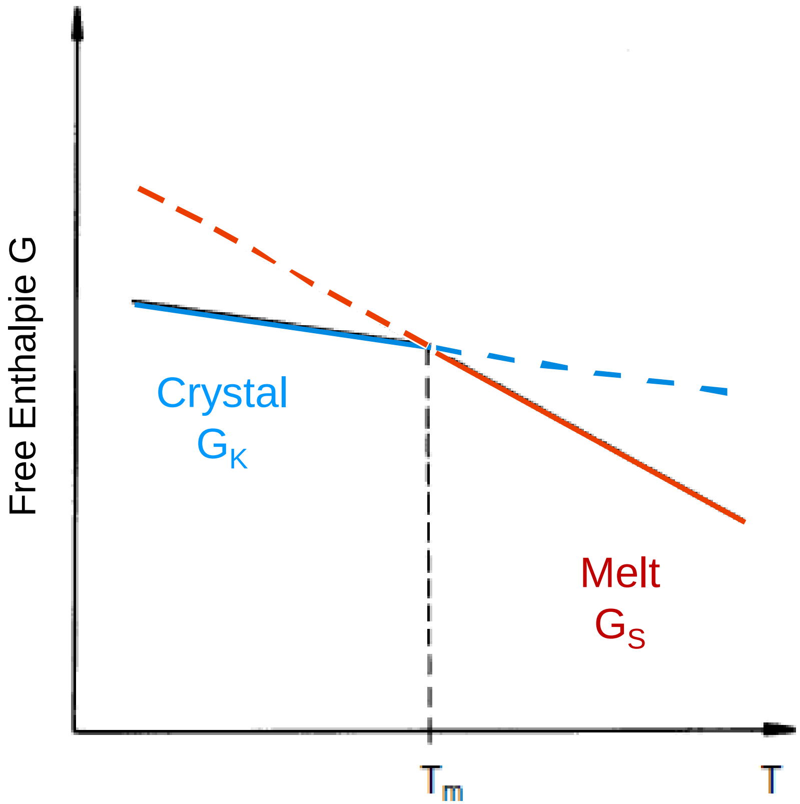


- Formed phases at eutectic point are called eutectic alloys
- Technical usage of eutectic alloys for brazing (Sn62Pb38)
- Popular application of eutectics in medical engineering are amalgam fillings

[11] Eutectic phase diagramm Ag-Cu

[11] E. Hornbogen. Metalle. Springer-Verlag, 2006.

Thermodynamical Illustrations

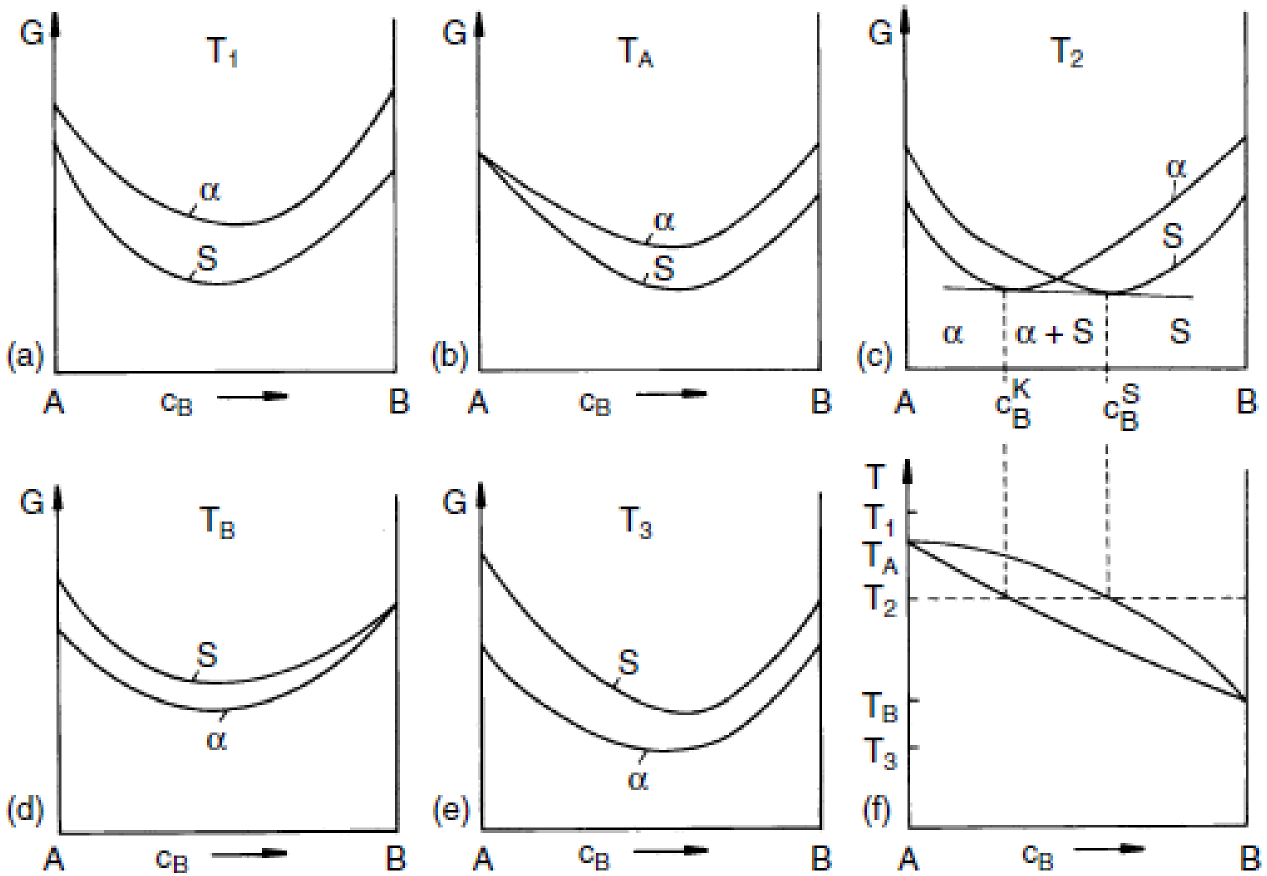


[12] Free Enthalpie of a pure metal as a function of temperature for solid and liquid phase.

- Generally the phase with the lowest free energy will appear
- Free energy of crystal and melt are different
  - ➡ intersection point
  - ➡ melting point

[12] G. Gottstein. Physikalische Grundlagen der Materialkunde. Springer-Verlag 2007.

Binary Alloys with full Miscibility

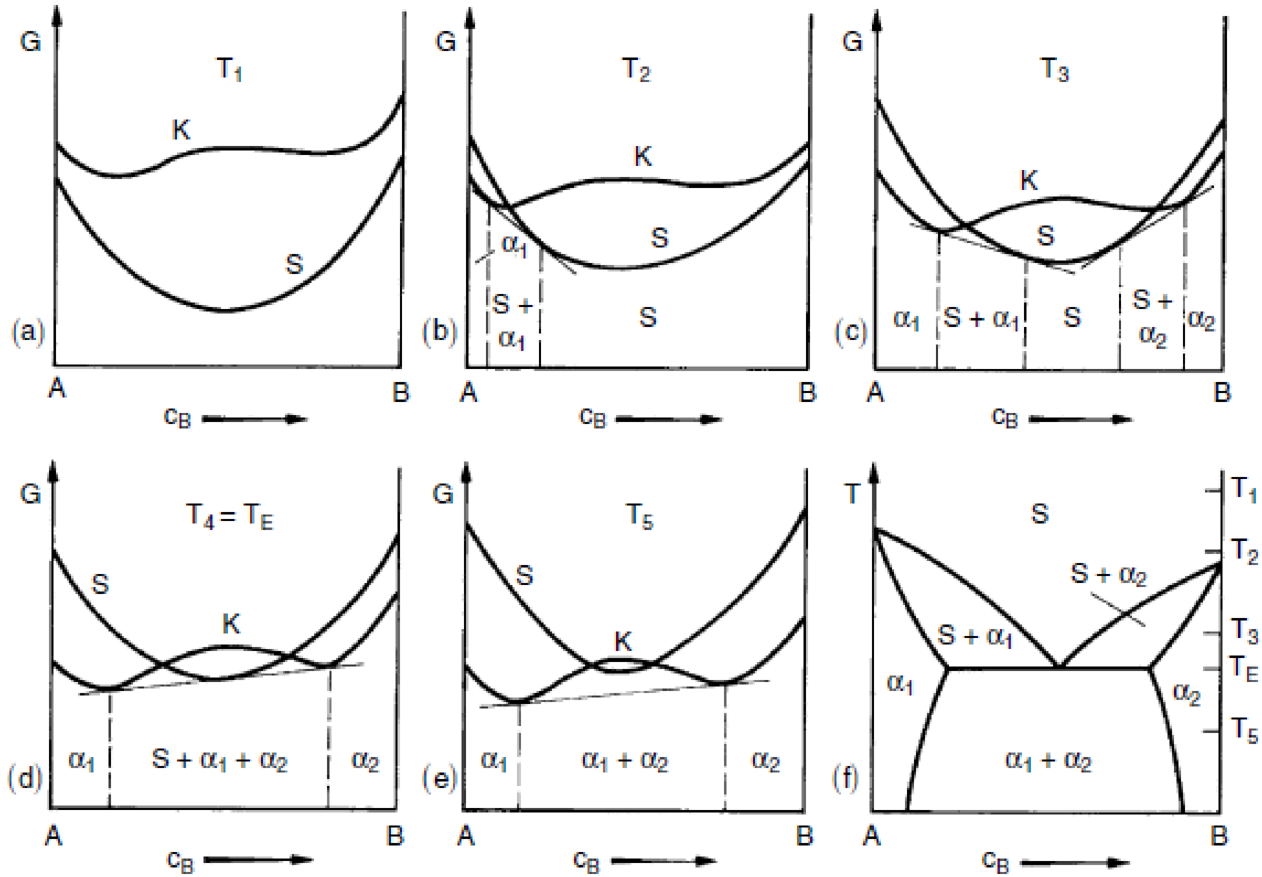


[12] Free enthalpie of crystal (α) and melt (S) of a binary alloy at different temperatures in (a)-(e), (f) phase diagram.

- Approximation of the free enthalpie of a binary alloy by a parabola
- phase with lowest free enthalphie appears, here also dependend on concentration

[12] G. Gottstein. Physikalische Grundlagen der Materialkunde. Springer-Verlag 2007.

Binary Eutectic System



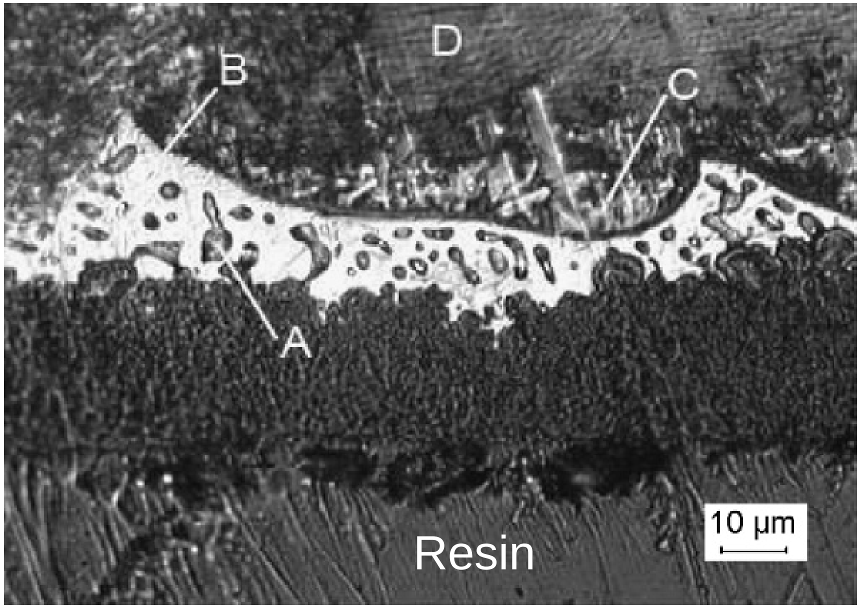
- miscibility gap in the solid state

➡ two minima in the free enthalphie curve of the crystal

[12] Free enthalpie of crystal (α) and melt (S) of a binary eutectic system at different temperatures in (a)-(e), (f) phase diagram.

[12] G. Gottstein. Physikalische Grundlagen der Materialkunde. Springer-Verlag 2007.

Thermal Treatment of coated AZ91

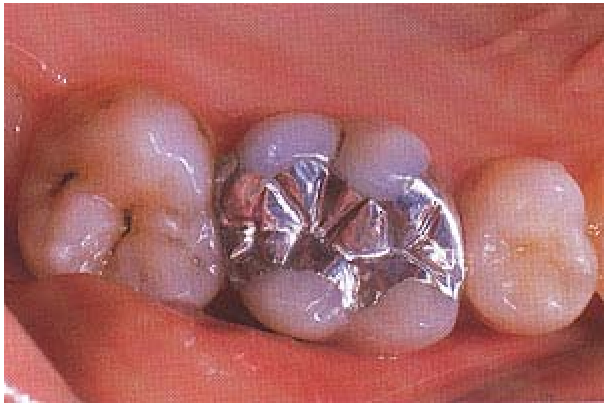


[13] Cross-section of a Zn, Al-coated AZ91 after thermal treatment at 700 K for 12 h.

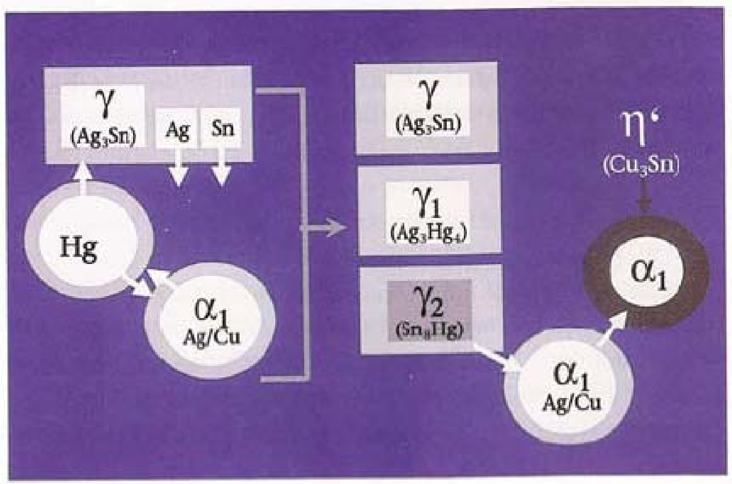
Area	Mg (at. %)	Zn (at. %)	Al (at. %)
A	54.33	8.67	37.00
B	48.57	16.20	35.23
C	83.63	4.24	12.13
D	88.29	1.70	10.01

[13] H. Meifeng et al. Journal of Alloys and Compounds 469 (2009) 417–421.

Amalgam Fillings



[14] Amalgam filling



[15] Phase-constitution of HCD-amalgam

- Hg + "Alloy" (metallic powder) ratio 1:1

  components of the "Alloy":

> 40 % Ag	< 5 % In
< 32 % Sn	< 3 % Hg
< 30 % Cu	< 2 % Zn

Usage of eutectic Ag-Cu (72 wt.% Ag, 28 wt.% Cu) and Ag_3Sn.

- dissolution of alloy in Hg and precipitation of new crystalline phases after exceeding the saturation concentration

  → hardening of the alloy (24 h)

[14] http://www.drstaschke.de/34/Füllungen%20&%20Inlays.html
[15] Kamann W. Die Amalgamfüllung. Deutscher Zahnärzteverlag, 2003.

State-of-the-art and Prospects

- Metals with good suitability for long-term implants
- Intensified research on bioabsorbable metals
- Efforts on the achievement of a better understanding of the processes on implant-surfaces (electrochemical processes, protein adsorption)
- Progress in stem cells research and tissue engineering could substitute implants in parts

Thank you for your attention!