

Structure and Properties of Titanium Oxide Layers prepared by Metal Plasma Immersion Ion Implantation and Deposition

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Motivation

For medical materials in contact with **blood** it is important to minimize the tendency of their surface to adsorb blood proteins and to induce blood clotting, hence, to reduce the danger of thrombosis. Coatings based on **titanium oxide** are a very promising approach in this direction.

Objectives

Synthesis of bioinert and **blood compatible** coatings based on **titanium oxide** by **Metal Plasma Immersion Ion Implantation and Deposition** (MePIIID), modification of the surface layers by **ion implantation (P and Cr)** and annealing

Study of the dependence of crystal structure (**crystalline rutile, anatase and brookite**, nanocrystalline, **amorphous TiO₂**), surface **roughness** and electrical properties of **titanium oxide** layers on the deposition parameters

Investigation of the relation between physical properties of the **titanium oxide** layers and **blood compatibility**

Summary

- MePIIID provides a useful technique to control composition and structure of **titanium oxide** films. In dependence on the deposition parameters **amorphous** and **nanocrystalline** structures, **crystalline** layers composed of **anatase** and **brookite** as well as layers dominated by the **rutile** phase have been produced
- Crystal structure and crystallite size of **titanium oxide** films seem to have only minimal influence on the activation of the plasmatic clotting system. As a trend, **amorphous**, **nanocrystalline** and fine-grained layers induce less **clotting of blood plasma** than well **crystallized rutile** films
- **P and Cr implantation** clearly reduces the **clot forming property** of the surface
- Microstructure of the **Ti oxides** showed a opposite effects on **platelet adherence** and **activation** of the clotting cascade. However, **P⁺-doped rutile** shows an improved behaviour in both cases
- **Roughness** of the surface below 50 nm seems to be no important parameter

Experimental

Deposition parameters:

Specimen temperature (T_{max}): 25 – 500 °C
Oxygen flow rate (F): 60 – 180 sccm
Bias voltage (ion energy): 0 – 2.5 kV
TiO₂ deposition rate (R_{dep}): 0.2 – 1.1 μm/min
Current of the cathodic arc discharge (I): 110 A
Basic vacuum: $0.5 - 1 \times 10^{-3}$ Pa
Working pressure: $0.5 - 1 \times 10^{-1}$ Pa
Substrate: SiO₂ on Si (100)

Implantation:

10^{15} P⁺/cm² (30 keV);
 5×10^{17} Cr⁺/cm² (30 keV)

Post-implantation annealing:

900 °C for 1 h (vacuum)

Analysis

AES: depth distribution of the elements
XRD: phase formation and identification
RBS: thickness of the deposited films
AFM: roughness of the deposited films

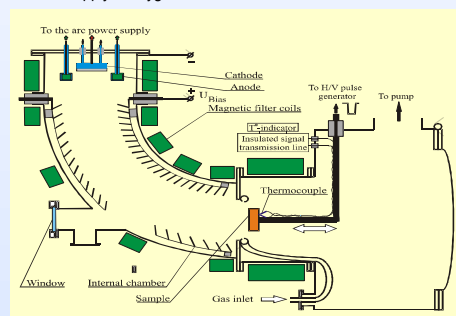
Four point probe technique:

sheet resistance

Blood compatibility:

blood clotting time
platelet adhesion and activation

MePIIID: metal deposition + plasma immersion ion implantation (PIII)
metal plasma by cathodic arc evaporation
implantation by pulsed negative substrate bias
supply of oxygen near the substrate



Schematic diagram of the MePIIID device

Blood compatibility

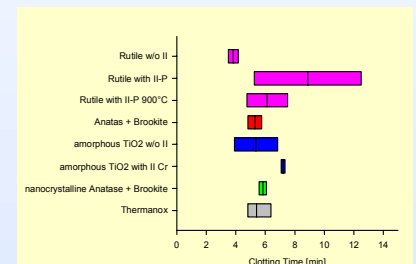


Fig.3. Clotting time:

Median and quartils of the blood clotting time on the test surfaces

Layer properties

Oxygen concentration and deposition rate

- oxygen concentration is nearly independent of oxygen flow rate F (see Fig. 1), substrate temperature and implantation voltage; TiO₂ is formed
- deposition rate increases strongly with substrate temperature 450 °C - 1.1 μm/60 s and 116 °C - 0.23 μm/60 s for U=2.5 kV and F=180 sccm
- increasing F reduces the deposition rate strongly 60 sccm - 540 nm/60 s, 120 sccm- 350 nm/60 s, 180 sccm- 240 nm/60 s for U=2.5 kV and $T_{max} \sim 120^\circ\text{C}$ (see Fig. 1)
- influence of the implantation voltage on the deposition rate is only weak

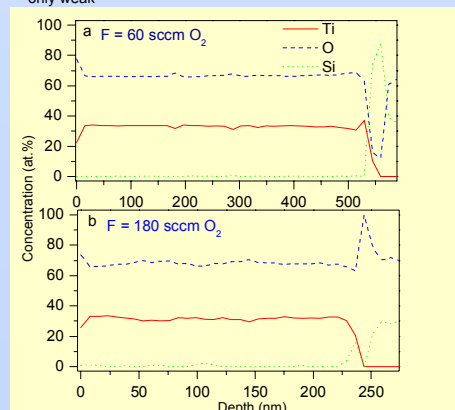


Fig.1. AES depth profiles of Ti oxide layers deposited with U = 2.5 kV at $T_{max} = 120^\circ\text{C}$ for different oxygen flow rates F

Phase composition of the oxide layer

Dependence of the Ti oxide structure on the deposition parameters

structure	T, °C	F, sccm	U, kV
rutile	~ 450	180	- 2.5
anatase + brookite	~ 350	60	- 2.5
amorphous TiO ₂ - layer	~ 80	180	0
nanocrystalline anatase + brookite	~ 60	60	0

Electrical properties and roughness of the different Ti oxide layers

structure	sheet resistance	roughness S_z , nm
rutile	>200 kOhm	high - 34.2
rutile + P ⁺ implantation (II)	~90 kOhm	high - 30.1
rutile + P ⁺ -II + annealing	~60 kOhm	high - 39.8
anatase + brookite	~25 Ohm	high - 42.7
amorphous TiO ₂ - layer	>200 kOhm	low - 4.15
amorphous TiO ₂ - layer + Cr ⁺ -II	~100 Ohm	high - 31.9
nanocrystalline anatase + brookite	~100 Ohm	low - 5.35

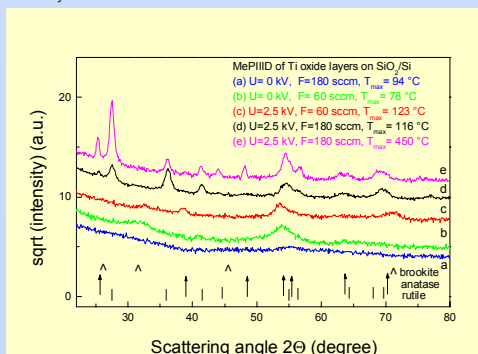


Fig.2. XRD pattern of Ti oxide layers deposited with different parameters

- both P⁺ and Cr⁺ ion implantation (II-P and II-Cr) increase the **clotting time**, i.e. reduce the activation of the clotting cascade by this surface
- well **crystallized** samples dominated by the **rutile** structure show the lowest **clotting time**
- the behaviour of the **amorphous** and nanocrystalline samples is in between

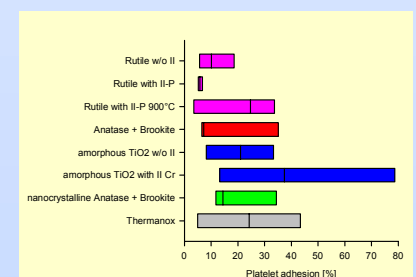


Fig.4. Platelet adhesion:

Bars indicate median and quartils of the percent adherent platelets from a sample platelet rich plasma on the test surfaces

- P⁺ ion implantation (II-P) reduces the **platelet adherence** to the surface, whereas Cr⁺ ion implantation (II-Cr) greatly increases it
- As a vague trend lower **platelet adherence** on **crystalline** coatings than on **amorphous** ones is found (contrary to the behaviour of the **clotting time**)