FORSCHUNGSZENTRUM ROSSENDORF
Institute of Ion Beam Physics and Materials Research

R&D Topic: Biocompatible Materials

Deposition of Ti Based Coatings with Different Surface Structure and Chemistry for Medical Devices

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Motivation

Cobalt chromium alloys are still mainly used for orthopaedic implants. However, the biocompatibility of cobalt-chromium alloys is inferior to titanium based implants. Titanium has the technical disadvantages of low shear resistance and high production of wear debris at cemented fixation or in case of loosening.

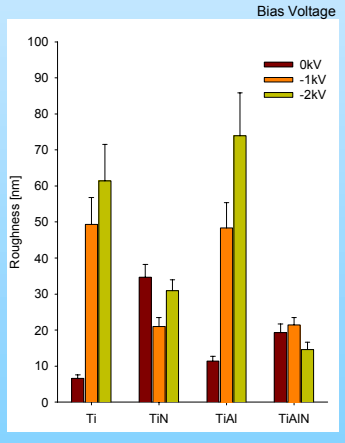
Hard Ti based coatings on stainless steel could be an economical method to improve the biocompatibility and corrosion resistance of steel without the the poor shear properties of titanium.

TiN coatings are widely accepted as hard coatings. Substitution of up to 60% Ti atoms with Al, maintaining the TiN crystal structure, results in the formation of TiAlN, which has even better hardness and corrosion resistance, thus allowing thinner layers to give the same effect as TiN.

Experimental Approach

- Deposition of Ti, TiN, TiAl and TiAlN coatings on mirror polished stainless steel by plasma immersion ion implantation assisted deposition. Samples of each type of coating were produced at 0kV, -1kV and -2 kV pulsed negative bias voltage.
- Measurement of the roughness by atomic force microscopy
- Adherence and spreading of rat bone marrow cells after six hours in medium without serum
- Adherence and spreading of rat bone marrow cells after six hours in medium with serum
- Metabolic activity (MTT test) at rat bone marrow cells after 14 days growth in a differentiation supporting medium medium with ascorbic acid, dexamethasone and β-glycerophosphate.
- Alkaline phosphatase activity as a differentiation marker of rat bone marrow cells after 14 days of growth in a differentiation supporting medium

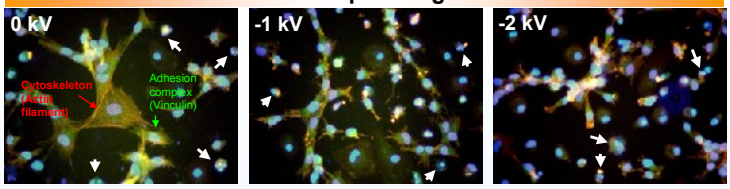
Surface Roughness



The roughness of all samples was below 100 nm. For coatings without nitrogen the roughness increased with the bias voltage, whereas for coatings with N the roughness was relatively independent from the bias voltage.

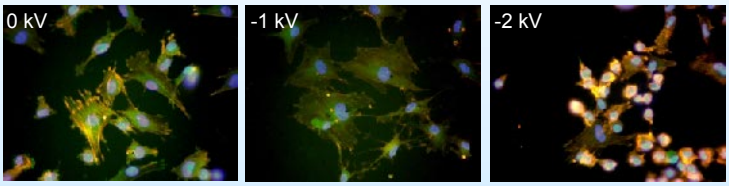
The roughness occurs from sputtering of the surface. Due to the hardness of the N containing coatings there is only minor sputtering on TiN and TiAlN than on Ti and TiAl at any bias voltage.

Cell Adherence and Spreading Without Serum



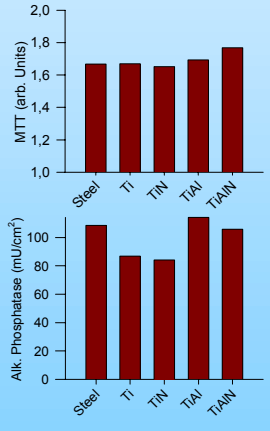
- TiAlN as a representative example. There was obviously the widest spreading of the cells and the best organisation of the cytoskeleton on the 0 kV biased samples (left). This was found also on the other types of coating, independent from chemistry or roughness.
- A high percentage of fragmented, pyknotic nuclei (white arrows) was seen only when working without serum.

Cell-Adherence in Presence of 15% Serum



- No influence of surface chemistry on cell adhesion and spreading
- No influence of surface roughness on surface adhesion and spreading
- Less influence of the synthesis parameter bias voltage than at serum-free adhesion
- No signs of apoptosis morphologically as well as in an annexin/ propidium iodide stain.

14 Days Performance



Functionally graded coatings, having a substrate-coating interphase deposited with -2 kV bias voltage and a top layer deposited without any bias were used for extended experiments.

After 14 days growth of the cells in a medium, which supports osteoblastic differentiation, there was nearly no difference in the metabolic activity rated by surface area with a slight trend to a higher metabolic activity on the Al containing coatings, i.e. TiAl and TiAlN, compared with steel, Ti and TiN (top). Also the alkaline phosphatase activity after that time of differentiation on TiAl and TiAlN was slightly higher than on Ti and TiN (bottom).

Summary and Conclusions

- ✓ The biocompatibility of hard, Ti based coatings with various chemistry, roughness and synthesis parameters was investigated.
- ✓ The hard Ti based coatings like TiAlN are acceptable surfaces for bone forming cells. Therefore, they can be considered as coatings for orthopaedic implants.
- ✓ As a trend on all types of coating the cell adherence and was better on unbiased deposited coatings, independent from roughness or chemistry. This is suggestive for effects of crystal structure or surface stress.
- ✓ The high rate of apoptosis in the adherence experiments without serum can be attributed to the lack of growth factors of the serum.

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