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Plasma Nanofilms as Biocompatible and Antibacterial Interface for In-Vivo Sensors

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Abstract

In this work the magnetron enhanced plasma polymerization was used to produce bio-hemocompatible surface coatings. Their physical and chemical properties as well as their behavior in biological environment in-vivo and in-vitro were investigated. By the precise detection of the protein adsorption, one could devise the best process parameters. The implantation of a coated sensor dummy proved a highly biocompatible respectively bioinert coating. This type of coating drastically increases the functionality and efficiency of many medical implants and in-vivo sensors.

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Keywords: biocompatibility, hemocompatibility, plasma nanofilm, plasma polymerization, bioinert

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1. Introduction

In the development of biocompatible materials for biomedical applications and biosensors, the foreign body response is an important issue [1]–[3]. The healing of tissue surrounding the device often interferes with its function. Events like protein deposition, hemostasis, inflammation, tissue repair, infections and the encapsulation of the functional part of the sensor for example are the main cause of failure of the implanted device [4]. In this study biocompatible nanofilms are produced by means of a plasma polymerization process using a low-pressure magnetron-enhanced 15 kHz glow discharge. This process allows the precise adaption of the surface properties to ensure a biocompatible and antibacterial interface.

2. Experimental Section and Discussion

2.1 Plasma Polymerization

A magnetron enhanced plasma polymerization process was conducted in a system from the company Shinko Seiki. This comprises two parallel titanium electrodes with a distance of 10 cm. In between the samples rotate on a wheel at floating potential. The circular movement of the samples ensures a good homogeneity of the resulting plasma nanofilms. Circularly arranged magnets behind the electrodes concentrate the plasma between the electrodes. This concentration leads to a higher efficiency as well as a better thickness homogeneity. Before every coating the plasma chamber is evacuated down to a pressure of 0.1 Pa to eliminate the possibility of cross contamination. Afterwards, the process is run at a pressure of 5 Pa. A mixture of methane and oxygen was used as starting material. Depending on the mixture of these gases different amount of oxygen was embedded into the film. Subsequently, different surface properties could be achieved. The different recipes are listed in Table 1. Further information can be found elsewhere [5], [6].

Table 1: process parameters used for the different model surfaces to be analyzed

<table>
<thead>
<tr>
<th>recipe</th>
<th>gases and flowrates [sccm]</th>
<th>growth rate [nm/min]</th>
<th>power [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2.5 CH₄ + 1.3 O₂</td>
<td>0.2</td>
<td>45</td>
</tr>
<tr>
<td>II</td>
<td>2.8 CH₄ + 1.1 O₂</td>
<td>0.9</td>
<td>45</td>
</tr>
<tr>
<td>III</td>
<td>3.0 CH₄ + 1.0 O₂</td>
<td>1.2</td>
<td>45</td>
</tr>
<tr>
<td>IV</td>
<td>5.0 CH₄</td>
<td>2.0</td>
<td>45</td>
</tr>
</tbody>
</table>

2.2 Physical and Chemical Characterization of the Plasma Nanofilms

The plasma nanofilms were investigated using different surface analytical methods such as x-ray photoelectron spectroscopy (XPS) and water contact angle (WCA).
X-ray photoelectron spectroscopy and dynamic contact angle measurements were performed to gain information about the chemical/physical properties of the plasma coatings and are correlated to the behavior of those surfaces in biological systems.

A higher amount of polar groups was embedded into the film [Table 2] when more oxygen was used in the precursor gas mix; this correlates well with the decreased water contact angle [Fig. 2]. The embedding of more oxygen and therefore more polar groups into the nanofilm leads to a decreasing dynamic water contact angle and the contact angle nearly can be tuned continuously. Also the aging of these nanofilms was investigated using this measurement technique. One noticed a very low aging when keeping the samples in a solution such as deionized water.

<table>
<thead>
<tr>
<th>Coating recipe [number]</th>
<th>C percentage in the nanofilm [%]</th>
<th>O percentage in the nanofilm [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>65</td>
<td>31</td>
</tr>
<tr>
<td>II</td>
<td>71</td>
<td>26</td>
</tr>
<tr>
<td>III</td>
<td>72</td>
<td>25</td>
</tr>
<tr>
<td>IV</td>
<td>89</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 2: Composition of the different nanofilms analysed by XPS and a take-off angle of 45°

2.3 Biological Characterization of the Plasma Nanofilms

Beyond the different surface analytical methods, the in-vitro interaction with different biological sample materials was also tested. As it is known from the foreign body response, one can notice that proteins are usually the first constituents arriving on a foreign surface implanted in to the human body. Therefore it is important to investigate this initial event, which determines the following events such as encapsulation. This was done in-vitro by quartz crystal microbalance measurements to detect the adsorbed amounts of proteins [Figure 3]. From these results it could be deduced that the amount of adsorbed proteins on the interface also correlates with the coating recipe. The adsorption of proteins could be tailored from a high deposition compared to a bare gold surface to a very low deposition on recipe I. Using the molar weight of the proteins and the maximum coverage of proteins on the surface, one can deduce a very native structure of adsorbed proteins on the surface. This was confirmed by measurements using Fourier transform infrared spectroscopy (FTIR) measuring a comparable protein structure on recipe I as native protein in buffer solution. [5]
The antibacterial behavior of the coating was tested using E. coli GFP. Different types of materials were coated and examined, including polystyrene, polymethylmethacrylat (PMMA), glass and silicon. These samples were inspected after 24 h via fluorescent microscopy. Figure 4 shows the immense reduction of attached bacteria.

This study clearly shows the antibacterial behavior of the plasma coating. Reduction in bacteria adhesion of up to 99 % could be reached, regarding the “first colonizers”.

Considering these promising in-vitro results, sensor dummies were implanted into a swine for 6 month. The place of implantation was the superior vena cava. The substrate material was titanium. After the implantation it could be seen that the sample was kept completely free of any encapsulation on the coated part whereas the uncoated part of the sensor was completely encapsulated by a collagen bag.

### 4. Conclusion

The flexibility of the coating process allows the tailoring of the substrate/surrounding interface. The implantation of polar groups like oxygen can be tuned continuously. Especially for biosensors this coating provides an opportunity to enhance the biocompatibility without disturbing the inherent functionality of the sensors.

### References


