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Interactions between carbon coatings and tissue ☆

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Abstract

The unique properties of thin diamond layers make them perspective candidates for producing advanced micro-electronic devices, coatings for cutting tools and optics. However, due to the highest biocompatibility of carbon resulting from the presence of this element in the human body, it appears to be a potential biomaterial.

Carbon, especially in the form of the nanocrystalline diamond film, have found industrial applications in the area of medical implants.

The studies of carbon films as coatings for implants in surgery were aimed at the investigations of biological resistance of implants, histopathological investigations on laboratory animals, tests of corrosion resistance, measurements of mechanical properties and a breakdown test in Tyrode's solution.

Different medical implants are covered by Nanocrystalline Diamond Coatings (NCD). NCD forms the barrier diffusion between implant and human environment. The research on NCD proved that diamond layers are biocompatible with living organisms.

Diamond Powder Particles (DPP) is an extended surface of NCD. Biological research with diamond powder can answer the basic question: what is the influence of DPP on cells, tissues and organs in human organism?

Keywords: Biocompatibility; Carbon films; Nanocrystalline Diamond Coatings (NCD); Diamond Powder Particles (DPP); Medical implants

1. Introduction

All allotropic forms of carbon meet the requirements for the implants. These requirements are for instance: biotolerance and mechanical strength. The tests of applications of different allotropic forms of carbon in medicine were made.

Without the element carbon, life as we know would not exist. Carbon provides the framework for all tissues of plants and animals. These tissues are built of elements grouped around in chains and rings made of carbon atoms.

Such an interesting element has obviously been investigated and because chemistry is based on outer-shell electrons (also known as the valence electrons), it is believed that the secret of carbon is hidden in these valence electrons. Out of six electrons surrounding the carbon atom nuclei, two are able to create chemical bonds. When certain amount of energy is spent, carbon atom is in the excited state and then four outer-shell electrons determine the variety of carbon structure as well in the chemical compounds as in the pure carbon modifications. In diamond lattice, each carbon atom is connected to four other ones. All valence electrons are involved in creating chemical bonds. Diamond crystal is an example of valence structure, because each atom of carbon, situated in tetrahedron, is connected with one another by a covalent bond. Diamond is considered to be one of the hardest materials. Besides, it is the best heat conductor.

The second modification–graphite–is a complete opposite of diamond. It splits easily and conducts electricity. Graphite is an example of intermediate structure. So except diamond and graphite, also other carbon modifications exist—these are carbines.

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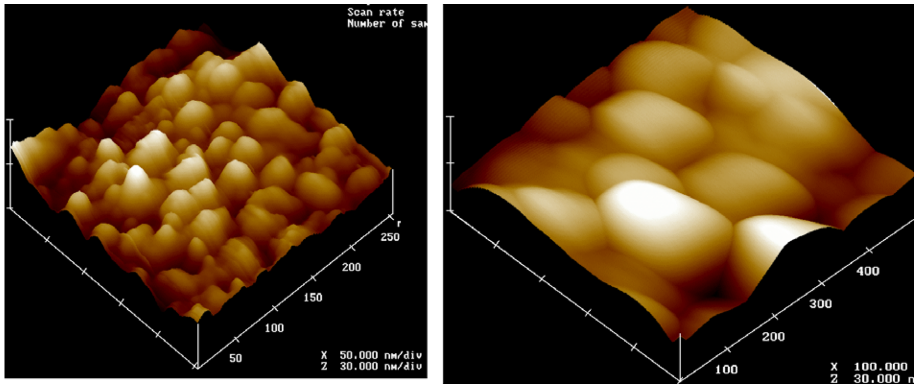

Fig. 1. AFM image of NCD (left) and DLC (right) film deposited by RF dense PCVD method.

Carbines are the least investigated and known allotropic form of carbon. Nowadays, there are more than six carbine modifications, but carbines α and β are best investigated [1].

Fullerens form another modification of pure carbon. Their archetype is the molecule C_{60}. This structure was firstly studied by American engineer and philosopher Buckminster Fuller. That is why the new molecule was named buckminsterfullerene. Nanotubes–another form of carbon–are clusters creating tubes whose length may reach even to 0.1 m. Tube walls are formed by regular hexagons and there are channels with diameters about 2 nm inside the tube.

All mentioned allotropic forms of carbon are revolutionary and change our today's look at technology work. Their application range is getting wider and wider, especially applications in electronics and medicine are worth being considered.

Diamond Powder Particles is the new antioxidant and anti-inflammatory factor in living organism [16]. This mechanism is probably based on the reaction between the surface of diamond [17] in nanoparticles and molecules in living organism which are responsible for toxic processes [18].

Oxidative stress is the phenomenon which takes part in the damage of cell membrane, for example: the erythrocyte membrane. This mechanism is based on the free radical chain reactions [19]. The result of this process are the products: free radicals—the cause of the damage of cell membrane structure and change properties of cell membrane fluidity and conformations of phospholipid bilayer. Lipid peroxidation is the cause of the damage of nucleus which contains a genetic material (DNA) of this cell. Erythrocyte membrane can be destroyed in mechanism of oxidative stress and it is the base of developing the phenomenon of haemolysis. The clinical name of this process is "anemia haemolytica"—the decrease in the amount of erythrocytes in the peripheral blood from egzogenic or endogenic factors. Haemolysis forms the toxic products—superoxides lipids in cell membrane, and the pathological process in human organism and in aspect of disease can be treated successfully. Medicines, which doctors use to treat this disorder are not completely good because the mechanism of its activity always contains only the symptomatic treatment. It seems that Diamond Powder Particles can be used as an alternative therapy of anemia haemolytica [20].

Carbon coatings of metallic implants—as the materials to be inserted into human body, should satisfy the following requirements [2]:

- Biocompatibility (hemocompatibility and histocompatibility) that means the ability of the human body to endure the implants without destruction of the tissue.
- Chemical stability, which requires that the material is not degraded by environmental agents such as alcohol, sterilants, etc.
- Biostability, which requires that the material is not degraded by biological interactions with the body; they must not initiate reactions in the tissues surrounding an implant.
- Additionally, the system implant/layer must present excellent adhesion and very good mechanical characteristics.

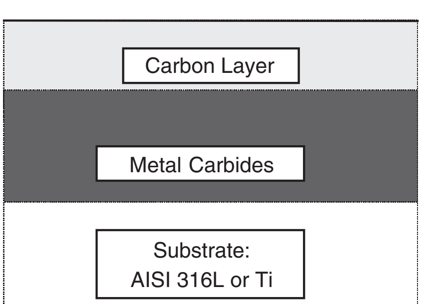

Fig. 2. The diagrammatic model of the carbon coating.

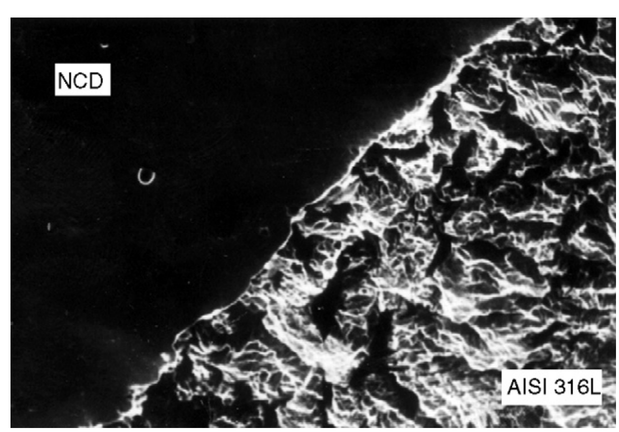

Fig. 3. The corrosion tests, AISI 316L substrates with carbon coatings (left side) and without coating (right side).