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ATOMIC LAYER DEPOSITION OF NOVEL NANOMATERIALS BASED ON METAL-DOPED TITANIUM DIOXIDE TO COMBAT ANTIBIOTIC-RESISTANT BACTERIA *

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Abstract

The new nanomaterials developed based on TiO_2 doped with vanadium, chromium and molybdenum atoms using atomic layer deposition technology have high antibacterial activity against pathogenic bacteria and are biocompatible during implementation into the body of animals. The developed nanotechnology will contribute to the treatment of bacterial infectious diseases, including those caused by antibiotic-resistant bacteria.

The problem of antibiotic resistance of bacteria is recognized by the World Health Organization as one of the ten global threats to humanity. The development of new antibacterial drugs is proposed as a solution to this problem, but the process of developing new antibiotics is complex and expensive, while bacteria quickly adapt to new drugs. Due to their universal mechanisms of antibacterial action, including the destruction of the cell membrane, stopping the division of bacterial cells and their destruction by oxidation of the cellular substance, nanomaterials with antibacterial properties are used to prevent bacterial infections caused by pathogenic microorganisms resistant to antimicrobial drugs. Among the widely used materials, TiO_2 is known due to its non-toxicity, chemical inertness and antibacterial properties. The mechanism of antibacterial action of TiO_2 is relatively well studied and is explained by its photocatalytic (PC) properties. Due to the PC properties, active oxygen species (ROS) are generated on the TiO_2 surface, causing oxidation of internal enzymes and lipid peroxidation of bacterial cells, which reduces respiratory activity and leads to their death. Doping with transition metals is a promising approach to reducing the absorption threshold of TiO_2 and shifting its optical absorption range from the UV light region to the visible part of the spectrum.

We have proposed new reaction systems for the synthesis of titanium dioxide nanofilms doped with vanadium, chromium and molybdenum atoms using atomic layer deposition (ALD) technology. Precursors such as titanium tetrachloride ($TiCl_4$), vanadium oxytrichloride ($VOCl_3$), chromium dichloride dioxide (CrO_2Cl_2), molybdenum oxytetrachloride ($MoOCl_4$), molybdenum dichloride dioxide (MoO_2Cl_2) and water are used to synthesize these nanofilms. The temperature of nanofilm synthesis varies from room temperature to 180 °C, which makes it possible to apply nanocoatings to substrates of various origins (polymer, metal, glass, etc.). To achieve antibacterial properties, a nanocoating thickness of approximately 5 nm is sufficient, which makes the technology cost-effective, scalable and easily commercialized. The use of the ALD method allows obtaining homogeneous highly conformal nanocoatings on the surface of products and substrates of various shapes and sizes with high adhesion, which prevents the release of nanocoating components (metal atoms) into the environment and allows for their long-term multiple use.

Serious complications associated with bacterial infections most often accompany surgeries to introduce implants into the body. Bacterial infection occurs as a result of the adhesion of bacteria and their colonization on the surface of implants and leads to the formation of a biofilm. Bacteria are not free-floating cells, but specifically organized biofilms attached to the substrate, so it is difficult to destroy this biofilm chemically, biologically or mechanically. In our works [1, 2] we demonstrated the efficiency of using ALD nanocoatings based on titanium dioxide doped with vanadium when introducing polypropylene hernia mesh implants and non-absorbable surgical suture materials into the body of rats and rabbits. ALD nanocoating made it possible to increase the biocompatibility and antibacterial properties of the implanted materials, which helps to reduce the inflammatory reaction of the tissues surrounding the implant and helps prevent the eosinophilic cellular response to a foreign body. Microbiological studies conducted using the Koch method showed high antibacterial efficiency of ALD nanocoatings based on titanium dioxide doped with vanadium, molybdenum and chromium in relation to microorganisms of the E.Coli and S.Aureus strains.

Thus, large-scale implementation of the achievements of modern nanotechnology and new synthesized antibacterial nanomaterials using atomic layer deposition (ALD) technology will allow progress in the field of nanomedical technologies in the treatment of bacterial infectious diseases.

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