Ultrananocrystalline diamond coating (UNCD™): Revolutionizing surface engineering

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Unique, low-cost ultrananocrystalline diamond (UNCD™) coating is facilitating new generations of industrial products, high-tech devices, medical devices, and prostheses

This article offers an overview of the materials science, properties, integration strategies, design, and development of new generations of industrial products, high-tech devices, external and implantable medical devices, and prostheses. It also covers the use of a unique, low-cost, and biocompatible ultrananocrystalline diamond (UNCD™) film in the treatment of medical conditions. The film has been developed and patented by Auciello et al. and aims to improve the quality of life of people worldwide.

Ultrananocrystalline Diamond Coatings

The intended audience for this information includes undergraduate and graduate students, postdocs, scientists, and engineers from academia and industry, specifically those in materials science, mechanical engineering, bioengineering, applied physics/chemistry, medical device design/manufacturing, and medical doctors/surgeons. The information provided is aimed at helping these professionals select the best materials/ devices for their work.

The information is also of great value to users of industrial/high-tech products and medical devices/prostheses such as dental implants, hips, knees, and more. Using UNCD™ coating, the current failure of metal products due to synergistic mechanical/chemical (body fluids-induced) degradation can be eliminated.

Moreover, this information is also valuable to doctors, surgeons, and the general public to understand the use of revolutionary UNCD™-coated products and UNCD™ scaffolds for efficient pluripotent cell growth and its differentiation to the human cell surface. This technology will enable the new artificial biological replacement of degenerated human cells.

UNCD™ coatings were developed and patented by Auciello et al. in 1990. These coatings are currently being researched by scientists worldwide. They are grown using microwave plasma chemical vapor deposition (MPCVD) and hot filament chemical vapor deposition (HFCVD). In both methods, a patented gas mixture of Ar/CH4 is flown into air-evacuated chambers. In MPCVD, the plasma cracks CH4 molecules, while in the HFCVD process, an array of filaments heated to approximately 2300˚C breaks CH4 molecules, impacting the surface. CH4 cracking yields C atoms that link to each other with diamond-type bonds on substrates and surfaces, producing the UNCD™ coatings. These coatings have 3-5nm grains – the smallest grains in polycrystalline diamond coatings available today.

N-UNCD Coatings

Another transformational process involves growing the unique N-UNCD coating with N atoms in grain boundaries that provide electrons for electrical conductivity. Boron atoms replacing C atoms in UNCD grains' lattice produce metallic B-UNCD coatings with metal-type electrical conductivity.

UNCD™ Coatings Properties

UNCD™ coatings possess a unique combination of physical, chemical, mechanical, electrical, and biological properties:

1. Hardness (98GPa)/Young's modulus (1000GPa), like a diamond gem;
2. Lowest friction coefficient (≤ 0.04) than other materials (≥ 0.5) used in pump seals/bearings, prostheses;
3. Chemical corrosion resistant to any fluids, including HF;
4. Best biocompatibility; and
5. Super-hydrophilic/hydrophobic UNCD surfaces are produced by O/CF_4-plasma processes, respectively.

Below the text is a brief description of the technologies and those in advanced/ less advanced development. For detailed information, please refer to Ref. 1.

UNCD™ Coating – Based Industrial, High-Tech, Medical Devices Technologies

Advanced Diamond Technologies Inc. has marketed UNCD-coated mechanical pump seals/bearings and atomic force microscope tips worldwide since the early 2000s. The company was founded by Auciello and colleagues and sold in 2019 to a larger company that manufactures UNCD-coated industrial products.

Between 2000 and 2010, a team of scientists, engineers, biologists, doctors, and surgeons from four universities, five national laboratories, and the company Second Sight researched and developed UNCD films. These films were an effective hermetic and biocompatible coating for encapsulating Si microchips (artificial retina) that can be implanted in the human eye's retina.

This technology aims to restore partial vision to people blinded by retinitis pigmentosa. The result of this research was the creation of the Argus II device. It is awaiting FDA approval and does not contain the UNCD-coated Si chip. The device is implanted outside the eye and connected to the retina by wires. So far, it has returned partial vision to approximately four hundred people in the USA and EU.

New generation lithium-ion batteries (LIBs) with a unique N-UNCD coating were used on commercial graphite and copper anodes and N-UNCD coating on commercial graphite/copper anodes eliminated Li-corrosion. The N-UNCD- based LIBs with N-UNCD-coated graphite/copper anodes are in an advanced state of development for new-generation defibrillators, pacemakers, implantable battery-powered medical devices, cell phones, and portable electronics.

Our water purification system features water-corrosion-resistant electrically conductive B-UNCD-coated metal electrodes that produce electrolysis in water, inducing ozone (O_3) molecules and killing all viruses, bacteria, and pathogens in approximately ten minutes.

Fifty patients in Mexico received UNCD-coated dental implants (DIs) in clinical trials from 2018 to present. These new revolutionary DIs eliminate chemical corrosion caused by oral fluids, which destroyed approximately 15% of current Ti-alloys DIs worldwide. Other UNCD-coated prostheses under development include, for example, metal hips, knees, stents, heart valves.

Human Retina Reattachment via Super-Paramagnetic Nanoparticles

Novel biocompatible super-paramagnetic Fe_2O_3 nanoparticles (FDA approved) are now available. They can be injected into the human eye and are attracted to a magnetic field generated by an external UNCD-coated magnet. The Fe_2O_3 nanoparticles pushes the detached retina back onto the inner wall of the eye, providing a new, safer, and more effective method for retina reattachment compared to current treatments that involve injecting gas or oil bubbles into the eye. Animal and initial clinical tests on humans have been conducted in Argentina by surgeon Saravia, Auciello, and their colleagues and have demonstrated the efficacy of this new retina reattachment process.

Super-Hydrophobic UNCD Coating for Glaucoma Treatment Valves

Researchers have demonstrated the effectiveness of a super-hydrophobic UNCD coating on commercial hydrophilic polymer-based valves. This coating provides significantly better performance than the current uncoated polymer valves. This technology could pump out fluid from the inner human eye in cases where trabecular tubes are clogged, a common condition in glaucoma patients. Glaucoma is the second leading cause of blindness worldwide.

N-UNCD Scaffolds for Artificial Human Cells Growth

Novel N-UNCD-based scaffolds provide superior surfaces for growing pluripotent stem cells. These scaffolds induced electric field-based differentiation into other human cells for developmental biology and biological treatment of human medical conditions via the implantation of human cells developed in the laboratory.

Integrated Piezoelectric/UNCD films for MEMS/NEMS Devices

Integrated multifunctional piezoelectric/ UNCD films on tailored substrates were developed to produce a new generation of unique microelectromechanical system (MEMS) cantilevers activated by the integrated piezoelectric layers. These enable new generations of biomedical MEMS energy generation, drug delivery, and biosensor devices.

References

1. O. Auciello, (Ed.), Book, ‘Ultrananocrystalline Diamond Coatings for New Generation High-Tech and Medical Devices,’ Cambridge Publisher (2022).