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Thin Sheet of Diamond Has Worlds of Uses

A new technique from Argonne National Laboratory creates thin diamond films that are helping industry save energy and could even be used in heart and eye implants.

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Courtesy of Argonne National Laboratory

These ultrananocrystalline diamond-coated pump seals garnered a 2008 R&D 100 award, which recognize the most important inventions in the previous year. They use 20% less energy during pumping.

Even as royalty set diamonds into crowns and rings, engineers lusted after the gems for different reasons: diamonds are stronger than any other natural material and are excellent electrical insulators and heat conductors. Today they are widely used in industry and factories. But the diamond supply is limited, and while artificial diamonds can be made in gem form, they have been hard to synthesize in thin films.

A new technique invented at Argonne National Laboratory creates thin films of diamond with grains so small they're called ultrananocrystalline diamond films. The films can be applied to an astounding array of surfaces and uses, ranging from better seals on pumps to heart pump walls so smooth that dangerous blood clots don't form. The grains of diamond in the film are just five nanometers across—about a billion of them would fit inside one red blood cell.

The innovation sprang from DOE Office of Science-funded research, when materials scientists Dieter Gruen, Alan Krauss, Orlando Auciello, and John Carlisle developed a gas-based method to form the diamond films to precise standards.

Gruen filed the original patent on the concept in 1991 and the second patent two years later, after he demonstrated the concept worked. He got the idea in 1990 when a paper by Wolfgang Kratschmer and Donald Huffman appeared in the journal *Nature* describing how to make large amounts of Buckminsterfullerene, a carbon-60 molecule shaped like a soccer ball and named after Buckminster Fuller, an architect who popularized the geodesic dome. The discovery of Buckminsterfullerene, also known as "buckyballs," earned Robert Curl, Harold Kroto, and Richard Smalley the 1996 Nobel Prize in chemistry. Initially, buckyballs could be produced only in small amounts in the gas phase, but Kratschmer and Huffman's method showed how to make them in quantity.

"When I read that paper," Gruen said, "I immediately went into my lab and modified a used titanium sublimation pump by installing two graphite electrodes, one at either end. I filled it with an argon atmosphere and struck an arc between the carbon electrodes. The result was a sublimed carbon deposit that contained copious amounts of buckyballs."

Gruen quickly became a major supplier of buckyballs to his Argonne colleagues while continuing his own research, which focused on buckyball fragmentation—how they break up when they collide with other molecules and with surfaces. He found they break up by spitting out a series of carbon dimers—two carbon atoms linked together. For example, in an excited mixture of carbon-60 and argon gas, collisions cause carbon-60 to emit a dimer and become carbon-58. In subsequent collisions, carbon-58 becomes carbon-56, which becomes carbon-54, etc.—each time emitting a new carbon dimer.

Gruen linked this fragmentation method with recent results from Japanese studies of diamond structure and realized he could use buckyballs as a source of carbon dimers to grow a diamond surface using chemical vapor deposition.

His next step was to introduce buckyballs into a microwave plasma machine with an argon atmosphere. When he examined the deposit, he found a thin diamond film composed of nanocrystals and dubbed it "ultrananocrystalline diamond."

Gruen's discovery and implementation of this new growth mechanism for CVD diamond is responsible for the existence of ultrananocrystalline diamond (UNCD). The worldwide diamond community recognizes his newfound method for synthesizing UNCD films, as distinct from conventional microcrystalline diamond films, as having had a major impact on the field of diamond CVD. In 2000, the Materials Research Society presented him with the MRS Medal for the synthesis and characterization of UNCD films.

The UNCD coating technology captures most of the natural properties of diamond in thin-film form: the highest hardness of any diamond film demonstrated today, an extremely low friction coefficient and surface adhesion, very high electron emission, chemical inertness, biocompatibility, and extremely high conductivity when doped with nitrogen or boron. Each film's properties can be precisely tailored.

UNCD films can be used in a broad range of applications from macro to nanodevices, such as energy-saving ultra-low friction and wear coatings for mechanical pump seals and tools; high-performance microelectromechanical and nanoelectromechanical system-based telecommunication devices; the next generation of high-definition flat panel displays; *in vivo* biomedical implants; and biosensors.

The technology was licensed to Advanced Diamond Technologies Inc., based in Romeoville, Ill., which is providing UNCD film and materials integration solutions to a variety of industries developing a broad range of applications.

When used in mechanical pump seals, the diamond coating improves the pumps' reliability, durability, and ability to prevent fluids from escaping into the environment. The surface of UNCD coatings is so smooth that it reduces the friction present when the seals run one upon each other, and this saves up to 20 percent of the energy used running the pump. The UNCD-coated seals are now commercialized worldwide through several manufacturers of seals (see photo). The coating has also been successfully used to develop atomic force microscope tips, to coat wafers that can be used to develop a new generation of microelectromechanical and nanoelectromechanical systems and as coatings on bearings of mixers used in the manufacturing of pharmaceutical and food-grade chemicals.

A U.S. Department of Defense agency is working to use the films to create sensors that would take quick readings to detect chemical and biological threats in water. Diamond, unlike most other materials, can bond with biomolecules like *E. coli, Salmonella, Listeria,* and other pathogens in water to detect their presence. The detectors could even be miniaturized so that anyone, such as soldiers, police, or public health officers, could carry them.

Finally, because diamond is chemically inert, it doesn't react with biological human tissue or body fluids—and the body doesn't reject the diamond as a foreign material. For this reason, UNCD films can be used in implants, including heart pumps to treat heart failure.

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Publications

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http://www.anl.gov/techtransfer/Available_Technologies/Chemistry/uncd_flc.html