Scientists design new super-hard material

UCLA scientists have made rhenium diboride, an “ultra-hard material.” Rhenium diboride is seen here in powder form (left), made from heating the elements in a furnace, and as a pellet made by a procedure called arc melting. Credit: UCLA

Ultra-hard materials are used for everything from drills that bore for oil and build new roads to scratch-resistant coatings for precision instruments and the face of your watch.

UCLA scientists are now reporting a promising new approach to designing super-hard materials, which are very difficult to scratch or crack. Their findings appear in the April 20 issue of the journal *Science*.

Diamond is the hardest material known, because its carbon atoms form very short covalent bonds, according to co-author Richard B. Kaner, UCLA professor of inorganic chemistry and materials science and engineering. Most of the diamond used in the world is actually synthetic and very expensive. Diamond powder is used for oil drills and machines that build roads and cut holes in mountains. Diamond cannot be used, however, to cut steel without ruining the diamond blade.

Cubic boron nitride is a diamond substitute used to cut steel; it is made synthetically under very high-temperature, high-pressure conditions, and is even more expensive than diamond, Kaner said.

There are two ways to make super-hard materials that are "ultra-incompressible," meaning they are resistant to shape deformation, which is a necessary condition for hardness: One is to imitate diamond by using carbon and combining it with boron or nitrogen to maintain short bonds; the other is to look for metals that are already incompressible and try to make them hard, said Kaner. He and his colleagues are developing the second approach.

"Our idea is to combine an incompressible metal, which happens to be soft, with short covalent bonds to make it hard," said Kaner, who is a member of the California NanoSystems Institute (CNSI) at UCLA, which encourages cross-disciplinary collaboration to solve problems in nanoscience and nanotechnology.

In 2005, Kaner's research team combined the relatively soft element osmium, the most incompressible metal known, with small covalent-bond forming atoms to make a material that is almost as incompressible as diamond, yet is so hard that it scratches sapphire, which is ranked 9 on a hardness scale of 1 to 10).

"We found that if we combine boron with osmium, we push the osmium atoms apart by only 10 percent from where they were in osmium metal, which is very good; you want to push them apart as little as possible," Kaner said. "Then we searched through the transition metals to see if we could do better than osmium, to get an expansion of less than 10 percent. The only metal we could find that had the potential for doing this is rhenium; hence, we made rhenium diboride.

Rhenium is a fairly dense, soft metal, which is next to osmium on the periodic table of chemical elements.

"We formed short covalent bonds, pushing the rheniums apart by just 5 percent from where they were in rhenium metal, making it both incompressible and very hard. The rhenium-rhenium distance expanded by only 5 percent from the metal — that's the key to this Science paper. Rhenium diboride is as incompressible as diamond in one direction, and in the other direction, just slightly more compressible."

At low applied forces, the hardness of rhenium diboride is equivalent to cubic boron nitride, the second-hardest material known, Kaner said. At higher applied forces, rhenium diboride is a little bit below that.

"Our material is hard enough to scratch diamond, and much harder than osmium diboride," he said.

While other super-hard materials, including diamond and cubic boron nitride, are made under expensive, high-pressure conditions, "our material is made in a simple process without applying pressure," Kaner said.

Speaking of the collaboration, Kaner said, "The reason I came to UCLA, and a reason I love this place, is because whatever you do — in my own case, whenever you make a new material — you often need equipment and expertise that you don't have. At UCLA, there will be an expert in that area who has the equipment, and every time I've asked, everybody is happy to help you do experiments and excited to collaborate with you."

Despite the potential of new super-hard materials, they are not likely to replace diamond any time soon, Kaner said.

Source: University of California - Los Angeles

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