Fanning the Hope for Flat Diamond

With a beam of carbon ions and a few laser blasts, scientists have stepped closer to diamond electronics

THE RUMOR ENGINE HUMMED INTO ACTION last month in the competitive world of synthetic diamond-makers. Word began spreading at a meeting of a diamond materials consortium based at Pennsylvania State University that somebody, somewhere, had pulled off one of the most elusive and widely sought goals of diamond-makers: to find a practical way of growing diamond sheets composed of exactly one flat, uninterrupted crystal.

While that might sound arcane, "the commercial implications would be huge," says William A. Yarbrough, a diamond-grower at Penn State. Such diamond films would spawn a new generation of electronic circuitry with capacities far beyond those of today's standard silicon-based chips. Diamond crystals, when made into semiconductors by riddling them with charge-relaying ions, can work faster and with more electrical power than any other electronic material. And the rugged diamond lattice would enable chips made of the material to operate under hellish conditions that would wreck silicon chips in an eye-blink. Next would come more powerful supercomputers, more rapid and compact communications systems for satellites, and electronic components for use inside jet engines or nuclear reactors.

Lucy Coulbourn, NCSU

Jagdish Narayan and co-workers transform carbon into diamond.

Like many rumors, this one about diamond films has some truth behind it. On page 416, Jagdish Narayan and Vijay Godbole of North Carolina State University and Clark White of Oak Ridge National Laboratory describe a novel method for growing superthin individual diamond films up to 100 square microns in area. That's not big enough for the envisioned electronic applications. "You won't start making devices tomorrow," Narayan cautions. But it is "a good step toward diamond electronics," says Max Swanson, a physicist at the University of North Carolina who is familiar with the work.

The strategy of Narayan and his colleagues is markedly different from that used by most of their diamond-growing brethren around the world. Many groups have recently achieved considerable progress in making diamond films by chemical vapor deposition (CVD). In this technique, a mist of hydrocarbon molecules is vented into a vacuum chamber where the molecules are broken into fragments by absorbing thermal or other forms of energy. Liberated carbon atoms then deposit as diamond films on heated surfaces also in the chamber. But these films do not form as a single crystal, as Narayan claims his do. Rather, they begin as tiny diamond islands, which then grow out into a polycrystalline sheet like closely spaced dollops of cookie dough on a baking sheet.

That's good enough for lots of uses, including superhard abrasive grit or thin protective coatings for car windows and missile guidance systems. Indeed, *Science* bestowed its "Molecule of the Year" title on the CVD diamond last year in recognition of those achievements. But the many boundaries between the crystal grains in CVD films make them poor candidates for diamond circuitry.

The challenge for the CVD diamond crowd has been to grow large films made of but a single, flat crystal. That might be achieved by limiting the number of diamond islands that form during the initial stages of film growth, or by aligning the multiple grains that do form so that they assemble in geometric register rather than in more random mosaic arrangements. But no major success has been reported along these fronts.

Narayan has turned to a non-CVD tactic and achieved a measure of success. His group uses an accelerator to ram carbon ions into a copper surface at a density of about one billion ions per square centimeter. Then they blast the carbon-laden copper with a series of powerful laser bursts, each lasting only billionths of a second.

According to Narayan, the laser treatment rapidly liquefies the topmost copper layer. Carbon atoms, which dissolve only sparingly in copper, take transient refuge in the liquid layer, concentrating there. When the laser pulses cease, the carbon-loaded liquid metal begins solidifying where it meets the solid metal underneath. As the solidification front races from that interface toward the surface, carbon atoms line up at the upwardly mobile solid metal surface and assemble there into a continuous diamond film a mere twentieth of a micron thick.

Narayan had good reasons for choosing copper as a substrate. The spacings between its atoms are nearly the same as the interatomic spacing in diamond. That suggested that copper might serve—and apparently it has—as a template to guide the carbon atoms depositing from the molten copper into the diamond structure. Other researchers had previously used CVD methods to grow single crystal diamond films on the natural diamond—the perfect template for the job. But suitable diamond crystals are rare and too expensive to be used commercially. Not so for copper substrates. Besides, Swanson notes, the metal might be nice to have around in subsequent processing steps for making actual diamond electronic devices.

Narayan downplays his work's technological promise, however. "The major breakthrough here is turning carbon directly into diamond with this laser method," he says. It's also possible to convert the all-carbon mineral graphite directly into diamond. But the process requires enormous pressures and temperatures, while the new technique works at normal pressures and temperatures, a plus for commercial application.

But a big question remains. Will the new technique be capable of making single crystal diamond films big enough for electronic use? Narayan thinks so. "I don't see any reason why we couldn't grow palm-sized films," he says. In actuality, postage-stamp sized films would do, says Rustom Roy, a codirector of Penn State's Diamond and Related Materials Consortium. Narayan's group may have already made them, but the researchers are still doing tests to verify that possibility.

Diamond-makers certainly won't believe it until they see the goods, but they have they're fingers crossed. "Nature doesn't give you a diamond bigger than a fist, and if you find one that big you're not going to use it for a scientific device," says Russell Messier, another Penn State materials scientist. A diamond of that size is more likely to end up in a museum or adorning the rich and famous. He, for one, would welcome a reliable synthetic source of big, single crystal diamond films. And that's no rumor.

■ IVAN AMATO