Nano Focus

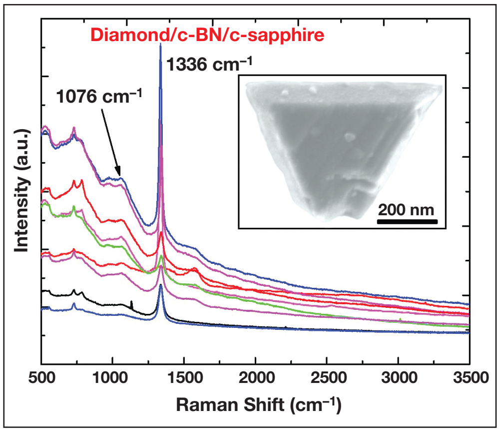
Hexagonal BN converted directly to cubic BN through a new phase

Often outshined by diamond, cubic boron nitride (c-BN) is nevertheless an impressive material. In a handful of important ways, c-BN even has an edge: a wider bandgap, more resistance to oxidation due to a passivating layer of durable boron oxide, and acceptance of both *p*- and *n*-type dopants, compared with diamond's acceptance of only *p*-type. The promise of exploiting these properties in future electronics makes clear the need for robust processing of BN.

Researchers at North Carolina State University have developed a method of fabricating phase-pure c-BN at ambient temperature and pressure in air—via a new phase of BN (named Q-BN) with its own exciting properties. Jagdish (Jay) Narayan led a team that extended previous, similar work on carbon into the BN material system. Narayan had a hypothesis that he could tweak the phase-changing behavior of carbon to directly convert graphite to diamond, bypassing the thermodynamic barrier by taking a "scenic route" through kinetics. Then, because carbon and BN are material cousins, he thought he could do the same for converting hexagonal BN (h-BN) to c-BN. This work is published in a recent issue of the *Journal of Applied Physics* (doi:10.1063/1.4948688).

With a 20-ns pulsed laser, liquid BN was undercooled by more than 700 K. Upon quenching, Narayan and his team observed a new phase, which they named, appropriately, Q-BN. The critical parameter in this process, in order to kinetically drive the transformation, is time: "We do it so rapidly the system is not able to equilibrate," says Narayan.

The team found that an intermediate undercooling of liquid h-BN resulted in c-BN directly, while a deeper undercooling resulted in the new Q-BN phase. By varying process parameters, the team was also able to nucleate and grow c-BN nanocrystallites in Q-BN. Upon further exploration, the team found they could grow c-BN thin films and nanoscale dots and needles, control twinning defects in c-BN, grow epitaxial diamond/c-BN and c-BN/diamond heterostructures, and give the Q-BN a semiconductor character, thereby opening up an even wider range of manufacturing possibilities for the process. Graduate student Anagh Bhaumik and postdoctoral research associate Weizong Xu carried out the characterization of the Q-BN phase, including Raman spectroscopy, HRTEM and EELS. Among other things, they determined that Q-BN's atomic density is higher than that of c-BN, which suggests increased hardness. Because Q-BN is isostructural to Q-carbon, Narayan expects a hardness greater than that of diamond—comparable to the 17% greater hardness of Q-carbon over diamond that he reported previously.



Raman spectra from diamond/c-BN single-crystal films.

The next step is to dope the materials, create a *p*-*n* junction, and start moving toward more complex devices. "The beauty of this [process]," says Narayan, "is that you can deposit these diamond/c-BN layers on heat-sensitive substrates, like polymers," which would then lead to uses in flexible electronics and other advanced devices.

Antonio Cruz

Bio Focus

Ionic liquid gels enable wearable bioelectronics sensors

The age of wearable electronics is here. With devices that can count our steps and track our heartbeat, scientists and engineers have devised increasingly creative, convenient, and even fashionable ways to monitor human health in real time. Despite their convenience, many of these devices may never be as accurate as the bulky transdermal electrodes and instruments used in medical practice—at least not in their current form. A team of researchers in France have developed a way to fabricate small bioelectronic sensors that are both highly sensitive and comfortable to wear and that could one day even help rehabilitate injured muscles.

A major problem faced by the bioelectronics industry, especially for sensors, is fundamentally a materials science issue: poor contact between dissimilar surfaces. How can soft, wet tissue be interfaced with dry, solid-state electronics to detect biosignals and transmit vital data?

In clinics and medical laboratories throughout the world, this problem is alleviated to some extent by spreading conducting pastes or gels on transdermal electrodes before attaching them to the skin. This helps improve adhesion and electrical conduction at first, but the stability of these electrodes tends to decrease over time as sweat builds up, seriously degrading the performance of the electrodes and devices. Most sensors of this type are therefore not well suited for continuous use.

Researchers have begun to develop bioelectronic sensors that incorporate conducting polymers. Water-soluble polymers of this type such as poly(3,4-ethylenedioxythiophene), or PEDOT, can be made compatible with human tissue while maintaining sufficient conductivity for monitoring. And because the flexibility of these polymers is limited only by the substrate on which they are coated, what better substrate to use for a wearable sensor than clothes?

That is the type of reasoning that led Esma Ismailova, a research engineer at École Nationale Supérieure des Mines de Saint-Étienne, and her team to develop an all-organic, textile-based electrode. Inspired by the Japanese art of hand-dyeing kimonos, the French researchers developed a special method for printing a PEDOT-based conductive ink directly onto polyester fabric, as reported in a recent issue of *Advanced Healthcare Materials* (doi:10.1002/adhm.201600299). By adding an ionic liquid gel between the printed electrode and the skin, the team showed that they could record electrical signals from muscles in the lower leg of human patients. The device was sensitive enough to differentiate between high and low amounts of effort as patients flexed their foot, rivaling the performance of the bulky systems used in the clinic.

"We showed that the textile electrode is highly conformable to the shape of the body. But also, something very interesting we observed is that we have less movement in artifacts using this textile platform than electrodes currently used in the medical field," says Ismailova.

Additionally, the researchers showed that the electrical signaling supported by their device could go both ways. By applying a voltage similar to that used to stimulate muscles during physical rehabilitation, they were able to induce involuntary flexing in their patients, a novel feature for an electrode containing no metallic parts.

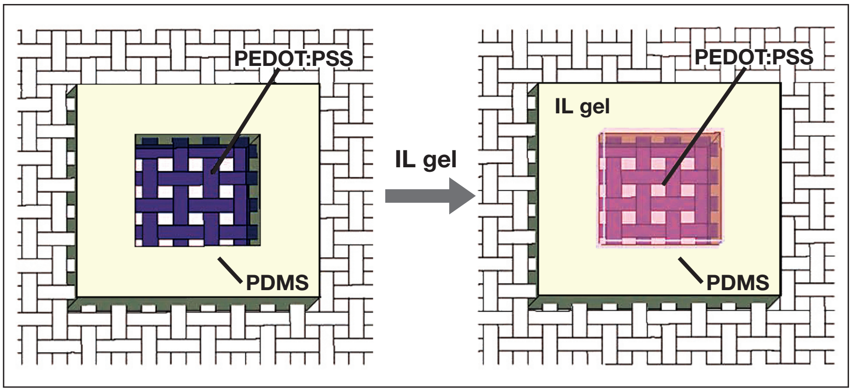
One of the most innovative components of the research team's electrode is the use of an ionic liquid gel as a conducting interface with the skin. "The use of ionic liquids in this context is pretty exciting," says Christopher Bettinger, an associate professor in the Departments of Materials Science and Biomedical Engineering at Carnegie Mellon University who was not affiliated with the study.

"Ionic liquids are usually thought of as exotic solvents for chemistry, or for making conducting layers in batteries," says Bettinger. "So to see them being used to interface directly with humans is very interesting."

The ionic liquid-based gel used by researchers offers a few advantages over the gels and pastes used in conventional medical-grade electrodes. It does not degrade when it mixes with sweat or dry over long periods of use, which means the sensor can maintain high performance during long periods of high activity. Ismailova envisions being able to integrate this type of sensor into a soccer player's sock, for example. The sensor could reliably monitor the athlete's performance but also provide stimulation in the case of a lower leg injury.

For now, however, Ismailova stresses that their work is largely a proof of concept. Despite the improved compatibility provided by the ionic liquid gel in their design, ensuring good contact under various environmental conditions and for various body types remains an ongoing challenge. Then, she says, there remains the question of how the electrode will be powered wirelessly to maximize wearability and comfort. But Ismailova looks forward to tackling these and other issues as she and her team work to make this technology affordable and available to everyone.

Omar Fabian



Schematic of a bioelectronics sensor shows the pattern of the poly(dimethylsiloxane) (PDMS) stencil in a textile and the selectively coated poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate) (PEDOT:PSS) area. An ionic liquid (IL) gel is then deposited on top of the PEDOT:PSS electrode defined by the PDMS layer. Credit: *Advanced Healthcare Materials*.