cability to the study of fundamental biological questions, by providing a direct means to study coupling between biochemical and biomechanical reaction cycles."

STEVEN TROHALAKI

High-Velocity Ballistic Impact with Boron Carbide Produces Localized Amorphization

Localized amorphization induced by shock has been observed in crystalline boron carbide. Mingwei Chen and Kevin Hemker of Johns Hopkins University and James McCauley of the U.S. Army Research Laboratory at Aberdeen Proving Ground have demonstrated that extremely high-rate deformation can initiate formation of amorphized bands in the rhombohedral crystal structure of B_4C.

Boron carbide is commonly used as ballistic armor. Although the material is effective for protection against low-energy projectiles such as bullets from handguns, it is less effective upon more powerful impacts. As reported in the March 7 issue of *Science*, Chen, McCauley, and Hemker found that the measured drop in the impact resistance of boron carbide at impact pressures in the range of 20–23 GPa could be attributed to the formation of nanoscale intragranular amorphous bands in the crystal.

The researchers observed the amorphous bands by high-resolution electron microscopy (HREM). They used transmission electron microscope electron energy-loss spectroscopy to compare the chemical composition of the amorphous regions to that of the crystalline B_4C. These spectra allowed the researchers to rule out the possibility of a pressure-induced decomposition or chemical reaction since there was no detectable difference in chemical composition. The researchers also determined the HREM images were not consistent with rebonding of two cracked surfaces or melting. Accordingly, they believe that the amorphization is a solid-state transformation instigated by the ballistic event.

Recent diamond anvil studies demonstrated a phase transition at a pressure around 20 GPa, and previous nanoindentation experiments at even higher pressures suggested amorphization, but this speculation was discounted based on Raman spectra. The researchers in this study suggest that their results warrant renewed scrutiny of the previous interpretations of the diamond anvil and nanoindentation results.

The drop in performance of boron carbide when exposed to high-impact pressures has been known for years. The current research provides a microscopic explanation for this highly unfavorable property for a material employed as ballistic armor. The researchers do not propose a means to avoid formation of the amorphization regions that appear to be responsible for the drop in strength of crystalline boron carbide. Nevertheless, they speculate that this improved understanding of how shock can alter materials properties and permit the synthesis of novel structures could further expand the realm of possibilities for innovative materials synthesis.

Chen said, "It's like having a sturdy table and suddenly kicking the legs out from underneath it."

"This discovery was very enlightening, because it tells us that under extremely high pressures the crystal structure collapses and forms these nanoscale amorphous bands," said Hemker. "Then the material fractures along these bands because the glassy material appears to be weaker than the crystalline boron carbide."

McCauley said, "The question now is, how should we try to change the boron carbide? We intend to try modifying the material's grain structure, its chemistry, and the additives used in making it. The goal will be to have the amorphization occur at higher impact pressures. Then the armor would provide better protection against a wider range of threats."

Although the findings have immediate implications in the production of improved armor materials, the researchers said that their observations also provide experimental evidence that extreme conditions in pressure, temperature, and/or loading and quenching rates can lead to the creation of entirely new materials or structures with substantially altered physical and mechanical properties.

"We have a new appreciation for how localized loss of crystalline structure can substantially alter materials properties," Hemker said. "I anticipate this understanding will allow scientists and engineers to tailor boron carbide's properties in a way that has not been exploited to date. We do not need to rely on chemical modifications or phase transformations to pursue novel materials properties. I hope our research will help to motivate exciting new avenues in materials design."

EMILY JARVIS

Carbon Nanofibers with Smaller Diameter Rather than Larger Promote More Osteoblast Functions

Nanomaterials in the form of ceramics, polymers, metals, and carbon nanofibers have recently been shown to improve bone, vascular, bladder, cartilage, and neural cell function. Doctoral student Rachel Price, under the direction of Thomas J. Webster in the Biomedical Engineering Department at Purdue University, has demonstrated that smaller-diameter carbon nanofibers promote more functions of the osteoblast, the bone-forming cell, than do nanofibers with larger diameters. Such a conclusion was based on evidence that a statistically larger number of osteoblasts adhered, proliferated, and deposited calcium-containing material on the smaller-diameter (60-nm) carbon-fiber compacts than to the larger-diameter (125-nm) carbon-fiber compacts, or to either a cobalt chromium or a titanium alloy. The latter two materials are currently used in dental and orthopedic applications.

As reported in the May issue of *Biomaterials* (**24**:11), there was a 33% increase in the number of adherent osteoblasts on the smaller carbon fibers than the larger and up to an 800% increase over the titanium alloy. In addition, in a carbon nanofiber/polycarbonate urethane composite, osteoblast adhesion increased on those composites when higher ratios of carbon nanofibers were incorporated.

Price said, "Another interesting finding is that competitive cell functions are adversely affected on the smaller carbon fibers over the same time span. Increased osteoblast function and decreased competitive cell functions imply that better bonding to juxtaposed bone can be achieved through the use of carbon nanofibers."

Novel Method for Control of Quantum Entanglement Developed

Entanglement refers to a quantum phenomenon whereby measurements performed on one particle affect another particle that is far away. Quantum entanglement can be exploited in quantum information applications such as cryptography and quantum computation. A recent report by Roberto Merlin and coworkers in the Departments of Physics at the University of Michigan, Ann Arbor, and the University of Notre Dame describes the controlled generation of entangled states involving the spin of Mn^{2+} and donor impurities in CdTe quantum wells. Their procedure relies on photoexcited excitons to mediate the interaction between spins. The method allows a previously unavailable level of control of particle entanglement. According to Merlin, "the procedure is potentially set-specific and scalable, thereby holding promise for quantum computing applications."

As described in the March issue of

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Nature Materials, the researchers prepared a multiple-quantum-well structure consisting of 100 CdTe layers 58 Å thick separated by 19-Å MnTe barriers. The Mn^{2+} impurity ions, present at ~0.5% doping levels, were not introduced into the CdTe intentionally, but diffused from the barrier layers. Photoluminescence (PL) as well as PL excitation and Raman scattering spectra were acquired by using a CW Ti:sapphire laser. An additional mode-locked Ti:sapphire laser emitting subpicosecond pulses was used to obtain the time-domain reflectivity data and generate the exciton states. The resonant Raman spectra show spin flip (SF) transitions of electrons bound to donors and to the Mn ions. The Mn spectrum exhibits a series of peaks at multitudes of the fundamental paramagnetic resonance.

The researchers were able to create entangled states by selectively irradiating the quantum-well structures with light pulses of central energy at 1.677 eV. The signature of entanglement was the observation of overtones of the SF transition in the coherent time-domain spectra. Specifically, their data reveal the first and second SF harmonics implying the existence of entangled states that involve three donor impurities. Their results also show indirect evidence of two Mn ion entanglement. Because exciton generation can be tuned by varying the wavelength of the exciting light, this system can in principle be used to generate and precisely control multiple sets of entangled states for an arbitrarily large number of impurities.

GREG KHITROV

GaAs Quantum Dots Exhibit Triggered Single Photon Emission

Materials capable of emitting Fourier transform limited single photons are needed for quantum computing and quantum cryptography schemes. Semiconductor quantum dots are attractive single photon emitters but usually operate far from the Fourier transform limit. As reported in the April 7 issue of *Applied Physics Letters*, a team of researchers from CNRS, Alcatel R&I, and CEA in France has recently observed single-photon emission from quantum dots formed at interface fluctuations of GaAs/GaAlAs quantum wells (see figure). The researchers indicate that the quantum dots have potential as a source of Fourier transform limited single photons.

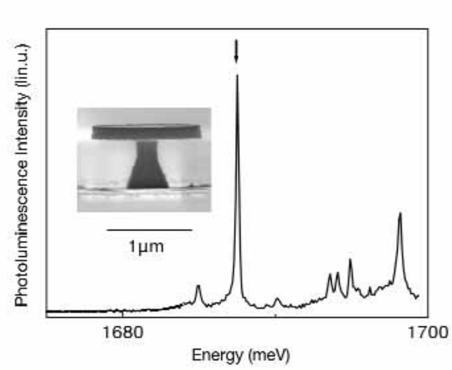

Figure. Microphotoluminescence spectrum measured in a 1-µm-diameter microdisk. The arrow points to the quantum-dot line selected for the photon correlation measurements. Inset: Image of a microdisk obtained by scanning electron microscopy.

The group used molecular-beam epitaxy to grow the sample, which included a single 3-nm GaAs quantum well surrounded by 50-nm $Ga_{0.67}Al_{0.33}As$ barriers. Quantum dots resulted from fluctuations in the thickness of the narrow well. Electron-beam lithography and chemical etching were used to cut microdisks from the sample, isolating several quantum dots. After measuring the emission spectrum of the isolated dots at 10 K and selecting a spectral line corresponding to an exciton transition, the team carried out photon correlation experiments using a Ti:sapphire laser delivering 1.5 ps pulses at an 82-MHz pulse repetition rate (i.e., 12.2 ns between pulses). Time intervals between successive photons were recorded. Emissions were largely in the form of single photons, separated by 12.2 ns (the time between laser pulses) with only a small probability of photon pair emission. The researchers said that, "compared with the coherent light pulses delivered by an attenuated laser, the probability of emitting a pair of photons is reduced by a factor of five."

The ability of GaAs quantum dots to emit single photons has not been demonstrated before. In particular, these recent results show that no significant refilling of the quantum dot from the reservoir of charge carriers in the nearby quantum well occurs once a photon has been emitted. The radiative lifetime of GaAs quantum dots occurring at quantum-well interfaces can be 50× shorter than the more commonly studied InAs quantum dots, making the former much less sensitive to decoherence processes and more likely to operate near the Fourier transform limit.

According to team members Jacqueline Bloch of CNRS and Jean-Michel Gérard of CEA, "Our next goals will be to probe precisely how close we are to the Fourier transform limit and to insert such quantum dots in a pillar microcavity." This insertion could allow emission of single photons even nearer the Fourier transform limit, with controlled mode and polarization, bringing GaAs quantum dots closer to application in quantum information technologies.

CATHERINE OERTEL

News of MRS Members/Materials Researchers

Lynn Boatner, a corporate fellow at Oak Ridge National Laboratory, has received the **Frank H. Spedding** Award in recognition of his research on the fundamental properties and applications of rare earth phosphates and other rare earth materials. The award was presented last year during the Rare Earth Research Conference in Davis, Calif.

Long-Qing Chen, professor of materials science and engineering at The Pennsylvania State University, has been awarded the University's **Faculty Scholar Medal** in engineering for his work in the area of computational materials science.

Sang-Hee Cho of Kyungpook National University, Daegu, Korea, has been elected to the **World Academy of Ceramics**.

Manish Chhowalla has joined the Department of Ceramic and Materials Engineering of Rutgers University from Cambridge University, in order to contribute to a growing multidepartment commitment to research and education in nanotechnology. Chhowalla focuses on thin films and the fabrication of new types of nanomaterials for electronic, mechanical, and optical applications.

Bruce Dunn of the University of California, Los Angeles, has been named holder of the **Nippon Sheet Glass Company Chair in Materials Science**.

Paul S. Follansbee has been selected as the new director of the Los Alamos National Laboratory's Materials Science and Technology Division. Follansbee suc-

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