from the ohmic behavior that is observed in pure InAs whiskers. Additional details on the electronic properties of these structures are reported in the February 11 issue of *Applied Physics Letters*.

To synthesize Si/SiGe nanowires with diameters ranging from 50 nm to 300 nm, Wu and co-workers periodically introduced Ge vapor through pulsed laser ablation of a Ge target in the presence of a Au nanocluster catalyst. At temperatures ranging from 850°C to 950°C, a Au thin film on a Si substrate forms an alloy with Si and separates into nanometer-sized droplets. Si continuously deposits into the Au-Si alloy droplets, and growth of the Si nanowire occurs upon supersaturation of the droplets. By turning the laser on, the researchers caused both Ge and Si to be deposited into the droplets, causing the precipitation of SiGe. By continuously switching the laser on and off, a Si/SiGe superlattice was formed in a block-by-block fashion. The researchers showed that the diameter and composition of the highly crystalline Si/SiGe nanowires could be controlled by adjusting the reaction conditions. Specifically, the nanowire diameter was varied from 20 nm to 100 nm by changing the thickness of the Au film from 1 nm to 20 nm.

The work performed by these three research teams signifies an important turning point in nanoscale research. Analogous to the way in which two-dimensional thin-film heterostructures transformed the planar semiconductor industry, heterostructures created inside nanowires offer the potential for diverse applications such as nanobarcodes, polarized nanoscale LEDs, 1D–0D–1D resonant tunneling devices, and improved thermoelectric devices.

STEFFEN K. KALDOR

Simple Method Can Suspend Individual Nanofibers

Researchers at Germany's Max Planck Institute have devised a technique to suspend an individual nanofiber over a Si/SiO_2 substrate by using coordinate markers and a sacrificial layer of electron-beam resist. Individual suspended nanofibers are required to study their electromechanical properties. The generality of this method is of key importance because it does not rely on the selectivity of particular etching processes or on the necessity of growing fibers by means of chemical vapor deposition. Gyu-Tae Kim and colleagues report in the March 11 issue of *Applied Physics Letters* that they have demonstrated their technique by suspending a 2.3-nm-diameter carbon nanotube and measuring its Young's modulus by using a calibrated atomic force microscope (AFM) tip.

To achieve this suspended-fiber configuration, Kim and co-workers prepared a Si/SiO_2 substrate with reference marks made by means of electron-beam deposition. They spin-coated this substrate with an electron-beam resist, poly(methyl methacrylate) (PMMA), then spin-deposited a solution that contained dispersed nanofibers. The researchers determined the locations of these fibers relative to the underlying coordinate system using AFM. More PMMA was spun on, effectively embedding and fixing the strands parallel to the substrate, much as amber might fix a fly. Next, a directed electron beam exposed the layers of resist at the head and tail of a selected nanofiber, and a PMMA developer removed the treated resist, forming two holes in the PMMA that opened through to the Si/SiO_2 underneath. At this point, the ends of the fiber protruded from the side of each of the pits so formed. The researchers then deposited a Au/Pd film that surrounded and cemented the now-encased fiber ends to the substrate beneath. They took care to deposit from two directions in order to prevent the nanofiber ends from shadowing the underlying Si/SiO_2. Finally, a lift-off procedure removed all of the remaining PMMA from around and under the fiber, leaving the now-suspended nanofiber spanning two metal blocks. When the distance between the metal posts exceeded 500 nm, most of the suspended nanotubes sagged to the point of touching the substrate.

Research into the electromechanical properties of nanofibers requires the suspended configuration, and this may also be an effective system for other studies, such as the synthesis of molecular electronic devices. The scientists said that their method can be applied to many different fibers, and will allow the comparison of a suspended fiber to one lying on the substrate.

RICHARD N. LOUIE

Internal Defects Observed by Two-Photon-Induced Photoluminescence

Structural imperfections in semiconductors play an important role in areas of high-efficiency emissive materials such as laser diodes. Researchers in the Department of Engineering at Shizuoka University in Japan have generated three-dimensional (3D) images of such imperfections through the first reported use of two-photon excitation, achieved using a laser scanning microscope. Y. Kawata and co-workers imaged regions of bulk polycrystalline ZnSe up to 200 μm below the surface by measuring the effect of position on photoluminescence (PL).

According to Kawata, "[T]wo-photon excitation is a significant improvement over conventional PL observation techniques, which allow only the surface defects to be observed because of the large absorption of the excitation light."

As reported in the March 1 issue of *Optics Letters*, the researchers used a 200-mW Ti:sapphire laser generating 80-fs pulses at 790 nm. The laser light was focused to a small spot by using a beam expander and an objective lens. The 5 mm × 5 mm × 3 mm polycrystalline ZnSe sample was mounted on a stage capable of 3D translation with 50-nm precision. The stage was used to position the polycrystal relative to the focused laser spot. Because the energy of the laser light is far below the bandgap energy of the semiconductor, the light is absorbed only in the focused region where the probability of simultaneous absorption of two photons is high. A dichroic mirror and interference filter were used to remove the exciting radiation from the PL before the intensity was measured with a photomultiplier tube. A defect map of the polycrystal was created by moving the stage and recording the PL intensity as a function of the position of the focused spot. The impurities, cavities, cracks, and other defects within the polycrystal absorbed or diffracted the PL and were seen as dark regions in the scanned images.

The depth limit of the two-photon technique results primarily from the refraction-induced spherical aberration of the exciting radiation inside the polycrystal. This aberration increases the laser spot size at focus, thus lowering the PL intensity and the contrast in the scanned images. Using higher laser power in an effort to increase the PL intensity results in photo damage to the semiconductor sample. The researchers are currently investigating the use of a liquid-crystal phase mask to reduce the spherical aberration.

GREG KHITROV

Lateral Color Integration Achieved with Rare-Earth-Doped GaN

D.S. Lee and A.J. Steckl of the Nanoelectronics Laboratory at the University of Cincinnati have used a rare-earth-doped GaN host to produce laterally integrated electroluminescent devices (ELDs) with red and green emissions. While vertical integration (deposition of different dopants on different layers) has provided a satisfactory visible spectrum, each dopant layer demands a different biasing condition in order to produce its representative color. Such layer-by-layer

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biasing tends to be overwhelming for device practicality. In an article published in the March 18 issue of *Applied Physics Letters*, Lee and Steckl proposed lateral color integration (different dopant species found on side-by-side regions of a single layer). They have found with their technique that fine-tuning within the visual spectrum is not only possible, but also improves the emission intensity.

The researchers grew GaN films on Si(111) substrates by means of molecular-beam epitaxy (MBE), doping with Er and Eu *in situ*. Indium tin oxide (ITO) electrodes were deposited after GaN growth, for electroluminescence (EL) characterization. ELDs were fabricated by two methods: by a shadow mask at 400°C and by photoresist (PR) lift-off at temperatures of <100°C. To obtain multiple colors within the visible spectrum, GaN layers doped with the appropriate rare-earth element were deposited and patterned serially, either by repeating the PR lift-off process or by translating the shadow mask. The integrated ELDs fabricated at 400°C were bright, while those made at <100°C were significantly less bright but still visible under normal ambient lighting. From the EL experiments, GaN:Er has green peaks at 537 nm and 558 nm, while GaN:Eu has a single red peak at 621 nm. Atomic force microscopy measurements show surface roughness of 5 nm RMS for the 400°C sample and 10 nm RMS for the <100°C sample.

In previous research, rare-earth dopants were incorporated in II–VI hosts. This research shows that GaN serves as a much better host than the II–VI elements because of charge neutrality with 3^+ rare-earth ions; GaN also possesses superior chemical and thermal stability.

JUNE LAU

Doping Ti in Superconducting MgB_2 Enhances Critical Current Density by Means of Refined Grain Structure

Researchers Y. Zhao and colleagues at ISTEC, Japan, and the University of New South Wales, Australia, studied the effect of Ti doping on the critical current density (J_c) of MgB_2, the newly discovered superconducting compound with T_c = 39 K. This was done to refine grain size and to create a fine and well-bonded structure of the superconducting phase for practical applications. The researchers observed a significantly improved J_c in Ti-doped bulk samples. By studying the microstructure of the samples, they found that Ti does not occupy atomic sites in the MgB_2 crystal structure, but forms a thin TiB_2 layer in the grain boundaries of the MgB_2. The researchers said that refined MgB_2 grains, forming a strongly coupled nanoparticle structure, may be responsible for the enhanced J_c.

As reported in the March 4 issue of *Applied Physics Letters*, the researchers prepared a series of Ti-doped MgB_2 samples with an atomic ratio of Mg:Ti:B = $(1 - x):x:2$ ($0 \le x \le 1.0$) by solid-state reaction at ambient pressure. At a doping level of 10% Ti in MgB_2, the superconducting properties of the MgB_2 bulk superconductor were significantly improved, and a J_c of 1 MA/cm^2 at 20 K in zero applied field was achieved. In order to understand the underlying mechanism for the effect of Ti doping on J_c, the researchers investigated the crystal structure of the bulk samples by powder x-ray diffraction and performed microstructural and compositional analysis by a field-emission high-resolution transmission electron microscope equipped with an energy-dispersive x-ray spectroscopy system.

The researchers reported that the lattice constants of the MgB_2 remain unchanged, and T_c decreases only slightly with the increasing Ti doping level from $x = 0$ to $x = 0.4$. With $x = 0.1$, the average size of the MgB_2 grains is about 8 nm. The connection between the nanoparticles is very tight because of the thinness of the grain boundaries (<1 nm). Ti was found in the grain boundaries, but could not be detected inside the MgB_2 grains. Therefore, the researchers believe that Ti does not occupy the atomic sites in the lattice, but merely forms impurity phases, remaining outside of the MgB_2 grains.

According to the researchers, because of the tight bonding between MgB_2 nanoparticles and the ultrathin TiB_2 grain boundaries, very little weak-link effect exists in the Ti-doped MgB_2. The researchers observed high J_c values at high magnetic field, for example, 5×10^4 A/cm^2 in 5 T at 5 K. The bulk pinning force of the Ti-doped samples is an order of magnitude higher than the best result of the pure MgB_2 bulk sample, and it is close to the pinning force of the established technological superconductors NbTi and Nb_3Sn.

SHIMING WU

Pin Printing of Xerogels Allows Rapid Formation of Chemical-Sensor Arrays

As reported in the March 1 issue of *Analytical Chemistry*, Frank V. Bright and Eun Jeong Cho from the State University of New York at Buffalo have developed a method to rapidly fabricate reusable chemical-sensor elements into arrays. In order to provide a simple method for simultaneous multianalyte quantification to allow for simultaneous determination of O_2 and pH in aqueous samples, the researchers fabricated micrometer-scale xerogel-based sensor elements on a planar substrate by combining pin printing and sol-gel processing techniques.

Two sol-gel stock solutions were prepared by hydrolyzing solution A, which contained tetraethylorthosilane, distilled deionized water, EtOH, and HCl, for 2 h; and solution B, which contained *n*-propyltrimethoxysilane, tetramethoxysilane, EtOH, and HCl, for 1 h. By doping and printing the stock solutions onto clean glass microscope slides, the gas-phase O_2-responsive sensor elements and the solution-phase pH-sensitive sensor elements making up the pin-printed chemical-sensor array (PPCSA) were formed, based on tris(4,7′-diphenyl-1,10′-phenanathroline)ruthenium(II) [$Ru(dpp)_3$] and fluorescein-labeled dextran, respectively. The center-to-center spacing from one sensor element to another is ~200 μm on the pH- and O_2-responsive PPCSAs. The dual-analyte PPCSAs were prepared by printing alternating columns of O_2- and pH-responsive sensor elements with column-to-column center spacing adjusted to 300 μm and row-to-row center spacing set at 200 μm. The xerogel sensor elements were 1–2-μm thick, as observed by scanning electron microscopy.

After the xerogel was fully formed, the PPCSAs were characterized by using a CW argon-ion laser, an epifluorescence microscope, and a CCD camera. The behavior of O_2- and pH-responsive PPCSAs was tested, and the results showed the response reproducibility and stability—in another words, PPCSA methodology is suitable for performing reproducible measurements in the gas or solution phase. From the tests of the dual-analyte PPCSAs, the pH sensors responded only to changes in the pH of the solution, and the O_2 sensor responded only to changes in the O_2 level. There was no significant cross talk among sensor elements nor interference in the response profiles.

According to the researchers, the combination of pin printing and sol-gel processing techniques not only provided a simple method to rapidly fabricate reusable chemical-sensor elements into arrays (<1 s/sensor element) that exhibit good analytical figures of merit, but also provided a straightforward means to fabricate reusable multianalyte sensor arrays. The researchers predicted the potential of the PPCSA strategy for simultaneous multianalyte quantification. More recently, Cho and Bright showed that they could extend this methodology to pin-print sensor elements directly onto the

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