physica status solidi rrl

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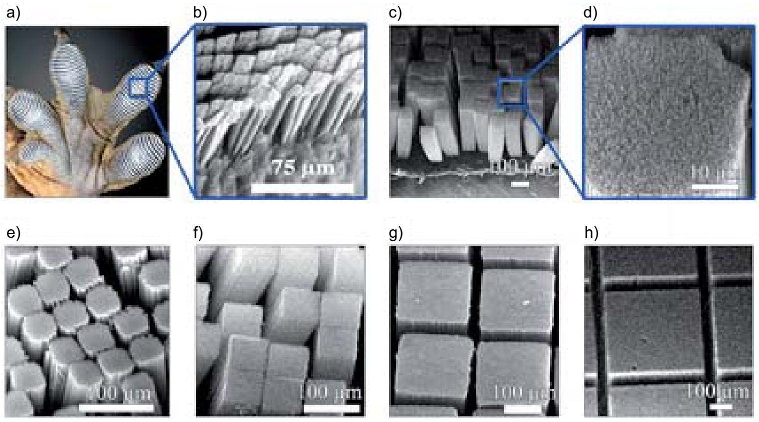
Solid state and materials research news



Microfabricated aligned multiwalled carbon nanotube setae and spatulas. (a) Optical picture of gecko foot showing that the setae are arranged in many lobes along the foot. (b) SEM image of natural gecko setae terminating into thousands of smaller spatulas. (e–h) SEM images of synthetic setae of width (e) 50, (f) 100, (g) 250, and (h) 500 µm. (c) Side views and (d) higher magnification SEM image of the 100 µm setae (Image courtesy of the University of Akron).

Nanotube adhesive sticks better than a gecko's foot

Mimicking the agile gecko, with its uncanny ability to run up walls and across ceilings, has long been a goal of materials scientists. Researchers at Rensselaer Polytechnic Institute and the University of Akron have taken one sticky step in the right direction, creating synthetic "gecko tape" with four times the sticking power of the real thing.

The researchers describe a process for making polymer surfaces covered with carbon nanotube hairs [1]. The nanotubes imitate the thousands of microscopic hairs on a gecko's footpad, which form weak bonds with whatever surface the creature touches, allowing it to "unstick" itself simply by shifting its foot. For the first time, the team has developed a prototype flexible patch that can stick and unstick repeatedly with properties better than the natural gecko foot. They fashioned their material into an adhesive tape that can be used on a wide variety of surfaces, including Teflon.

Pulickel Ajayan, Professor of Materials Science and Engineering at Rensselaer, and postdoctoral research associate Lijie Ci created the material in collaboration with Ali Dhinojwala, Professor of Polymer Science at Akron, and graduate students Liehui Ge and Sunny Sethi.

"We have shown that the patchy structures from micropatterned nanotubes are essential for this unique engineering feat to work. The nanotubes also need to be the right kind, with the right dimensions and compliance," Ajayan said. "Geckos inspired us to develop a synthetic gecko tape unlike any you'll find in a hardware store," Dhinojwala says. "Synthetic gecko tape uses van der Waals interactions to stick to a variety of surfaces without using sticky glues." The material could have a number of applications, including feet for wall-climbing robots, a dry, reversible adhesive in electronic devices, and outer space, where most adhesives do not work because of the vacuum. (Source: RPI)

[1] Proc. Natl. Acad. Sci., **DOI** 10.1073/pnas.0703505104 (2007).

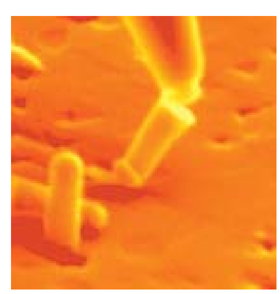
Measuring internal stresses with the perfect tip

Empa materials expert Johann Michler in Thun, Switzerland, and Silke Christiansen from the Max Planck Institute for Microstructure Physics in Halle, Germany, have now constructed probe tips out of silicon nanowires which improve the precision of Raman spectroscopy significantly by a factor of up to a hundred. This allows changes at the molecular level – such as those on a microchip – to be observed.

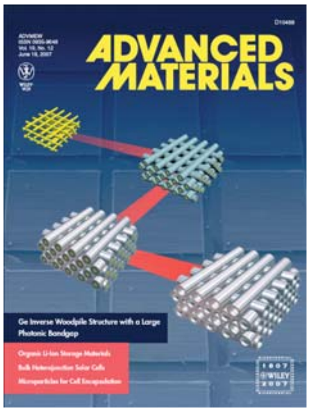
Johann Michler and his team are conducting research into the inner structure of solids with the help of tip enhanced Raman spectroscopy (TERS). A rounded tip coated with gold or silver can be used to efficiently couple laser light into molecules or crystals. In practice, to date the factor limiting the resolution of the method has been the fineness of the tip which can be achieved. The sputtered gold surface of the tips takes on randomly different shapes, so that each one is slightly different in shape and size.

Now the researchers have developed a new method of creating even finer Raman tips [2]. They grow silicon nanowires with gold heads on a silicon substrate. They are just a few micrometers long, with diameters selectable between 25 to 500 nm. The most important feature is that all the nanowires have identical, perfectly round gold tips. The nanowires are then welded onto a holder in an electron microscope, moved and adhered to the tip, and welded in place using the electron beam, as explained by Stephan Fahlbusch, the nanotools specialist in Michler's team. The sensitivity of the new method is demonstrated by the colleagues in Halle, where the tip was scanned over a layer of malachite green. Although only single molecules of the dye were present on the substrate, the equipment produced a definite Raman signal. This means that the resolution of the technique is high enough to measure changes in the internal mechanical stresses of semiconductor materials, for example. This is important because it indicates the presence of defects or material fatigue. (Source: Empa)

[2] Nanotechnology **18**, 035503 (2007).



The still-unfinished tip of the spectro-scope contacts the nanowires.



Inverse woodpile structure has extremely large photonic band gap of 25%

The latest photonic device built by researchers at the University of Illinois, a so-called inverse woodpile structure, is made of germanium which has a higher refractive index than silicon.

"Until now, all woodpile structures have been composed of solid or hollow rods in an air matrix," said Paul Braun, Professor of Materials Science and Engineering. Their new germanium matrix containing a periodic array of tubular holes has one of the widest photonic band gaps ever reported (as large as 25%) [3]. "In many applications, from low-threshold lasers to highly efficient solar cells, photonic crystals with wide band gaps may be required" [4].

To create their structure, the researchers first produced a polymer template by using a robotic direct-write assembly deposition. The process employs a concentrated polymeric ink, dispensed as a filament to form the woodpile rods, from a nozzle approximately 1 μm in diameter. The nozzle dispenses the ink into a reservoir on a computer-controlled, three-axis micropositioner. After the pattern for the first layer is generated, the nozzle is raised and another layer is deposited. This process is repeated until the desired 3D structure is produced. Next, the researchers deposited a sacrificial coating of aluminum oxide and silicon dioxide onto the entire structure. The coating enlarged the rods and increased the contact area between them. The space between the rods was subsequently filled with Ge. The researchers then heated the structure to burn away the polymer template. Lastly, the sacrificial oxide coating was dissolved by acid, leaving behind a tiny block of Ge with an inner network of interconnected tubes and channels. The finished structure consists of 12 layers of tubes, measures approximately 0.5 mm × 0.5 mm, and is about 15 μm thick.

"The direct-write template approach offers new design rules, which allows us to fabricate structures we otherwise could not have made," said co-author Jennifer Lewis. "Our technique also can be adopted for converting other polymeric woodpile templates, such as those made by laser-writing or electron-beam lithography."

In addition to their potential as photonic materials, the interconnected, inverse woodpile structures could find use as low-cost microelectromechanical systems, microfluidic networks for heat dissipation, and biological devices. (Source: University of Illinois at Urbana-Champaign)

[3] Adv. Mater. **19**, 1567 (2007).
[4] Special issue on Photonic Crystals (eds. R. Wehrspohn, H. Kiterzow, and K. Busch), phys. stat. sol. (a), forthcoming.

New fabrication technique yields nanoscale UV LEDs

Researchers at the National Institute of Standards and Technology (NIST) in collaboration with scientists from the University of Maryland and Howard University, have developed a technique to create tiny, highly efficient light-emitting diodes (LEDs) from nanowires [5]. The fabricated LEDs emit ultraviolet light – a key wavelength range required for many light-based nanotechnologies – and the assembly technique is well-suited for scaling to commercial production.

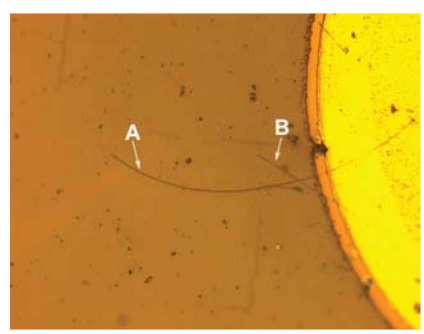
Light-based nanoscale devices, such as LEDs, could be important building blocks for a new generation of ultracompact, inexpensive technologies, including sensors and optical communications [6]. Ultraviolet LEDs are particularly important for data-storage and biological sensing devices, such as detectors for airborne pathogens. Nanowires made of a particular class of semiconductors that includes AlN, GaN and InN are the most promising candidates for nanoscale LEDs. But, says NIST researcher Abhishek Motayed, "the current nanowire LEDs are created using tedious nanowire manipulation methods and one-by-one fabrication techniques, which makes them unsuitable for commercial realization."

The team used batch fabrication techniques, such as photolithography (printing a pattern into a material using light, similar to photography), wet etching and metal deposition. They aligned the nanowires using an electric field, eliminating the delicate and time-consuming task of placing each nanowire separately.

A key feature of the new nanowire LEDs is that they are made from a single compound, gallium nitride. p–n junctions made from the same basic compound yield more efficient LEDs than those made with different compounds, and so can operate at lower power.

When the proper voltage is applied to the junction, it emits light with a peak wavelength of 365 nm. The group produced and tested more than 40 of these LEDs; all showed very similar emission properties. They also displayed excellent thermal stability – withstanding temperatures up to 750 °C – and operational stability, showing no signs of deterioration even after two continuous hours of operation at room temperature. These properties indicate that this LED production method yields reliable, stable devices. The researchers say their method could be used to fabricate other nanowire structures as well as applications requiring a large area of nanoscale light sources. (Source: NIST Tech Beat)

[5] Appl. Phys. Lett. **90**, 183120 (2007).
[6] Proceedings of IWN 2006, phys. stat. sol. (a), (b), and (c), June 2007.



Micrograph of a complete nanowire LED with the end contact. The long nanowire (A) is about 110 μm long, a shorter nanowire (B) crosses it. The bright circular section is the metal post from which the nanowires are aligned.

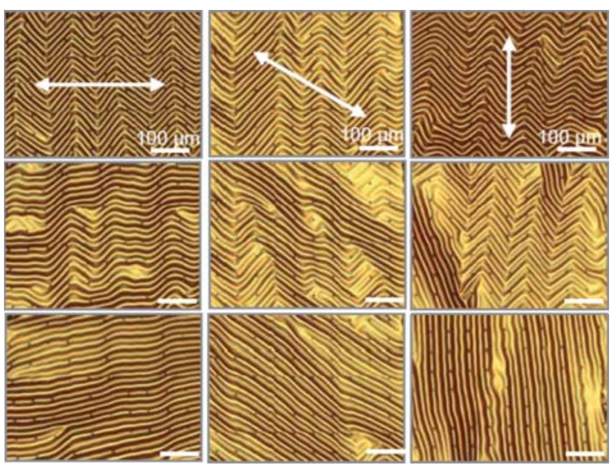
Switchable two-colour light source on a silicon chip

Silicon is the most important material for electronic chips and processors. Yet it has a big drawback: being an indirect semiconductor, it hardly emits any light. Physicists at the Forschungszentrum Dresden-Rossendorf (FZD), Germany, now managed to make silicon shine red and blue in an alternating fashion.
The FZD has worked successfully for several years on the realization of silicon based light emitters. Initially the physicists made a blue-violet emitter, which was then the basis of a Si-based optocoupler. In 2004 they demonstrated ultraviolet, and then green light emitters [7]. Now the physicists can switch the characteristics of the emitted light between two colours – red and blue – at will, depending only on the electrical current flowing through the device [8]. The compatibility of these emitters with standard Si microelectronic technology is crucial, since the two-colour nano-switch could easily be integrated into common silicon microchips.
For the fabrication of the test devices the group around Wolfgang Skorupa deposits a 100 nm thin insulating silicon dioxide layer on the surface of the silicon wafer. Then the rare-earth element europium is ion-beam implanted. The peculiarity of Eu lies in the fact that it forms two different types of impurities carrying a different charge (oxidation state). These are the origin of the red and blue luminescence. Depending on the strength of the electrical current one or the other impurity type is excited to emit photons. Possible applications of this two-colour device lie in the area of biosensing. For example, the new Si based light source could be used in the fast and cost-effective point-of-care analysis in health and environmental protection. (Source: FZD)

[7] phys. stat. sol. (c) **2**, 2941 (2005).
[8] Appl. Phys. Lett. **90**, 181121 (2007).

News in brief

➔ **“Wavy” silicon** has been introduced by the research group of John Rogers from the University of Illinois at Urbana-Champaign. By applying sheets of Si to a stretched rubber sheet, the silicon can be buckled into herringbone patterns in two directions by releasing the tension on the underlying rubber [9].



[9] Nano Lett. **7**, 1655 (2007).

➔ **Narrow-bandwidth photodetector:** A photosensitive layer of non-polar GaN on $LiAlO_2$ substrate forms a new device with only 6 nm bandwidth. It has been designed by S. Ghosh, H. T. Grahn et al. from PDI Berlin, UPM Madrid, and Tata Institute Mumbai for real-time identification of biological and chemical agents in air which produce UV fluorescence at 360 nm [10].

[10] Appl. Phys. Lett. **90**, 091110 (2007), phys. stat. sol. (c) **4**, 86 (2007).

➔ **Diamond quantum computer:** M. V. Gurudev Dutt, F. Jelezko et al. [11] from Stuttgart University have demonstrated qubit operation in diamond based on the nitrogen–vacancy colour centre. The defects were produced by nitrogen ion implantation [12].

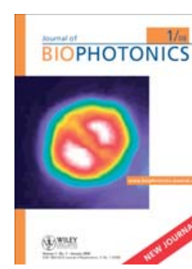
[11] Science **316**, 1312 (2007).
[12] See also the Review Article in phys. stat. sol. (a) **203**, 3207 (2006).

➔ **Magnetic racetrack:** G. Meier et al. from the University of Hamburg have demonstrated fast motion of a magnetic domain wall through a ferromagnetic permalloy wire. Nanosecond electric current pulses induced a speed of 110 m/s as imaged by polarized X-rays [13].

[13] Phys. Rev. Lett. **98**, 187202 (2007).

➔ The US National Science Foundation has chosen **Peidong Yang** from the University of California, Berkeley, to receive the 2007 Alan T. Waterman Award for his pioneering research on nanowires.

➔ The Julius Springer Prize for Applied Physics 2007 went to **Stefan Hell**, MPI for Biophysical Chemistry Göttingen, for his revolutionary discovery of resolutions far below the diffraction limit in fluorescence microscopy. Hell is Editor of the new Wiley Journal of Biophotonics to be launched in 2008.



➔ The new book “Brilliant!” by Bob Johnstone (Prometheus Books) tells the story of **Shuji Nakamura**, the Japanese engineer who laid the foundation for today’s solid-state lighting revolution with his blue, green, and white LEDs and laser diodes [14].

[14] See, e.g., phys. stat. sol. (RRL) **1**, 162 (2007) (current issue).