Phys. Status Solidi RRL **3**, No. 2–3, A33–A36 (2009) / **DOI** 10.1002/pssr.200950110

Solid state and materials research news

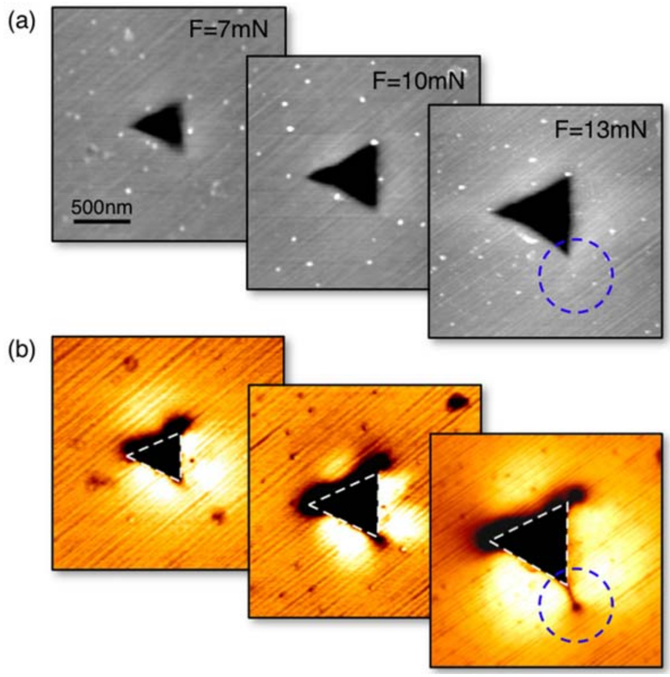
Auxetic graphene

Bristol (UK) – The mechanical properties of single layer graphene sheets (SLGS) have been a subject of intensive research in recent years. On the basis of mathematical models and calculation methods, different results have been published. Researchers at the Universities of Bristol, Swansea and British Columbia now developed a new model that suggests an auxetic structure of graphene sheets [1]. Whereas existing mechanical models employ Euler–Bernoulli beams rigidly jointed to the lattice atoms, the team led by Fabrizio Scarpa used truss-type analytical models and an approach based on cellular material mechanics theory to describe the in-plane linear elastic properties of SLGS. In the cellular material model, the carbon–carbon bonds are represented by equivalent mechanical beams having full stretching, hinging, bending and deep shear beam deformation mechanisms. Closed form expressions for Young's modulus, the shear modulus and Poisson's ratio for the graphene sheets are derived in terms of the equivalent mechanical C–C bond properties. The approach allows the scientists to identify the thickness and length of the C–C bonds, and gives insight into the in-plane mechanical characteristics of the graphene sheets. The equivalent mechanical deformation mechanisms when the SLGS undergoes small strain uniaxial and pure shear loading can be described. The model shows good agreement with the experimental results available from open literature. A peculiar marked auxetic (negative Poisson's ratio) behavior for the C–C bonds was identified for SLGS under pure shear loading. Other than classical structures and materials, auxetic structures expand when pulled along one direction. The research activities of Scarpa's team include the field of auxetics (foams and honeycombs). Some of his work has been published in the two 2008 special issues of physica status solidi (b) dedicated to auxetic materials [2].

[1] Nanotechnology **20**, 065709 (2009); DOI 10.1088/0957-4484/20/6/065709.
[2] Phys. Status Solidi B **245**(3), **245**(11) (2008).
nanotechweb.org/cws/article/tech/37389

Visualizing strain

Munich (Germany) – Strain determines the mechanical and electrical properties of high-performance ceramics and modern electronic devices. Its visualization at length scales below 100 nm is a key requirement, yet, the non-invasive mapping of strain with nanoscale spatial resolution is still a challenge. A new infrared mapping method based on near-field microscopy, developed by a German–Spanish team, now opens new avenues for analyzing mechanical properties of high-performance materials and for contact-free mapping of local conductivity in strain-engineered electronic devices. A promising route for highly sensitive and non-invasive mapping of nanoscale material properties is scattering-type scanning near-field optical microscopy (s-SNOM). The technique makes use of extreme light concentration at the sharp tip of an atomic force microscope (AFM), yielding nanoscale resolved images at visible, infrared and terahertz frequencies. It breaks the diffraction barrier throughout the electromagnetic spectrum, yielding a 20 nm resolution. Now, the research team has provided first experimental evidence that the microscopy technique is capable of

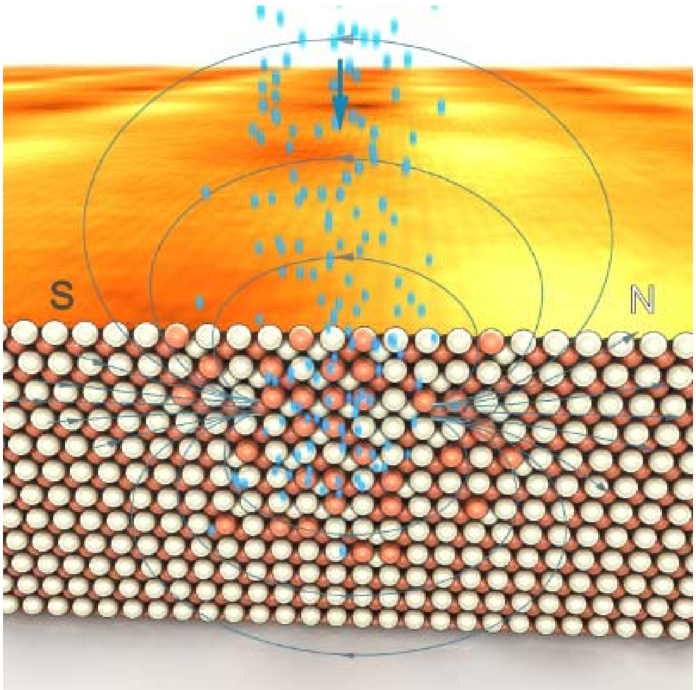


Infrared visualization of nanocrack evolution. a) Topography of triangular indents (depressions) at the surface of a SiC crystal. b) Infrared near-field images show the regions around the indent where the crystal lattice is compressed (bright) or stretched (dark). The onset and formation of nanoscale cracks (marked by dashed blue circles) can be visualized. (Image: Max-Planck-Institute for Biochemistry/ Andreas Huber) mapping local strain and cracks of nanoscale dimensions [3]. This was demonstrated by pressing a sharp diamond tip into the surface of a silicon carbide crystal. With the near-field microscope the researchers were able to visualize the nanoscopic strain field around the depression and the generation of nanocracks. Applications of technological interest could be the detection of nanocracks before they reach critical dimensions, and the study of crack propagation. s-SNOM also offers, for the first time, the possibility of mapping free-carrier properties such as density and mobility in strained silicon. By controlled straining of silicon, the properties of the free carriers can be designed, which is essential to further shrink and speed-up future computer chips.

[3] Nature Nanotechnol., DOI 10.1038/nnano.2008.399 (2009).
www.mpg.de/english/illustrationsDocumentation/documentation/pressReleases/2009/pressRelease20090112

Magnetic patterning

Dresden (Germany) – The interest in magnetic nanostructures has been steadily increasing during the last decades due to both current and potential applications (e.g., sensors or patterned media) and appealing novel magnetic properties. A new concept uses ion irradiation to fabricate arrays of sub-100-nm ferromagnetic structures at the surface of nonmagnetic intermetallic $Fe_{60}Al_{40}$ sheets, while preserving smooth surfaces.
Other than conventional techniques, the concept is based on the generation, rather than destruction, of magnetism by using relatively low fluence ion irradiation of non-magnetic $Fe_{60}Al_{40}$ alloys. When irradiated either by focused ion beam or broad beam ion irradiation through patterned polymer resist masks, disorder is selectively generated in the alloy. In the disordered regions, the material becomes ferromagnetic. The phenomenon can be partially explained by the so-called local environment model which takes into account that the magnetic moment of a given atom, such as Fe, depends on the number of nearest-neighbor atoms of the same species. Hence, the change in atomic environment of the Fe atoms caused by the atomic intermixing can qualitatively explain the induced magnetism. Nevertheless, the origin of the magnetic interactions in these disordered alloys does also emerge from changes in the band structure of the material induced by changes in the atomic order and the lattice cell parameters.
By means of focused ion beam Ga^+ irradiation sub-100-nm structures were generated. Larger arrays of dots, with sizes in the range of 100–400 nm, were produced using broad beam Xe^+ ion irradiation through lithographically defined masks. The magnetic patterning is fully removable by annealing. Due to the low fluences used, this method results in practically no alteration of the surface roughness.
The new technique may be interesting for a wide range of applications, such as patterned media, magnetic separators, or sensors. The ability to maintain a flat surface during fabrication is particularly attractive for nanoscale patterned media, where any surface roughness will lead to tribological problems as the magnetic recording head passes over the media at a height of a few nanometers. It is also ideal for magnetic separators, where a perfectly flat surface is essential for control of the sticking probability of functionalized magnetic nanoparticles.



An originally ordered binary alloy (white and red atoms) is disordered by means of focused ion irradiation (visualized as blue spheres in the 3D sketch). The disordered phase is magnetic and hence produces a magnetic field with north and south poles, similar to a bar magnet. The arrangement of north and south pole is used to store the information. (Image: FZD)

[4] Small **5**, 229 (2009), DOI 10.1002/smll.200800783.
www.fzd.de/db/Cms?pOid=27942&pNid=473

Disturbing hydrogen

Bochum (Germany) – Doping is the most important factor during the production of semiconductor devices. This standard process in the manufacturing of conventional semiconductors has, however, been problematic for zinc oxide to date [5]. In particular, it has been difficult to achieve p-doping, which made it impossible to construct semiconductor devices such as transistors or light emitting diodes. A research team around Christof Wöll in Bochum now identified a significant obstacle in the production of intrinsic ZnO: hydrogen atoms. In the presence of H atoms, always n-doping occurs [6]. Hydrogen impurities are almost impossible to avoid during the production process, thus preventing the targeted p-doping. High purity, in particular a hydrogen-free environment, is thus a decisive factor for the production of intrinsic zinc oxide.

The researchers investigated the electronic effects of H atoms at interstitial sites in ZnO by high resolution electron energy loss spectroscopy (HREELS). At low temperatures, interstitial H atoms form shallow donor states. At sufficiently high temperatures, the electrons are excited into the conduction band. Using EELS, the presence of plasmons resulting from this finite density of charge carriers in the conduction band could be demonstrated. Above 100 K, a strong, plasmon-induced broadening of the quasielastic peak in the HREELS data was observed. The analysis of the temperature dependence yielded a donor level ionization energy of 25 ± 5 meV.

Wöll and his team were able to resolve a scientific controversy with their results: to date it had often been postulated that the doping problems are caused by imperfections in the zinc oxide crystal lattice, by additional Zn atoms or oxygen defects. The results obtained in Bochum are a basis for the production of higher performance ZnO-based electronic circuits. Currently the scientists are doing intensive research to attain p-doping with an intrinsic, i.e. hydrogen-free, ZnO substrate by incorporating appropriate foreign atoms. Wöll has been a Guest Editor of the recent pss (a) Special Issue “Organic Electronics” [7].

[5] H. Morkoç and Ü. Özgür, Zinc Oxide (Wiley-VCH, Weinheim, 2009).
[6] Phys. Rev. Lett. **101**, 236401 (2008), DOI 10.1103/PhysRevLett.101.236401.
[7] Phys. Status Solidi A **205**(3) (2008).
[8] Phys. Status Solidi B **244**, 3027 (2007), DOI 10.1002/pssb.200743072.

Deep-center luminescence of various ZnO samples (taken from the Review Article by C. Klingshirn, ZnO: From basics towards applications [8]).

Switching between insulating and superconducting state

Geneva (Switzerland) – Interfaces between complex oxides are emerging as one of the most interesting systems in condensed matter physics. A research team now used the electric field effect to explore the phase diagram of the conducting interface between the band insulators $LaAlO_3$ and $SrTiO_3$ [9].

Recently, two possible ground states had been experimentally identified in this system: a magnetic state and a two-dimensional superconducting condensate. With help of an electric field, scientists now reversibly pumped charge carriers into or out of the interface, a process called charge doping. By doing this, a variety of new and unusual electronic phases can be promoted. The team was able to map out a region of the phase diagram of the interface state – a plot of temperature versus charge carrier concentration – that shows the phase boundary between an insulating and a superconducting state. The electrostatic tuning of the carrier density allows an on/off switching of superconductivity and drives a quantum phase transition between the two-dimensional superconducting state and the insulating state. Analyses of the magnetotransport properties in the insulating state are consistent with weak localization and do not provide any evidence for magnetism.

The electric field control of superconductivity might open the way to the development of new mesoscopic superconducting circuits. This approach might also facilitate, for example, the development of rewritable arrays of Josephson junctions (two superconductors separated by a thin, non-superconducting region).

[9] Nature **456**, 624 (2008), DOI 10.1038/nature07576.

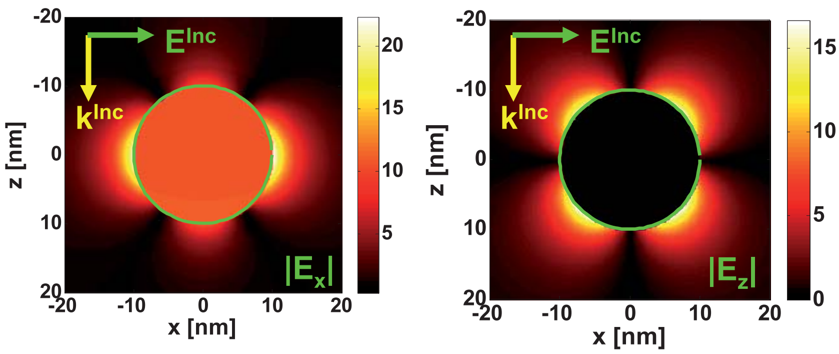
physicsworld.com/cws/article/news/36943

Plasmons and solar cells

Amsterdam (The Netherlands) – To make electricity from photovoltaics competitive with fossil fuel technologies, the price needs to be reduced by a factor of 2–5. Thin-film solar cells are a way to reduce cost. A 1–2 μm thin film is deposited on cheap substrates such as glass, plastic or stainless steel. A promising new way of increasing the light absorption in such thin-film solar cells is the scattering from metal nanoparticles near their localized plasmon resonance. Enhancements in photocurrent have been observed for a wide range of semiconductors and solar cell configurations.

The films can be made from a variety of semiconductors including cadmium telluride and copper indium diselenide, as well as amorphous and polycrystalline silicon. A major limitation in all thin film solar cell technologies is that their absorbance of near-bandgap light is ineffective, in particular for the indirect-bandgap semiconductor silicon. Therefore, structuring the solar cell so that light is trapped inside, in order to increase the absorption, is very important.

A new method for increasing the light absorption that has emerged recently is the use of scattering from noble



Amplitude distribution of selected electric field components near a spherical nanoparticle upon exciting a localized surface plasmon polariton (from [11]).

metal nanoparticles excited at their surface plasmon resonance. Kylie Catchpole and Albert Polman were able to show that light capture for long-wavelength light can be improved by a factor of more than ten. The overall light-gathering efficiency for solar cells using metallic nano-particles can be improved by 30 percent. In a review article, they give an overview about the underlying concepts, the experimental and theoretical progress in the field, and provide an outlook [10].

Florian Hallermann and co-workers from Germany quantified how the strong field enhancement and the large scattering cross-section of plasmons at the resonance wavelength can be employed directly to enhance light absorption in thin-film solar cells. They show first experimental results on tailoring appropriate materials [11].

[10] Opt. Express **16**, 21793 (2008), DOI 10.1364/OE.16.021793.
[11] Special Issue: Photon Management in Solar Cells, Phys. Status Solidi A **205**, 2844 (2008), DOI 10.1002/pssa.200880451.

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