ISSUE 7 SEPTEMBER 2009

MAX-PLANCK-GESELLSCHAFT

No. 7 FOCUS on Materials

MAX PLANCK INSTITUTE FOR METALS RESEARCH STUTTGART

An Organizer for Structuring Silicon

Materials Scientists Control the Crystallization Temperature of Amorphous Silicon

Aluminum could help the semiconductor industry to convert silicon from a disordered to an ordered form at low temperatures. This crystalline Si (*c*-Si) functions much more efficiently in solar cells, for example. However up to now it has only been possible to manufacture it at high temperatures (~ 700 °C) and it could therefore not be applied on heat-sensitive substrate materials such as plastic.

Researchers in the department "Phase Transformations" of Prof. Mittemeijer have now found a way to systematically lower the crystallization temperature of amorphous Si (*a*-Si) from 700° to 150 °C and to any temperature within that range. They succeeded in doing this by applying a thin film (< 20 nm) of Aluminium metal to *a*-Si; the thickness of the Al overlayer determined the crystallization temperature. On the basis of thermodynamic model calculations, the researchers have also explained why this happens. These findings could help to manufacture solar cells and other electronic components (e.g. rollable displays) on cheap, lightweight and flexible materials such as glass, plastic or even paper.

Vapor-deposited and magnetron-sputtered Si thin films are generally amorphous. It was already known that Al metal can weak-

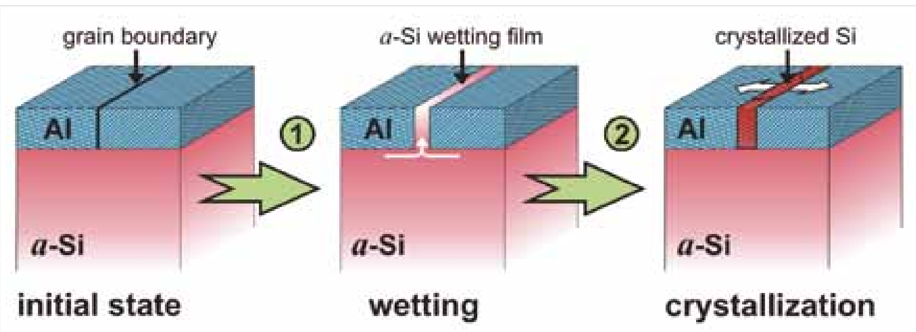


Figure 1: Atomic ordering in the gap: a covering layer of aluminum lowers the crystallization temperature of amorphous silicon (a-Si). First the a-Si covers ("wets") the grain boundaries in the aluminum layer. Once the wetting a-Si film has reached a critical thickness, crystallization starts at the grain boundaries.

continued on page 2

Dear Readers,

Focus on Materials has a new look. After more than three years the layout has changed slightly to better reflect the character of the magazine's visual impact – the columns and the content have remained the same.

By contrast, our homepage **http://www.mf.mpg.de** sports a complete new look – and we are convinced to have facilitated and improved a lot of things. The navigation through the whole website is much easier than before. One click on the respective graphic of the homepage directly leads you to the corresponding group of research. The link bars on the left and on top of the page provide access to further information about the Institute and its staff members as well as current news and events.

On behalf of the Institute, I wish you a great and interesting time reading the magazine and surfing our new homepage!

Joachim Spatz

Prof. Dr. Joachim Spatz
Acting Director

EDITORIAL

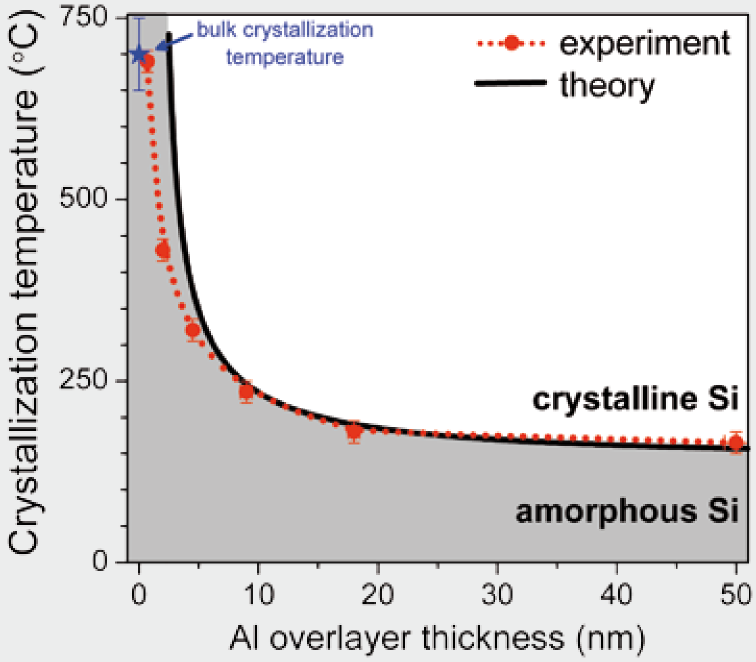


Figure 2: The dependence of the crystallization temperature of amorphous silicon on the aluminum overlayer thickness: Theoretical prediction versus experimental verification (by real-time spectroscopic ellipsometry under ultra-high vacuum conditions).

en the bonds between these *a*-Si atoms, thereby allowing them to rearrange themselves in an ordered form (i.e. to crystallize) at low temperatures. If there is no Al metal to loosen the bonds in the *a*-Si, a high temperature of about 700 ºC is required for the crystallization, which is incompatible with using heat-sensitive substrate materials.

The extent to which a thin Al overlayer lowers the crystallization temperature of a thicker *a*-Si block depends on the variations of energy contributions in the system (Fig. 1). The energies at the interface between the semiconductor and the metal play a major role. In order to lower the total energy of the system, the Si atoms first position themselves in a disordered way at the Al grain boundaries ('wetting'). As soon as a thin, disordered Si film has formed at the Al grain boundary, there is another opportunity to save energy: The Si atoms arrange themselves neatly into a crystal.

The crystallization energy and the change of interface energy are decisive here, because they determine the temperature at which the crystallization process starts. The researchers manipulate this delicate energy balance deliberately by varying the thickness of the Al layer, which leads to a striking dependence of the crystallization temperature of *a*-Si on the Al overlayer thickness in this nano-sized system (Fig. 2). This contribution not only provides pronounced fundamental insight into the process of metal-induced crystallization, but also demonstrates in general how surface and interface energetics control diffusion, wetting and phase transformations in low-dimensional systems.

Contact: e.j.mittemeijer@mf.mpg.de

Zumin Wang, Jiang Y. Wang, Lars P. H. Jeurgens, and Eric J. Mittemeijer
Tailoring the ultrathin Al-induced crystallization temperature of amorphous Si by application of interface thermodynamics
Physical Review Letters 100 (2008) 125503.

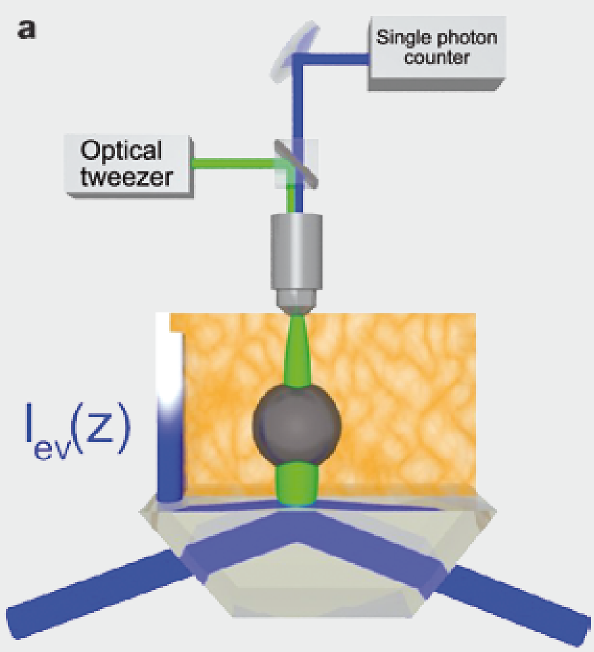
Looking Back and Ahead

Farewell of Professor Helmut Dosch

"To unravel the secrets of matter" – this will be Prof. Dosch's guiding principle for the next years as the new Chair of the Directorate of the Research Centre DESY in Hamburg. On March 20, 2009, the staff of our Institute celebrated a farewell party for and with Prof. Dosch, where Prof. Joachim Spatz symbolically gave him three-dimensional glasses to take along.

On the one hand, these glasses are a reminder of the time when Prof. Dosch was Managing Director at the Institute (2005 – 2006). At the time, he ordered a lot of them to give exciting and high-profile presentations for the interested public. On the other hand, these glasses are supposed to sharpen his view for the research, the challenges and the activities lying ahead.

During the last twelve years here at the Institute, Prof. Dosch has become internationally renowned for his research on interfaces and nanomaterials with synchrotron radiation and neutron technologies. He and his staff focused on advancing the microscopic understanding of matter and materials in confinement, in reduced dimensions, and in metastable states. The Board of Directors and all the staff wish him all the best for his future.



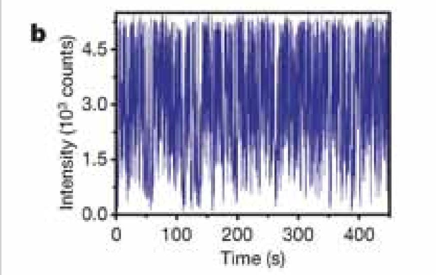
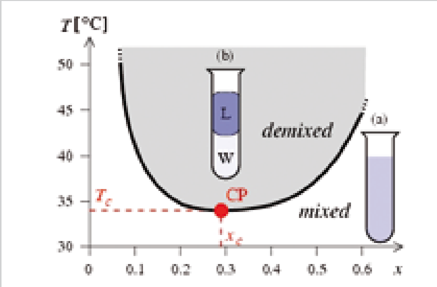


Fig. 2: TIRM apparatus. (a) A colloid (dark grey) floating in the mixture (light brown) scatters light out of an evanescent laser field. The time-dependent intensity of the scattered light (b) reflects the Brownian random motion of the colloid.

Fig. 1: Phase diagram of the mixture of water and lutidine. If mixed in a test tube with a certain molar fraction x of lutidine, the two components form a homogeneous mixed solution (a) at low temperature T whereas they demix (b) upon increasing T.



Critical Casimir Forces at Work

Targeted Control of Minimal Forces

Thermal fluctuations occurring in binary liquid mixtures give rise to forces at the sub-micrometer scale which can be harnessed to serve dedicated purposes, as the group of Prof. Dietrich has demonstrated in a joint work with the experimental group of Prof. Bechinger (Max-Planck Fellow).

Depending on the temperature and lutidine concentration, the binary mixture formed by this oily liquid and water is either mixed or demixed. At the so-called *critical point* (CP, see Fig.1) the transition between these two different states occurs continuously, and close to it the thermal fluctuations of the local concentration of lutidine become particularly large. By monitoring via Total Internal Reflection Microscopy (TIRM) the Brownian motion of a sphere of micrometer size *(colloid)* immersed in the mixture (see Fig.2), it is possible to determine the potential of the forces acting on the sphere (see Fig.3).

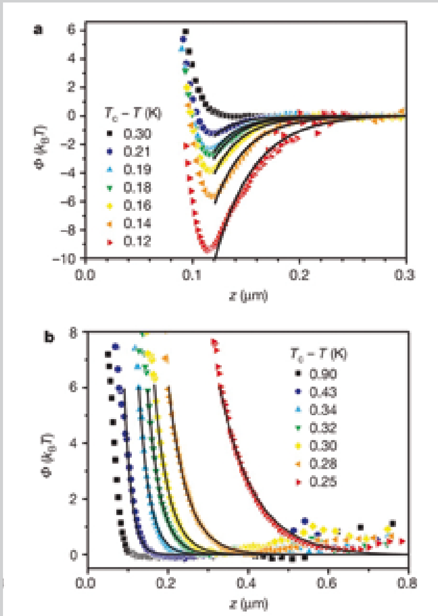
Part of this potential results from confining the critical fluctuations of the mixture in the space in between the sphere and the glass prism beneath. This is the so-called *critical Casimir effect*. If the surfaces of the sphere and of the prism preferentially adsorb the same component of the mixture, an attractive force (pushing the sphere towards the prism) up to 500 femto-Newton is observed experimentally upon approaching the critical point, in striking quantitative agreement with the theoretical predictions (see Fig.3(a)). A minute change in temperature results in a significant change in the potential, which even turns repulsive if the preferential adsorption of the sphere is suitably changed (see Fig.3(b)).

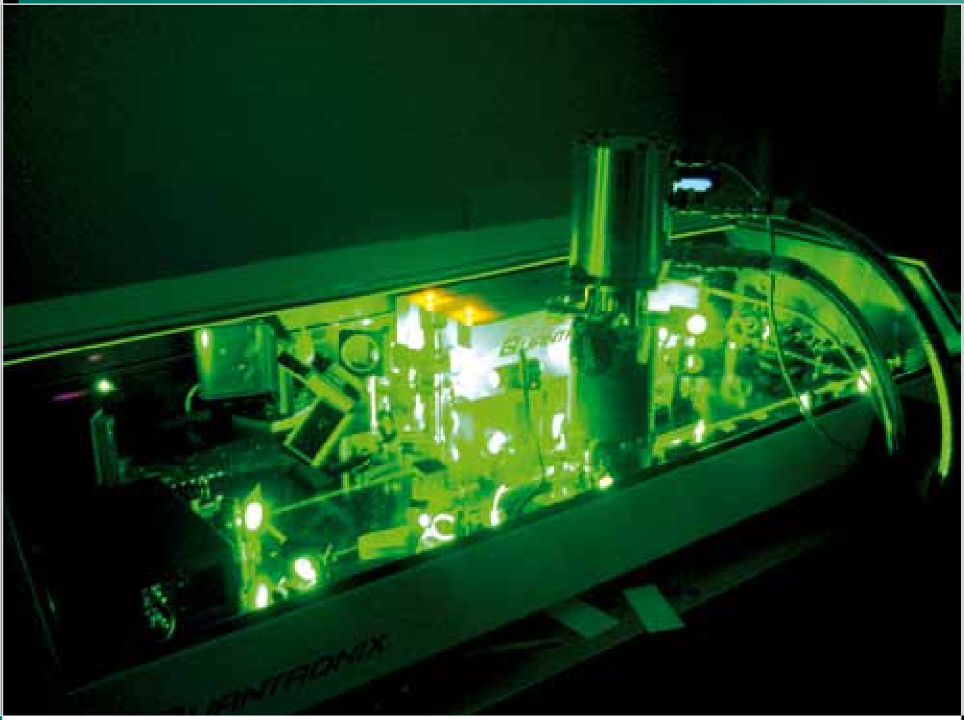
The tunability of this force can be used, for example, in order to control the aggregation of colloids or to neutralize the attractive and omnipresent quantum mechanical Casimir force which brings the movable parts of nanometer-sized machines to a standstill.

Contact: dietrich@mf.mpg.de

C. Hertlein, L. Helden, A. Gambassi, S. Dietrich, and C. Bechinger,
Direct measurement of critical Casimir forces,
Nature 451, 172-175 (2008).
(Online: http://www.nature.com/nature/journal/v451/n7175/abs/nature06443.html)

Fig. 3: Potential of the forces acting on the colloid, as a function of the temperature T of the mixture (at the critical concentration) and of the minimal distance z between the surface of the colloid and the prism. The solid lines are the theoretical predictions for the contribution of the critical Casimir effect to the potential.





"Super-Laser"
The Junior Research Group Roke investigates molecules at interfaces via nonlinear, optical methods. For this kind of research, a powerful laser-beam with high energetic femto second radiation (10^{-15} s) is needed.

Digging for Buried Microstructures

Clues for why a medicinal compound works

Each year, worldwide over 600,000 people develop hepatocellular carcinoma (HCC) and cancer of the biliary tree (cholangiocarcinoma), while at least as much are diagnosed with liver metastases, often originating from tumors, arising in organs drained by the portal vein. The most commonly diagnosed of such tumors is colorectal carcinoma, with about one million new cases every year, of which more than 50 % will develop hepatic metastases. For both primary liver cancer and colorectal cancer mortality is high; it was estimated that in 2002 close to 600,000 persons died from primary liver cancer and over 500,000 from colorectal cancer.

At the nuclear medicine department of the University Medical Center Utrecht (Utrecht, The Netherlands) the team around Dr. Frank Nijsen is busy developing a possible new treatment for these forms of liver cancer. They propose to use radio-activated holmium-166 loaded poly (L-lactic acid) microspheres (166HoMS). These 20 – 50 micron-sized microspheres can be injected into the hepatic artery, from where they will lodge around the tumor sites. First experiments show that the prepared microspheres have a unique robustness that may be the key to the functionality of the microspheres. The physico-chemical reason for this robustness is somewhat mysterious however, since a small metal compound and a large polymer should normally not give rise to a robust structure.

The team of Dr. Sylvie Rokes Junior Group at our Institute has used nonlinear light scattering spectroscopy to look at the inner life of the biodegradable microspheres. Nonlinear light scattering spectroscopy is a combination of light scattering and nonlinear optics, and can be used to probe non-invasively and in-situ the chemical structure of domain boundaries and surfaces of small particles. The researchers applied the method to the spheres and found that they were not measuring the surface of the microspheres but rather small domains inside the microspheres. This became apparent from appropriate modeling that predicted that the spheres have crystalline inclusions of 500 nm. These domains consist of crystalline poly-lactic acid polymer and are a host matrix for the metal complex that can interdigitate with the crystal structure of the polymer.

The ability to look inside a solid matrix without cutting open the material opens up new avenues for the study of heterogeneities in chemistry and physics, such as the monitoring of crystal nucleation and growth, or the detection of small amounts of biological crystals (such as proteins and biopolymers).

Contact: roke@mf.mpg.de

A.G.F. de Beer, H.B. de Aguiar, J.F.W. Nijsen, S. Roke
Detection of buried microstructures by nonlinear light scattering spectroscopy
Physical Review Letters, 102, 095502 (2009)

PEOPLE AND NEWS

Honors and Awards

Dr. Lars Jeurgens, Department "Phase Transformations", received the "Masing-Gedächtnis-Preis 2008"(Masing Memorial Award) from the "Deutsche Gesellschaft für Materialkunde e.V." (German Society for Materials Research) for his scientific work on the thermodynamics and oxidation of metals.

Dr. Barbara Schmitz, Department "Modern Magnetic Materials", won the second prize in the competition "She-Study Award 2008" of the mineral oil company Shell for her diploma thesis ("Physisorption von Wasserstoff in neuen Materialien mit großer spezifischer Oberfläche"). The prize was awarded for the 12^{th} time and promotes female scientists only.

Dr. Udo Welzel, Department "Phase Transformations", received the Günter Petzow Award 2008 on July 17, 2008 (see page 5).

The image produced with an FIB (Focused Ion Beam) by **Ulrike Eigenthaler** and **Dr. Michael Hirscher,** Department "Modern Magnetic Materials" was among the prize winners of an image competition of the journal "Materials Today" (see page 8).

The poster entitled "*In-situ* X-ray Study of Fe_3Al (110) subsurface superlattice disorder during oxidation" by **Dr. Vedran Vonk,** Department "Low-dimensional and Metastable Materials", won the prize for best poster at the ESFR user meeting in February, 2009.

During the 7th Paul-Peter Ewald Colloquium, Prof. Günter Petzow (right) and Prof. Joachim Spatz (left) awarded Dr. Udo Welzel (middle) the Günter Petzow Award 2008.
He received this Award for his outstanding research on the residual stress analysis of thin films by X-ray diffraction and especially for revealing and quantifying the surface anisotropy.

Günter Petzow Award 2008 for Dr. Udo Welzel

Investigation of the Surface Anisotropy of Polycrystalline Materials

The Günter Petzow Award honors the outstanding achievements of young researchers of the Institute. Dr. Udo Welzel's work fundamentally contributes to the theory of grain interaction in polycrystalline materials. His experiments during the last years enabled him to reveal the so-called surface anisotropy. Furthermore, he developed models which are able to describe this phenomenon quantitatively.

Udo Welzel is a scientific staff member of the Department "Phase Transformations" (Prof. Mittemeijer) as well as head of the Central Scientific Facility (ZWE) "X-ray diffraction". X-ray diffraction analysis is a powerful method for the quantitative analysis of the microstructure of materials which strongly influences materials' properties.

Dr. Welzel's current research topics focus on methodological developments for the diffraction analysis of anisotropic and inhomogeneous microstructures, grain interaction in thin films and surface layers of bulk materials, the analysis of (stress) gradients, the origins of residual stresses as well as defects, diffusion and phase transformation in stressed thin films and nanoscale materials.

In close collaboration with PhD students and co-workers of the Department of Prof. Mittemeijer, in-situ X-ray diffraction measurements revealed that the coefficient of thermal expansion is larger in materials with nanosized grains as compared to coarse-grained materials (Applied Physics Letters 90 (2007) 243113). Investigations of iron-nitrides revealed the stability of phases in microstructures with nanosized grains, which are unstable in coarse-grained materials (Applied Physics Letters 91 (2007) 141901). Methodological developments for the diffraction analysis of stress gradients enabled the identification of stress gradients as driving force for the whisker growth on Sn coatings (Applied Physics Letters 93 (2008) 011906). This research, conducted in collaboration with the Robert Bosch GmbH Reutlingen, has a great practical relevance, as the whisker growth pheno-menon poses a serious problem for the reliability of microelectronic components.

The Institute wishes Udo Welzel an enjoyable and successful continuation of his research activities.

Note: The prize winner of the Günter Petzow Award 2009 will be featured in the next issue.

EVENTS CALENDAR

Mondays, 5:00 pm, during semester
Materials Science Colloquium
Werner Köster Lecture Hall 2R4

Tuesdays, 5:15 pm, during semester
Physics Colloquium
Universität Stuttgart:
Lecture Hall V57.01
Pfaffenwaldring 57
MPI Campus: Lecture Hall 2D5

November 2/3, 2009
Workshop NIMS-MANA/ MPI-MF
all day, Room 2P4
We welcome our colleagues from the National Institute for Materials Science (NIMS), Tsukuba, Japan.

November 19, 2009
5:00 pm, Room 2R4 (Werner Köster Lecture Hall)
Public Lectures by Young Scientists of the Institute (in German):
Dr. Gunther Richter:
"Genese metallischer Haarkristalle"
Dr. Ralf Kemkemer:
"Wie Kräfte lebende Zellen formen"

July 9, 2010
1:30 pm, Lecture Hall 2 D5
Paul Peter Ewald Colloquium
5:00 pm, Summer Festival on the grounds of the MPI Campus

For more details see:
www.mf.mpg.de > News

Winter School in Stuttgart

Five professors and 20 Ph.D. students/post-doctorates from Boston attended the first joint Winter School of the IMPRS-AM organized by the MPI-MF and the MIT's Department of Materials Science and Engineering, Cambridge, MA, USA.
A long-term cooperation is intended – scientists from Stuttgart plan to travel to Boston for a return visit in about two years.

The Lord of the Nanocrystals

Max Planck Lecture – Professor A. Paul Alivisatos

In the Max Planck Lecture 2008, Professor A. Paul Alivisatos from Berkeley presented his vision of a universal toolbox for the production of colloidal nanocrystals. The ultimate goal of the tools and operations comprised in this toolbox is to assemble colloidal nanocrystals into larger entities and thus build molecule-like structures. The constituents of these assemblies, the nanocrystals, contribute with their individual properties to the entire system, albeit interactions between different components might lead to unexpected results.

In the first part of his presentation, Professor Alivisatos discussed an application of such an assembly and how it employs the interactions between two nanocrystals in close vicinity. He presented a molecular ruler composed of two gold nanocrystals interconnected through a double stranded DNA. The principle of measurement relies on the sensitive alternation of the optical properties of the gold nanocrystals in function of their distance. With this system the group of Professor Alivisatos could successfully follow the dynamics of the cutting of DNA with a restriction enzyme.

The second part of the lecture was on different methods for the construction of larger structures composed of nanocrystals. With the help of these methods the tedious and sometimes unstable interconnection with biological molecules can be circumvented.

Text: Stefan Kudera

During his talk, Professor Alivisatos sparked the audience's enthusiasm for his field of research.

New Look for Our Homepage

A few months ago our new homepage went online. This means: old address – new look under http://www.mf.mpg.de.

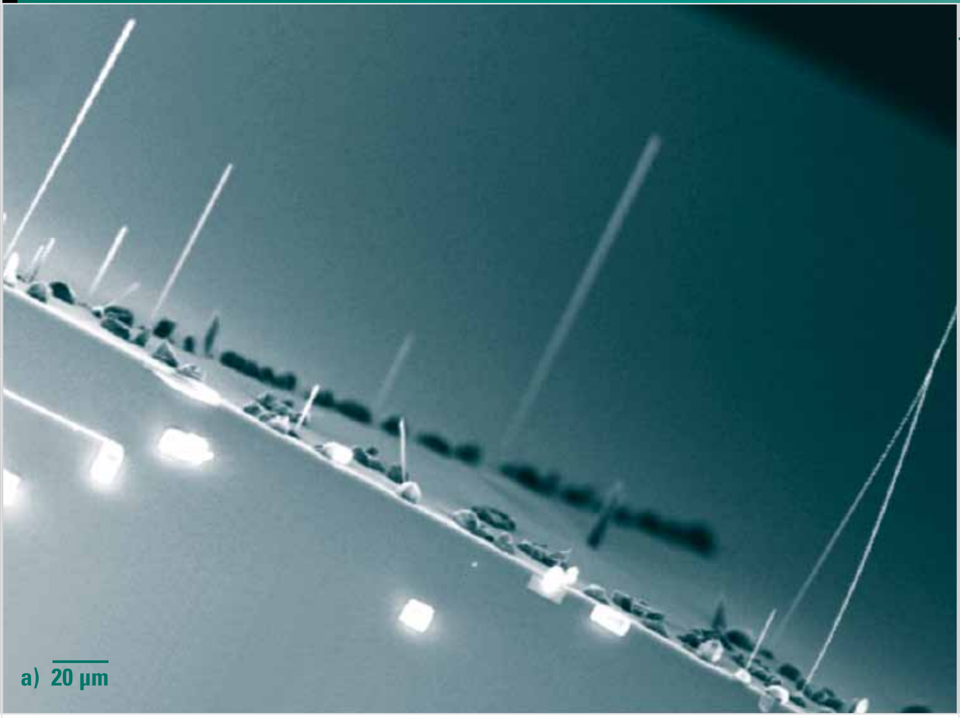
For several months, the staff of the Institute in a common effort compiled new texts, pictures and information and posted everything in the Content Management System used by the MPG.

The main menu bar on the left is kept deliberately short; you can find further topics and themes in the meta-navigation on the top of the page.

Up to now, the new homepage still links to the "old" pages some of the research groups. Step-by-step, all contents are to be transferred to the CMS. Visitors can easily and directly find information on events, seminars and colloquia as well as documents of interest for the public (press releases, Focus on Materials).

Look and see!

www.mf.mpg.de



Scanning electron microscopy picture of Copper-whisker grown on a Silicon surface. The projected length is ~ 65 µm, the diameter ~ 100 nm.

Transmission electron microscopy micrographs of a (b) axial layered composite formed by a 20 nm Cobalt film on a Copper whisker and a (c) Gold(Silver) nano-tubule with wall thickness of ~ 10 nm.

Old Materials for New Applications: One-Dimensional Metal-Whiskers

Initiator Mediated Filamentary Crystal Growth Process Closes a Gap in Nanotechnology

Two-dimensional thin films are the backbone of contemporary nano-technology devices. The next generations of applications have to differ considerably in materials selection and structural assembly. Three-dimensional, self-organized grown nano-structures, acting as active and passive elements, will play an important role in future MEMS, sensor or optoelectronic applications.

One-dimensional, freestanding structures exhibit fascinating properties and are under investigation since the 18^{th} century, promising to meet the challenge for future nanotechnology. Recently carbon and semiconductor based materials were synthesised as high aspect ratio structures with conventional methods. Only the metals as one of the oldest used materials in technology are not easily fabricated in such geometries and microstructures.

The thin film laboratory spearheads new research activities for metallic nanostructures. An initiator mediated filamentary crystal growth process based on the physical vapour deposition technique was developed, producing freestanding, single crystalline and defect free metal whiskers with a aspect ratio of up to 2000:1. Metals with face centred (Cu, Ag, Au, Pd), body centred (Fe), and hexagonal (Co) crystal structure were synthesized successfully with the new technique. The shape of the filamentary crystals is governed by the surface energies of its confining crystal facets. Typical diameters of the whiskers are 100 nm and lengths of up to 200 μm are observed.

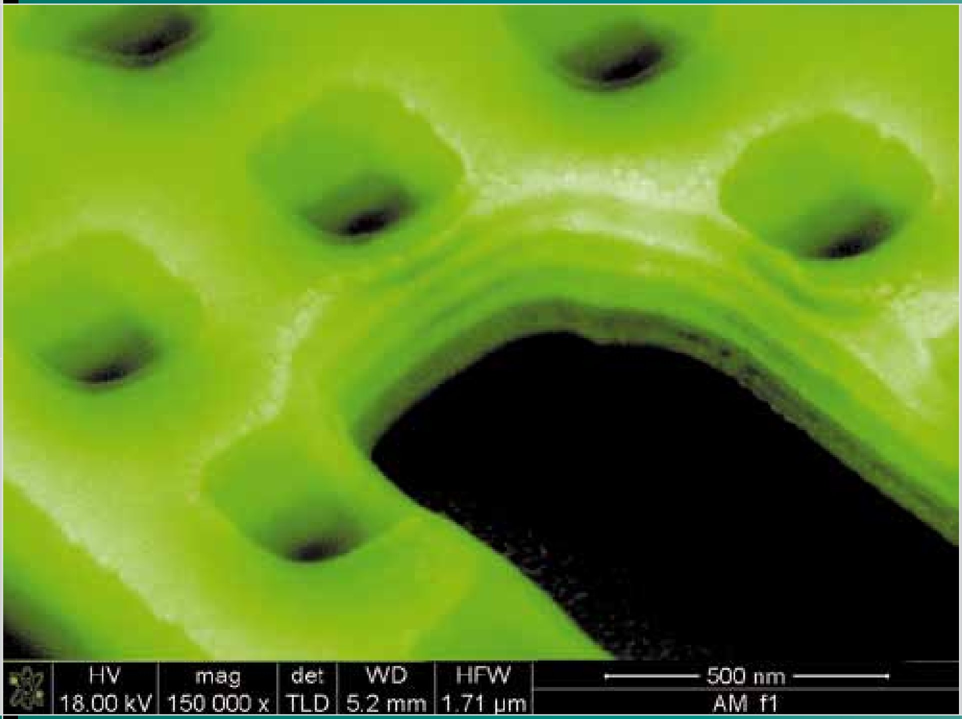
Preliminary tensile testing measurements, in collaboration with the Forschungszentrum Karlsruhe, resulted in a strength of 6 GPa for 70 nm diameter Cu nanowhiskers. This is close to the theoretical strength limit of Cu and exceeds all previous values for fcc micro-pillar and thin film tests and demonstrates the remarkable properties of the whiskers. Due to the absolute absence of dislocations or grain boundaries it is possible to investigate the genuine materials properties of metals in the nanometer regime.

Apart studying the inherent properties of pure materials, whiskers can be used for fabrication of nano-composites from different materials. Tailored microstructures enable the formation of different configuration, such as axial or lengthwise multilayered whisker, or hollow metallic nanotubulars.

A bridge between metallic macro-devices and structures down to those dominated by the quantum effect, and between metal and semiconductor devices is formed by the fabrication by initiator mediated whisker growth.

Contact: richter@mf.mpg.de

G. Richter, K. Hillerich, D. S. Gianola, R. Mönig, O. Kraft, C. A. Volkert, **Ultrahigh Strength Single Crystalline Nanowhiskers Grown by Physical Vapor Deposition,** Nano Letters Vol. 9, No. 8, 3048-3052 (2009).



Fishnet in Focus

This image was taken by Ulrike Eigenthaler and Dr. Michael Hirscher with the FEI-Nova Nanolab 600 and has been selected as one of the 13 prize-winning images in the 2008 competition of the journal "Materials today".
The electron micrograph shows a focused ion beam cut of a five-layer "fishnet metamaterial". The stacking of the fine gold wire netting leads to the coupling of the plasmons. Thus special magnetic and optic properties of the metamaterial are generated which are the preconditions for a negative refractive index.

Further information on the according research: "Plasmonic Building Blocks for Magnetic Molecules in Three-Dimensional Optical Metamaterials", by N. Liu, L. Fu, S. Kaiser, H. Schweizer, H. Giessen. Advanced Materials, Vol. 20, Issue 20, October 17, 2008, p. 3859-3865.

Opening: Day Care Center "Forscherzwerge"

Stuttgart's Max Planck Institutes Open their Own Day Care Center

Since the opening of the day care center "Forscherzwerge" (i.e. "research midgets"), the Max Planck Institutes in Stuttgart balancing family and career has become much easier for the staff. This attractive facility situated directly on the campus in Stuttgart Büsnau represents a huge advantage of location for basic research: short distances for the parents, convenient opening hours, professional care and education for the very young children.

The day care center "Forscherzwerge" was officially inaugurated on February 17, 2009. Prof. Joachim Spatz, chairman of the Joint Commission of the MPI-MF and of the MPI-FKF, handed the prospective researchers a small present with "basic equipment", consisting of 3-D glasses, magnifying glass, pencil and a Max Planck key chain. Let's go, little researchers!

Just like the atmosphere on the Max Planck Campus in Stuttgart is international, the day care center "Forscherzwerge" is also multicultural. The parents of Berk, Daniel, Helene, Marvin, Matias, Nina, Shiwan and Sitan come from Turkey, Germany, Spain or China. Though the facility is German-speaking, it offers one extraordinary feature: One of the teachers is an American and only speaks English with the kids.

We are proud that "Konzept-e GmbH", a well-known company in Stuttgart, is operating the "Forscherzwerge" based on its pedagogic concept "*element-i*".

IMPRINT

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