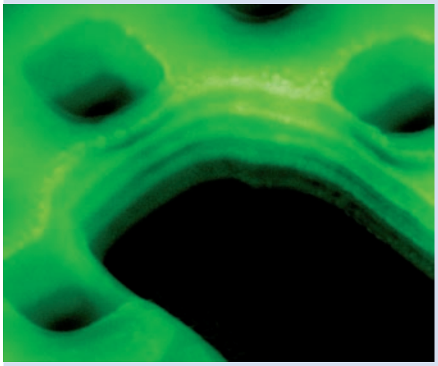
METAMATERIALS
An added dimension



Adv. Mater. doi: 10.1002/adma.200702950 (2008)
The design, fabrication and use of metamaterials comprise a burgeoning field in modern optics research. Following the initial ground work in the field by investigating two-dimensional structures, there is now a drive to add extra functionality by developing thicker structures, taking metamaterials into the third dimension. Researchers at the University of Stuttgart have now extended the understanding of these thicker metamaterials by developing the concept of the 'magnetic molecule', an effect arising from coupling effects in stacked layers of magnetic metamaterials.

To fulfil their potential, metamaterials need a magnetic component. Incident light can excite a current that circulates each unit cell, such as a split-ring resonator or a cut-wire pair. This forms a close analogy to the orbital current in atoms. Na Liu and co-workers have now studied the interplay between these 'magnetic atoms' in a stacked layer, forming the metamaterial equivalent of molecules — magnetic molecules.

The metamaterial investigated was made up of five layers, each consisting of a combination of silver cut-wire pairs and continuous strips — a so-called fishnet structure — separated by layers of a photopolymer. Liu *et al.* observe resonances characteristic of coupling in the reflectance spectra in both numerical models and experimental results. The number of resonances grows with an increasing number of fishnet layers.

The results provide a deeper understanding of the differences between two- and three-dimensional metamaterials. The concept of magnetic molecules allows the complex reflectance spectra of multilayer metamaterials to be easily understood and classified.

TERAHERTZ EMITTERS
Black is back

Appl. Phys. Lett. **93,** 091106 (2008)
Necessity, so they say, is the mother of invention. This is certainly true in the case of sources of light at terahertz frequencies, which were once practically unavailable. Researchers in Germany have now devised another technique for this frequency range by producing terahertz emission using so-called black silicon.

One approach that has been investigated is the use of changes in the polarization of pulses of laser light induced by an interaction with above-the-bandgap carriers in semiconductors. Indirect-bandgap semiconductors, such as silicon, usually show only weak terahertz emission because of the large depth of penetration of the incident photons, which means that many carriers are generated far from the surface and do not contribute to light generation.

The remedy proposed is to modify the surface. Using a dry-etching technique, a layer of silicon can be converted into a forest of thin needles, in this case, 300 nm across and 2 μm tall. This patterning drastically enhances the light-absorbing properties of the semiconductor and has therefore been dubbed 'black silicon'. Hoyer *et al.* used pulses of 780-nm light to excite terahertz light from black silicon. To prove that the needles were important for the generation of the terahertz radiation, the same experiment was performed once the surface had been damaged. As expected, the intensity of the emission decreased.

QUANTUM PHOTONICS
Sensitively entangled

Science **321,** 1463–1465 (2008)
Entanglement has been used with quantum bits to enhance the ability of distinguishing measured photons. Seth Lloyd from Massachusetts Institute of Technology has now demonstrated that it can also be used for enhancing the sensitivity of photon counting.

The percentage of light reflected from an object that is far away is small, and noise can make this reflected signal even harder to distinguish. Lloyd modelled the object as a beam splitter with a reflectivity of zero when the object was not there and a small but non-zero reflectivity when the object was there.

Expressions for the probability of detecting a photon were devised for both high- and low-noise regimes. In the low-noise regime, detection of a single photon is sufficient to confirm that the object is present. In the high-noise regime, enough signal photons must be sent so that the probability distribution for detected photons that are all noise can be distinguished from the probability distribution for both noise and reflected signal photons.

Next Lloyd considered entangled signal photons from a spontaneous parametric down-converter, with a time–bandwidth product matching that of the detector. He showed that in the low-noise regime the signal-to-noise ratio was enhanced by a factor equal to the time–bandwidth product. In the high-noise regime the number of trials needed to confirm that the object was present was reduced by the same factor. In addition, this factor scaled exponentially with the number of bits of entanglement.

QUANTUM OPTICS
Taking shape

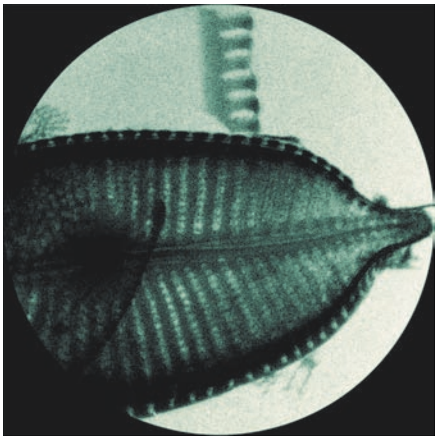
Phys. Rev. Lett. **101,** 103601 (2008)
Scientists from Stanford University have now shown how it is possible to control the waveform of a single photon. The key challenge here is to find a way of knowing when to start the modulation.

Pavel Kolchin and colleagues start with two photons. These are generated in a cloud of rubidium atoms by parametric down-conversion. The two photons are time–energy entangled and shoot out of the atomic gas in opposite directions. A second important property of the photons is that their group velocity is much lower than the speed of light in a vacuum owing to an effect known as electromagnetically induced transparency. This means that the pulse length of the photons is very long. In fact it can be varied between 50 ns and 900 ns and is much longer than the temporal resolution of the single-photon detectors (about 40 ps). Thus detection of the first photon can be used to define the time origin of the modulation of the second. Once this is accomplished, the waveform of the second photon can be shaped in much the same way as is done for classical light pulses, using an electro–optical modulator.

Kolchin *et al.* put this into practice by shaping the wave form of a single photon into two rectangular pulses, a Gaussian shape and a time-reversed exponential shape.

X-RAYS

Bright sparks



Opt. Lett. Doc. ID: 96458 (2008)

The short wavelength of soft-X-ray radiation makes it a good candidate for high-resolution imaging. However, progress is held back by the lack of a suitable laboratory-scale source. Markus Benk and colleagues from Germany have now developed a soft-X-ray microscope that uses a gas discharge light source.

The researchers pass electrical sparks, up to 1,000 every second, through nitrogen, thus generating a plasma. The ions emit light at a wavelength of 2.88 nm (other spectral lines are filtered out), which is directed onto a sample by a grazing incidence collector. By optimizing this collector, the source can produce as many as 10^7 photons μm^{-1} s^{-1}. Enough to image thick samples with an exposure time of as little as 10 s. The principle was validated using samples of diatoms and latex spheres.

Soft-X-ray microscopes are a great hope for the future in applications where high-resolution imaging is required, such as the structural characterization of semiconductor chips, or when investigating thick samples, such as biological specimens. The development of a table-top microscope is important for opening up this technology to the entire research community.

PLASMONICS

Designer deposit

Nano Lett. **8,** 3278–3282 (2008)

Research has shown that nanoparticles of materials, such as gold, can catalyse reactions where the bulk form is ineffective. Now Stephen Cronin and colleagues from the University of Southern California have exploited plasmon resonances to manipulate the growth of carbonaceous nanomaterials.

The researchers deposited 5-nm films of gold onto glass and silicon substrates, forming islands. They then irradiated the sample with a 532-nm-wavelength laser, as carbon monoxide flowed through the reaction chamber.

Raman spectroscopy revealed that on irradiating for a few minutes with a laser power of 12.3 mW, amorphous carbon formed. The researchers were also surprised to see the characteristic Raman signatures of haematite. Although ultrapure carbon monoxide was used, the formation of haematite from trace amounts of iron present from the gas cylinder was efficiently catalysed despite no deliberate feedstock.

By increasing the laser power to 23 mW and the exposure time to 10 minutes, graphite and carbon nanotubes were formed. By moving the laser focus, nanotubes up to 8 μm could be grown in the direction of the laser movement.

Using 785-nm laser light, no carbon was deposited — evidence of the role of resonant plasmons. There was also no deposition when the temperature in the chamber was raised to 900 °C, indicating that temperature gradients due to the excited plasmons were also crucial to enable the dissociation of carbon monoxide simultaneously with formation of iron oxide and carbon-nanotube structures.

OPTICAL FORCES

Trapped nanotubes

Nano Lett. **8,** 3211–3216 (2008)

A collaboration of scientists in Italy and the UK led by Andrea Ferrari has exploited single-walled carbon nanotubes (SWNTs) to achieve optical tweezing with higher spatial and force resolutions than ever before.

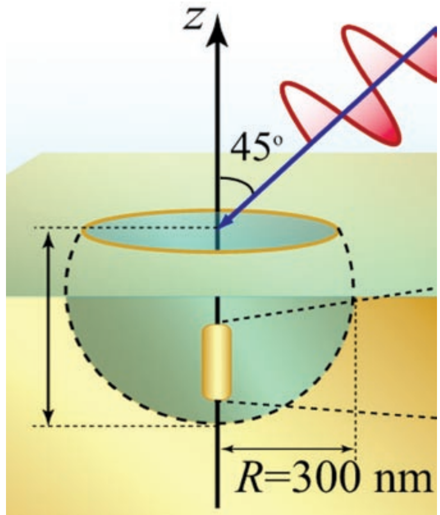
To optimize the resolution a full understanding of Brownian dynamics extended to non-spherical objects is required. The researchers imaged SWNTs using a CCD camera. As the image acquisition rate was slow, positional and angular displacements were detected using back-focal-plane interferometry and imaged onto a quadrant photodiode. The researchers compared the Brownian motion of SWNTs with latex spheres, and found that SWNTs have increased axial mobility.

From a combination of measurements and calculations the team was able to derive optical force constants. They then quantified the asymmetry of the spring constants arising from light polarization and found this value to be consistent with the calculated value for spherical particles that are much smaller than the trapping wavelength. This indicated that polarization effects are also important for extended structures and only depend on the nanoscale transverse size. A plot of a variable quantifying the aspect ratio of the trap's force constants revealed how the optical confining potential strongly depends on the geometry of the trapped particle.

The team achieved a force resolution of 20 fN in the axial direction and a transverse spatial resolution of 40 nm. In addition, the researchers were able to discriminate linear and angular motion by correlation function analysis, which is very important for developing a fundamental understanding of the optical trapping mechanisms.

OPTICAL MANIPULATION

Drowning nanorods



Phys. Rev. Lett. **101,** 136802 (2008)

Placing gold nanorods inside water-filled nanocavities creates a structured surface with optical properties that can be tuned by an external light beam. This is the recent finding of researchers from the Institute of Optics (CSIC) in Madrid, Spain. Rebecca Sainidou and Francisco Garcia de Abajo took gold nanorods approximately 20 nm in diameter and 100 nm long and placed them in spherical craters (300 nm in radius), which were formed on the surface of a gold substrate and submerged in water. They then illuminated the nanocavity with infrared light and discovered that, owing to plasmonic effects, the nanocavity's optical absorption and reflection strongly depends on the position and orientation of the gold nanorod. By applying a 'trapping' light beam to manipulate the gold nanorod the cavity's optical properties can thus be tuned. The researchers say that the effects are also strongly dependent on the wavelength of the trapping beam and believe that the approach could be a useful scheme for all-optical switching.