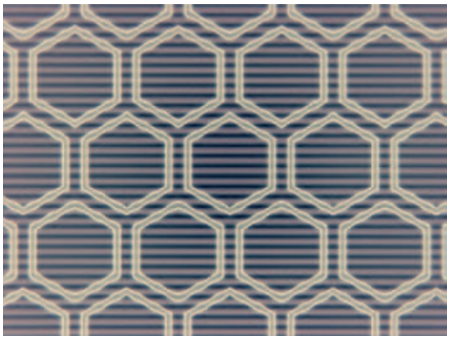
the sample by observing the wavelength dependence on the measured phase difference. Because terahertz waves allow for the probing of samples on the millimetre-to-centimetre scale, the researchers hope that their polarization-sensitive imaging technique may contribute to developments in the non-destructive mapping of material anisotropy. *SA*

GRAPHENE METAMATERIALS

Switching terahertz waves

Nature Mater. http://dx.doi.org/10.1038/nmat3433 (2012)



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Although graphene possesses gate-controlled electronic properties that make it possible to manipulate light, these effects are not strong enough for practical use. Now, by combining graphene and metamaterials, Seung Hoon Lee and co-workers from Korea and the USA have demonstrated a compact device that can perform efficient terahertz wave switching and modulation. The device is made from a thin and flexible polymeric substrate that features an array of meta-atoms, an atomically thin gated graphene layer and an array of metallic wire gate electrodes. The meta-atoms comprise a hexagonal metallic frame of asymmetric double split rings exhibiting a Fano-like resonance. By applying a gate voltage to one of the electrodes, graphene's Fermi level — and hence its carrier density — can be dynamically controlled with a corresponding change in conductivity. This alters the complex permittivity of the graphene layer and thus changes the transmission of terahertz waves through the metamaterial. The researchers obtained amplitude and phase modulations of up to 47% and 32.2°, respectively, despite the graphene layer being six orders of magnitude thinner than the wavelength of incident light. They attribute this substantial increase in modulation to the enhanced light–matter interaction in the graphene layer, which is due to the strong resonances of the metamaterial. The researchers also observed hysteresis-like behaviour in the terahertz wave transmission, indicating persistent photonic memory effects that could be useful for an electrically controllable photonic memory. Other possible applications include tunable or reconfigurable terahertz devices. *RW*

QUANTUM METROLOGY

Squeeze with care

Science **337,** 1514-1517 (2012)

Hidehiro Yonezawa and researchers from Japan and Australia have demonstrated unconstrained tracking of an optical phase that varies stochastically over time. Most notably, the tracking was performed over a substantial angular range, with no post-selected data or loss compensation. The researchers employed a phase-squeezed beam modulated by a classically generated Wiener process, which ensured the stochastic nature of the varying phase. They then estimated the phase by employing the Kalman filter, a real-time feedback-based algorithm. The researchers report that, contrary to popular belief, more squeezing does not always improve the measurement precision. They optimized the squeezing amount by considering the magnitude and bandwidth of the phase noise, as well as the amplitude of the phase-squeezed beam, and were able to achieve an efficient phase-tracking scheme with a mean square error of 15 ± 4% below the coherent-state limit. *SA*

OPTICAL TRAPS

Cooling gradients

Phys. Rev. Lett. **109,** 103603 (2012)

Jan Gieseler and colleagues from Spain, the USA and Switzerland have cooled a silica nanoparticle from room temperature to around 50 mK using an optical gradient trap. Traditional optical cooling requires a laser beam in every direction of motion; that is, six beams for three-dimensional trapping. However, a gradient force pointing towards the centre of a trap requires only one laser beam. To cool the centre-of-mass motion, the researchers employed parametric feedback after pumping down the chamber. The feedback effectively opposes the particle's motion by increasing the trap stiffness when the particle moves away from the trap centre. The researchers put this approach to use by performing modulation at twice the trap frequency, with an appropriate phase shift. The cooling action is in competition with reheating due to collisions with air molecules, which sets an upper limit to cooling at a given pressure. Although the technique suffers from a trade-off between measurement uncertainty and recoil heating, theoretical analysis indicates that temperatures close to the quantum ground state may be achievable. *DP*

NANOPHOTONICS

Luminescent QR codes

Nanotechnol. **23,** 395201 (2012)

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Upconversion luminescence — emission produced at wavelengths shorter than the excitation light — could have unique applications for security printing. Compared with standard fluorescent inks, which typically emit visible light upon ultraviolet excitation, upconversion inks that involve near-infrared to visible conversion are more difficult to duplicate and therefore offer higher security. Now, using green and blue upconversion inks comprised of Yb^{3+}/Er^{3+} and Yb^{3+}/Tm^{3+} doped β-$NaYF_4$ nanoparticles, respectively, Jeevan Meruga and colleagues from the USA have printed luminescent quick response (QR) codes: two-dimensional barcodes that can be scanned using most smartphones. They used design software and direct-write aerosol jetting to make the codes and employed a 980 nm continuous-wave laser for illumination. Using oleic acid as the capping agent and a 90:10 solution of toluene and methyl benzoate with poly(methyl methacraylate) as the binding agent for the nanoparticles, the team printed QR codes on paper and transparent tape that were invisible under ambient lighting, but exhibited single- and multicolour upconversion luminescence under near-infrared excitation. They also showed that combining green and blue upconversion inks offers a higher level of security than standard inks, owing to the multiphoton emission processes involved. *RW*

Written by Seiji Armstrong, Oliver Graydon, David Pile and Rachel Won.