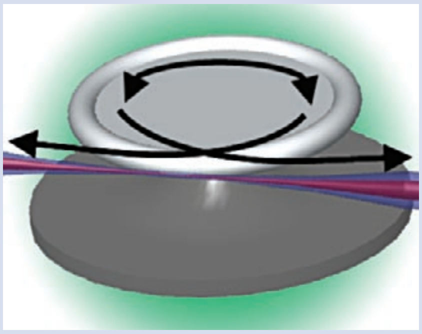
QUANTUM OPTICS

One at a time



Science **319,** 1062–1065 (2008)

Nonlinear optics usually involves the interaction of a large number of photons with a large number of atoms. To reduce this down to the single-atom and single-photon level, the strength of the interaction between light and matter must be enhanced. Barak Dayan and colleagues at the California Institute of Technology have now used microresonators to achieve this enhancement, enabling them to dynamically control the flow of individual photons using just one atom.

High-quality cavities or resonators are now frequently used as a means for investigating the quantum interaction of individual atoms and photons. Dayan *et al.* created silica, toroid-shaped cavities with a major diameter of 25 μm and a minor diameter of 6 μm. A caesium atom, laser-trapped and cooled to approximately 10 μK, is then dropped into the resonator. Weak laser light is coupled into and out of the cavity through a tapered waveguide that passes near the resonator. The interaction between the incoming light and the atom creates a 'photon turnstile', where the detection of an initial photon in the forward-propagating direction results in subsequent photons from the incident flux being re-routed. As a result, whereas the number of photons entering the photon turnstile is governed by statistics, the photons exiting in the forward-propagating direction do so one at a time. Such single-photon sources could one day play a key role in quantum information processing, and the small size of the resonators means that they are compatible with atom-chip technology.

OPTICAL CLOCKS

Beating the standard

Science doi: 10.1126/science.1153341 (2008)

The timing accuracy offered by optical atomic clocks makes the mind boggle, far surpassing many other timekeeping techniques. Now, Andrew Ludlow and co-workers at the National Institute of Standards and Technology (NIST) and the University of Colorado have overcome the limitations in measuring the accuracy of these devices.

The only way to get an idea of the accuracy of one clock is by comparing it to another. But when just a single device requires a large amount of expensive, complicated and stable optics, the chance of having two in the same laboratory is very slim. The alternative is to compare two remote set-ups. However, conventional ways of doing this, for example the use of global-positioning satellites or microwave-frequency networks, are simply not stable enough to transfer the phenomenal accuracy of optical clocks.

Ludlow *et al.* have now shown how an optical link can be used to compare two optical atomic clocks. Their aim was to assess the accuracy of a clock at the University of Colorado, which uses an ensemble of neutral strontium atoms, using a calcium-atom-based clock at NIST, 4 km away. Optical frequency combs are the key: each optical clock can be phase-locked to a frequency comb. The comb at the University of Colorado can in turn be locked to a 1,064-nm laser beam, which is sent to NIST along an optical-fibre link, enabling a comparison. In this way, the team show that the uncertainty of their strontium-based clock now surpasses that of the caesium clocks used as the primary standard.

TERAHERTZ WAVEGUIDES

Low-loss guides

Appl. Phys. Lett. **92,** 064105 (2008)

High dielectric loss and conduction in metals have been troublesome for the design of optical-fibre and metal-waveguide systems at terahertz frequencies. To overcome these problems, a collaboration of scientists in Taiwan has proposed the use of terahertz air-core microstructure fibres.

The researchers fabricated fibres comprising a hollow core surrounded by a cladding layer formed from periodic arrangements of flexible, commercially available polytetrafluorethylene tubes. They made four different fibres with inner and outer diameters varying between 0.81 mm and 1.68 mm, and between 1.11 mm and 2.08 mm, respectively. They also varied the centre-to-centre distance between the cladding tubes.

The combined coupling and propagation losses of the fibres were measured to be much less than 0.01 cm^{-1}, and the band of frequencies across which each fibre operated could be adjusted by linear scaling of the fibre size. At 770 GHz, an attenuation as low as 0.002 cm^{-1} was achieved.

Simulations of the terahertz transmission spectra, calculated using the finite-difference time-domain method, were in quite good agreement with the experimental results. However, the photonic-bandgap spectra did not match so well, suggesting that the bandgap does not dominate the guiding mechanism. The same frequency-dependent behaviour was shown for both one ring and three rings of cladding tubes. According to the researchers, these trends suggest that the guiding mechanism is similar to a phenomenon known as antiresonant reflecting optical guiding (ARROW).

METAMATERIALS

Tunable transmission

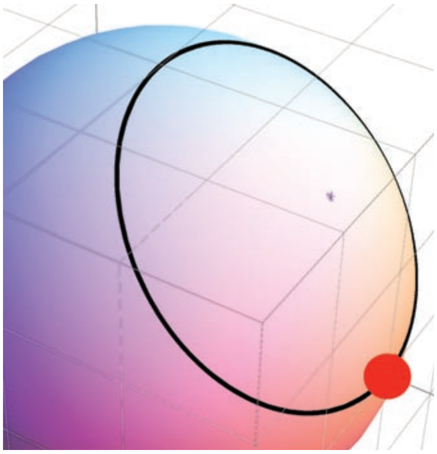
Opt. Lett. **33,** 545–547 (2008)

Metamaterials have captured the imagination recently owing to the unique optical properties gained from their artificial structure and the fascinating phenomena they make possible, such as superlensing and cloaking. With the aim of extending their usefulness still further, researchers from Pennsylvania State University in the USA have proposed a near-infrared, metamaterial film that has reconfigurable transmission and reflection properties.

To achieve this, Do-Hoon Kwon and co-workers exploit the characteristics of nematic liquid crystals. Their metamaterial design consists of a planar, periodic array of subwavelength resonators embedded in silica: each resonator is made up of two silver nanoplates sandwiching a spacer layer of anisotropic nematic liquid crystals. By rotating the orientation of the liquid crystals, their optical behaviour can be controlled. This, in turn, enables tuning of the material parameters of the metamaterials. Numerical calculations were used to optimize the dimensions of the resonators and to maximize the difference between the achievable transmittance and reflectance: the thickness of the silver nanoplates should be 149 nm, and that of the liquid-crystal spacer 200 nm, the minimum practical value. Both should have a width of 391 nm. Further simulations predicted that the transmittance of 1.1-μm light through this structure could be continuously tuned from 0.1% to 98.7%.

QUANTUM INFORMATION

Higher-level control



Phys. Rev. Lett. **100,** 060504 (2008)

Qubits, the quantum equivalent of classical data bits, can be made from any system that exists in one of two states. Schemes with more than two states, however, offer many more advantages, including increased security for quantum-communication protocols and new fundamental tests for quantum mechanics. Such systems based on optical transitions have already been realized, but manipulating them remains a problem. A team of scientists from the University of Queensland, Australia, the University of Bristol, UK, and the University of Waterloo, Canada, have now significantly extended the level of control over optical systems with more than two states.

Their three-level system, or qutrit, consisted of two photons in the same spatiotemporal mode; the two photons can either be polarized both vertically, both horizontally, or one horizontally and one vertically. The researchers exploit non-classical interference between a qutrit and a qubit — a so-called Fock filter — to extend the range of transformations that can be achieved.

The two pairs of photons were generated by spontaneous parametric down-conversion from a BiBO crystal. Both pairs were sent through a variety of beam splitters and polarizers so that a qutrit and ancillary qubit arrived at a central beam splitter simultaneously. The Fock filter blocks light of the same polarization as the ancillary qubit. By varying the polarization of the qubit and the reflectivity of the central beam splitter, the researchers could select which qutrit states were blocked. Thus the transformation of the qutrit from one state to another could be controlled.

RAMAN LASERS

A whispering gallery

J. Opt. Soc. Am. B Doc. ID: 90479 (2008)

Raman lasers — a source of coherent light based on nonlinear Raman scattering — can lase at any wavelength within the transparency window of a Raman-active material, provided there is an appropriate pump source. This unique ability has meant that Raman lasers have become important in spectroscopy for chemistry and condensed-matter physics. Now, Ivan Grudinin and Lute Maleki from the California Institute of Technology in the USA have demonstrated an ultralow-threshold, efficient, single-mode Raman laser constructed using a CaF_2 whispering-gallery-mode resonator.

The scientists fabricate the resonator, with a diameter of 5 mm, out of a CaF_2 crystal by using a simple polishing technique. They then use angle-polished fibre couplers to pump the resonator and to monitor the output. A conversion efficiency of more than 60% and a lasing threshold at the microwatt level were obtained. The scientists attribute these impressive results to the high quality factor of the whispering-gallery mode, of the order of 10^{10}, and the high Raman gain of fluorite. They have also shown single-mode operation of the laser in a multimode cavity, and vice versa, potentially extending the laser's applications from spectroscopic functions to gigahertz-range beatnote frequency generation. Applications in compact optoelectronics devices are also anticipated because of the compactness and fibre-compatibility of the device.

CHIRAL LASERS

Chameleon style

Opt. Express **16,** 2965–2970 (2008)

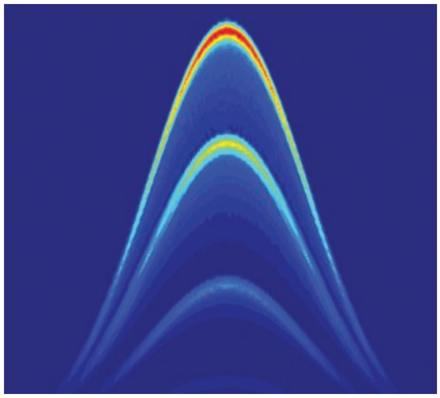
Materials that can change their optical properties when physically deformed are not only interesting from a scientific point of view, they could prove useful too. Petr Shibaev and colleagues have now reported a new type of liquid-crystal-based material that undergoes large colour changes when put under mechanical strain, and can be used to create a reversible, tunable laser.

Cholesteric liquid crystals are chiral and have helical conformations that can self-assemble. They form flat structures that reflect light at wavelengths that depend on the helical pitch of the liquid crystal. If the pitch changes, the position of the structure's photonic bandgap changes and its colour varies. Not only that, but by doping such structures with laser dyes, it is possible to produce tunable lasers with unique properties, such as the ability to self-assemble and relatively low lasing thresholds.

Shibaev *et al.* create a highly viscous material consisting of chiral and non-chiral liquid crystals and a laser dye. Under applied strain, the material undergoes a large colour change from far red to blue, and its selective reflection-band shifts from the near-infrared to UV (about 250 nm). When optically pumped, the material lases at a wavelength that can be tuned by up to 80 nm, through applied strain. The results could have implications for laser and sensing technology.

ULTRAFAST PHYSICS

Electron guns



Opt. Express **16,** 2887–2893 (2008)

The method of surface-plasmon-enhanced electron acceleration is a relatively recent discovery, a process in which electrons have been shown to be accelerated up to kiloelectronvolt energies. Along these lines, Péter Dombi and Péter Rácz propose a new ultrafast photoelectron source that is controlled by just an ultrashort light pulse containing just a few optical cycles.

Dombi and Rácz, who are based in Budapest, model the various physical processes that occur in surface-plasmon-enhanced electron acceleration from a flat metal surface or from a surface-integrated nanostructure. These processes include the coupling of free-space and plasmonic electromagnetic fields, photoelectron emission from the metal layer and the subsequent acceleration of free electrons by the decaying plasmon fields on the vacuum side of the surface. By studying the spatial characteristics of the emission on the nanoscale, they come up with 'acceleration maps' that describe the spatial and spectral information of the process in fine detail. They find that by using just a few optical cycles in the generating laser pulse, the acceleration process provides a better behaved electron beam that is highly directional and quasi-monoenergetic.