NANOPHOTONICS

Scattered away

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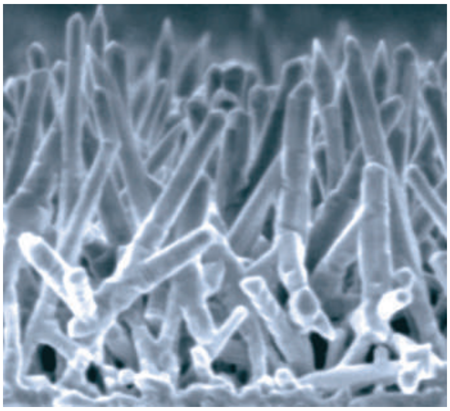


Optical scattering is important not just from a technological point of view, but also because it lies at the heart of striking fundamental effects such as random lasers and the Anderson localization of light (where multiple scattering in random media prevents the diffusion of waves). Otto Muskens and colleagues in the Netherlands have now studied light trapping and Anderson localization effects in nanowire arrays and concluded that once optimized they offer one of the most strongly scattering materials yet created.

Muskens *et al.* chose gallium phosphide (GaP) nanowires as their testbed because the bandgap of GaP, 548 nm, is relatively wide, making it easier for the effects of multiple scattering to be unambiguously identified and distinguished from those of light absorption. The researchers investigated how the diameter of the wires, their volume fractions and their alignment on the substrate affected their scattering. As the nanowire diameter increased, the mean free path of light decreased, reaching a minimum of 0.16 μm. This is shorter than that of the most strongly scattering titanium dioxide powders and is comparable to that of porous GaP networking materials, two of the strongest scatterers in existence. From a practical aspect, the findings could help improve light trapping in solar cells.

DIFFRACTION

In focus

Phys. Rev. Lett. **102,** 043601 (2009)

The phenomenon of diffraction, which causes waves to spread out and diverge as they propagate, is often troublesome. In recent times, researchers have used electromagnetically induced transparency (in which a signal field propagates through an atomic medium with a slower group velocity in the presence of a second control field) to reduce or eliminate the diffraction spreading of beam-like fields. Israeli scientists have now proposed an interesting new way to eliminate diffraction in arbitrary images imprinted on slow light, preserving both the intensity and phase information throughout.

The approach presented by Ofer Firstenberg *et al.* is unique because it uses moving atoms and the associated Doppler effect to correct the path of diverging light. Their scheme makes use of a strong plane-wave control beam, a uniform atomic vapour and a weak signal. As a result of the Doppler effect, any deviations of the control and signal beams from collinear propagation lead to a so-called two-photon detuning effect. By adjusting the relative frequency of the two light fields, this detuning can be tweaked so that the slowly propagating signal pulse is 'pulled' back to the central region, preserving the spatial profile of the field and completely eliminating beam spreading. The technique could be used in high-resolution imaging, image storage and nonlinear optics.

QUANTUM OPTICS

All aboard the quantum train

Science **323,** 486–489 (2009)

Quantum states can be transferred from one system to another through the process of quantum teleportation. However, to perform this feat, scientists must first establish entanglement between the two systems and use only classical communication during the transmission. Now, Steven Olmschenk and his colleagues have reported the first successful transfer of a quantum bit of information, or qubit, between two distant ytterbium ions spaced one metre apart.

Olmschenk and co-workers use microwave and ultrafast laser pulses and a beamsplitter to perform the entanglement. The energy of the photons emitted by each of the ytterbium ions during photonic excitation becomes entangled with the original atomic state. Using a technique known as entanglement swapping, this atom–photon entanglement can be transferred to the other system. The outcome is that measuring the state of one of the ions (which destroys the entanglement) yields a qubit (a 0 or 1), and the information of this measurement result is 'teleported' to the other ion.

The fidelity of the process is 90% but the entanglement efficiency — 1 out of 100 million — is still too low to be useful for a practical scheme. Nevertheless, the ability to teleport quantum states of stationary, massive particles over macroscopic distances is an important first, because atoms are ultimately much better suited as quantum memory banks than photons.

SINGLE-PHOTON SOURCES

Nanowire funnels

Opt. Express **17,** 2095–2110 (2009)

Solid-state single-photon sources are in great demand in the fields of quantum communication and information processing. They typically consist of a quantum dot as the photon emitter, buried inside a semiconductor microcavity. But even after a decade of intense research, scientists do not have a source that uses a nano-sized resonator and offers extraction efficiencies close to unity.

French researchers have now investigated several designs for single-photon sources that are based on the emission of a quantum dot inside a gallium arsenide nanowire. Through suitable tapering, the nanowire's ends can be made to form efficient metallic–dielectric mirrors that redirect photons towards the substrate, and the divergence of the far-field radiation can be reduced. With careful choice of geometry, the nanowires can act as nano-antennas with a volume of just $0.05\lambda^3$ (λ being the wavelength) that help to funnel the emitted photons into a single-mode channel. Calculations suggest that very high efficiencies, exceeding 90%, should be attainable using collection optics with a numerical aperture of 0.85. In contrast to optical nano-antennas based on plasmonic physics, this approach does not rely on resonance effects and is compatible with a broad spectral range (70 nm at a wavelength of 950 nm).

MEDICAL OPTICS

Therapeutic light

Opt. Lett. **34,** 232–234 (2009)

New Swedish research could help to improve light-based cancer treatment schemes. Johan Axelsson and co-workers have demonstrated a way to map the distribution of a photosensitizer — a light-activated chemical that is central to photodynamic therapy — inside the prostate gland.

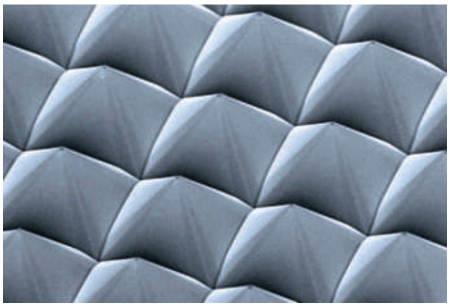
In interstitial photodynamic therapy (IPDT), optical fibres are implanted into cancerous tissue. The light that they deliver excites a photosensitizer which has been previously administered to the patient, resulting in the generation of radicals such as singlet-state oxygen molecules that kill local cells, and thus the tumour. The success of IPDT depends on careful optimization of the distributions of light, photosensitizer and tissue oxygenation. However, it is difficult to obtain knowledge of the photosensitizer distribution.

Using data collected from clinical trials and optical phantoms, Axelsson *et al.* devised an algorithm that successfully reconstructs the spatial distribution of a fluorescent photosensitizer. A total of 18 optical fibres, which are coupled through a fibre switch to 18 diode lasers, are used to perform photodynamic therapy, and are arranged so as to maximize the light dose within the prostate while surrounding tissues are spared.

TERAHERTZ TRIALS

The Great Pyramids of silicon

Appl. Phys. Lett. **94,** 041106 (2009)



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Researchers in New York have found that etching tiny pyramidal structures into the surface of silicon can significantly improve the transmission of terahertz waves. When silicon is covered with micropyramids, the researchers found it to be 89% less reflective over a broad range of terahertz frequencies.

Silicon, in particular high-resistivity silicon, is widely used in terahertz components because it is transparent from the microwave to the infrared. But silicon also tends to be very reflective at an air interface, and as much as 30% of the incoming terahertz power is lost from a single surface. By improving impedance matching, these reflection losses can be mitigated. Chen *et al.* use crystallographic wet etching to create an array of sub-wavelength pyramids on one side of a silicon substrate. The pyramids have apex angles of 72° and base lengths ranging from 110 to 30 μm.

Using pyramids with a 60-μm period, the team finds that reflections are reduced by a maximum value of up to 89% for frequencies ranging from 0.2 to 3.2 THz. This enhanced transmission band can be further increased by tuning the base length of the pyramid. Optimization of the pyramid design should allow further improvements to be made in the anti-reflectivity properties.

SLOW LIGHT

With a view to a chip

Phys. Rev. Lett. **102,** 056801 (2009)

The past few years have witnessed breakthroughs in our ability to slow down and stop light, in media ranging from photonic crystals to optical fibres and metamaterials. In 2007, scientists showed how terahertz light could be brought to a halt in metamaterials while being separated into its constituent colours, producing a 'trapped rainbow'. Qiaoqiang Gan and collaborators now offer a prescription for how to achieve the rainbow trapping of light in the telecommunication wavelength regime, which is of greater practical importance.

Using finite-difference time domain calculations and nanometre-scale metal gratings, they show how the dispersion properties can be tailored such that the cut-off frequency falls within the telecoms region. The team uses graded structures (with a graded grating depth) to gradually couple light into surface plasmon polariton modes with a very low group velocity. As the grating depth changes, the cut-off frequency varies, and incoming waves at different frequencies are trapped at different positions, leading to the trapped rainbow effect. The next step will be to back up these feasibility studies with real experiments.

BIO-IMAGING

In the iPALM of your hand

Proc. Natl Acad. Sci. USA
doi:10.1073/pnas.0813131106 (2009)

Scientists in the United States have developed a microscopy technique that can take three-dimensional pictures of proteins and other structures with a resolution of better than 20 nm. The method — interferometric photoactivated localization microscopy (iPALM) — will shed light on how nanometre-scale biomolecules are organized into micrometre-scale structures in cells.

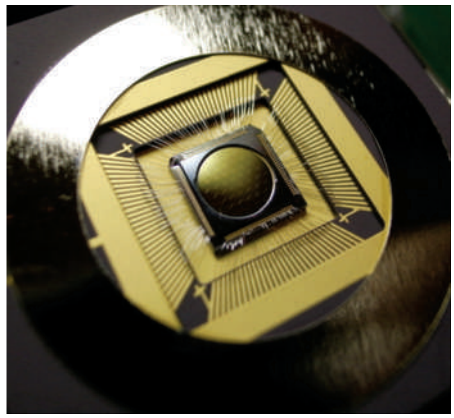
The power of iPALM stems from its ability to combine the resolution of a single-photon, multiphase interferometric scheme with the molecular specificity offered by PALM. At the heart of this is the concept that fluorescent molecules such as proteins are intrinsic quantum sources. Thanks to wave–particle duality, this means that an emitted photon can simultaneously travel along two optical paths, which can be recombined so that the photon interferes with itself.

The iPALM collects the fluorescent photon into an upper and lower objective lens and passes that wavefront through a three-way beamsplitter. If the fluorescent molecule is centred between the two objectives when the wavefront passes through, no interference is seen. If the molecule is located off-centre, the reunited wavefront will interfere with itself, which can be detected as a change in intensity. Researchers can pinpoint the location of a fluorescent molecule to 10–20 nm, which is the same resolution as that offered by electron microscopy.

ASTRONOMY

Eye on the prize

Opt. Express **17,** 1925–1934 (2009)



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Are there Earth-like planets out there? This is one of the burning questions facing astrophysicists today, but is difficult to answer because of the challenge of observing faint, distant planets against their parent stars. Scientists in France and Australia have proposed a new instrument that uses optical fibres to alter the pupil geometry of a telescope and improve its eye for extrasolar planets.

Telescope pupils are not well suited for high dynamical range imaging. But the single-mode fibres that Kotani *et al.* discuss are perfect spatial filters; any light injected into them emerges as a Gaussian beam with a coherent, flat wavefront. When separate beams filtered in this way are allowed to interfere, the combination is uncorrupted by phase corrugations. As a result, speckle noise, one of the main sources of loss and noise when studying faint planetary candidates, is eliminated.

The authors use this approach to retrieve the image of a simulated binary star. Laser beams injected into 5-μm pinholes generate the binary star light, and a microlens array divides the input pupil into 36 sub-apertures. Each beam is focused onto the core of an individual fibre, and the reconstructed image successfully shows two point-like sources (the binary star). Fringe visibilities are measured with an accuracy of 2%.