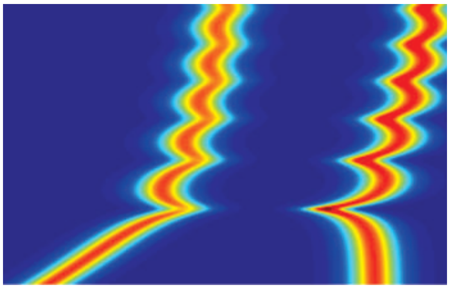
SOLITONS

Moving or still?

J. Opt. Soc. Am. B Doc. ID: 133880 (2010)



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Nonlinear pulse propagation in an optical fibre is usually modelled by z-stepping schemes based on the nonlinear Schrödinger equation and its generalizations. However, problems often arise when the propagation constant becomes zero. Now, Jesper Lægsgaard from the Technical University of Denmark has derived a time-propagating generalized nonlinear Schrödinger equation that includes both instantaneous (Kerr) and delayed (Raman) nonlinear responses. The research investigates the nonlinear propagation of slow-light states in solid-core chalcogenide photonic crystal fibres, and numerically demonstrates that such fibres can support moving spatial solitons. The work also shows that the Raman effect can exponentially decrease the velocity of slow-state solitons, such that the zero-velocity soliton becomes an attractor state. The presence of a second soliton causes the soliton interaction to be repulsive for most values of the relative phase between the solitons. This formalism may help scientists to understand the nonlinear properties of slow modes in fibres, with potential applications including tunable delay lines and optical buffers.

STRAIN SENSING

Combs boost sensitivity

Science **330,** 1081–1084 (2010)

The ultimate performance of a fibre-optic sensor is hindered by thermally induced phase noise, which traditionally restricts strain sensitivities to the range of 10^{-6}–10^{-9} ε $Hz^{-1/2}$. By exploiting the high stability of the optical frequency comb — an optical spectrum with equidistant longitudinal laser modes — Gianluca Gagliardi and colleagues in Italy have now pushed this sensitivity to 10^{-13} ε $Hz^{-1/2}$, limited only by thermodynamic phase fluctuations in the fibre. Their set-up consists of a sensing element, an extended cavity-diode laser emitting at ~1,560 nm, an optical frequency comb with a reference oscillator, and a laser–comb phase-lock unit. The sensing element is a Fabry–Pérot resonator comprising two fibre-Bragg-grating reflectors. The laser is stabilized against the quartz-disciplined optical frequency comb by phase-locking. This results in a phase-coherent link between the laser and the radiofrequency oscillator, allowing an almost frequency-noise-free interrogation system to be achieved. Changes in the cavity resonance frequency resulting from mechanical perturbations are translated into frequency changes in the comb spectrum, which can be measured by a precision counter. This high-strain sensitivity may help scientists to design new sensors for measuring fundamental physical quantities.

OPTICAL CAVITIES

Extending enhancement

Opt. Express **18,** 23204–23211 (2010)

Dielectric coatings with custom reflectivity and group-delay dispersion (GDD) over a particular spectral range are essential for many applications in the field of ultrafast optics. In particular, zero-GDD mirrors sets, which consist of two of more mirrors with opposite GDD, can be used to form an optical cavity with vanishing dispersion over a wider bandwidth than traditional low-GDD mirrors. So far, such cavities have mostly been constructed from dielectric mirrors that are individually designed to have negligible dispersion or compensate for the GDD of intracavity materials at a certain wavelength range. Li-Jin Chen and co-workers in the USA have now demonstrated a broadband, dispersion-free optical cavity that allows the simultaneous optimization of many zero-GDD mirrors. Their design consists of a mirror pair with chirped layer thicknesses, creating complementary, wavelength-dependent penetration depth in both mirror coatings. Using Nb_2O_5/SiO_2 layer pairs, the design covers a bandwidth of 480–580 nm in a ~40 GHz filtering cavity and achieves a reflectivity of 99.2%, offering the potential for pulse enhancement and repetition-rate multiplication in laser frequency combs. The researchers say that the spectral coverage of their zero-GDD mirror set can be easily shifted to other wavelengths by proper structure scaling and re-optimization, and could enable many other frequency-comb-based applications that demand large comb spacing or high peak intensity.

HARD X-RAYS

Tabletop size

Nature Phys. **6,** 980–983 (2010)

Coherent hard X-rays are typically produced using large and costly synchrotron facilities. However, for many applications, conventional laboratory-sized sources would be a much more convenient alternative. Researchers now show that processes similar to those of synchrotron sources can be applied at the microscale, providing hard X-rays with a spatial coherence 1,000 times greater than previous techniques. Stefan Kneip and colleagues from the UK, USA, Portugal and France first created a plasma by focusing an intense (2 J) and short (~30 fs) laser pulse onto a millimetre-scale helium gas jet. This produces an inner bubble of positively charged helium ions surrounded by a sheath of negatively charged electrons. The charge separation is associated with a strong electric field that accelerates the electrons. The charges experience transverse oscillations when subject to the focusing fields of the plasma wave producing the micrometre-diameter

OPTICAL MANIPULATION

Nonlinear split trap

Nature Phys. **6,** 1005–1009 (2010)

Optical trapping uses a highly focused continuous-wave laser to manipulate individual particles. All trapping phenomena studied so far have been essentially based on interactions between optical electric fields and induced linear polarizations. Hiromi Okamoto and co-workers in Japan have now devised a completely new trapping mechanism based on the interaction between optical electric fields and nonlinear polarization. The researchers trapped 60 nm gold nanoparticles in distilled water using a Ti:Sapphire laser that could be readily switched between continuous-wave and pulsed mode (with a tunable wavelength of 780–920 nm, pulse width of 100 fs and repetition rate of 80 MHz). Laser pulses above a certain threshold were found to split the trap in two, with the split orientation being determined by the polarization direction of the laser. The trap spacing was controlled by carefully adjusting the incident optical power, but was also found to decrease as the wavelength of the incident light was tuned from ~810 nm to 910 nm. The researchers show that the origin of this splitting and its orientation is the nonlinear polarization of the gold nanoparticle induced by the high peak power of the femtosecond laser. This phenomenon is appropriate for a variety of materials with sizable optical nonlinearities, and may lead to new applications of optical manipulation in micromachining, nanofabrication and biology.

X-ray beam. The transverse coherence length of 3 μm was enough to observe one Fresnel fringe, thus allowing the spatial coherence to be measured using Fresnel fringes. The process occurs over less than a centimetre, and the entire set-up (housed in a vacuum chamber) measures approximately 1 m^2.

SILICON PHOTONICS

Plasma-enhanced nonlinearity

Appl. Phys. Lett. **97,** 161107 (2010)

Generating second-order nonlinearities in silicon photonic structures often involves cladding with additional electro-optic materials and poling. Unfortunately, this process can be difficult to integrate into various systems, including the complementary metal-oxide-semiconductor (CMOS) platform. Markus Wächter and colleagues in Germany have now demonstrated enhanced second-order nonlinear activity in silicon components induced by chemical surface treatment using reactive HBr plasma, a standard CMOS process often used for the anisotropic etching of silicon. The susceptibility for second-harmonic generation was enhanced by a factor of >24 for an input pulse with a central wavelength of 810 nm, a repetition rate of 80 MHz and a pulse width of 120 fs. The team also demonstrated terahertz signal generation through difference-frequency generation. The signals, generated in a traditional pump–probe scheme at a central wavelength of 1,550 nm, were detected using a photoconductive probe-tip held in contact with the silicon surface. A 64-fold improvement in signal intensity was observed at the plasma-activated silicon waveguide. The researchers say that this technique could be useful for realizing silicon waveguides with local electro-optic activity induced by a simple fabrication method.

QUANTUM LITHOGRAPHY

Beyond the diffraction limit

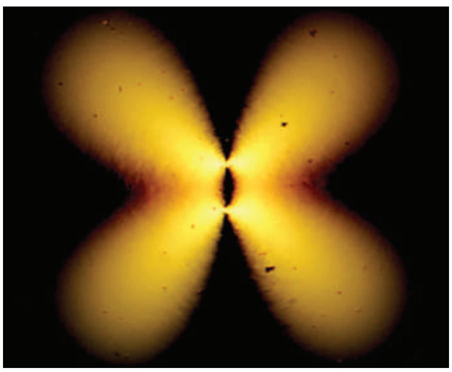
Phys. Rev. Lett. **105,** 183601 (2010)

Microfabrication technology capable of operating beyond the diffraction limit is needed for creating next-generation nanostructured optical devices. Although several techniques based on both classical and quantum optics have already been proposed, the experimental conditions associated with such schemes are unrealistic. Zeyang Liao and co-workers from the USA and Saudi Arabia have now proposed a quantum optical subwavelength lithography technique that does not require multiphoton absorption or photon entanglement. Their method makes use of the nonlinearity of the atom–field interaction — the Rabi oscillations between two atomic levels. Two beams of Gaussian pulses with matching amplitude, spatial profile and frequency (set to the Rabi frequency of the molecules) irradiate the photoresist from opposite directions. The pattern of the interference depends on the strength and duration of the pulses. Subsequent irradiation of the interference area with a non-Rabi-frequency beam causes molecules at the excited states to dissociate, which induces changes in the chemical properties of the photoresist, particularly in its solubility. The resulting patterns of the photoresist therefore depend on the spatial distribution of the excited states induced by the first laser pulse. Taking into account the realistic timescale obtained in 1-bromonaphthalene (fluorescence decay rate of 10^6 Hz, phosphorescense rate of 30 Hz, intersystem crossing time of 10^9 Hz and decoherence time of 5 ps at room temperature), the researchers concluded that a resolution of $\lambda/10$ in the wavelength of the incident light is achievable.

ELECTROPHORESIS

Flexible motion

Nature **467,** 947–950 (2010)



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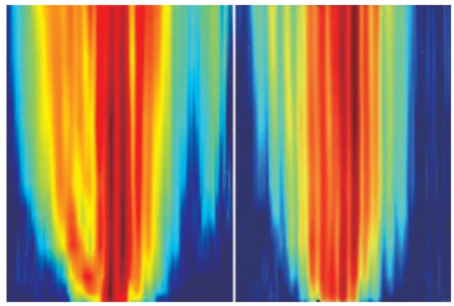
A charged particle in a fluid can be propelled by an electromagnetic field at a velocity linearly proportional to the applied field, in an effect known as electrophoresis. Applications of this technique include microfluidics, displays, the sorting of macromolecules and the controlled assembly of colloidal particles. Because the particle velocity is linearly proportional to the applied field, a.c. driving results in no net displacement. However, d.c. driving is often undesirable for electrochemical reactions as it offers little control over the displacement. Oleg Lavrentovich and colleagues from Kent State University in the USA have now demonstrated electrophoresis for dielectric and gold microscale spheres in a nematic liquid-crystal environment in which the particle velocity is proportional to the quadratic of the electric field. Thus, in this scheme changing the direction of the field does not change the direction of the particle, making electrophoresis possible with a symmetric a.c. field. The team determined that the nonlinear phenomenon is caused by asymmetric distortions in the orientation of the liquid-crystal molecules around the particles. Furthermore, because linear and quadratic velocities generally have different directions, the researchers found it was possible to demonstrate motion parallel, antiparallel and perpendicular to the electric field. Curvilinear tracks were also achieved by spatially varying the orientation of the liquid crystal.

NONLINEAR OPTICS

Spatiotemporal dynamics

Phys. Rev. A **82,** 041802(R) (2010)



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A group of researchers from the University of Bath and the University of Glasgow in the UK have reported spatiotemporal nonlinear optical effects that may stimulate further research into the use of periodic photonic nanostructures for frequency conversion and switching applications. The structure investigated was an array of three silicon photonic wires (220 nm × 380 nm × 3.2 mm) equidistantly spaced by 600 nm, allowing the photons escaping from one wire to be recaptured by the two neighbouring wires. By shifting 120 fs pulses at 1.54 μm from the edge to the centre of the array, Dmitry Skryabin and co-workers observed a change in the spectral broadening effect, opening and closing the spectral gap at around 1.72 μm. Through numerical modelling, the team showed that this effect is due to the change in the relative strength of the excited eigenmodes of the array when the pump beam is shifted from the edge to the centre. Frequency conversion involving low-energy optical solitons is prohibited when the pump beam is aligned with the geometrical centre of symmetry of the array. The observed effects indicate that the light dynamics across the array are inherently coupled to pulse dispersion in the time domain, showing that nanoscale photonics breaks the principle of spatiotemporal analogy — a rule applied almost universally for large-scale photonic structures and pulses propagating in bulk materials.