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vibrational resonances in ZnTe and is expected to be less restrictive in other material systems. A further noteworthy advance by the RPI group is the exploitation of this technique for efficient terahertz imaging.⁶

References

1. D. Grischkowsky *et al.*, "Far-infrared time-domain spectroscopy with terahertz beams of dielectric and semiconductors," *J. Opt. Soc. B* 7, 2006–2015 (1990).
2. Q. Wu and X.-C. Zhang, "Free-space electro-optic sampling of terahertz beams," *Appl. Phys. Lett.* 67, 3523–3525 (1995); P. Uhd Jepsen *et al.*, "Detection of THz pulses by phase retardation in lithium tantalate," *Phys. Rev. E* 53, 3052–3054 (1996).
3. A. Nahata *et al.*, "Coherent detection of freely propagating terahertz radiation by electro-optic sampling," *Appl. Phys. Lett.* 68, 150–152 (1996).
4. A. Nahata *et al.*, "A wideband terahertz spectroscopy system using optical rectification and electro-optic sampling," *Appl. Phys. Lett.* 69, 2321–2323 (1996).
5. Q. Wu *et al.*, "Broadband detection capability of ZnTe electro-optic field detectors," *Appl. Phys. Lett.* 68, 2924–2926 (1996).
6. Q. Wu *et al.*, "Two-dimensional electro-optic imaging of THz beams," *Appl. Phys. Lett.* 69, 1026–1028 (1996).

OPTICAL MANIPULATION

Interferometric Optical Tweezers

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Optical trapping of micron-size, dielectric microspheres using a single beam gradient force (Fig. 1a) was first demonstrated by Ashkin¹ in 1986. Since then, extensive research and development of this technique has turned it into a practical device (known as optical tweezers) which has been used in a wide variety of biological and biomedical applications.² In conventional optical tweezers, a water-immersed or oil-immersed microscope objective lens with a high numerical aperture (NA ~ 1.25) is usually used to focus the trapping laser beam to a micron-size spot to achieve a sufficiently strong axial trapping force.³ This imposes some restriction on the geometry of the sample cell, since the working distance of a high NA objective lens is limited to a few tens of microns below a cover glass (which is matched to the objective lens). High numerical aperture, however, is not required for lateral stability; even weakly focused beams can produce relatively strong lateral trapping force.³ For example, gradual accumulation and self-alignment of dielectric microspheres into a two-dimensional lattice-like mosaic pattern generated by the interference of two or more beams have been reported.⁴

Recently, we have successfully demonstrated⁵ for the first time the trapping and manipulation of dielectric particles (2.8 μm diameter latex microspheres suspended in water inside a thin sample cell) by a set of two-beam interference fringes (Fig. 1b) using a 20x objective lens (NA=0.4). The interferometric fringes at the sample plane are swept by retro-reflecting one of the beams from a moving mirror that is attached to a piezoelectric

transducer. When the fringes (with total optical power of a few milliwatts) are swept at a speed of 5–10 mm/sec, a sample particle that is trapped in the bright fringes moves along with the fringes until it reaches the edge of the focal spot, where it is stopped by the optical potential barrier introduced by the focused beam spot. Visually, the boundary of the bright spot acts like a wall against which the impinging particle bounces. The particle keeps striking the "wall" as long as the fringes continue to sweep. When the sweeping direction of the fringes is reversed, the particle moves toward the other direction and repeats the action described above at the opposite edge of the spot.

An alternative, and simpler, approach to two-beam interference, generates a similar (fringe-like) pattern using a single beam to project a reduced image of a Ronchi ruling at the focal plane of the microscope objective (Fig. 1c). In our experiment, we illuminated (with a single beam) a Ronchi ruling (250 line-pairs/inch) placed at the back focal plane of a 20x objective lens (Fig. 1c), and projected at its front focal plane, a set of fringes, *i.e.*, alternating bright and dark lines, with line-width on the order of 5 μm . In this approach, the fringes are shifted by translating the Ronchi ruling along the direction perpendicular to the rulings. A sequence of three selected frames from a video record illustrating the trapping and sweeping of a particle from the left to the right is shown in Figure 1d.

From a practical point of view, the second approach is perhaps more favorable for the following reasons. First, it requires only a single beam and the configuration is simpler and more compact. Secondly, it can be easily modified for two-dimensional micro-manipulation of two (or more) particles independently. For example, one can project several micron-size cross-hair

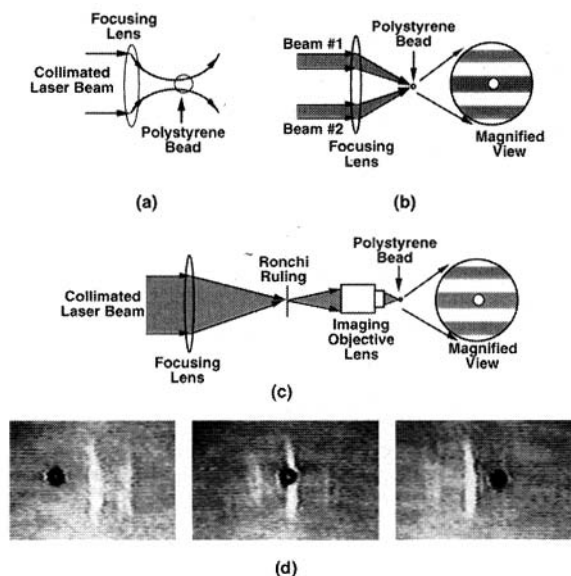


Figure 1. A schematic illustration of (a) a single-beam gradient force trap, (b) a dual-beam interferometric trap, (c) an interferometric trap using the image of a Ronchi ruling, (d) a sequence of three selected frames from a video record of experimental results demonstrating the manipulation of a trapped particle from left to right by sweeping the fringes across the field of view.

patterns, using each to trap and manipulate individual particles and to control the relative position of two or more particles. The cross-hairs together with the actuators (for very high precision x,y,z control) can be integrated into a compact device by Micro-Opto-Electro-Mechanical (MOEM) technology. This can potentially reduce the size, the complexity, and the cost of optical tweezers for biological and biomedical applications.

References

1. A. Ashkin *et al.*, "Observation of a single beam gradient force optical trap for dielectric particles," *Opt. Lett.* **11**, 288 (1986).
2. K. Svoboda and S. M. Block, "Biological applications of optical forces," *Annu. Rev. Biophys. Biomol. Struct.* **23**, 247-285 (1994).
3. G. J. Sonek and W. Wang, "Theory of optical forces: A review," *Rev. Laser Eng.* **24**, in print (1996).
4. M. M. Burns *et al.*, "Optical matter: Crystallization and binding in intense optical fields," *Science* **249**, 749 (1990).
5. A. Chiou *et al.*, "Interferometric optical tweezers," accepted for publication in *Optics Communications*; (also in Conference on Lasers and Electro-Optics OSA Technical Digest Series, Optical Society of America, Washington, D. C. 9, 1996 pp. 104-105).

Optical Patterning of Three-Dimensional Spatio-Tensorial Micro-Structures in Polymers

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One challenging requirement for the design of devices for photonic applications is to achieve complete manipulation of molecular order.

The great latitude and flexibility of optical methods offers interesting prospects for material engineering using light-matter interactions. Efficient spatial modulation of polymer macroscopic properties is usually achieved using holographic recording of an interference pattern between intense light-waves. For second-order optical nonlinear processes, a full control of the molecular orientation is mandatory. However, patterning with polarized monochromatic beams results only in molecular alignment. We report on a new, purely optical technique based on a non-classical holographic process with coherent mixing of dual-frequency fields. It enables efficient and complete three-dimensional spatio-tensorial control of polymer micro-structures.

Stolen and Tom have shown in glass optical fibers¹ that the coherent superposition of two beams at fundamental and second harmonic frequencies results in a polar field $E = E_{\omega} + E_{2\omega}$. Indeed, the temporal average of the field cube E^3 is non-zero.² In organics, this results in a selective excitation of the molecules oriented in a given direction and sense, depending on the local polarity of the dual-frequency field E .²⁻³ The process is depicted in the upper part of Figure 1. Its peculiar physical origin is a simultaneous one- and two-photon absorption on the same excited electronic level.³ The orientation-selective excitation relaxes thermally inside the polymer. Using appropriate molecules it results in a quasi-permanent molecular angular redistribution.⁴ A spatially modulated $\chi^{(2)}$ -susceptibility is thus recorded. Poling efficiency depends both on the relative phase and the relative intensities between the writing beams at funda-

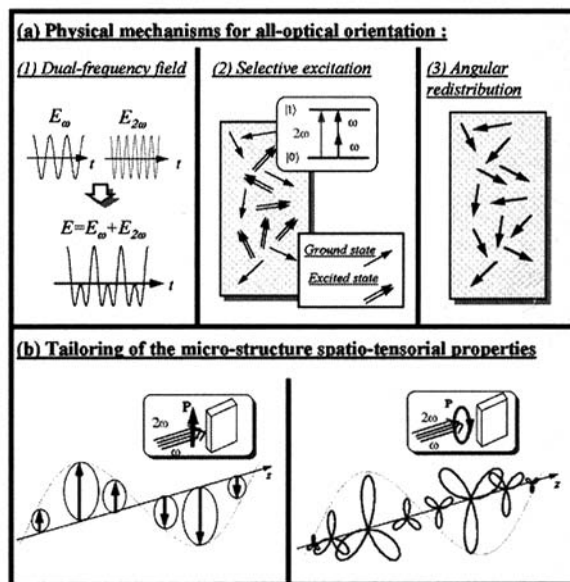


Figure 1. (a) Schematic description of the physical origin of the photoinduced order. The nonlinear molecules are represented as arrows. (b) Polar representation of the tensorial properties of the photoinduced $\chi^{(2)}$, as a function of the propagation coordinate z . Left column shows the case of linear and parallel polarization of the writing beams at fundamental and second harmonic frequencies, ω and 2ω . Right column corresponds to cohelically polarized writing beams. Note that the geometry of this latter case can also be obtained using octupolar dye molecules and a combination of writing beams with parallel polarizations.⁵

mental and second harmonic frequencies.⁴ The tensorial properties of the photoinduced $\chi^{(2)}$ describes the in-plane polar geometry of the pattern. The lower part of Figure 1 illustrates $\chi^{(2)}$ tailoring using appropriate molecular geometry or appropriate combinations of polarized light.⁵ Tailoring of the modulation periodicity of the molecular order over the propagation length is achieved by varying the writing fields' wavevector mismatch. For normal incidence of both the writing fields at fundamental and second harmonic frequencies, we get exactly the period for phase-matched frequency-doubling. The conversion efficiency then varies quadratically with the propagation length. This offers an interesting route for the development of low power frequency doubling for compact blue laser devices.

We have demonstrated that, due to coherent interactions, the coupling of two beams at fundamental and second harmonic frequencies permits a polar organization of molecules in periodic structures. One breakthrough with this all-optical technique is that it enables the complete three-dimensional control of the material's spatial and tensorial properties, without sophisticated electrode shaping or multilayer deposition techniques. More importantly, this patterning technique is based on self-organization of the molecules at a micron-scale level. It opens new perspectives in the field of smart materials for photonic devices technology.

References

1. R. H. Stolen and H. W. K. Tom, "Self-organized phase-matched harmonic generation in optical fibers," *Opt. Lett.* **12** (8), 585 (1987).
2. N. B. Baranova and B. Ya. Zeldovich, "Extension of holography to multi-