Optics in 2006

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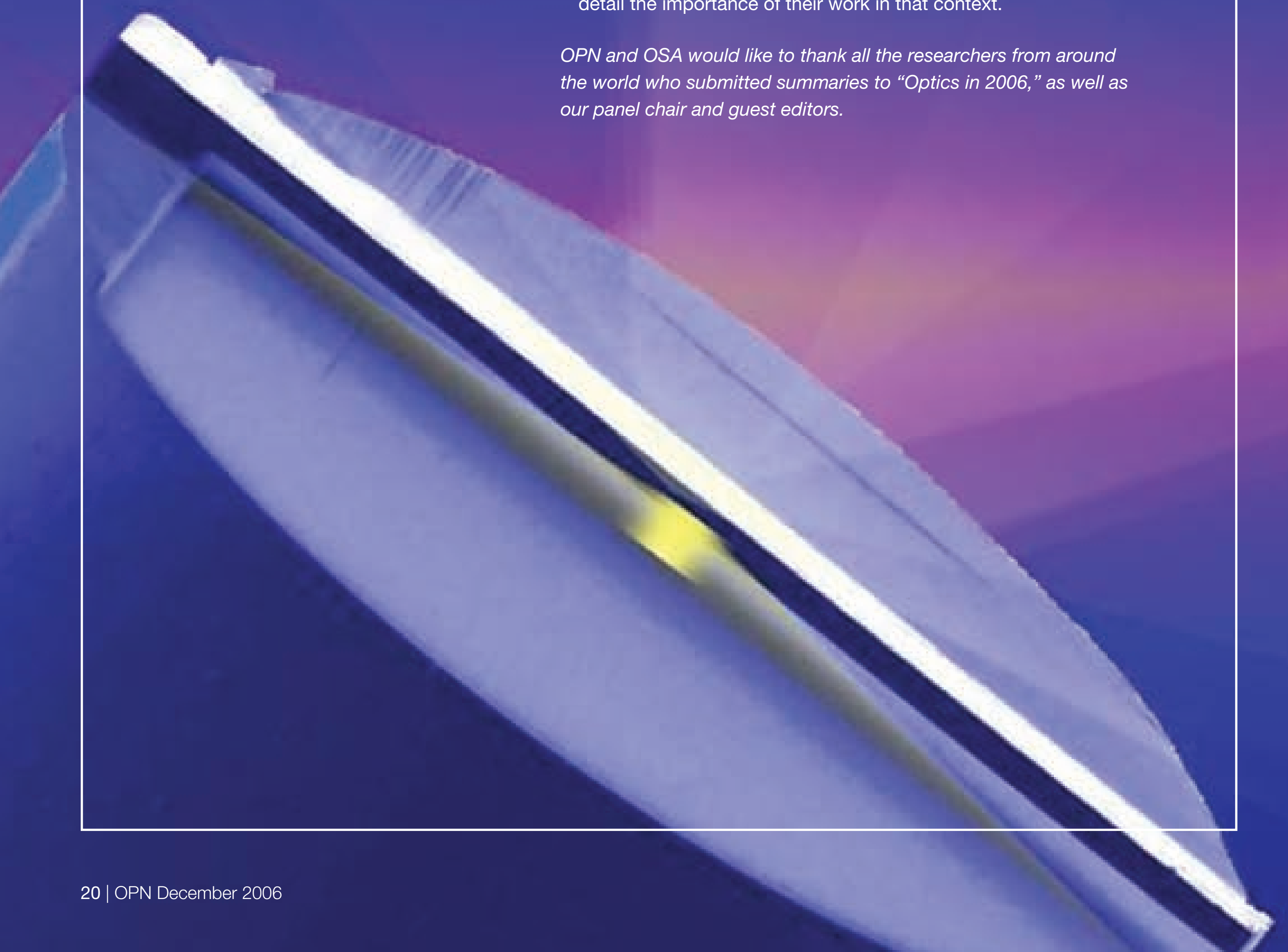
This special issue highlights the most exciting research to emerge in the preceding 12 months in the fast-paced world of optics. The areas covered in 2006 include array detectors, Bloch oscillations, coherent imaging, diffractive optics, imaging, metamaterials, nonlinear optics, optical beams, opto-mechanics, polarization, Raman spectroscopy, soft X-rays and ultrafast science.

This year's issue comprises 30 summaries that represent the work of 185 authors. There were 74 submissions from 374 authors representing 16 countries. Submissions were judged on the basis of the following criteria:

- The accomplishments described must have been published in a refereed journal in the year prior to publication in OPN.
- The work should be illustrated in a clear, concise manner that is readily accessible to the at-large optics community.
- The authors should describe the topical area as a whole and then detail the importance of their work in that context.

OPN and OSA would like to thank all the researchers from around the world who submitted summaries to "Optics in 2006," as well as our panel chair and guest editors.



METAMATERIALS

Nano-Dispersed Liquid Crystal with Tunable Negative-Zero-Positive Refractive Indices

I.C. Khoo, D.H. Werner and A. Diaz

Perhaps the most important optical property of a material is its refractive index, with the real part of it affecting the phase of an optical wave and the imaginary part controlling the amplitude. Until a few years ago, the conventional wisdom in most optics books had been that the real part of the refractive index should be positive and greater than unity.

A flurry of theoretical and experimental studies have confirmed the idea first proposed almost three decades ago, that the refractive index could be any values from negative to positive. Material systems that exhibit such amazing properties include periodic structures[1,2,3] as well as bulk metamaterials containing random distribution of nano-particulates.[4]

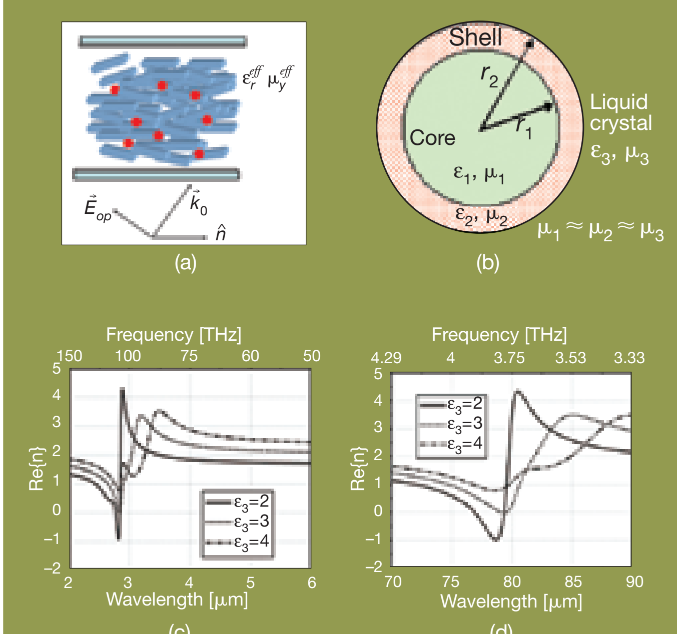
Recently, researchers at Pennsylvania State University have demonstrated that nematic liquid crystals containing core-shell nano-spheres could form a new type of metamaterial whose index of refraction is tunable from negative through zero to positive values,[5] as shown in part (a) of the figure. The core-shell nano-spheres shown in (b) may be made of polaritonic or semiconductor materials, and the liquid crystal host could be in any of the nematic, ferroelectric or cholesteric phases in which the director axis, and therefore the dielectric constant as seen by polarized lights, can be reoriented by an applied field.

Usually, in order to achieve negative index, both the permittivity ε and permeability μ must be negative. In this case, although the constituent materials are non-magnetic with relative permeability equal to 1, the combination of the permittivities at the appropriate resonances, in conjunction with the field-induced permittivity change in the LC host, give rise to the effective refractive index that can vary from negative through zero to positive values.

For a given set of core and shell material parameters, the real part of the effective refractive index of the nano-spheres dispersed liquid crystal (NDLC) for three representative values of the optical dielectric constant ε_3 of the liquid crystal can be computed using the Maxwell Garnet mixing rule. The results for the near-infrared regime [wavelength λ ~ 2.8 μm; frequency around 110 THz] are depicted in the figure, part (c).

The latter process may be accomplished by an applied AC electric field, a magnetic field, another polarized optical field or simply by changing the temperature of the sample. By scaling the size of the spheres and their dielectric material properties, one can vary the operating frequency over a very large dynamic range—for example, from visible to the terahertz and microwave region. For example, part (d) of the figure shows the corresponding tunable refractive index around the 3.8 THz resonance.

Such reconfigurable materials will be very useful for designing tunable "flat" lenses operating in the optical domain, as well as novel antenna coatings for microwave applications, in view of the broadband large birefringence of nematic liquid crystal in the optical microwave region.



(a) A planar aligned nematic liquid crystal containing core-shell nano-spheres. (b) Cross-section of the core [μ_1, ε_1]-shell [μ_2, ε_2] nanosphere with the liquid crystal host [μ_3, ε_3]. (c) Tunable refractive index of the nano-sphere dispersed liquid crystal as a function of liquid crystal host permittivity in the optical region. (d) Tunable refractive index as a function of liquid crystal host permittivity in the terahertz region.

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Metallic Metamaterials with a High Index of Refraction

Peter B. Catrysse, J.-T. Shen, Georgios Veronis,
Hocheol Shin and Shanhui Fan

There is great interest in exploiting subwavelength resonances in metallic structures to create artificial materials with unusual effective electromagnetic responses. The most notable example is the creation of negative refractive index metamaterials.[1] Recently, we described a method for designing metamaterials that feature arbitrary high, positive indices.[2] Such a capability is potentially important for miniaturizing optical or electromagnetic devices, improving imaging resolution and slowing down light.

In our design, the effective index is controlled by geometry. Since refractive index is commonly regarded as an intrinsic material property directly related to the underlying electronic states, this work carries fundamental implications as well. In particular, it adds evidence to the important potential of replacing electronic states with subwavelength electromagnetic resonances—which could open up a new world of possibilities in optical physics.

We showed that a metallic film with a periodic arrangement of cut-through slits can be regarded as a dielectric slab with a frequency-independent effective refractive index. The key to creating the desired effective index behavior lies in the existence of subwavelength propagating modes. In slits, regardless of how small their width is, there always exists a propagating transverse electromagnetic mode (electric field perpendicular to the slits).

We showed that the properties of a perfect metal film for transverse-magnetic (TM, magnetic field parallel to the slits) polarization—i.e., transmission *and* waveguiding—asymptotically approach those of a dielectric slab with a uniquely defined refractive index $n = d/a$ and a width L/n, where L is film thickness, d is periodicity and a is slit width. In the figure, (a) and (b) depict the fundamental waveguide modes in the metal film and the corresponding effective dielectric slab. Identical spatial periodicity, indicated by arrows, clearly demonstrates the equivalence of the two systems.

The surprising waveguiding properties are directly applicable from microwave to far-infrared wavelengths, where loss and plasmonic effects in metals can be largely neglected. In the optical wavelength range, however, the presence of the plasmonic response leads to additional subwavelength propagating modes, which may also be exploited in creating novel optical materials. In fact, we confirmed the presence of two distinct types of TM guided modes propagating in a direction perpendicular to the slits. In the figure, (c) shows the band diagram for those guided modes at optical frequencies. The first type is a well-known surface plasmon mode [red curves and inset (i)].

The second type originates from a subwavelength electromagnetic state supported by the slits and gives rise to guided modes [blue curves and inset (ii)], which closely resemble waveguide modes in a dielectric slab.[3] This finding indicates the possibility of extending our method for designing high-index metamaterials all the way into the optical regime.

Since the structure considered is two-dimensional, its behavior is strongly polarization dependent. However, the mechanism of creating effective high refractive index dielectric structures is not restricted to two dimensions. Subwavelength propagating modes exist in many geometries and may be used to create high-index materials in three dimensions.

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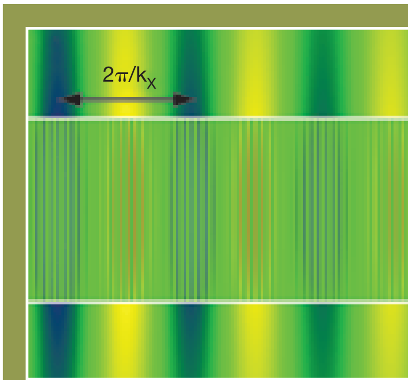
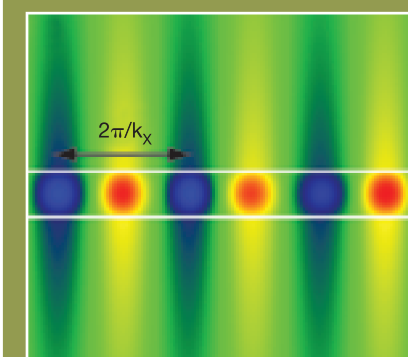
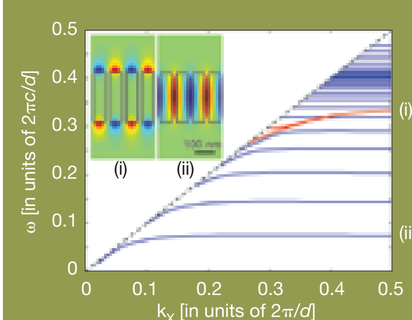


(a)



(b)



(c)

Magnetic field distributions for the fundamental waveguide modes of (a), a perfect metal film, and (b) the corresponding effective dielectric slab for $n = d/a = 4$, $L/d = 25/4$, and $\omega = d/\lambda = 0.0516$. Red and blue indicate positive and negative amplitude, respectively. White lines outline the film in (a) and the slab in (b). Arrows indicate the identical periodicity of the fields. (c) Guided-mode band diagram for a metal film at optical frequencies (TM polarization, first Brillouin zone) when $L = 256$ nm, $d = 80$ nm, $a = 20$ nm. Shown are two degenerate surface modes (red curves) and a series of effective dielectric slab modes (blue curves). The dashed line is the light line in vacuum. Insets show magnetic field distributions for (i) one of the degenerate surface modes and (ii) the fundamental effective dielectric slab mode.