BNA Yields Widely Tunable THz Source

The terahertz (THz) region has attracted much attention in recent years for its numerous potential spectroscopic applications in astronomy, earth science, biology, and medicine, as well as applications in communications and national security. However, in most cases, THz sources are limited in their tunability requiring a relative large number of different source systems when trying to cover a wide frequency range. Only organic nonlinear optical (NLO) materials have shown promise for wide tunability.

K. Miyamoto and H. Minamide at RIKEN Sendai, M. Fujiwera and H. Hashimoto at Osaka City University, and H. Ito at RIKEN Sendai and Tohoku University, Sendai, have demonstrated a widely tunable THz-wave generation system using difference-frequency generation (DFG) in N-benzyl- 2-methyl-4-nitroaniline (BNA) which has a large tuning capability from 0.1 THz to 15 THz and the highest NLO coefficient d33 for any yellow NLO material with 234 pm/V.

As described in the February 1 issue of *Optics Letters* (p. 252), researchers at RIKEN Sendai, Japan prepared large BNA crystals (φ8×30 mm) using the vertical Bridgman method. BNA is an N-derivative of 2-methyl-4-nitroaniline (MNA). BNA was developed to replace MNA because of the difficulty in growing large crystals of MNA due to its unfavorable morphology and thermal decomposition behavior as well as its hygroscopicity. With the development of BNA, the researchers were able to eliminate these drawbacks. In addition, BNA exhibits large second-order optical nonlinearity and low refractive index dispersion between the optical and the THz region.

The researchers excited DFG in BNA using a double-crystal $KTiOPO_4$ (KTP) optical parametric oscillator (OPO) pumped by a frequency-doubled Nd:YAG laser. The maximum energy was measured at 1.1 mJ/pulse at dual wavelength (887/902 nm). The conversion efficiency was nearly 11%, corresponding to a quantum efficiency of 19% with a peak power of 160 kW and an oscillation threshold of 2.5 mJ/pulse (~5 MW/cm^2).

By controlling the KTP OPO at high speed, the BNA can jump to any THz frequency without scanning through the intermediate wavelengths and at the same time permits continuous-frequency scanning in the 0.1–15 THz range by mixing the output of the KTP OPO over 860–902 nm. The researchers said that an ultrawide band (0.1–40 THz) THz-wave source is achievable by combining BNA (0.1–15 THz) and 4-dimethylamino-N-methyl-1-4-stilbazolium-tosylate (DAST) (which the researchers had previously shown to be tunable over the range 1.5–40 THz) organic nonlinear optical crystals.

ALFRED A. ZINN

Microstructured Monolithic Dielectric Surface Provides High Optical Reflectivity and Low Mechanical Loss

Optomechanical systems have attracted more and more research interest in many fields of physics. The interface between the light field and the solid-state matter needs to provide high reflectivity and low mechanical losses to enable applications such as laser cooling of mechanical oscillators, optical traps for mirrors, generation of entangled test masses, quantum nondemolition interferometry, and gravitational wave detection. However, current approaches using multilayer dielectric coatings attached to monocrystalline materials cannot realize high optical and mechanical quality simultaneously. F. Brückner of Friedrich Schiller University Jena, O. Burmeister of Leibniz University Hannover, and their colleagues have found that a microstructured monolithic dielectric surface with a subwavelength T-shaped grating profile can theoretically provide 100% reflectivity and lowest mechanical loss.

As reported in the February 1 issue of *Optics Letters* (p. 264), the researchers proposed a new approach by etching T-shaped gratings into the surface of a monolithic device to replace the thick multilayer stack. The T-shaped grating structure consists of a high fill factor grating on top of a low fill factor grating, which acts as an effective media low-index layer. By utilizing the resonant behavior of light coupling, this structure can be optimized to create 100% reflectivity for particular conditions of light incident from air. This approach avoids the need to add additional material to the mirror device that would potentially increase the mechanical loss.

A crystalline silicon surface was chosen to demonstrate their theory. The calculation showed that such a T-shaped grating surface can reach 95% reflectivity for a broad wavelength range of 1550 nm ± 175 nm ($\varphi = 0^\circ$) and an angle of incidence of $\varphi = 0^\circ \pm 23^\circ$ ($\lambda = 1550$ nm) for TM-polarized light. Furthermore, the reflectivity was calculated to exceed a value of 99.99% for $1.48\ \mu m < \lambda < 1.58\ \mu m$ and $\varphi = 0^\circ \pm 4.5^\circ$, respectively. Based on these evidences, the researchers concluded that their proposed novel monolithic mirror architecture offers new routes for many fields of experimental physics to prevent mechanical as well as optical loss in optomechanical devices.

ZHAOYONG SUN

Negative Refractive Index Demonstrated in 3D Metamaterials at Optical Frequencies

The prospect of invisibility cloaking through artificially structured metamaterials with negative refractive index has received a lot of media attention. For optical frequencies, however, the principle has previously only been demonstrated in two-dimensional systems unsuitable for practical applications. In the January issue of *Nature Materials* (p. 31; DOI: 10.1038/nmat2072), N. Liu and colleagues from the University of Stuttgart, Germany, have reported a procedure for creating three-dimensional (3D) metamaterials with negative values of magnetic permeability (μ) and electric permittivity (ε) in regions of the optical spectrum, as required for a negative index material.

The researchers built stacks of split ring resonators (SRRs), conducting nanoscale structures shaped like square horseshoes that mimic magnetism at high frequencies. They fabricated the SRRs by electron beam lithography of gold thin films, adding layers by spin coating a spacer layer of solidifiable photopolymer and repeating the gold deposition and lithography. Gold markers on the substrate enabled registry of subsequent layers and uniform stacking of SRRs. The researchers built structures up to four layers thick and measured the reflectance spectra with a Fourier transform spectrometer paired with an infrared microscope. They compared the spectral reflectance to numerical simulations and determined the physical origins of the spectral features through snapshots of the simulated current distributions in the SRRs.

Negative permittivity ε occurred around 80 THz for parallel-polarized light and corresponded to the currents in all four stacked SRRs circulating in-phase. For perpendicularly polarized light, negative permeability μ occurred around 120 THz and corresponded to an antisymmetric mode of current oscillation. The researchers interpreted this behavior using a model of plasmon hybridization, in which plasmon-like oscillations of charge density couple between adjacent SRRs, resulting in hybridized symmetric and antisymmetric modes. The antisymmetric modes that lead to negative μ are only possible due to the vertical stacking of SRRs.

The spectral features and magnitude of the effect depend on the number of stacked layers and the vertical spacing