Monolithic lithium niobate metasurfaces for magnetic-dipole driven second-harmonic generation

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We demonstrate monolithic lithium niobate metasurfaces for enhanced second-harmonic generation in the visible spectrum. We predict a conversion efficiency up to 5×10^{-5}, enabling applications to novel nonlinear and quantum light sources.
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Nonlinear metasurfaces based on III-V semiconductors for second-harmonic generation (SHG) have proven a versatile tool as ultrathin sources of light with engineered spatial wavefronts. However, light generation at visible and ultra-violet frequencies is hampered by the strong absorption losses of these materials and the off-diagonal terms in the second-order susceptibility tensor complicates control on the SHG radiation pattern. This has driven the search for new material platforms, such as lithium niobate ($LiNbO_3$). Various approaches [1-3] have been recently explored, albeit with limited applicability. Recently, we proposed a new design of $LiNbO_3$-on-$LiNbO_3$ (monolithic) metasurfaces for SHG enhancement [4], which is not limited by the availability of thin crystalline films and can be applied to any non-centrosymmetric material. In this work, we demonstrate the fabrication of such metasurfaces by patterning a bulk $LiNbO_3$ substrate through a combination of electron-beam (e-beam) lithography with reactive ion etching. With numerical simulations reproducing the geometry of the fabricated resonators, we predict a SHG conversion efficiency up to 5×10^{-5} with a 1 GW/cm^2 pump intensity.

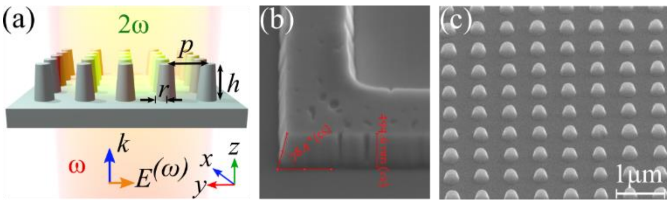

Fig. 1 (a) Schematic design of the monolithic metasurface for SHG. The pump beam direction and electric field are indicated by k and $E^{(\omega)}$. The crystalline axes are represented by x, y, and z vectors. The truncated cone nanoantennas have a bottom radius r and a height h. The periodicity of the squared unit cell is p. (b) SEM micrograph of a test structure after optimization of sidewall verticality (78°) with etching depth of 500 nm. (c) SEM micrograph showing a monolithic $LiNbO_3$ architecture realized with the optimized etching procedure.

A schematic representation of a monolithic $LiNbO_3$ metasurface for enhancement of SHG is shown in Fig. 1(a). The etching process has been optimized to achieve high sidewall verticality (see Fig. 1(b)). A representative example of the fabricated monolithic $LiNbO_3$ metasurface is shown in Fig. 1(c).

The linear and nonlinear optical response of the metasurface is investigated with full-vectorial numerical simulations in COMSOL [5]. In our study, we consider a fixed height of the nanoantennas of 440 nm as in [4]. The multipolar decomposition of the optical response shows that the metasurfaces exhibit a magnetic dipole (MD) resonance (see Fig. 2(a)) at a wavelength of 830 nm. The SHG conversion efficiency peaks along the dispersion of the MD resonance at the pump wavelength (see Fig. 2(b)) and, by optimization of the geometrical parameters, it can achieve a value that surpasses 5×10^{-5}.

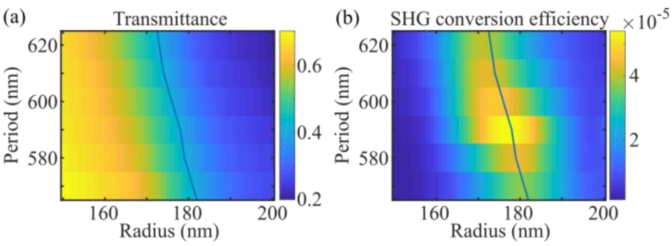

Fig. 2 (a) Transmittance and (b) SHG conversion efficiency of $LiNbO_3$ metasurfaces at a wavelength of 830 nm as a function of radius and periodicity. The continuous line shows the MD resonance at the fundamental wavelength of 830 nm.

We have proposed and experimentally demonstrated a new concept of nonlinear metasurface of monolithic material for enhanced SHG. Fabrication based on e-beam lithography and reactive ion etching has shown promising perspectives toward large area patterning of dense arrays of high aspect ratio nanostructures.

References

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