

THz Generation via LSPhP-Enhanced Optical Rectification in LiNbO₃ Metasurfaces

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Abstract: We demonstrate THz generation in LiNbO₃ rod metasurfaces mediated by localized surface phonon polaritons (LSPhPs). Our theoretical model predicts tunable LSPhP-enhanced emission. Preliminary characterization of fabricated structures confirms enhancement of generated THz spectrum based on the rod geometry.

Generation of THz radiation from dielectric metasurfaces has recently emerged as a promising pathway toward compact, efficient, and versatile THz sources [1–5]. While most demonstrations primarily rely on local enhancement of the optical pump field and on the dispersive $\chi^{(2)}$ response, engineering the electromagnetic properties at THz frequencies provides level of control that can substantially improve optical-to-THz conversion efficiency. Localized surface phonon polaritons (LSPhPs) supported by polar dielectrics offer strong field confinement, making them excellent candidates for enhancing and tailoring optical-to-THz generation.

In this work, we introduce a phonon-polariton–assisted THz source based on LiNbO₃ rod metasurface designed to excite LSPhP resonances efficiently coupled to second-order optical rectification. The structure consists of a periodic array of LiNbO₃ rods on a fused-quartz substrate, with geometry shown in Fig. 1a. The periodicity perpendicular to the rod axis is fixed, while the periodicity along the rod axis is varied with the rod length, L , to maintain a constant fill factor. The THz electromagnetic response is analyzed using finite-element-method simulations implemented in COMSOL Multiphysics. As shown in Fig. 1b, the metasurface absorbance exhibits a pronounced peak that is due to the LSPhP resonance, which red-shifts as the rod length increases.

The THz spectra generated by optical rectification of an ultrafast pump pulse calculated with full-wave electromagnetic simulations is shown in Fig. 1c. To provide additional physical insight and facilitate the design process, we also developed a simplified semi-analytical model capturing the essential LSPhP-driven emission mechanism. The model incorporates the dispersive $\chi^{(2)}$ response of LiNbO₃ near its transverse-optical phonon and accurately reproduces the trends obtained from full-wave calculations. Both approaches consistently show that the rod length controls the LSPhP resonance, leading to a systematic red-shift in the generated THz spectrum.

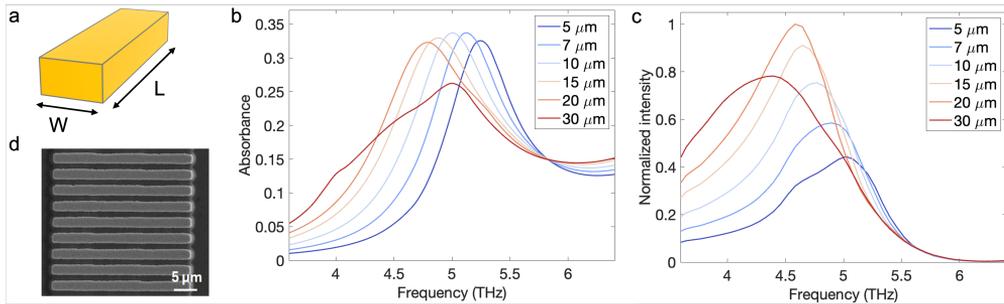


Fig.1 | **a** Schematic of the LiNbO_3 rod geometry, defined by width W and length L . **b** Numerically calculated THz absorbance spectra for different rod lengths L with the incident electric field polarized along the rod axis. **c** Numerically computed THz spectra generated via optical rectification as a function of L . **d** SEM image of a section of a fabricated LiNbO_3 rod metasurface.

Finally, LiNbO_3 metasurfaces were fabricated on 500-nm-thick LiNbO_3 films on fused quartz (NanoLN). An SEM image of one fabricated array is shown in Fig. 1d. The THz emission produced through optical rectification was characterized via THz time-domain spectroscopy. Preliminary measurements reveal a clear enhancement in both peak THz electric field and integrated THz power compared to unpatterned LiNbO_3 films, confirming the expected LSPHP-mediated enhancement. These results highlight LSPHP-engineered metasurfaces as a promising novel platform for compact, tunable, and high-efficiency nonlinear THz generation schemes.

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