Optimizing Two-Dimensional Tilted-Front Laser Pulses for Efficient Terahertz Generation

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***Abstract*—We developed a theory that describes terahertz generation with tilted-front femtosecond laser pulses in electro-optic crystals, a technique providing record experimental efficiencies nowadays. The theory accounts for the transverse size of the laser beam and allows us to explore the dependence of the conversion efficiency on laser focusing. We calculated the radiation patterns inside the crystal and studied the terahertz emission from the crystal. Two typical experimental situations - $LiNbO_3$ excited with Ti:sapphire laser at room and cryogenic temperatures – were considered. Our theory predicts optimal parameters of the laser pulse and crystal size maximizing the terahertz yield.**

I. Introduction And Background

OPTICAL rectification of ultrashort laser pulses in electro-optic crystals is a proven way to generate broadband terahertz radiation. The optical-to-terahertz conversion efficiency is essentially affected by the velocity mismatch between the optical pulse and terahertz waves. In the materials with high optical nonlinearity, such as $LiNbO_3$, the optical group velocity is about two times larger than the highest phase velocity of terahertz waves. A promising technique to achieve phase-matching in such materials is to use optical pulses with tilted fronts[1]. In such a pulse, the intensity front is tilted at a certain angle with respect to the phase fronts; by proper choice of the tilt angle the projection of the pulse group velocity onto the normal to the intensity front direction can be made equal to the phase velocity of a terahertz wave of a given frequency. Using this technique subpicosecond terahertz pulses were generated by Ti:sapphire laser in $LiNbO_3$ with a record conversion efficiency of 5×10^{-4} at room temperature[2]. Recently, the technique was extended to the conversion of fiber laser pulses[3].

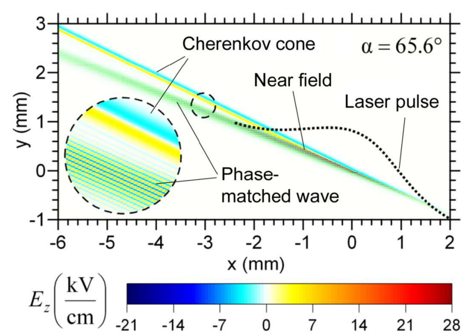
In this work, we develop a theory that describes the terahertz emission from an optical pulse with tilted intensity front. We apply the theory to typical experiments with $LiNbO_3$ at room and cryogenic temperatures and show that depending on the temperature the dominating contribution to the terahertz energy comes from different parts of the radiation pattern – the phase-matched wave or the Cherenkov cone and near field. We give recommendations how to optimize the parameters of the optical pump for increasing the terahertz yield.

II. Results

We consider a femtosecond laser pulse propagating with a group velocity V in the $+x$-direction in an electro-optic crystal; the intensity front of the pulse is tilted at an angle α to the y-axis. Assuming that the pulse width in the z-direction is much greater than the terahertz wavelength, we treat it as two-dimensional. The nonlinear polarization produced via optical rectification follows the pulse intensity $I \sim \exp[-y^2/l_\perp^2 - (t - x/V - y\tan\alpha/V)^2/\tau^2]$, V exceeds the highest phase velocity of terahertz waves. We use a one-phonon-resonance formula for the dielectric constant of the crystal with the parameters typical for 0.68 mol% Mg-doped stoichiometric lithium niobate.

Figure shows the terahertz pattern generated in $LiNbO_3$ at 10 K by an optical pulse with typical parameters $l_{\perp\,FWHM} = 1$ mm, $\tau_{FWHM} = 150$ fs, the peak intensity of 10 GW/cm^2, and $\alpha = 65.6°$ that provides phase matching at 3 THz. Three parts are visible in the pattern - the phase-matched wave, the Cherenkov cone, and near field of the nonlinear source. The terahertz energy is provided mainly by the phase-matched wave for 10 K and by the near field and the Cherenkov cone for 300 K.

For efficient generation at 10 K, the crystal size should be ≥ 1 cm and $\alpha \sim 65.1°$-$66°$. For a fixed energy of the laser pulse, $l_{\perp\,FWHM}$ and τ_{FWHM} should be as small as it is admitted by the diffractive and dispersion broadening of the laser pulse and higher-order nonlinear effects. For a fixed optical intensity, it is advantageous to increase $l_{\perp\,FWHM}$, whereas τ_{FWHM} should be in the interval 180 fs < τ_{FWHM} < 320 fs for the excitation of a 1.5 THz wave. For 300 K, it is useless to increase the crystal size above ~5 mm. The optimal α is 63.5°-64.5°. For a fixed energy of the laser pulse, $l_{\perp\,FWHM} \leq 100$ μm and $\tau_{FWHM} \leq 150$ fs are preferable. For a fixed optical intensity, the efficiency is maximal for $\tau_{FWHM} \sim 150$-250 fs and $l_{\perp\,FWHM} \geq 1.5$ mm.



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