Terahertz Pulses with High-Field Unipolar Precursors

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1. Introduction

Strong electric and magnetic fields in the terahertz frequency range are required for many applications, including particle acceleration, molecular orientation, and terahertz streaking techniques. The strongest fields are currently generated by optical rectification of ultrashort laser pulses in nonlinear crystals. Multiphoton absorption is considered as one of the main factors that limits the optical pump intensity. It leads to a depletion of the pump pulse and photogeneration of free carriers that absorb terahertz radiation.

Recently, it was however found that concurrent processes of optical rectification and free carrier generation can give rise to quasistatic electromagnetic fields (DC precursor) propagating ahead of the pump pulse [1]. The precursor's fields can exceed the ordinary terahertz wave generated behind the laser pulse. The detrimental effect of the pump depletion on the precursor generation can be circumvented by using chirped-pulse pumping [2].

Here, we propose a way to enhance the precursor's fields by orders of magnitude by using tilted-pulse-front excitation scheme and higher orders of multiphoton absorption. Three cases are considered: $LiNbO_3$ pumped at 0.8 μm and 1.05 μm and ZnTe pumped at 1.7 μm.

2. Approach

We consider a tilted-pulse-front laser pulse propagating in an electro-optic crystal in the normal to its phase fronts direction with a group velocity c/n_g (n_g is the group refractive index, c is the speed of light). The pulse front is tilted at angle α to the phase fronts. The projection of the group velocity on the z direction normal to the pulse front is $V = (c/n_g)\cos\alpha = c/n_{\text{eff}}$. The optical intensity, with the envelope $I(z,t)$, in the crystal is assumed high enough to produce n-photon ionization with the density of free carriers

$$N(z,t) = \frac{\beta_n}{n\hbar\omega}\int_{-\infty}^{t} dt I^n(z,t), \qquad (1)$$

where β_n is the n-photon absorption coefficient and $\hbar\omega$ is the quantum energy of the laser. We put n = 3 and 4 for pumping $LiNbO_3$ at 0.8 μm and 1.05 μm, respectively, and n = 4 for pumping ZnTe at 1.7 μm. Due to optical rectification, the laser pulse induces the nonlinear polarization

$$\mathbf{P}^{\text{NL}}(z,t) = \mathbf{P}_0 D(z,\xi)\exp(-\xi^2/\tau^2) \qquad (2)$$

with the depletion factor $D(z,\xi)$ [3] and $\xi = t - z/V$. To find the fields emitted by $\mathbf{P}^{\text{NL}}(z,t)$, we solve the Maxwell equations and equations of the photogenerated time-varying plasma by using in-house developed FDTD code.

3. Results

In Fig. 1, the precursor is a unipolar pulse of negative polarity. Its magnitude is two orders of magnitude higher than for the collinear excitation scheme [1,2]. The magnitude can be further increased by using chirped-pulse pumping at higher intensities [2].

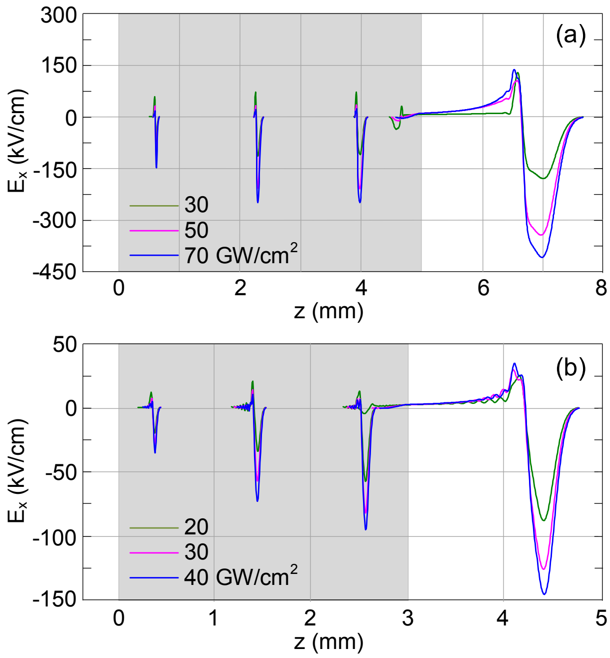

Fig. 1. Snapshots of the electric field at four moments of time for τ = 300 fs and different I_0. (a) $LiNbO_3$ at 1.05 μm, n_{eff} = 5.05. (b) ZnTe at 1.7 μm, n_{eff} = 3.27. The shaded regions show the crystals.

4. Conclusions

Tilted-pulse-front excitation with high-order multiphoton absorption is promising for generating high-field DC precursors in $LiNbO_3$ and ZnTe. Strong unipolar fields can be a useful tool for particle acceleration, molecular orientation, and in terahertz streaking techniques.

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References

[1] M.I. Bakunov, A.V. Maslov, and M.V. Tsarev, Phys. Rev. A **95** (2017) 063817.
[2] E.S. Efimenko, S.A. Sychugin, M.V. Tsarev, and M.I. Bakunov, Phys. Rev. A **98** (2018) 013842.
[3] M.V. Tsarev and M.I. Bakunov, Opt. Express **27** (2019) 5154.