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Terahertz Generation by Imaging-free Nonlinear Echelon Slab

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Abstract: The imaging-free nonlinear echelon slab (IFNLES) terahertz source suppresses some of the limitations of the conventional tilted pulse front setup. It enables the generation of terahertz pulses with mJ level energy.

Introduction

Tilted pump pulse front pumped lithium niobate (LN) crystal [1] is a widely used, highly efficient terahertz (THz) source. However, the large (63°) wedge angle of the crystal, the setup's imaging part and the angular dispersion significantly reduce the applicable pump beam size [2]. To mitigate these effects, a new setup was recently suggested [3]. Fig. 1. shows the scheme of such a setup. It consists of a transmission grating and a nearly plan-parallel LN crystal, with a stair-like structure on its input surface. This structure can contain crystals with different wedge angles. The stair-like structure splits the pump pulse into smaller beamlets and delays them to each other. The time delay and the grating tilt together determine an average pulse front tilt in the crystal that fulfills the velocity matching required for efficient THz generation. The following parameters of the setup were optimized: wedge angle of the LN crystal (δ), the angle between the grating and the crystal (ε), and the orientation of the grating (γ_g).

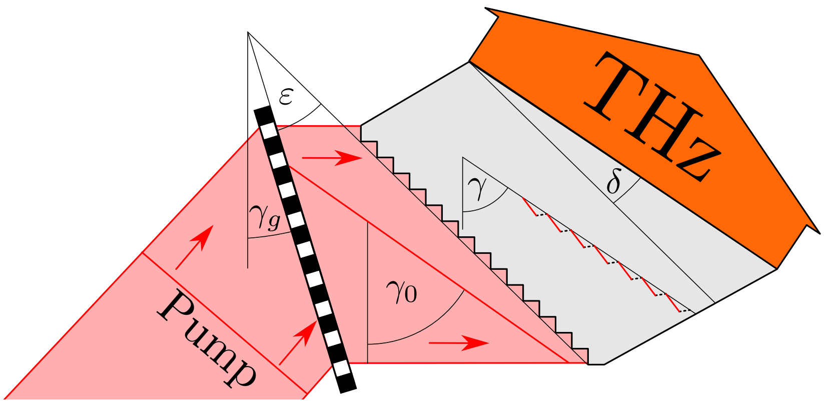

Fig. 1. Scheme of the IFNLES configuration

1. Basic working principle of the source

The setup optimization was done by running numerical simulations according to the mathematical model used in [3], and also the transmission efficiencies of the grating were calculated using COMSOL. The best-case scenario would be that both sides of the crystal and the grating would be parallel to each other (Fig. 2.a), but to achieve this, the grating orientation would be such that its transmission efficiency would be only about 33%.

By assuming a parallel crystal ($\delta = 0°$), and a grating in its most efficient orientation, the angle of the grating and the front of the crystal would be $\varepsilon = 18.4°$. This means that across the cross-section of the pump beam would vary the distance between the grating and the surface of the crystal, thus having different pump pulse lengths across the pump beam (because of the group-delay-dispersion introduced by angular dispersion). This causes a difference in the THz pulse shape perpendicularly to its propagation. (Fig. 2. b)

Assuming a grating parallel to the front of the crystal ($\varepsilon = 0°$), the most efficient setup would have a crystal with $\delta = 9.47°$ wedge angle. This means that the THz field is generated at different distances throughout its pulse front. It results in the THz signal's pulse shape longer towards the thicker side of the crystal. Having a non-zero wedge angle also limits the waist size of the pump. (Fig. 2. c)

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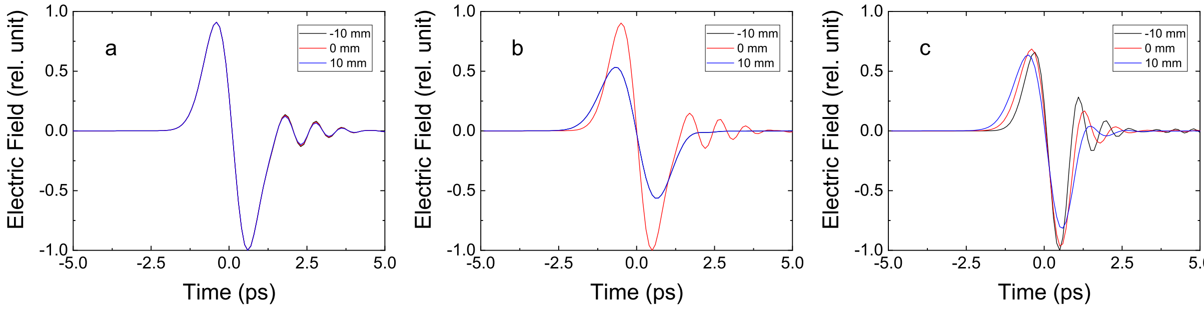

Fig. 2. Generated THz pulse of a: fully parallel, b: parallel crystal, c: wedge-shaped crystal setups

2. Optimal configuration

Based on the results discussed above, we assumed that an optimal configuration would be such that neither plane would be parallel, and the grating is not used in its most efficient orientation. With a 10° deviation from the optimal grating orientation, efficiency drops by 25%. Doing this enables δ and ε to be smaller, so the configuration is closer to the fully parallel setup. This means that a wider pump beam waist can be used, which results in higher input power without increasing the intensity of pump, ultimately overcoming the grating losses. Having parallel planes also means that the THz field will be more homogeneous across its front.

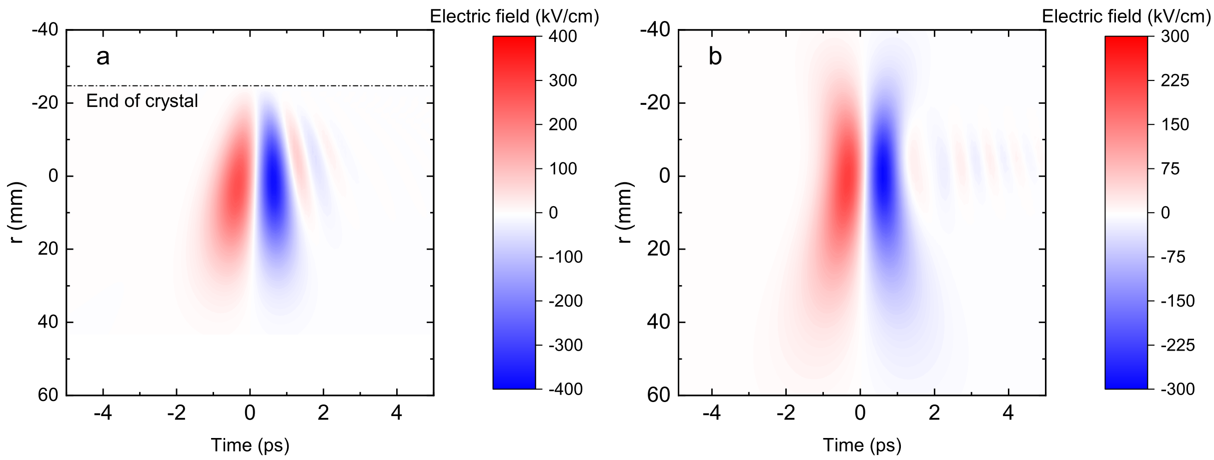

Fig. 3. Comparison of electric fields on the output, a: wedge-shaped crystal, b: optimized setup

Several numerical simulations were done, and the optimal setup was found to be the case where the grating is tilted 10° from its most efficient position, the wedge angle of the crystal is $\delta = 3.7°$ and the angle between the crystal and the grating is $\varepsilon = 5°$. Using this setting, 3.5 mJ THz pulse energy could be achieved with 0.7% efficiency. The other setting was such that the grating was in its most efficient orientation, in which case the THz energy is 2 mJ. The electric field distribution of the generated THz fields in these two cases is shown in Fig.3. It is worth noting that these results are showing slightly higher figures than achievable due to some effects that the model used here does not account for [4].

Acknowledgement

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