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Demonstration of a tilted-pulse-front pumped planparallel slab terahertz source

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Abstract. THz pulse generation in a nonlinear optical slab with an entrance surface having an echelon structure is demonstrated. The setup uses a transmission grating and a planeparallel lithium-niobate crystal slab, and ensures a good-quality, symmetric THz beam and enables scalability to high pulse energies.

1 Introduction

Acceleration of electrons [1] and protons [2] are new, promising applications of intense THz pulses. Optical rectification of ultrashort laser pulses with tilted-pulse-front (TPF) in lithium niobate (LN) [3] has become a standard technique for efficient THz generation. In the conventional scheme, a prism-shaped LN crystal is needed with a wedge angle equal to the pulse-front tilt (63° in LN). Such a large angle negatively affects the THz beam quality and is especially problematic in case of high-energy THz generation experiments, where a large-diameter pump beam is needed.

A modified version of the TPF pumped THz generation scheme was demonstrated by reflecting the pump beam on a stair-step echelon [4]. Contrary to the case of the conventional scheme, where the pulse front is continuous, a segmented TPF is formed in this case. Although, a high THz generation efficiency was achieved, this setup also requires a prism-shaped nonlinear crystal with 63° wedge angle in case of LN.

In this work we summarise the results of a proof of principle experiment obtained with a recently proposed new hybrid-type setup with uniform crystal length [5]. It enables to produce a good-quality, symmetric THz beam and easy energy scalability.

2 The investigated NLES set-up

The proposed hybrid-type setup is a combination of the conventional scheme, containing diffraction optics and imaging, and a nonlinear material with an echelon-like profile on its entrance surface (nonlinear echelon slab, NLES, Fig. 1a) [5]. Contrary

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to all the setups used so far, a planeparallel LN crystal can be used here. Hence, the absorption and the dispersion of both the pump and the generated THz pulses are uniform across the THz beam profile. This advantage, together with the reduced imaging errors [5], may lead to the realization of a scalable THz pulse source with good THz beam quality (enabling excellent focusability) for high-field applications.

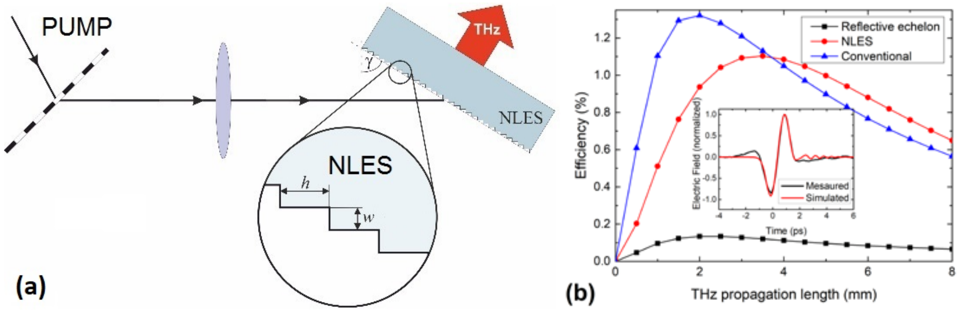

Fig. 1. (a) Scheme of the proposed nonlinear echelon slab (NLES) THz source. (b) Calculated conversion efficiencies of the conventional tilted-pulse-front pumped set-up, and the ones containing reflecting echelon [4], and NLES [5], respectively. Inset: Simulated and measured THz waveform of NLES set-up.

We adopted the 1D model originally suggested in Refs. [6,7] to the case of a segmented tilted pulse front to estimate the performance of the NLES introduced in Ref. [5] and compare it to the reflective stair-step echelon of Ref. [4], and to the conventional tilted-pulse-front pumping set-up. The model takes into account the diffraction of the pump, the periodic phase shift of the THz wavelets, and the absorption and dispersion of the generated THz pulse [5]. In the calculations 1030 nm (800 nm for reflecting echelon) pump wavelength, 200 fs Fourier limited pump pulse duration, 50 GW/cm^2 peak pump intensity, and 100 K crystal temperature (to reduce THz absorption) were assumed. The calculations predict about eight times higher efficiency for the NLES as compared to the reflective echelon (Fig. 1b). The calculated peak electric field strength directly behind the crystal output reaches 400 kV/cm for the NLES, and can be increased by at least one order of magnitude by focusing. We note that the waveform is nearly perfectly single-cycle. In addition, calculations carried out for ZnTe and GaP show that semiconductor NLES sources, pumped at longer infrared wavelengths [8], can also be competitive.

To prove the concept in experiment, a prototype NLES device has been manufactured by diamond milling (Fig. 2a). The surface size was 5 mm along the milled grooves and 8 mm in the perpendicular direction. The slab thickness was 3 mm. The steps size was w = 50 µm and h = 92 µm (Fig. 1a).

3 Experimental results

THz pulses with up-to 1 µJ energy were generated with 5.1×10^{-2} % efficiency at room temperature (Fig. 2b) clearly demonstrating the working of the concept. An order of magnitude increase of the efficiency is predicted for cooling a larger and thicker NLES. In agreement with the simulation, the waveform of the measured THz pulse is perfectly single-cycle, without any oscillation on the trailing side. This is advantageous in many particle acceleration and manipulation application.

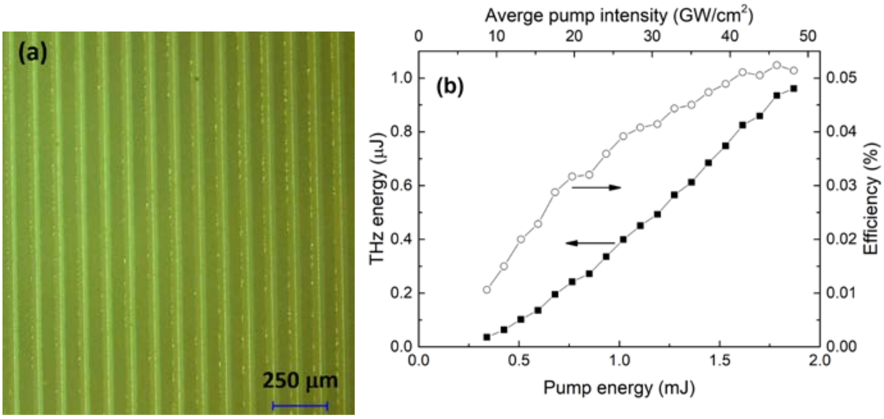

Fig. 2. (a) Microscope image of the prototype NLES surface showing the stair-step structure. (b) Measured THz pulse energy (left axis) and THz generation efficiency (right axis) as functions of the pump energy and intensity.

4 Summary

A novel hybrid-type THz source was proposed for efficient generation of high-energy THz pulses. The scheme is a combination of the conventional tilted-pulse-front setup and a transmission stair-step echelon faced nonlinear crystal with a period in the hundred-micrometer range. The uniform average crystal length can enable efficient production of good quality, symmetric THz beams and scalability to high pulse energies. Calculations for LN predict approximately ten times larger efficiency for the NLES setup than for the reflective stair-step echelon setup. A prototype NLES THz source was demonstrated to deliver 1 μJ THz pulse energy with 0.05% efficiency.

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