Progress Towards a Highly Efficient, Compact, Scalable THz Pulse Source

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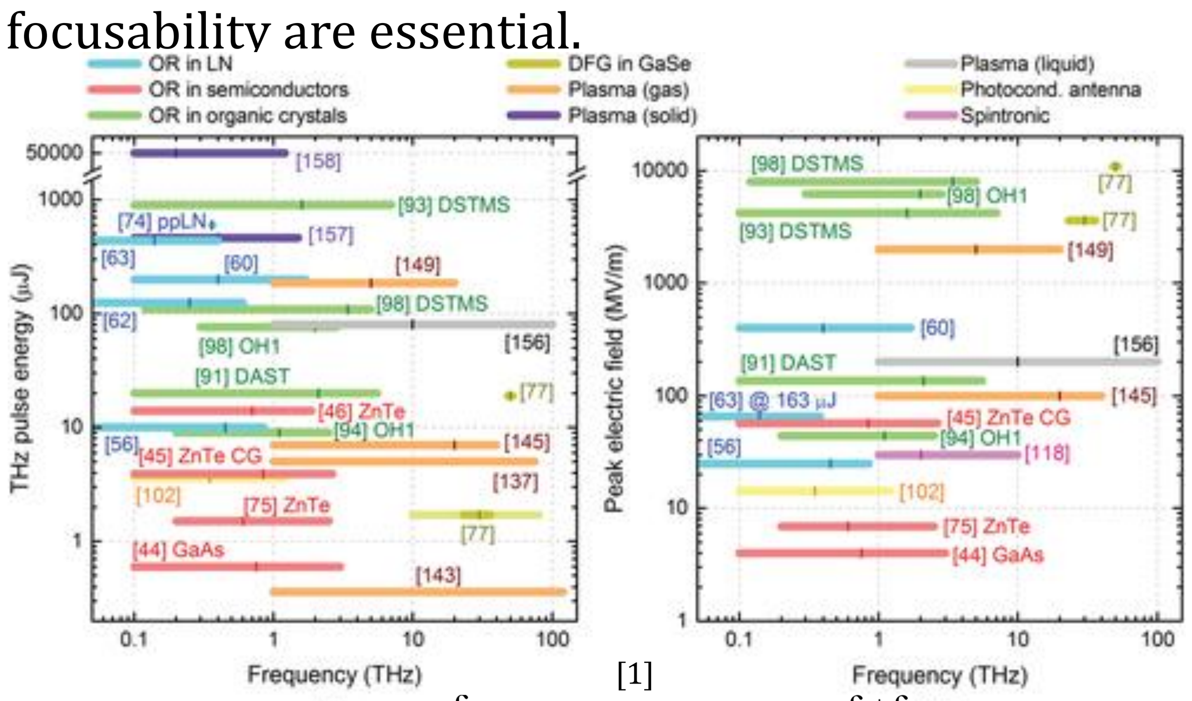
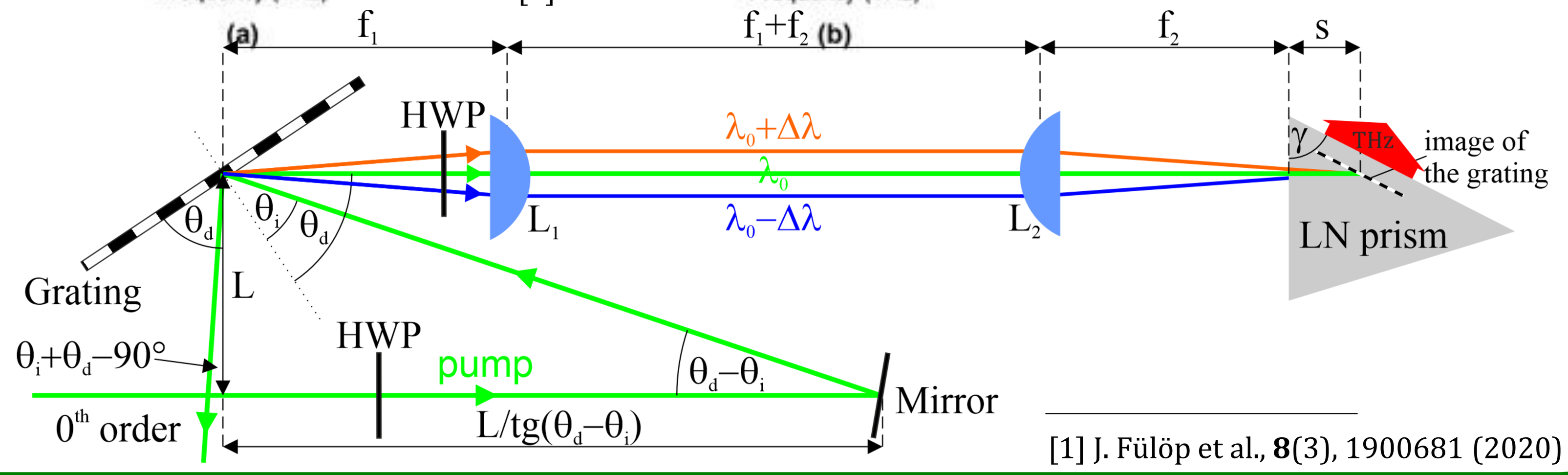
Introduction

Terahertz (THz) pulse applications such as strong-field control of matter, charged particle manipulation, and acceleration require the highest possible field strengths. To achieve that, high pulse energy and excellent focusability are essential.



[1]

Tilted-pulse-front pumping (TPFP) of LiNbO3 has been providing the highest THz pulse energies and efficiencies in the low-frequency part of the THz spectrum.

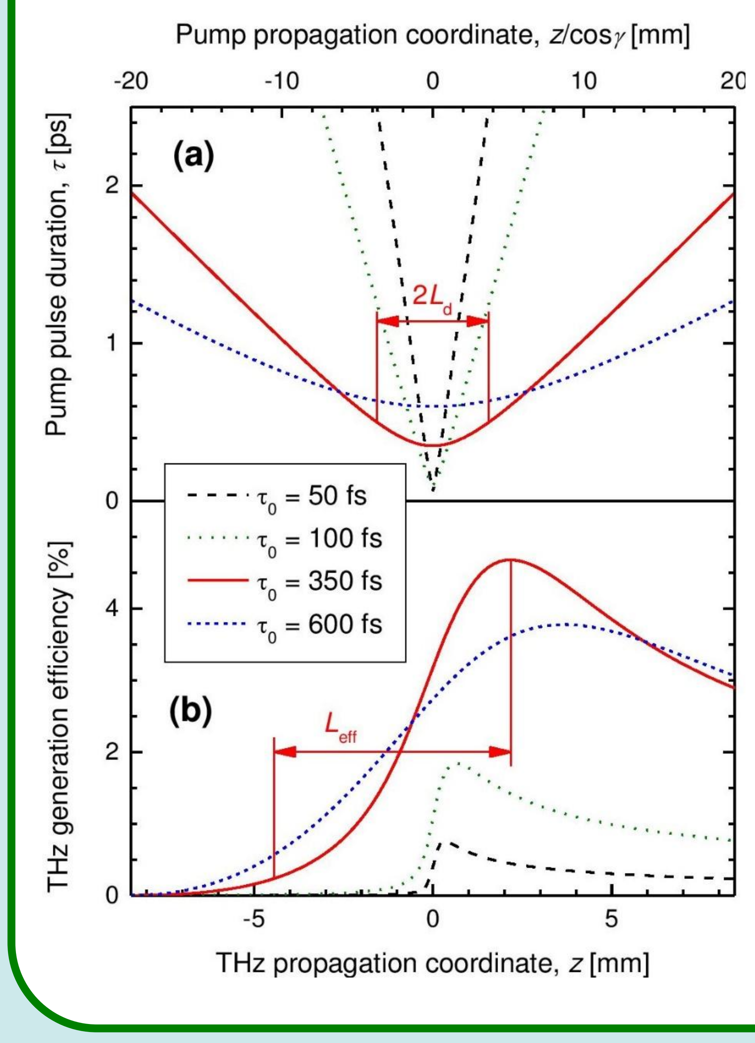


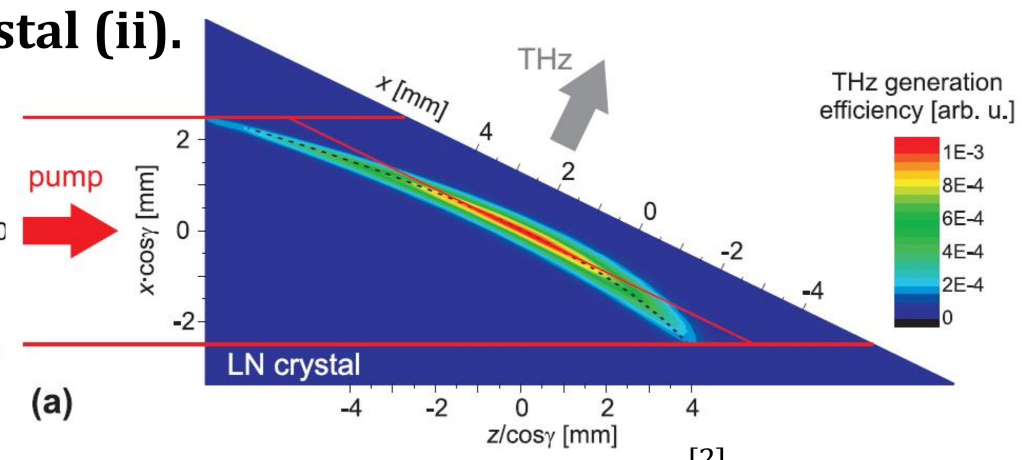
[1] J. Fülöp et al., **8**(3), 1900681 (2020)

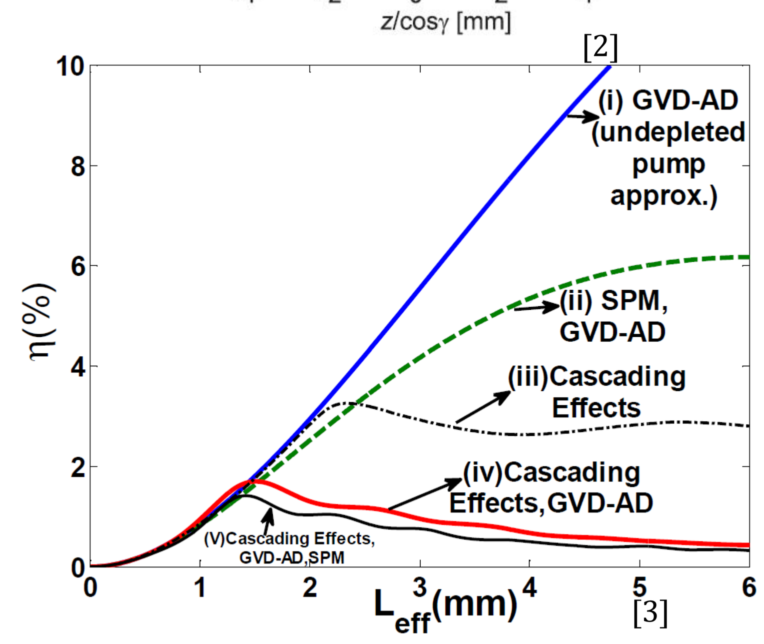
Limitation factors of the conventional THz pulse sources

There are three main limitation factors for energy scalability and THz beam quality :

- **Limited interaction length due to angular dispersion (i).**
- **Prism shape of the LN crystal (ii).**
- **Imaging errors (iii).**



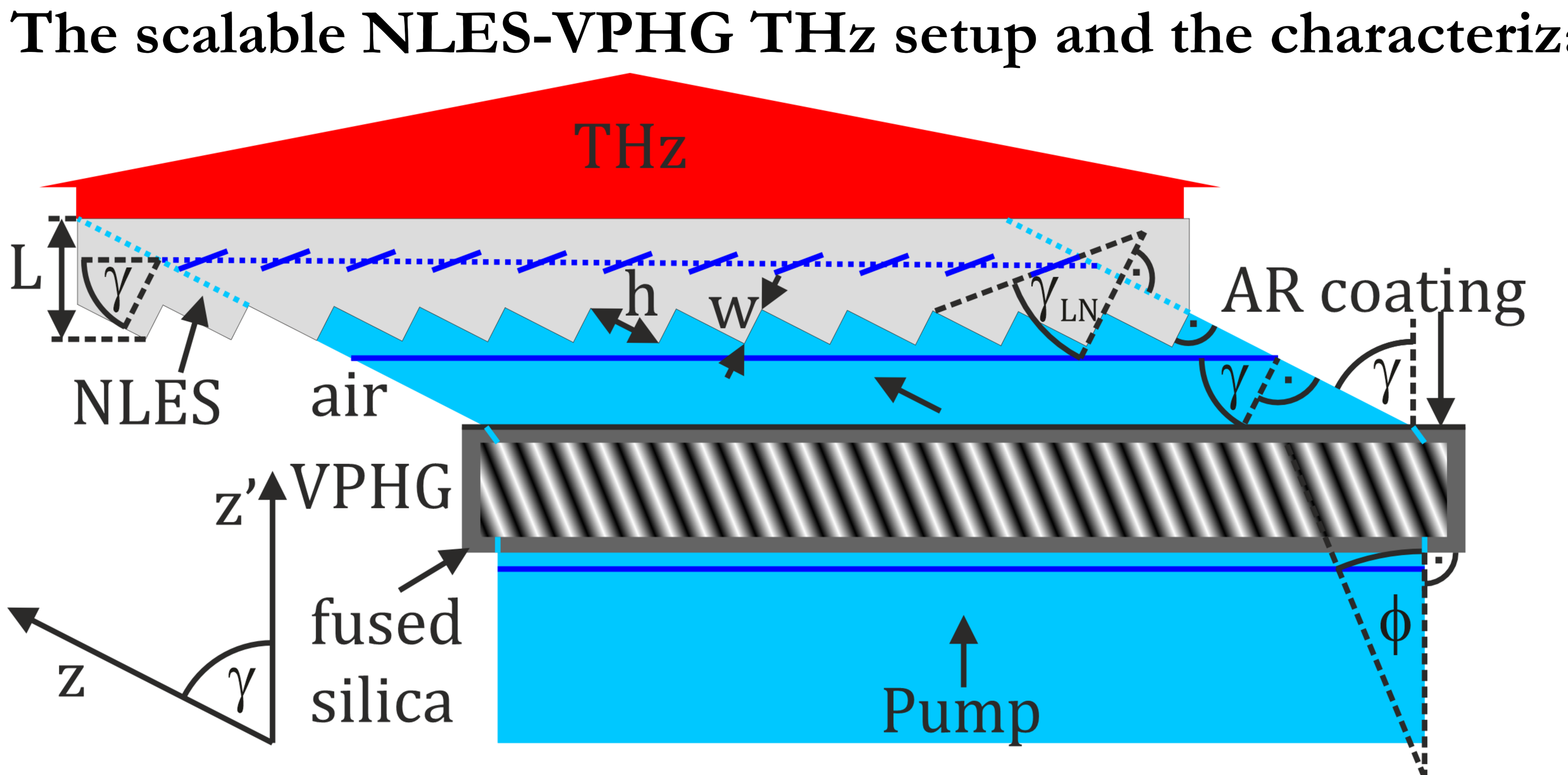


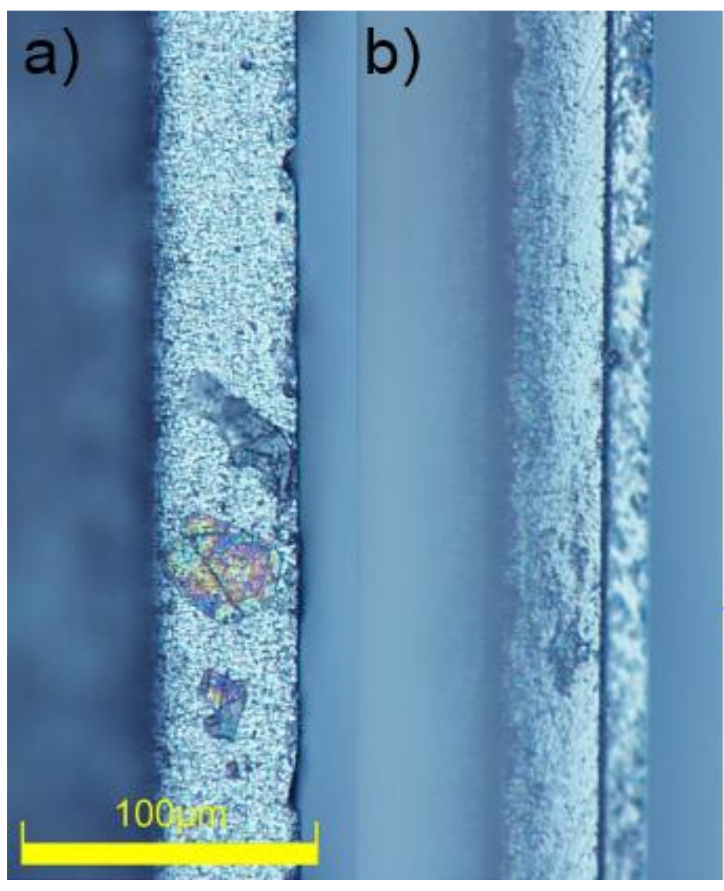


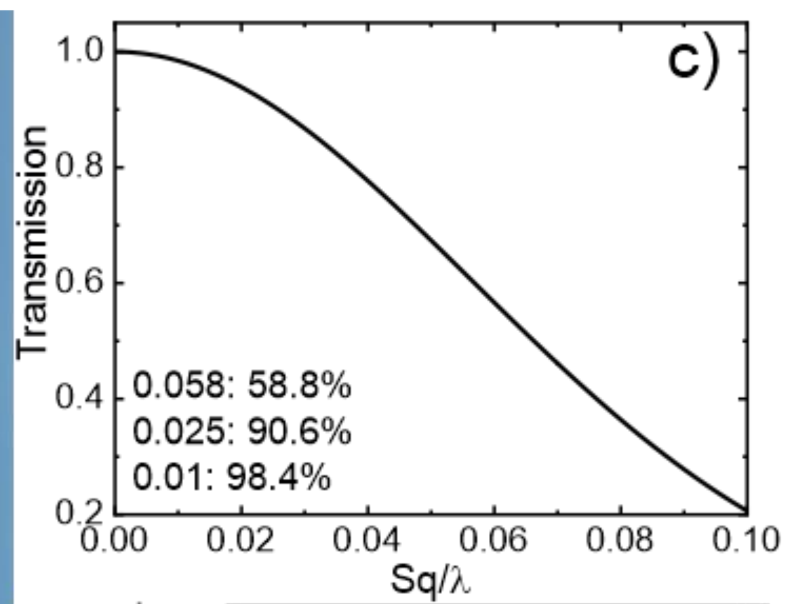
[2] J. A. Fülöp et al., Opt. Exp **18**, 12311 (2010)
[3] K. Ravi et al., Opt. Exp. **22**, 20239 (2014)

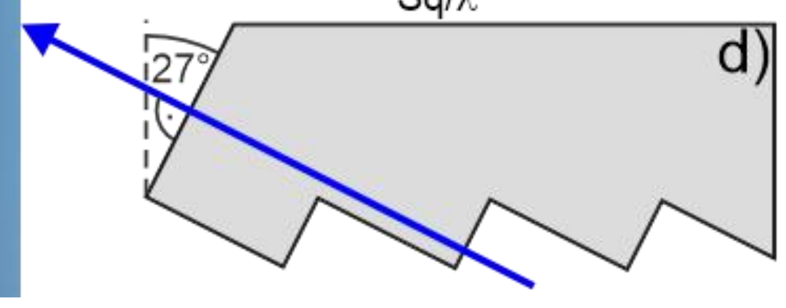
The scalable NLES-VPHG THz setup and the characterization of the micromachined surface

$$T = \exp\left(-\frac{4\pi S_q}{\lambda}\right)^2$$



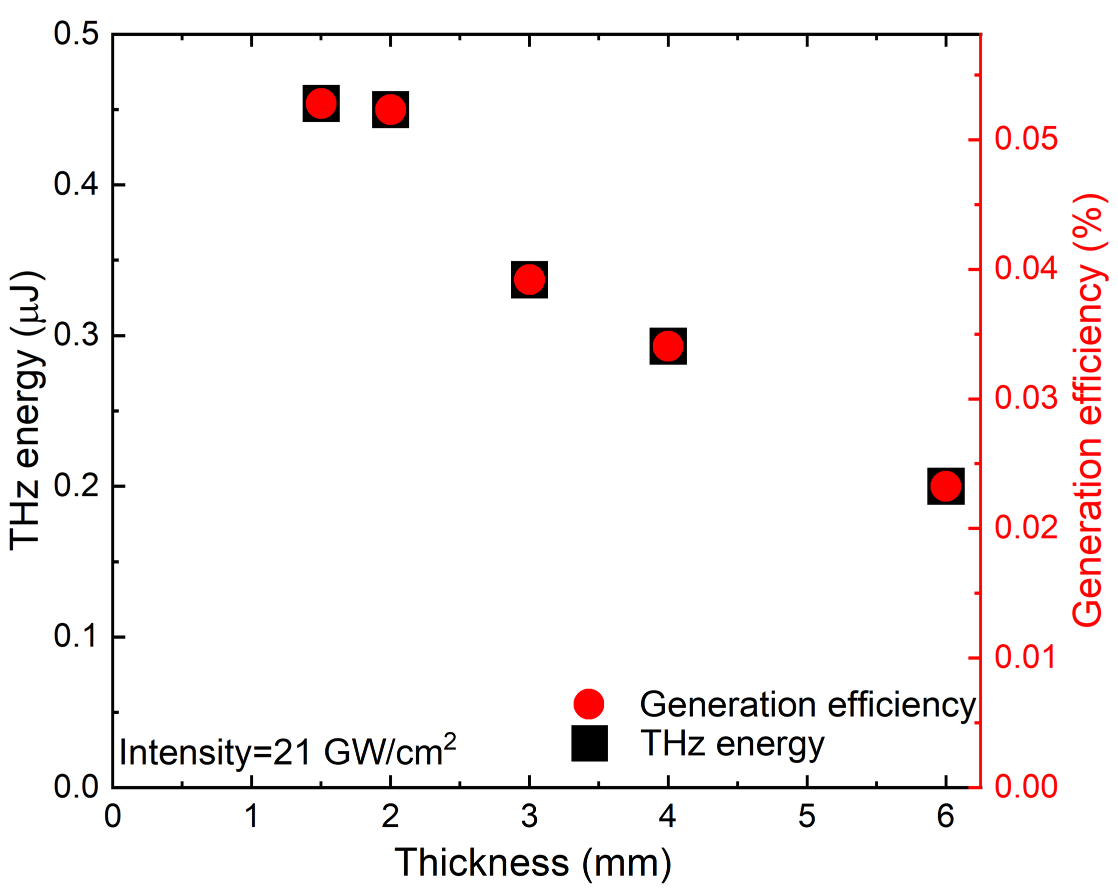


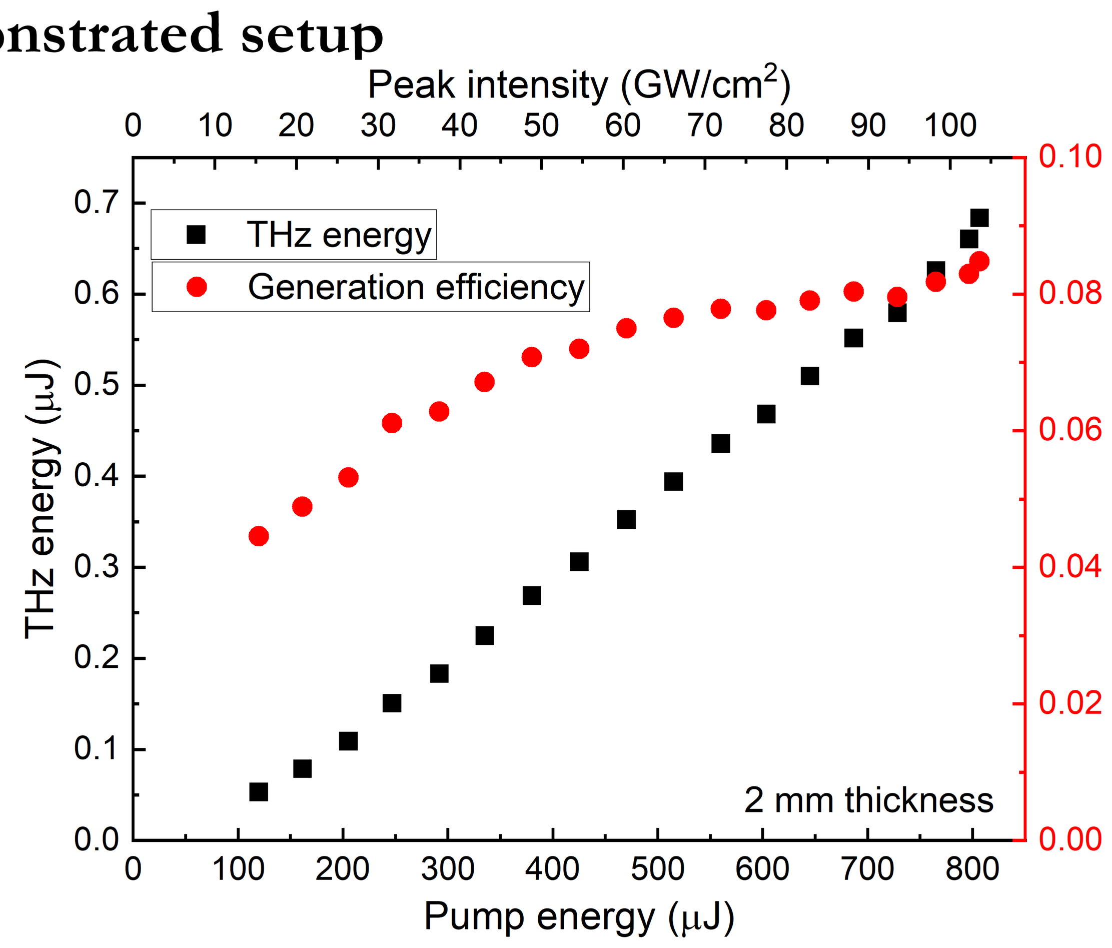


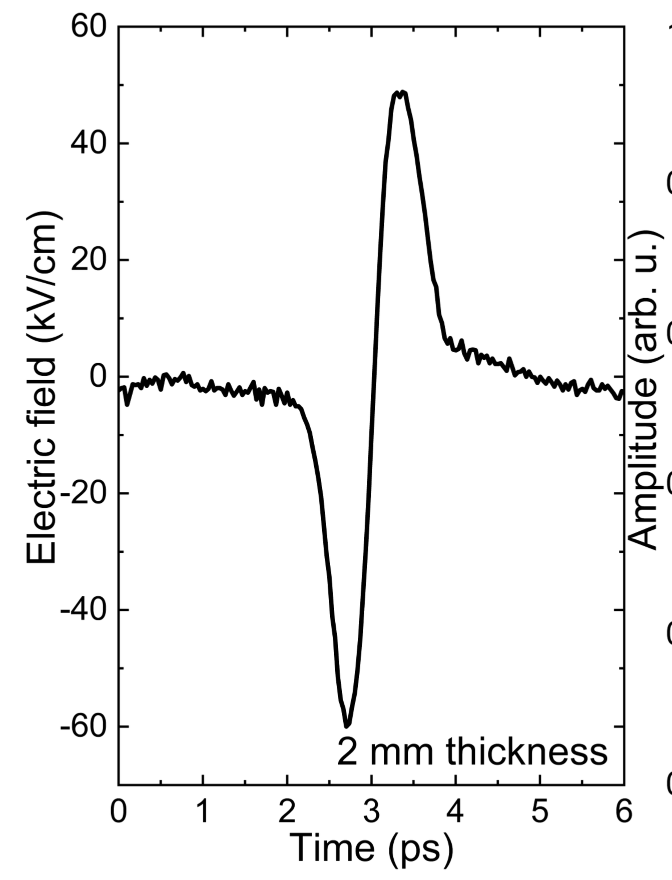


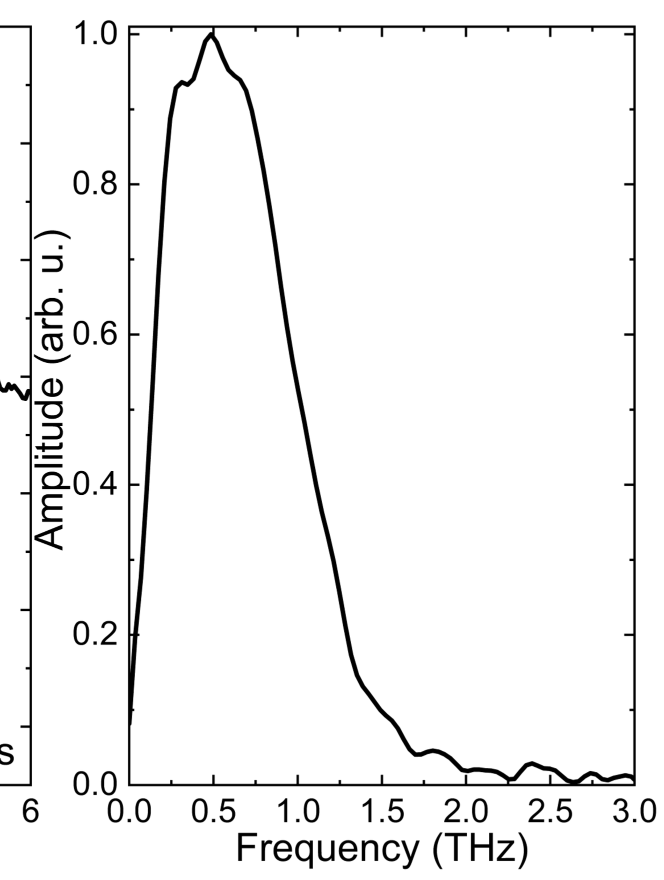
The surface roughness measured by optical microscopy was ~53 nm (a). In case of an ideal surface the transmission through the NLES should be 68% (d). Instead of that only 40% was measured. This correspond to an $S_q/\lambda = 0.058$ and $S_q = 60$ nm. Furthermore, the measured divergence after the NLES was 43 mrad, which is larger than expected from a 50 μm slit (26 mrad). This further reduce the generation efficiency by lowering the intensity inside the NLES.

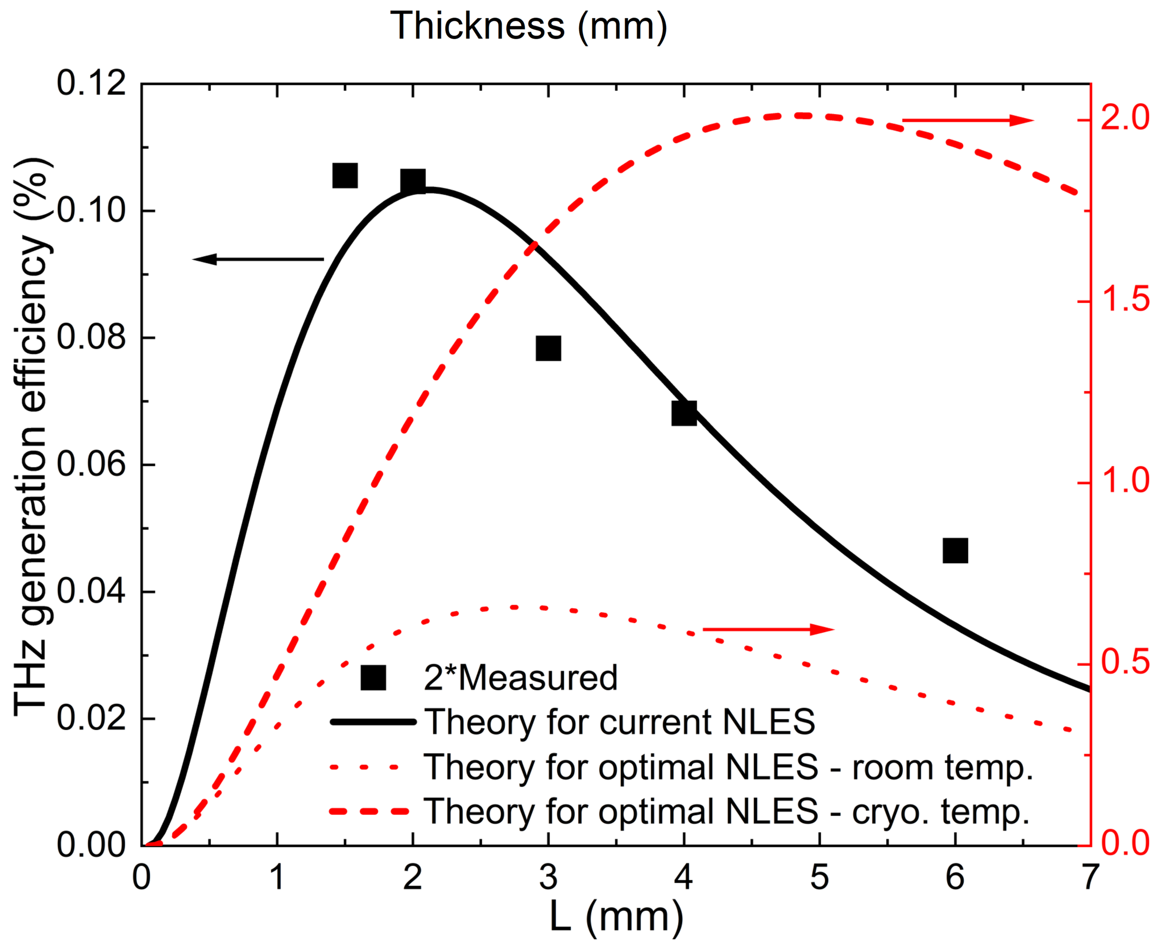
THz generation characteristic of the demonstrated setup











A simple model was created to compare the measured THz generation efficiency with the theoretical predictions:

$$\eta_{THz} = \frac{2\Omega^2 d_{eff}^2 I}{\varepsilon n_{NIR}^2 n_{THz} c^3} \exp(\alpha_{THz} L/2) \frac{\sinh^2(\alpha_{THz} L/4)}{(\alpha_{THz} L/4)^2} \left(\int_0^L f(z') g(z')\, dz'\right)^2$$

Pumping the presented (optimal) setup at room temperature with a pump beam having a 20 mm × 30 mm elliptical cross-section (matching to the size of the used NLES) and pulses with 64 mJ energy and 200 fs duration (corresponding to an intensity of 150 GW/cm² significantly below the damage threshold of the NLES), the THz generation efficiency would exceed 0.12% (0.65%) (approaching (significantly exceeding) the 0.16% measured for a conventional TPFP LN source using the same pump laser and THz detector), yielding a THz energy of 77 (416) μJ. Focusing this THz beam by NA=0.6 numerical aperture optic would result in an electric field as high as 1.7 MV/cm (~4.5 MV/cm).

Funding

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