Selective THz mode generation in a PPLN waveguide via chirped and delayed laser pulses

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Ilyes Betka[1], Moïse Deroh, [2,3] Gabriel Taton[1], Moses Eshovo Ojo[1], Frédéric Fauquet[1], Coralie Fourcade-Dutin[1], Hervé Maillotte[2], Mathieu Chauvet[2], Patrick Mounaix[1], and Damien Bigourd[1]

1. *Laboratoire IMS, UMR CNRS 5218, Université de Bordeaux, 33400 Talence, France*
2. *Université Marie et Louis Pasteur, CNRS, institut FEMTO-ST, F-25000 Besançon, France*
3. *National Polytechnic Institute - Felix Houphouet Boigny, Yamoussoukro, Côte d'Ivoire*

Corresponding author: Ilyes.betka@u-bordeaux.fr

Terahertz (THz) generation from Lithium Niobate (LN) platform using nonlinear optical processes has garnered significant interest due to its potential in numerous applications [1]. In particular, THz generation in periodically poled LN (PPLN) via chirped and delayed laser pulses (CDLP) manifests a great potential in applications such as spectroscopy and particle accelerator [2]. Recent studies have demonstrated such approach using large-scale PPLN pumped by Ti:Saphire-based laser sources with pulse energies of several Joules [3]. However, these systems face substantial challenges for miniaturization, limiting the development of compact, portable THz sources essential for integration. In this work, we demonstrate the generation of narrowband THz waves in a PPLN waveguide using low energy pulses of several µJ at a wavelength of 1 µm. In addition, by precisely adjusting the delay between two chirped pulses, we show the potential of this technique for modal phase-matching, selecting specific THz modes within a waveguide. In our approach, two chirped and delayed laser pulses with a pulse duration of 5 ps and a delay of 2.2 ps are generated using a parallel grating pair and a Michelson interferometer (Fig.1.a). The laser beam is then focused with a 300 mm lens in the middle of the 16 mm-long-PPLN THz waveguide. This latter has been fabricated with a poling period of 223 µm to generate a THz wave at ~ 488 GHz and has a cross-section of 500×500 µm² (Fig. 1.b).

The generated THz waves are detected using the electro-optic sampling technique. Fig. 1.c and 1.d display the measured THz electric field and its corresponding spectrum obtained via fast Fourier transform. The spectrum reveals a narrowband response at the expected frequency. Numerical simulations based on the coupled wave equations that account for the nonlinear interactions between terahertz and optical waves (including pump depletion), cascaded difference frequency generation, self-phase modulation, cascaded second harmonic generation, Raman processes, and the integral overlap between the pump and THz fields, show good agreements with the experimental results predicting an efficiency of 1.5×10^{-2} %. By including higher-order transverse electric modes (TE_{20} and TE_{30}) in the simulation, we demonstrate that selective excitation of a specific THz mode can be achieved by adjusting the relative delay. A delay of 42 ps enables the generation mostly of the TE_{10} (~ 488 GHz) mode with high efficiency (Fig. 1e). Adjusting the delay to 42.5 ps or 43 ps leads to a generation in favour of the TE_{20} (~ 492 GHz) (Fig. 1.f) or the TE_{30} (~ 509 GHz) modes (Fig.1g).

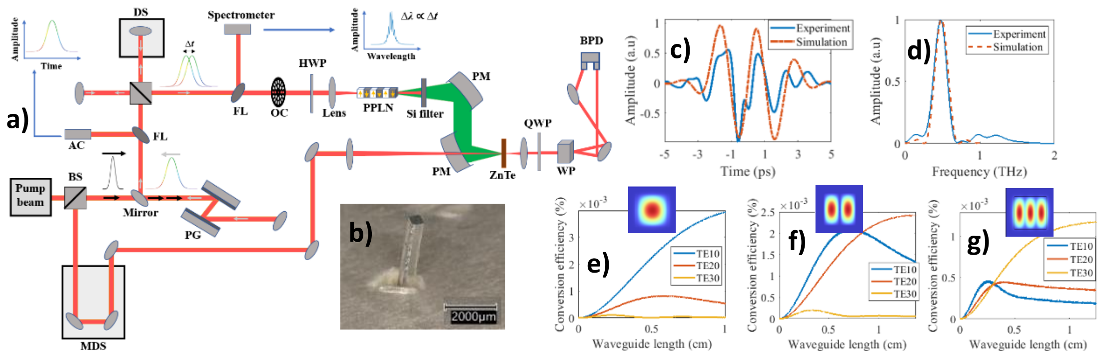

Fig. 1 *a) Experimental setup; BS : Beam splitter; PG: Parallel grating; MDS: Motorized delay stage; FL: Folding mirror; DS: Delay stage; AC: autocorrelator; OC: Optical chopper; HWP: Half wave plate; PM: Parabolic mirror; QWP: Quarter wave plate; WP: Wollaston prism; BPD: Balanced photodetector b) Microscopic image of the PPLN waveguide. c-d) Temporal THz waveform and corresponding spectrum. e,f,g) Efficiency as a function of crystal length for different pulse delay along with the spatial mode profile (42, 42.5 and 43 ps respectively)*

In summary, we have demonstrated THz generation via CDLP in a miniaturized system utilizing low-power pumping and a PPLN waveguide. Additionally, we showcased the ability of this approach to selectively excite specific spatial modes by simply adjusting the delay between the two pulses. This capability underscores the potential of this method to achieve precise mode confinement and dynamic mode switching, paving the way for compact and versatile THz sources.

Reference:

[1] I. Betka et al, "Generation of broadband THz radiation by polariton parametric scattering in a $LiNbO_3$ waveguide," Opt. Continuum 4, 687-693 (2025)

[2] F. Ahr et al, "Narrowband terahertz generation with chirped-and-delayed laser pulses in periodically poled lithium niobate," Opt. Lett. **42**, 2118-2121 (2017)

[3] S.W. Jolly et al. "Spectral phase control of interfering chirped pulses for high-energy narrowband terahertz generation, " Nat Commun **10**, 2591 (2019)