Broadband terahertz generation in the sub-picosecond regime via polariton parametric scattering in a LiNbO_3 waveguide

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Broadband Terahertz generation in the sub-picosecond regime via polariton parametric scattering in a LiNbO$_3$ Waveguide

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The presentation will focus on polariton parametric scattering in a rectangular waveguide made of Lithium Niobate to generate THz radiation. We highlight an emission of ultra-short THz pulse with a spectrum centered around 3 THz with a large bandwidth of 4 THz.

Keywords: Lithium Niobate, Terahertz generation, Waveguide

I. INTRODUCTION

Terahertz (THz) waves, lying between 0.1 and 10 THz on the electromagnetic spectrum, have garnered significant attention for their utility in various applications such as spectroscopy [1], imaging and telecommunication [2]. Different sources have been developed to generate these waves, including Optical Rectification (OR) [3], Difference Frequency Generation (DFG) [4], and parametric scattering [5]. Polariton parametric scattering in polar crystals such as Lithium Niobate (LN) is a promising technique to generate THz radiations from a second and third order nonlinear processes, delivering large or narrow bandwidths. Particularly, polariton scattering have been investigated when a long pulse pumps the material to generate tunable long THz pulses [6,7]. A significant challenge hindering this technique lies in the generation of a THz spectrum centred at frequencies exceeding 2 THz, primarily due to the gain spectrum of LN, and the important absorption coefficient at higher frequencies [8]. In this submission, we highlight the possibility to overcome this limitation by pumping a waveguide made of LN with a high optical intensity in the sub-picosecond regime.

II. PRINCIPLE AND EXPERIMENTAL SETUP

The generation of THz pulse is the result of light scattering from a polariton, i.e a coupling between optical phonons and photons in the polar-Raman active LN. The scattering involves the second and third order nonlinear processes. The strong interaction of the pump pulse in the material creates an optical idler and a polariton pulse in the THz frequency. From the photon energy conservation, the generated optical idler is spectrally shifted from the pump by the THz spectrum while the momentum conservation law leads to the angle-dispersive properties of the emitted pulses.

In this investigation, the THz radiation was generated and guided in a rectangular LN waveguide (0.5×0.5×16 mm^3) such that the THz radiation propagates in the pump propagation direction. The experimental set-up is shown in Figure 1. The crystal has been pumped by ultra-short pulses at a repetition rate of 85 kHz with a pulse-energy of 7 µJ. The spectrum is centered at 1025 nm and the pulse duration is 400 fs. The pump was focused with a 150 mm lens and polarized along the z axis of the crystal. The temporal waveform of the generated THz electric field was measured with the electro-optic sampling technique using a small fraction of the laser beam. The THz beam is collimated and focused into a GaP crystal to perform the EO sampling using a thin silicon filter and two parabolic mirrors.

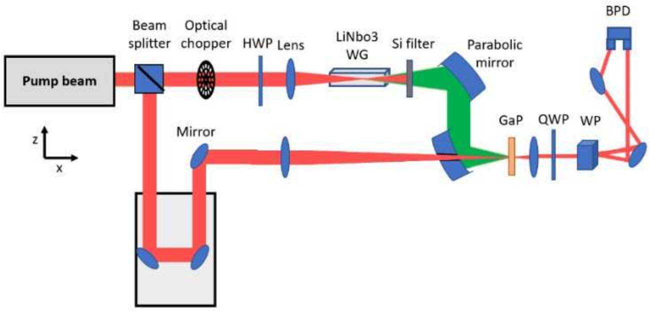

Figure 1 Experimental set-up. QWP/HWP-quarter/half wave plate; WP-Wollaston prism; BPD- balanced photodetector

III. RESULTS AND ANALYSIS

Figure 2 shows an example of a recorded temporal trace when the pulse energy is set at 7 µJ. The spectrum, obtained from the fast Fourier transform of the temporal trace, is broad with a width of ~ 4 THz centered at 3 THz (Figure 3). The spectrum displays distinct peaks caused by the preceding fluctuation observed in the temporal profile prior to the main pulse, potentially arising from artifacts, additional weak pulses or high order modes. To focus on the main pulse, we filtered out the wavy pattern (Figure 2). The resulting spectrum keeps a similar overall appearance, indicating that the wavy part does not add any new spectral features.

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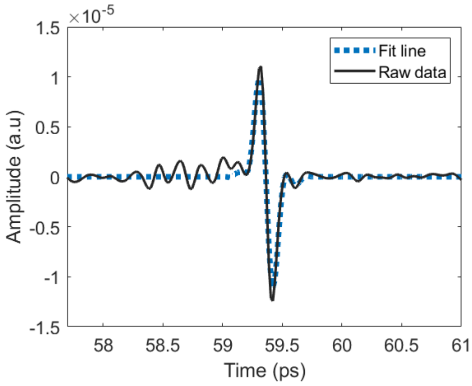

Figure 2 temporal waveform of the detected THz pulse and its fit

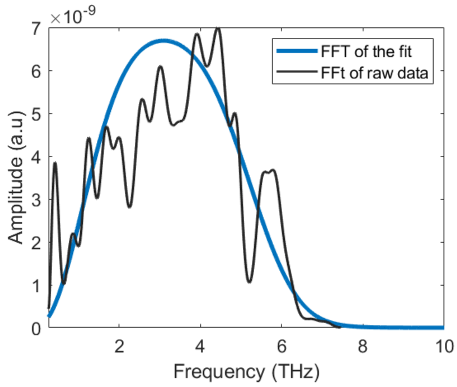

Figure 3 Corresponding spectra obtained by FFT

The optical spectrum at the output of the waveguide is also shown in Figure 4 and corresponds to the idler simultaneously generated with the THz. The spectrum has multiple Stokes peaks emitted from the spontaneous polariton parametric scattering process. The spectral shifts of the peaks relative to the pump are in good agreement with the THz spectrum. As the idler is angularly emitted at the output, the spectrum is not smooth and depends on the spectrometer orientation. We also calculated the expected THz spectrum from the phonon polariton dispersion curve and the diffraction modified Schwarz-Maier plane wave model [9]. The analytical expression of the exponential gain (g) for the THz wave is provided by:

$$g(\nu) = \frac{\alpha(\nu)+\alpha_{WO}}{2}\left(\sqrt{1 + 16\,cos(\theta)\,\left(\frac{g_0}{\alpha(\nu)+\alpha_{WO}}\right)^2} - 1\right) \quad (1)$$

With $\boldsymbol{g_0}$ the parametric gain coefficient in the low-loss limit, $\boldsymbol{\alpha_{WO}}$ represent the special walk-off between the pump and the THz beam. $\boldsymbol{\alpha(\nu)}$ accounts for THz absorption coefficient. $\boldsymbol{\theta}$ represent the emission angle of the THz field. Ip is the pump intensity; n_T, n_s and n_p the refractive indices of the THz, signal and pump. $\boldsymbol{\chi_P}$ is the second-order susceptibility. By including the mode area mismatch (given by $\left(\sqrt{\frac{\boldsymbol{W}}{\boldsymbol{W}+\frac{\boldsymbol{0.5}}{\boldsymbol{\alpha(\nu)}}}}\right)$) between the optical and the THz fields together with the limited diffraction geometry, we corroborate the emission of a very large spectrum centered at 3 THz.

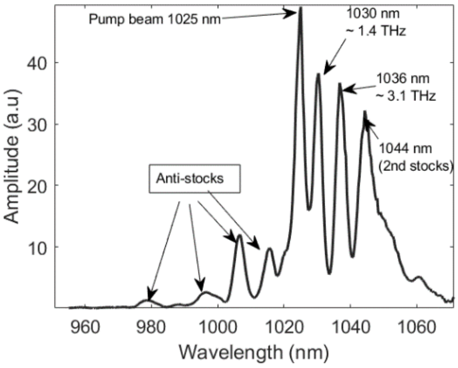

Figure 4 Optical spectra at the output of the waveguide

IV. CONCLUSION

Polariton parametric scattering in LN made waveguide has been presented to generate THz radiations with a large band of ~ 4 THz centred at 3 THz. The generated optical spectrum of the idler and the predicted spectral THz gain are consistent and confirms our observations. This result is an excellent step toward the development of ultra-fast THz amplifier.

V. ACKNOWLEDGMENT

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