Upper Pulse Energy Limit of Narrowband THz Generation

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Abstract: We generate tunable narrowband THz radiation using BNA bonded to sapphire in tandem with a chirp and delay technique. Using a Ti:Sapphire laser, we test the limits of intense THz generation (0.1 to 5 THz).

1. Introduction

Terahertz frequencies (0.1 to 10 THz) have a wide range of applications, from studying phonon modes and mapping out carrier dynamics, to noninvasive hyperspectral imaging. One of the most efficient sources of single-cycle broadband THz is through optical rectification of ultrafast light pulses with organic nonlinear optical (NLO) crystals. However, there are several applications of multi-cycle tunable narrowband THz generation across the same range of frequencies, such as selective excitation of phonon modes. Several groups have developed chirp-and-delay techniques to modulate the optical pulse sent into the THz generation crystal [1-3]. The beam is linearly chirped, split, and recombined to interfere with a time-delay such that there is a single frequency present in the multiple oscillations of the modulated pulse. The frequency of the oscillations can be controlled by varying the delay between the two pulses and the chirp. Optical rectification of these modulated pulses generates narrowband THz, whose frequency is tunable with the time delay and the chirp.

The frequency ranges of these chirp-and-delay setups have previously been restricted to 0.1 to 1.5 THz, or have used special, custom laser technologies to achieve tunability up to 6 THz. We propose a simple setup that generates narrowband THz from 0.1 to 5 THz using the output of an 800 nm Ti:Sapphire laser. Organic NLO crystals are more efficient than inorganic crystals for optical rectification due to high molecular hyperpolarizabilities. However, they have much lower damage thresholds, making efficient generation with high-power lasers difficult. To circumvent these issues, we use the organic NLO crystal BNA bonded to sapphire; the high thermal conductivity of the sapphire raises the damage threshold of the crystal so that we can expose it to fluences of up to ~15 mJ cm^{-2} [4].

2. Experimental

The experimental setup is shown in **Figure 1**. The 800 nm pulses originate with a pulse duration of 100 fs, but are linearly chirped to longer durations up to ~3 ps. The typical pulse energy is 3 mJ. The beam is directed to a beam-splitter (30:70 R:T) mounted on a moving stage. The resultant chirped-and-delayed pulses are sent into a BNA-sapphire crystal and the THz is detected through electro-optic sampling with GaP.

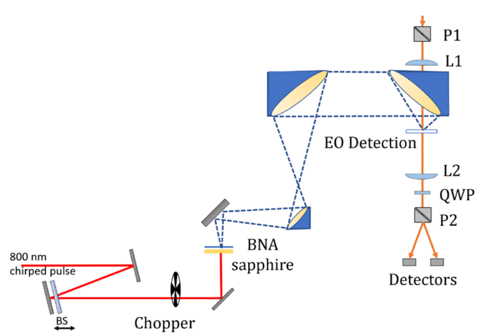

Fig. 1. Chirp-and-delay THz generation setup

3. Results

We modeled the intensity profile of the modulated chirped and delayed optical pulses and applied a Fourier transform to extract the frequencies generated by a given pulse duration and relative delay between pulses as controlled by the stage delay. Because we used a beam-splitter that reflected 30% of the intensity and transmitted 70%, there were three pulses delayed by the same interval. Our modeling takes into account the relative intensities of each of these three pulses to model the THz electric field. The results of a relative time delay of 0.7 ps and a chirped pulse duration of 3.1 ps is shown in **Figure 2.**

The damage threshold of organic NLO crystals is related to the peak power. Chirping the pump pulses and spreading the pulse energy out over a longer time period lowers the peak power associated with a particular pulse energy. Therefore, we can pump the crystal with a higher fluence before reaching the peak power. **Figure 2a** shows the intensity profile of the delayed 3.1 ps pulses. The inset shows the intensity profile of a 100 fs pulse that generates a broadband THz spectrum. As shown with the Fourier transforms in **Figure 2b**, we expect the narrowband THz produced to be higher amplitude than that which could be achieved with a broadband pulse, because the crystal can be pumped with higher energy before reaching its damage threshold.

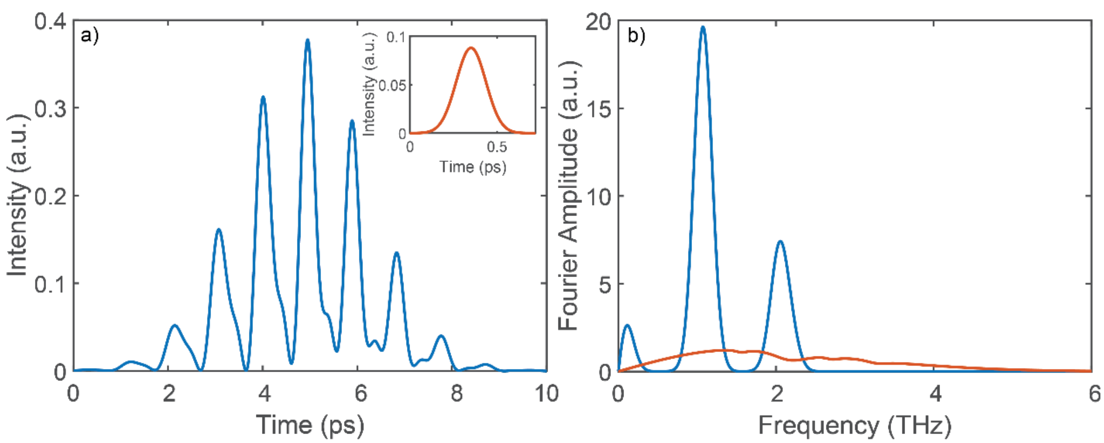

Fig. 2. (a) Modeled intensity profile of pulses chirped to 3.1 ps duration and delayed 0.7 ps relative to each other. The inset of (a) shows an unchirped 100 fs pulse. (b) Frequency-domain electric fields as generated by chirped and delayed pulses and short Gaussian pulses.

4. Summary

This simple chirp-and-delay THz generation setup using BNA sapphire at 800 nm proves to be one of the most efficient narrowband THz generators using optical rectification. The high damage threshold of sapphire coupled with high conversion efficiency of BNA at that wavelength will yield strong narrowband THz pulses. The setup allows for complete tunability of desired frequency within the range from 0.5 to 5 THz.

5. References

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