Terahertz Generation via Optical Rectification in GaAs using a Supercontinuum Source

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***Abstract*— We demonstrate the use of a supercontinuum laser in the generation of terahertz waves via optical rectification in GaAs. Broadband THz output with 170 nW of average power was produced using 170 mW of mid-IR power filtered from a supercontinuum fiber laser.**

I. Introduction And Background

THE development of supercontinuum fiber lasers present opportunities to use a single source for synchronous multi-color applications of coherent radiation. One application is a two color terahertz time domain spectrometer (THz-TDS). One two color system was built at Oregon State University using the 2 µm and 0.8 µm outputs of a coherent OPerA OPA powered by a Legend 1 W 1KHz repetition rate 100 femtosecond regenerative amplifier[1]. The use of two different wavelengths as the THz generating pump and interrogating probe opens many different possibilities for optimized nonlinear sources and detection materials, enabling more versatile pump-probe systems. Supercontinuum fiber lasers have power spectra ranging across 400-2500 nm that can be filtered providing a multi-color source for similar applications such as pump-probe experiments. First demonstration of THz generation using a supercontinuum laser extends applications of these systems to THz spectral range.

II. Results

Supercontinuum lasers (such as Fianium SC450) produce high power (up to 8W) of broadband output covering the spectral range from 400 nm to 2500 nm, These systems are based on ultrafast fiber lasers generating 10 ps pulses at 20-60 MHz repetition rates. Pulse duration of supercontinuum output varies from 15 ps in the visible spectral range to less than 0,2 ps in the long wavelength tail[2], which are sufficiently short for THz generation via optical rectification.

In order to demonstrate THz generation in GaAs, we first filtered the spectral range of 1.9 and 2.5 µm (Fig. 1) from the overall spectrum of a 4W supercontinuum laser to avoid 1 and 2 photon absorption. After filtering, we measured 286 mW.

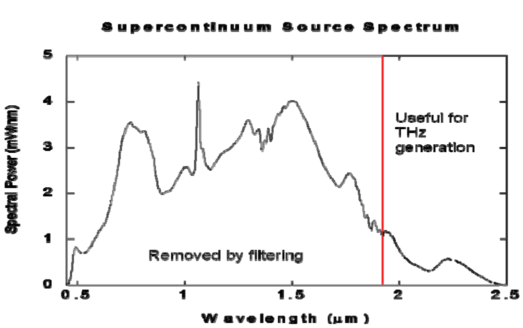

Figure 1: Filtering mid IR spectrum from supercontinuum source.

The filtered laser beam was focused to ~15 µm beam waist with a Rayleigh length of ~700 µm. The lens was not AR coated for 2 µm so after Fresnel reflection losses 170 mW remained. A 508 µm thin 2 µm AR coated GaAs wafer was inserted at the focal plane 29 mm from the lens where the beam waist was 15 µm. A THz low pass filter separated the 2 µm from the THz wave. A 2” diameter f=50 mm Tsurupica lens was used to collimate the beam. The THz waves were then focused using an identical Tsurupica lens through a polystyrene filter (30% THz transmission) into a polyethylene windowed Golay cell. The measured signal was then filtered and amplified with an SR560 preamplifier and the signal averaged (128) and measured on a digital oscilloscope (Fig. 2).

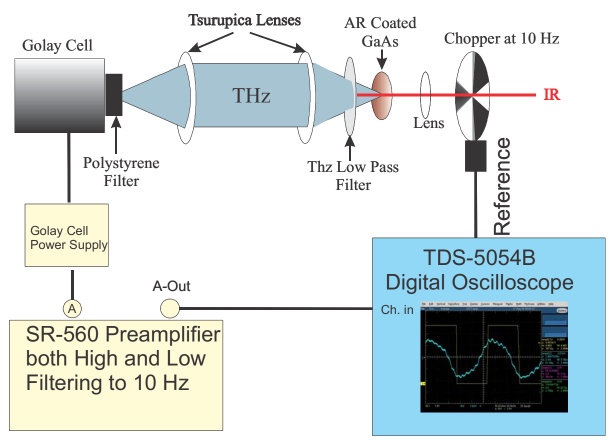

Figure 2: THz generation and detection

Overall system responsivity was 14,800V/W. To check that the generated signal was in fact THz the sample was rotated about the beam and the signal was observed to go through maxima and minima with the expected angular dependence (due to the angular dependence of $\chi^{(2)}$). The minimum was 1.8 mV at 54 degrees from the maximum while the maximum was 3.9 mV. The minimum was consistent with theory provided one accounted for the 1.8 mV as background IR left after filtering. At the minimum the z-axis was aligned with the 2 µm polarization which is the expected behavior as per theory for a [1 1 0] face cut zincblende material such as GaAs. After subtraction of the remnant background IR signal then a 2.1 mV THz signal which corresponds to 140 nW remained. The calculated optical-to-THz conversion efficiency is 8 x 10^{-7}. Theory predicts 1.94 10^{-6} for the optical-to-THz conversion efficiency. While this is not a record, this is the first instance known to the authors of THz generation from a supercontinuum source.

The longer than optimal (100 femtoseconds) pulse duration for the majority of the mid IR power in the usable spectrum along with introduced dispersion in the filtering process is probably responsible for the low conversion efficiency. The 2 μm losses due to use of uncoated lenses contributed to lower input power. Additionally, the short Rayleigh length limited the thickness of the GaAs sample to a single wafer producing broadband THz centered at 1.5 THz. Since the pulse duration was more appropriate to generating .5-1 THz across a significant portion of the spectral range a minimum of 1 mm Raleigh length would have been preferred. Additionally, the dispersion effectively creates a set of pulses each slightly separated in time[4] so the Fluence of each pulse would have to be analyzed and phase effects accounted for.

With improved optics (anti-reflection coated) and chosen to provide the desired beam waist and Rayleigh length one could use QPM GaAs structures increasing the THz power and narrowing the spectral bandwidth. By judicious choice of the period one could choose the central frequency of the THz generated to target specific transitions. Whether one is looking for rotational transitions such as 625 GHz rotational transition in HCL gas or a dark state in a GaAs quantum well structure[5] one could quickly change the configuration between experiments.

By using a dichroic mirror to separate the 2 μm one would then have the NIR and visible components separately available. This would enable pump probe experiments. Acousto-optic tunable filters are readily available to make selection and control of the visible and NIR components available for this application. So, pump-probe experiments could be quickly varied across large spectral ranges to explore interactions involving various transitions with optical or THz spacing. Optimization for mid IR generation could generate more THz power making this a viable and compact source for pump-probe experiments (Fig. 4).

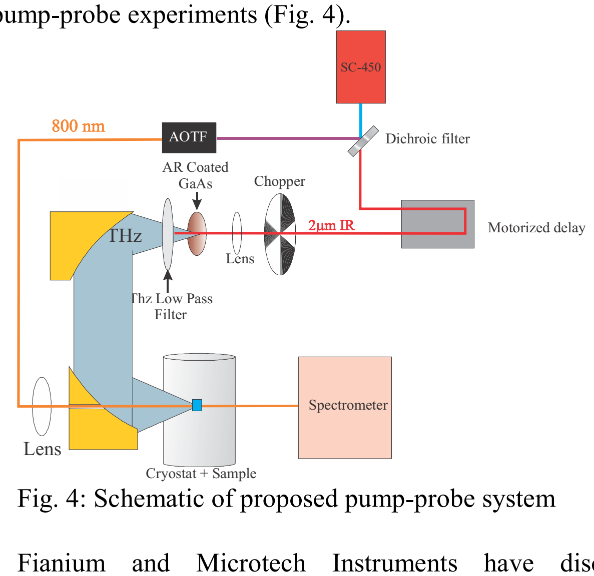

Fig. 4: Schematic of proposed pump-probe system

Fianium and Microtech Instruments have discussed construction of a femtosecond supercontinuum laser so that THz-TDS systems with flexibility in the probe wavelength would be an option. Then one could choose and even switch between various materials, such as DAST, InAs, GaSe, GaP, as electro-optic crystals. This would allow for rapidly reconfigurable spectrally flexible alternative THz-TDS systems such as proposed in Figure 5.

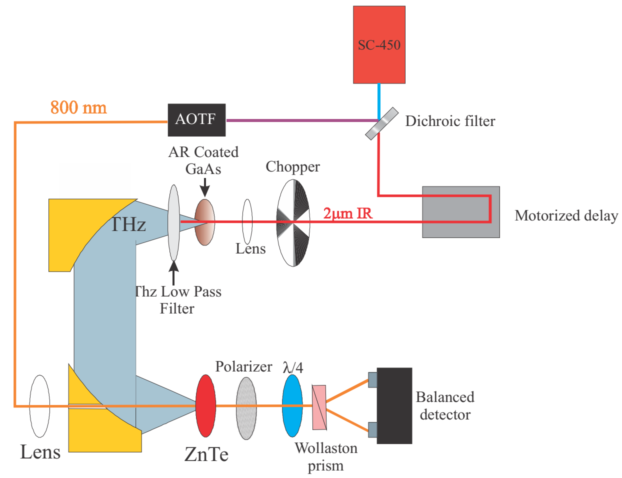

Figure 5: Proposed rapidly reconfigurable THz-TDS system. Changing the AOTF output, the ZnTe, and the waveplate would allow reconfiguration.

We have demonstrated supercontinuum lasers are suitable for a compact multi-color THz source. Additionally using either bulk or a QPM GaAs sample so that both broad and narrow bandwidth THz waves may be generated can add more flexibility. Supercontinuum lasers with higher mid-IR output are under development which will lead to generation of more THz power. Since efficiency (η) is proportional to the fluence and $P_{THz} = P_{opt}\ \eta$, we can expect significant improvements in THz output in supercontinuum based sources with increased mid IR power. These are interesting and novel sources with the potential development into flexible experimental systems.

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