Tunable 0.8-3.5 THz Source based on Fiber-laser Pumped Orientation-patterned GaAs

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Abstract: We demonstrate a μW-level broadly tunable THz source based on parametric down-conversion in orientation-patterned GaAs pumped by femtosecond pulses from a Tm-doped fiber laser. Generated THz powers should be scalable to mW-levels with this approach.

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Optical rectification (OR) of femtosecond pulses [1] is an established technique for generation of broadband THz transients. Typically, strong THz absorption and the lack of phase-matching limit the length of the nonlinear crystal to ~1 mm. Lee et. al. [2] demonstrated that one can increase THz efficiency in the OR process by using quasi-phase-matched (QPM) nonlinear materials, e.g. lithium niobate. In addition, in the latter case, using femtosecond pulses one can generate *narrow-band* terahertz packets whose center frequency is determined by the QPM period. Orientation-patterned GaAs (OP-GaAs) is a promising new QPM material for THz generation: it has pretty high nonlinearity, excellent THz transparency and low index mismatch between optical and THz waves. To avoid two-photon-absorption, GaAs must be pumped at λ>1.74 μm. Efficient generation of THz radiation in OP-GaAs has been demonstrated recently [3] using an OPA femtosecond source with 3-4 μm wavelength, 1-2 μJ pulse energy and 1 kHz repetition rate.

In this paper we demonstrate a high-repetition-rate THz source that rely on the robustness and favorable THz properties of orientation-patterned GaAs and compactness and environmental reliability of a fiber-laser-pump.

The pump source was an all-fiber laser that produced 120-fs pulses at a repetition rate of 100 MHz with an average power of 3 W at 1980-nm wavelength. Briefly, the source consisted of a Raman-shifted Er-fiber laser whose output was amplified in a large-mode-area Tm-doped fiber [4]. A variety of OP-GaAs samples with QPM periods varying between 500 and 1300 μm, 0.4-mm-thick, 3-5-mm-wide, and with the length L=3-10 mm, were grown by a combination of molecular beam and hydride vapor phase epitaxy [5].

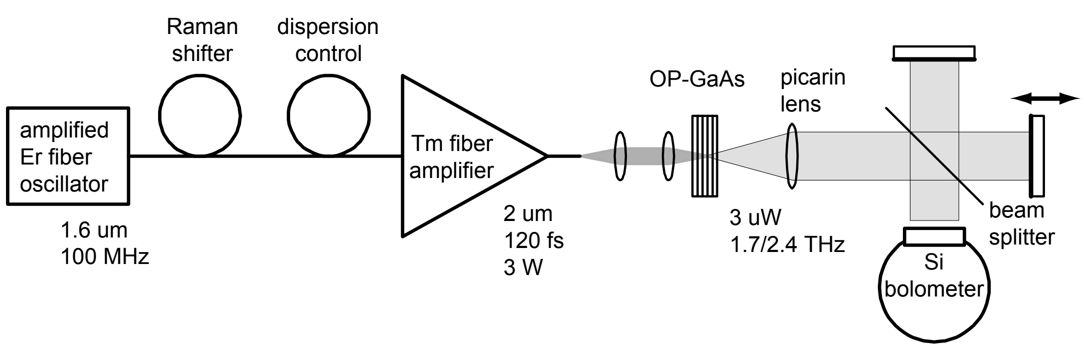

Fig. 1. Schematic of the setup for THz generation and characterization.

The pump beam (Fig.1) was propagating along the <110> direction of the OP-GaAs and was polarized along <111> to maximize the effective nonlinear optical coefficient. The focusing of the pump beam was optimized to produce the maximum THz power: the resulting beam size (1/e^2 radius) was w_0= 65μm, in agreement with theoretical findings for the optimal focusing [6]. THz beam was collimated by an f=50mm 'Picarin' lens and detected by a Si-bolometer (4K). The spectral properties of the generated THz radiation were measured using a Michelson interferometer composed of two gold mirrors and a 25-μm-thick mylar beamsplitter.

For the OP-GaAs samples A3 (1277-μm QPM period, L=3mm) and B3 (759-μm period, L=3mm), the THz spectra were centered (Fig.2a) at 1.78 THz (width 0.3 THz) and at 2.49 THz (width 0.25 THz), respectively – in total

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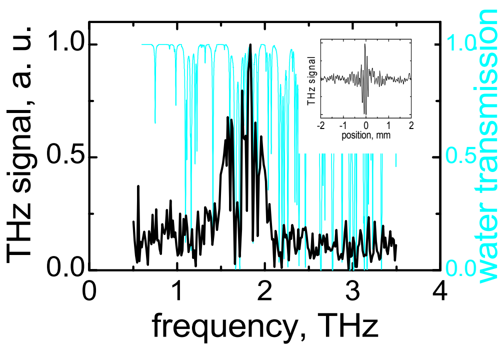
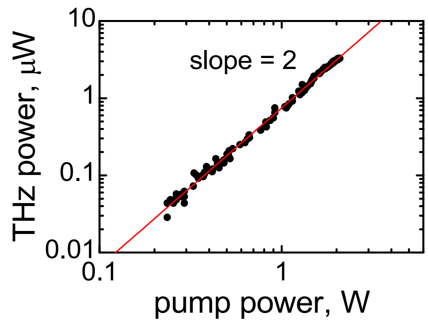
agreement with the predicted QPM peak position and width. Strong spectral modulation was observed due to water vapor absorption in the air. At the highest optical power of 2.1 W incident on the sample (peak focused intensity ~ 2 GW/cm^2), we obtained 3.3-μW THz power for both samples A3 and B3. The THz output power was quadratic (Fig.2b) with respect to the incident pump power and did not show any saturation effects, which says in favor of the possibility of further power scaling. The maximum THz efficiency achieved was about 1.5×10^{-6}, corresponding to internal efficiency of ~4.5×10^{-6} (the GaAs samples were not AR-coated). This corresponds to 2.1×10^{-4} / μJ normalized conversion efficiency. This value is about 25% of the calculated; the discrepancy can be accounted for by the following factors: (i) clipping of the THz beam (the thickness of the OP-GaAs sample, 400 μm, is comparable to the THz wavelength); (ii) THz attenuation in air due to water vapor absorption; and (iii) the pump pulses being about 2x the transform limit.



(a)



(b)

Fig. 2. (a) THz-wave spectrum obtained from sample A3 (period 1277 μm). Inset: original Michelson interferogram. Also shown is transmission spectrum of air (path length 20 cm, HITRAN database). (b) Log-log plot of the THz output power vs optical pump power.

In a separate set of experiments we used a *picosecond* instead of a femtosecond pump source: a near-degenerate type-II PPLN OPO, synchronously pumped at 1.06μm (6 ps, 50 MHz, High Q picoTRAIN IC-10000 laser). The singly-resonant OPO emitted two narrow-linewidth (~$3cm^{-1}$) outputs near the 2.13-μm degeneracy at slightly different wavelengths separated by a THz frequency, with the average output power of 0.2W (signal) and 1W (idler). The OPO signal and the idler beams, with orthogonal polarizations, were focused onto a OP-GaAs crystal, with $1/e^2$ radius of ~80 μm. The output THz frequency was tuned by tuning the spectral separation between the OPO lines (through changing the PPLN temperature). By using OP-GaAs samples with only three QPM periods (564, 759 and 932 μm), we covered the whole range of THz frequencies between 0.8 and 3.5 THz (with ~0.1 THz linewidth). At 2.4 THz, the output reached 0.3 μW, corresponding to the normalized internal conversion efficiency of 2.7×10^{-4}/μJ. This corresponds to ~ 40% of theoretical efficiency. Again, THz output was quadratic with respect to the incident pump power and showed no saturation.

The fact that femto- and picosecond normalized (per unit pump energy) THz efficiencies are very similar, is in accord with theoretical predictions [7] that conversion efficiency is fluence- (not intensity-) dependent and has the same scaling for femto- (OR) and picosecond (DFG) pulse energy. Pumping with picosecond pulses though has a potential for a better power scalability due to lower peak intensities and hence reduced unwanted nonlinear effects.

In conclusion, we demonstrated a tunable, μW-level, 100-MHz repetition rate THz source based on parametric down-conversion in orientation-patterned GaAs pumped with a femtosecond all-fiber 2-μm laser, as well as by a picosecond dual-wavelength OPO source at 2 μm. The output power (and conversion efficiency) can be further scaled by increasing the energy per pulse of the pump laser or by placing the OP-GaAs inside the OPO cavity, and improving the quality of the OP-GaAs samples (primarily increasing thickness). The demonstrated source should be suitable for many applications including THz imaging and spectroscopy.

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