Tunable THz Source Based on Intracavity Parametric Down-Conversion in Quasi-Phase-Matched GaAs

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Abstract: We developed an efficient frequency-tunable THz source using intracavity mixing between the two resonant waves of a synchronously pumped doubly resonant OPO. Three types of quasi-phase-matched GaAs were utilized: optically contacted, orientation-patterned, and diffusion-bonded GaAs.

OCIS codes: (040.2235) Far infrared or terahertz; (190.4970) Parametric oscillators and amplifiers; (190.4400) Nonlinear optics, materials

1. Introduction

Parametric frequency down-conversion is a known method for generating terahertz-frequency (THz) radiation. This technique generates THz radiation using difference frequency generation (DFG) between two laser input beams [1] or by optical rectification (OR) of ultrashort (usually femtosecond) pulses [2]. GaAs is an attractive material for THz generation due to its large optical nonlinearity, small THz absorption, large coherence length due to a small difference between the THz phase and optical group velocities, and well-known quasi-phase-matching (QPM) fabrication techniques [3]. QPM increases the effective length of the nonlinear material and allows the center THz frequency to be tuned as was demonstrated in GaAs using OR and DFG [4,5]. We generated THz radiation by placing QPM-GaAs inside the cavity of a synchronously pumped doubly resonant optical parametric oscillator (DRO) where the GaAs samples large intracavity optical powers. The THz frequency was tuned by changing the frequency spacing of the DRO signal and idler and by using a GaAs sample with the correct QPM grating period.

2. Experimental Setup and Results

A schematic of the intracavity THz source is shown in Fig. 1. The QPM-GaAs was placed inside a high-finesse DRO cavity synchronously pumped by a mode-locked laser with a 1064-nm wavelength, 7-ps pulse width, and an average power of 10 W. DFG between the resonant signal and idler created picosecond-pulse THz wave-packets which were out-coupled from the cavity by mirror M9. The optical-to-THz conversion efficiency reached $\eta \sim 10^{-4}$ with mW-level THz average powers [5] and intracavity signal and idler average powers reaching 40-50 W each. The pump, signal, and idler waves were type-II quasi-phase-matched using periodically poled lithium niobate (PPLN) allowing narrow signal and idler bandwidths (100-200 GHz) operating near degeneracy ($\lambda_{sig} \approx \lambda_{idl} \approx 2\lambda_{pump}$). The signal and idler fields were linearly polarized and orthogonal to one another.

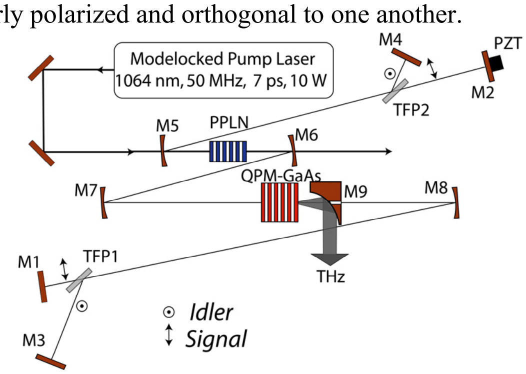

Fig. 1 Schematic of the experimental setup used to perform intracavity parametric down-conversion inside QPM-GaAs using the resonant signal and idler within a high-finesse DRO cavity.

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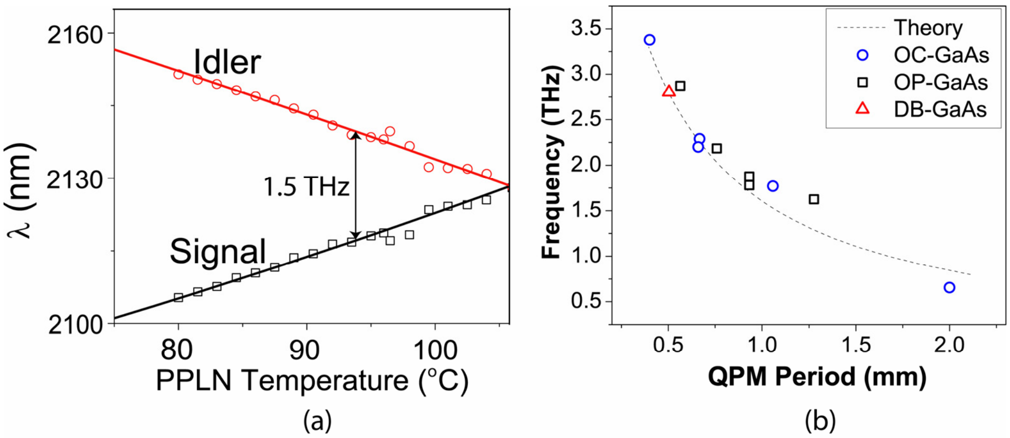

Fig. 2 (a) DRO signal and idler center wavelengths (experimental data points and solid-line polynomial fits) versus PPLN temperature (b) The center THz frequency versus GaAs QPM period for 3 different GaAs micro-structures: OC-GaAs, OP-GaAs, and DB-GaAs. Experimental data points are plotted along with a dashed-line theoretical tuning curve.

The center THz frequency was tuned by setting the frequency spacing between the signal and idler and using a GaAs sample with the appropriate QPM period. Fig. 2(a) shows the measured tuning curves of the signal and idler center wavelengths versus PPLN-crystal temperature. For example, the signal and idler wavelength spacing at 93.8°C was 22.5 nm at average wavelengths of 2128 nm, corresponding to a frequency spacing of 1.5 THz. We generated THz radiation with three types of micro-structured GaAs: optically contacted GaAs (OC-GaAs), orientation-patterned GaAs (OP-GaAs), and diffusion-bonded GaAs (DB-GaAs). Fig. 2(b) shows the measured center THz frequencies for OC-, OP-, and DB-GaAs samples, which agreed well with the theoretical tuning curve calculated using GaAs dispersion information for the mid-IR and far-IR. Recent work has concentrated on improving the quality of OP- and OC-GaAs with emphasis on increasing the area of the low-loss aperture. OP-GaAs samples have lengths ~1 cm, apertures of 3 mm x 1 mm, and a 2-μm absorption coefficient < 0.005 cm^{-1}. 15-wafers-thick OC-GaAs samples have been constructed with a useful aperture of 3 mm x 3 mm and a 2-μm absorption coefficient < 0.01 cm^{-1}.

A DRO is known to be sensitive to cavity-length perturbations on a sub-micron scale; therefore, we employed an electronic cavity-locking technique involving a piezo-electric transducer attached to a cavity end mirror (PZT in Fig. 1). In this way, we stabilized both the signal and idler intracavity powers to within 5% of the maximum powers. When GaAs was placed inside the DRO cavity, it was passively stabilized by a thermo-optic feedback effect [6] provided by weak signal and idler absorption in the GaAs. This maintained DRO oscillation for > 30 minutes with power fluctuations < 5%.

3. Conclusions

We have developed an efficient frequency-tunable THz source based on intracavity DFG between the signal and idler waves within a high-finesse DRO cavity. The center THz frequency was tuned from 0.65-3.4 THz, and the THz average power was on the mW-level. GaAs losses were <1% for cm-long samples with useful apertures ~6 mm^2. The signal and idler powers absorbed by the GaAs deposited heat and provided a thermo-optic negative-feedback effect that passively stabilized the DRO intracavity power levels.

4. References

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