An efficient THz source with a tuning range of 71.1–2830 μm (0.106–4.22 THz) based on frequency mixing in a GaP crystal

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Frequency mixing in nonlinear optical (NLO) crystals represents an efficient method for the generation of widely-tunable monochromatic THz radiation [1,2]. In order to achieve phase-matching, birefringence is usually required. The disadvantage for the birefringence-based phase-matching is the necessity of rotating NLO crystals as demonstrated in Refs. [1,2]. Recently, we showed [3,4] that for cubic NLO crystals such as GaAs and GaP, phase-matching can be still achieved for specific sets of the three parametric wavelengths. GaP is attractive for the THz generation since it has large second-order NLO coefficients and low absorption coefficients in the THz region [5]. Furthermore, GaP has very low two-photon absorption coefficients. Although GaP crystals were used recently for the efficient THz generation under a *noncollinear* phase-matched condition [6], the tuning ranges were narrow and the output peak power was very low. Indeed, among all the previous results based on GaP the widest tuning range and highest peak power achieved so far are 42.8-600 μm and 100 mW, respectively. Here, we present our result of efficiently producing the THz radiations by using *collinear* phase-matched difference-frequency generation (DFG) in a GaP crystal. We have extended the THz output wavelengths to as long as 2830 μm. In addition, the peak power has reached 15.6 W. Since GaP is a cubic crystal, we do not need to rotate this crystal in order to tune the output wavelength in a wide range. The two mixing beams used for the DFG experiments were an idler beam (0.73−1.8 μm) from a BBO-based master oscillator/power oscillator pumped by a frequency-tripled Nd:YAG laser and a Nd:YAG laser beam (1.064 μm) with the pulse width of 10 ns. A GaP crystal with a dimension of 19.9 mm along [001] and 25 mm × 25 mm for the cross section was used. According to our calculation, the collinear DFG for the THz generation is perfectly phase-matched when the pump wavelength is in the range of 0.995-1.033 μm (the corresponding output wavelengths are in the range of 90-1000 μm) [3,4]. If the pump wavelength is longer than 1.033 μm, however, the coherence length for the DFG can be in the same order of magnitude as the length of the crystal. Therefore, such a DFG process is still phase-matched. In our experiments, the generated THz energy per pulse was measured by a calibrated bolometer. Consider the *parallel* and *orthogonal* polarization states for the two mixing beams. In the former case the two mixing beams were polarized in a plane perpendicular to the [010] axis, whereas in the latter case the first mixing beam was polarized parallel to the [010] axis. According to Fig. 1 the highest output powers at the different THz wavelengths all occured at the external angles of about 62° and 53° for the parallel and orthogonal polarizations, respectively. Since GaP is an isotropic semiconductor crystal, the momentum mismatch is independent of the propagation directions and polarizations of the two mixing beams. However, the propagation directions and polarizations can still affect the effective second-order NLO coefficient for the DFG, and therefore, the output power. When the wavelength of the second mixing beam was tuned to those longer than 1.064 μm, the tuning ranges of 84−1134 μm (0.26-3.57 THz) and 83−810 μm (0.37-3.61 THz) for the parallel and orthogonal polarizations were achieved, respectively, see Fig. 2(a). The highest output peak power achieved by us

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was 15.6 W at 173 μm (a conversion efficiency of ~ 0.002%). The several dips appearing in the spectra were caused by the absorption of water vapor in air. On the other hand, when the wavelength of the second mixing beam was tuned to those shorter than 1.064 μm, the output wavelengths covered the range from 71.1 μm to 2830 μm (0.106-4.22 THz) for the parallel polarization state, see Fig. 2(b). Such a tuning range is much wider than those for the rest of the configurations. This range was achieved simply by tuning the wavelength of the second mixing beam within a narrow bandwidth of ~15.3 nm.

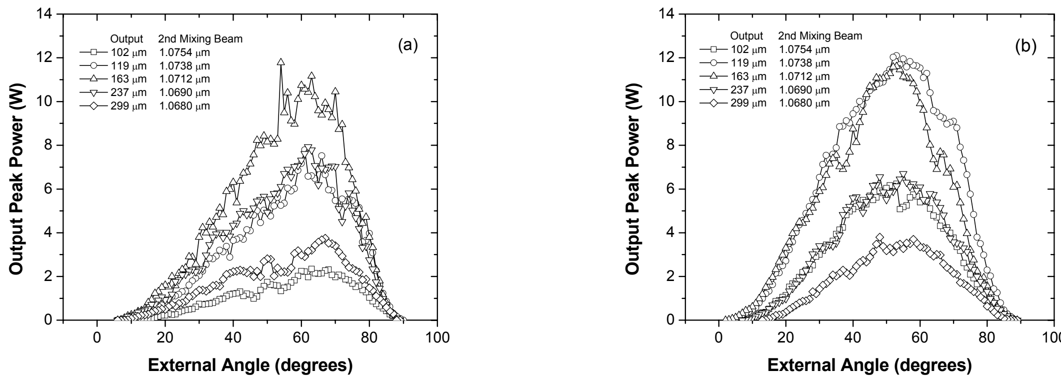

Fig. 1. Angle-tuning spectra for several different wavelengths of the second mixing beam, which were longer than 1.064 μm: (a) the parallel and (b) the orthogonal polarizations.

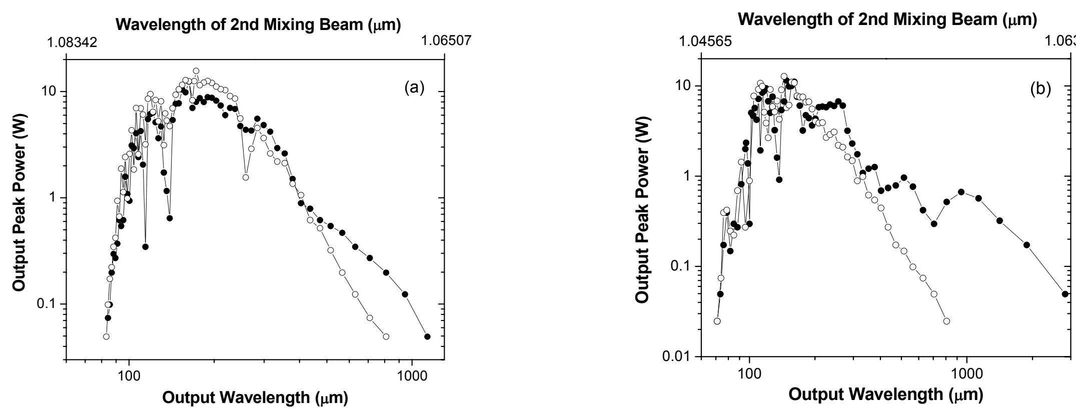

Fig. 2. When the wavelength of the second mixing beam was (a) longer and (b) shorter than 1.064 μm, output peak power was measured vs. output wavelength for the parallel (external angle ≈ 62°, dots) and the orthogonal (external angle ≈ 53°, open circles) polarizations.

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