Compact and Portable Terahertz Source Based on Frequency Mixing of Solid-State Laser Beams

Pu Zhao, Srinivasa Ragam, and Yujie J. Ding
Department of Electrical and Computer Engineering, Lehigh University, Bethlehem, PA 18015, USA

Ioulia B. Zotova
ArkLight, P.O. Box 2, Center Valley, PA 18034, USA

***Abstract*-We report the progress made by us on terahertz (THz) generation by mixing two frequencies generated from a solid-state laser.**

I. INTRODUCTION

A. *Parametric Processes for THz Generation*

Due to the lack of the efficient, compact, and portable terahertz (THz) sources operating at room temperature, the applications of THz waves have been impeded. THz parametric oscillation [1] and difference-frequency generation (DFG) [2] can be used to efficiently generate monochromatic THz beams. However, the efficient conversion has been made possible only by using input beams with relatively high peak powers [1-3]. As a result, the corresponding THz sources are still rather bulky.

B. *This Work*

In this proceedings paper, we report the progress made by us on the THz generation in a nonlinear crystal by mixing two frequencies simultaneously generated by a single Q-switched solid-state laser.

II. EXPERIMENT AND RESULT

A. *Experiment*

In our first experiment, we have chosen a Nd:YLF crystal as the lasing medium since two different frequencies of 286.5 THz and 284.9 THz (wavelengths of 1047 nm and 1053 nm) can be generated from a single Nd:YLF laser. In addition, since the two transitions have the stimulated emission cross sections of 1.8×10^{-19} cm^{-2} and 1.2×10^{-19} cm^{-2}, it may be possible for us to tailor the output powers at these two wavelengths from a single laser crystal to be close to each other. In such a case, the corresponding THz power reaches an optimal value under the same sum of the two input powers. Moreover, the THz output frequency generated by mixing these two laser beams is 1.643 THz (i.e. the wavelength of 182.4 μm), which is quite close to 200 μm, and therefore, the THz output power is close to the maximum value from a GaSe crystal [2,3]. Furthermore, a Nd:YLF crystal is known for its low thermal effect and long upper-state lifetime.

B. *Balancing Laser Powers and Alleviating Gain Competition*

One can simultaneously generate the coherent beams at 1047 nm and 1053 nm from a single Nd:YLF laser cavity. However, under such a case balancing the output powers at the two wavelengths is out of question due to the strong competition between the gains for the two transitions within the same laser cavity. In our experiment, we introduced an intracavity polarizer to separate the two perpendicularly-polarized beams into two laser cavities both of which shared the same lasing medium for alleviating the gain competition. The typical dimension of the entire THz source is about 12″×12″×6″. In addition, such a compact THz source consumes the electrical power of ≤ 20 W. Therefore, it is a rather compact and portable device.

C. *RESULT AND DISCUSSION*

The lasing thresholds were measured to be 1.17 W and 1.64 W at 1047 nm and 1053 nm, respectively [4]. Below 5 W, both of the output powers increased linearly with the pump power. In addition, the powers at 1047 nm are significantly higher. Above 5 W, however, the output power at 1047 nm became slightly saturated whereas the output power at 1047 nm was increased at a higher rate. This is due to the fact that two transitions accessed the same population of the electrons in the upper lasing level. When the gain for one transition was saturated, the gain for the second one was increased faster than the linear rate. Therefore, the dependence on the sum of the output powers is still linear, which agrees well with the theory for the solid-state laser. By measuring the output powers as a function the repetition rate, we found an optimal repetition rate of 3.9 kHz for the Q-switch in terms of the THz output powers. At the pump power of 9.69 W, we generated the output powers of 1.196 W and 0.608 W at 1047 nm and 1053 nm, respectively, corresponding to the net conversion efficiency of 18.6%. The ratio of the output powers at the two wavelengths is measured to be around 2:1. By further optimizing the design of the optical cavities, we can reduce the ratio to nearly 1:1. The two pulse trains were measured simultaneously by using two photodiodes. According to Ref. [4], the two pulses were synchronized. At 9.69 W, the pulse widths were measured to be 15.47 ns and 18.59 ns at 1047 nm and 1053 nm, respectively.

The external phase matching angle for the THz generation was measured to be 11.5º, which is close to the theoretical value of 11º [5]. The azimuthal angle was optimized in our experiment in order to reach the optimal value of the effective nonlinear coefficient [5]. The output wavelength was measured by scanning a Si-based etalon. The output wavelength was measured to be 183.3 μm, which agrees well with 182.4 μm, calculated from the two input wavelengths of 1.04666 μm and 1.0527 μm. When the sum of the input powers was 1.8 W, the average THz output power from the GaSe crystal was 0.948 μW [4]. Much higher output powers are achievable. The pulse width for

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the THz beam was 12.36 ns by measuring the temporal profile of the sum-frequency signal in a KTP crystal. Using such a pulse width, the highest THz peak power was determined to be 19.7 mW. The linewidth of the THz wave was determined to be 65 GHz by measuring the linewidth of the sum-frequency signal (i.e. 0.06 nm).

In my most recent work [6], we investigate power scalability and frequency agility of a terahertz (THz) source by mixing two frequencies generated by solid-state lasers in a nonlinear crystal. They are made possible by introducing two solid-state laser crystals sharing the same Q switch and output coupler, with the same laser beams decoupled to each other by a polarizer. Following the optimization, we have improved the THz output power nearly fivefold at 1.64 THz. By replacing one of the Neodymium-doped lithium yttrium fluoride (Nd:YLF) crystals with a Neodymium-doped yttrium aluminum garnet (Nd:YAG) crystal, we have produced 2.1 μW at 2.98 THz.

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