temporal overlap of 1064 nm and 1544 nm pulses in the 2 cm long PPKTP.

The uncoated PPKTP sample was poled with 15 μm period for first-order SFG of 1064 nm and 1544 nm and was thermally stabilized at 104°C. The SFG quasi-phase-matching profile (Fig. 2a) corresponded to a QPM bandwidth value of 8.5°C (0.54 nm). The ellipticity of polarization of 1064 nm and 1544 nm outputs was less than 3×10^{-2}. With 7.3 W internal 1064 nm power (370 W peak) and about 9.4 W average power at 1544 nm, 1.4 W of 630 nm radiation was generated with $\eta = 2.1\%/\text{Wcm}$ efficiency. At 1.4 W power level, the beam profile was recorded (insert, Fig. 2b); we attribute the slight deviation from the Gaussian profile to the non-ideal spatial overlap of the pump profiles inside the PPKTP. Neither photorefraction nor gray-tracking has been detected, although this naturally requires longer-term thorough analysis which we plan to present.

We have also examined the required power budget issues which relate to the presence of ASE, the temporal profile of the pulses, and the linewidths of the Yb and Er seeded sources. Once these are rectified, our estimates show that several Watts of SFG at 630 nm is possible.

The demonstrated source shows up to 3-fold power increase in the red compared to previously reported PPKTP/PPLN and solid-state-laser based systems,[4,5] and may find potential use in projection display, spectroscopic and lidar/adaptive optics applications.

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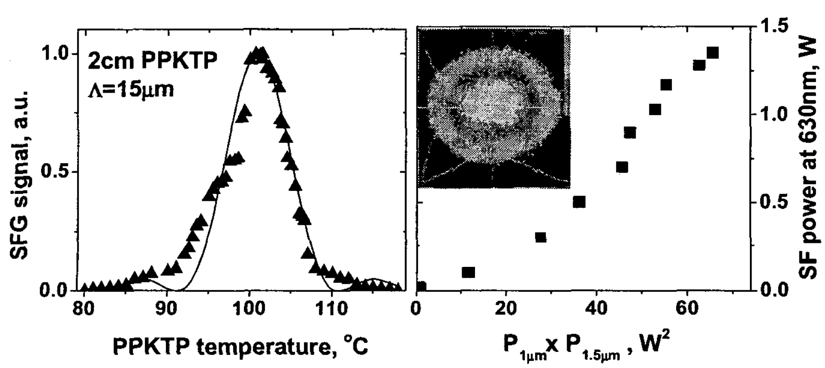

CTuB6 Fig. 2. a) SFG, QPM profile in PPKTP; b) SFG power.

CTuC 8:00 am–9:45 am
Room: 104A

THz and IR Sources

Valentin Petrov, Max Born Inst., Germany, Presider

CTuC1 8:00 am

Coherent and Widely-tunable THz and Millimeter Source: New Application for GaSe

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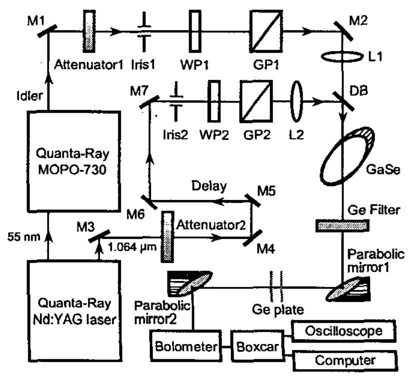
1. Introduction

Continuously-tunable and coherent THz and millimeter sources are in great demand for applications including high-resolution spectroscopy, communications, and bio-medical imaging. However, these applications cannot be put into practice until compact THz lasers are available. On the other hand, parametric processes based on second-order optical nonlinearities such as difference-frequency generation (DFG)[1,2] offer a simple method for efficient THz and millimeter emitters. So far, $LiNbO_3$, $ZnGeP_2$ and DAST[3] have been used based on this scheme. However, all of them have very large absorption coefficients in the THz domain. Among all second-order nonlinear crystals GaSe has the lowest absorption coefficients in the THz domain.[4] As one of the important NLO crystals, GaSe can satisfy phase matching (PM) conditions in a large wavelength range.[5] Moreover, this crystal possesses large second-order susceptibility. All these properties make GaSe a winner for efficient generation of THz and millimeter waves based on DFG. In this report, we have implemented a new coherent THz and millimeter source with the output wavelength continuously tunable in the range of 56.8–1618 μm (5.27–0.18 THz) in a GaSe crystal.

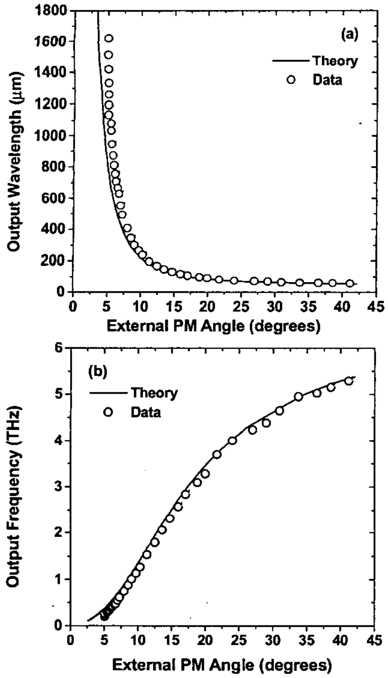
2. Experiment

Our experimental setup is schematically shown in Fig. 1. The two mixing beams used for the DFG are the idler beam (0.73–1.8 μm) of an OPO pumped by a Nd:YAG laser and the residual Nd:YAG fundamental beam (1.064 μm). The Nd:YAG pulses had a pulse duration of 10 ns and a repetition rate of 10 Hz. A GaSe crystal with 15 mm thickness (along z axis) and 25 mm × 18 mm cleaved ellipsoidal face was used. We have chosen the polarizations of the input beams in such a way that the OPO and pump beams become the extraordinary and ordinary waves inside the GaSe crystal. The generated *e*-polarized THz and millimeter radiation was detected by a bolometer, amplified and averaged in a boxcar integrator. In Fig. 2 the phase-matching (PM) tuning curves for the eoe interaction in the GaSe crystal are depicted. Solid curve corresponds to our calculation by using the refractive-index dispersion relations.[6] Extremely-wide, tunable and coherent output wavelengths in the range of 56.8–1618 μm that corresponds the frequency range of 0.18–5.27 THz [see Fig. 2] have been achieved for the eoe interaction in a GaSe crystal. The wavelengths of the monochromatic THz wave were determined by using a scanning etalon made from two Ge plates. These output wavelengths are consistent with those calculated from DFG. The short-wavelength side for the THz DFG is limited by the lattice absorption band of GaSe. On the other hand, at the long-wavelength side (millimeter waves) the conversion efficiencies for DFG decrease as the millimeter wavelength increases. As a result, our noise level in the Bolometer sets a limit to the longest detectable wavelength. As one may see in Fig. 2 our data slightly deviate from our calculations on the long-wavelength side. This difference is due to the fact that the Sellmeier equations in Ref. 6 were derived for a much narrower range of the wavelengths.

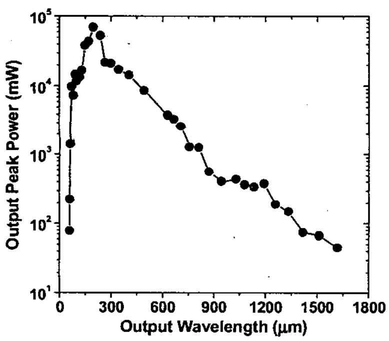
The pulse energy of the generated DFG THz and millimeter radiation was measured by a R-752 Universal laser Radiometer with a P-444 Pyroelectric Probe and calibrated bolometer. The measured THz and millimeter peak output powers are shown in Fig. 3. The highest output peak



CTuC1 Fig. 1. Experimental setup for THz and millimeter radiation based on DFG in a GaSe crystal.



CTuC1 Fig. 2. Output wavelength (a) and output frequency (b) vs. external PM angle for efficient generation of THz and millimeter waves based on eoe DFG.



CTuC1 Fig. 3. Output peak power vs. output wavelength for THz and millimeter generation based on DFG.

power of 69.4 W was measured at the output wavelength of 196 μm (1.53 THz), with the highest conversion efficiency of ~0.018%. The corresponding photon conversion efficiency is 3.32%. It is one order of magnitude higher than the highest previous value achieved based on DFG in the THz and millimeter domains.[5]

3. Conclusions

Tunable and coherent THz and millimeter radiations in the extremely-wide wavelength range of 56.8–1618 μm (5.27–0.18 THz) in a GaSe crystal have been achieved. The maximum output peak power of the DFG THz radiation is about 69.4 W at the output wavelength of 196 μm (1.53 THz). Almost over the entire range, the output powers are high enough for certain applications.

References

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CTuC2 **8:15 am**

Tunable and Coherent Radiation in the Range of 2.7–29 μm Based on Phase-matched Difference-frequency Generation in GaSe

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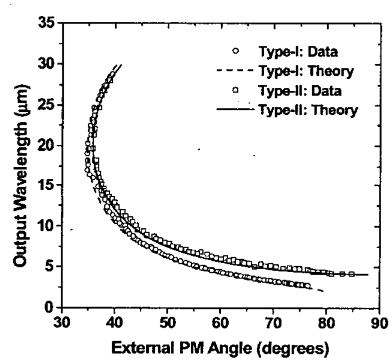
1. Introduction

The generation of coherent infrared radiation in nonlinear optical (NLO) crystals represents an effective method due to high efficiency and wide tunability. Among all the NLO crystals that are transparent in the mid-IR and far-IR, GaSe is very attractive since it can satisfy phase matching (PM) conditions in a large wavelength range.[1,2] There has been impressive progress of using GaSe crystals towards the efficient generation of mid-IR in the past. Among all the previous results the widest tuning range is 3–20 μm, which is generated by using intense femtosecond laser pulses.[3] Here, we report our first result of achieving the coherent mid-IR and far-IR radiations with extremely-wide tunability and narrow linewidth in a GaSe crystal. As shown below, we have extended the output wavelengths to the far-IR.

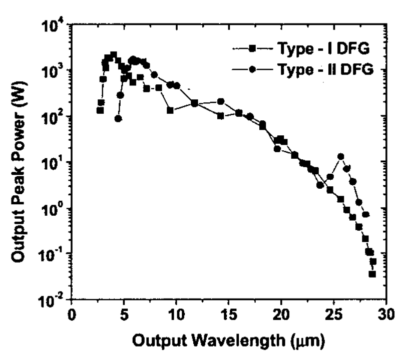
2. Experiment, results, and discussion

In our DFG experiment, the two mixing beams used for the DFG consists of the idler beam (0.73–1.8 μm) of an OPO pumped by a frequency-tripled Nd:YAG laser and the residual Nd:YAG fundamental beam (1.064 μm). The Nd:YAG laser pulses have a pulse duration of 10 ns and a repetition rate of 10 Hz. A GaSe crystal with 7 mm thickness (along z axis) and 25 mm × 18 mm cleaved ellipsoidal face was used. The generated IR radiation was detected by a cryogenically-cooled InSb/MCT detector and bolometer, amplified and averaged in a boxcar integrator. These detectors were calibrated for their entire detectable ranges in terms of the measured input energy per pulse. Fig. 1 shows the angle-tuning curves for type-I and type-II DFG in the GaSe crystal, respectively. Solid and dot curves correspond to calculations by using the dispersion relations available.[2] Extremely-wide, tunable and coherent output wavelengths in the range of 2.7–29 μm for type-I DFG and 4.1–28 μm for type-II DFG in the GaSe crystal have been achieved, respectively. We would like to stress that this is the first time to achieve the IR beam tunable beyond 20 μm, deeply into the far-IR domain, in GaSe. Although GaSe has a transparency range of 0.62–20 μm,[1] we observed strong dependences of the difference-frequency energy per pulse on the crystal orientation (θ and ϕ) and input wavelengths, for the entire wavelength ranges. Therefore, for the entire ranges of 2.7–29 μm and 4.1–28 μm DFG is phase-matched. We therefore conclude that the absorption of GaSe crystals beyond 20 μm has weak effect on the two DFG processes.

The pulse energy of the generated IR radiation was measured by a calibrated R-752 Universal laser Radiometer with a P-444 Pyroelectric Probe and by using the calibrated detectors mentioned above. The measured IR peak output powers (P) are shown in Fig. 2. For the type-I IR generation,



CTuC2 Fig. 1. Output wavelength vs. external phase-matching (PM) angle for type-I and type-II DFG, respectively.



CTuC2 Fig. 2. Output peak power vs. output wavelength for type-I and type-II DFG, respectively.