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Coherent THz repetitive pulse generation in a GaSe crystal by dual-wavelength Nd:YLF laser

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Abstract

We present modification of difference frequency generator of coherent THz radiation in a nonlinear GaSe crystal using dual-wavelength diode-pumped solid-state Nd:YLF laser. Generation at the two wavelengths (1.047 and 1.053 µm) was carried out by equalization of the gains at these wavelengths near the frequency degeneracy of the transverse modes in resonator cavity, Q-switched by acousto-optical modulator. The main parameters of the device were measured: angular synchronism (width 0.6 degrees), polarization ratio (1:100), conversion efficiency (10^{-7}), pulse power (0.8 mW), frequency and width (53,8 cm^{-1}, 0,6 cm^{-1}), pulse width and repetition rate (10 ns ,7 kHz). The method is promising for practical purposes.

Keywords: Dual-wavelength operation; difference–frequency generation; diodes pumped solide state laser; THz generation; frequency degeneracy of the transverse modes; cooled superconducting HEB-bolometer; Fourier transform infrared spectrometer.

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1. Main text

Here introduce the paper, and put a nomenclature if necessary, in a box with the same font size as the rest of the paper.

Difference frequency generation (DFG) has been utilized as an efficient method for the generation of coherent THz waves by Zerike and Berman (1965), Shi et al. (2002), Shi et al. (2004). The implementation of such a method involves the use of a dual-wavelength laser source. Possible schemes of dual-wavelength diode-pumped lasers based on a number of vanadate (Nd: YVO_4, Nd: $GdVO_4$, Nd: $GdYVO_4$) are considered, for example, in - Vlasov et al. (2007). Dual-wavelength operation (DWO) has been obtained by us in a Nd:YLF laser near degenerate cavity configurations with longitudinal (end) ingomogenius pumping by Bezotosnyi et al. (2011). The latter method is attractive due to its technical simplicity and efficiency.

In this paper, we discuss the results of experiments on the DFG in GaSe crystal (oee interaction) of a dual-wavelength Nd: YLF laser radiation (1.047 and 1.053 µm), which was obtained near degenerate resonator configurations. Experimental scheme is shown in Fig. 1. We have used diode-end-pumped Nd: YLF laser crystal (orientation of the crystallographic axes [100]) and acousto-optical modulator (AOM) for the Q-mode. The laser cavity is formed by a spherical mirror M1 with a radius of curvature of 120 mm and a flat mirror M2. The cavity length (L) was chosen near cavity semiconfocal configuration (≈70 mm). For pumping of the Nd:YLF lasers we used experimental samples of high-power laser diodes (LD) operating at 806-808 nm developed and produced in our laboratory. Typical parameters of LD assembled on C-mount heatsink under CW operation are the following: resonator length 3 mm, stripe width 100-130 µm, threshold current 0.9 A, slope 1.1 W/A, output power up to 8 W at 20 °C – Ashkinazi et al. (2012), Bezotosnyi et al. (2014 a), Bezotosnyi et al. (2014 b). High-power LD radiation was collimated into an active element (AE) by cylindrical (CL) and spherical (SL) lenses so that the size of the pump beam in the AE was twice smaller than the diameter of the Gaussian mode.

The repetitively pulsed laser operates with a peak power of 15 kW at a repetition rate of up to 7 kHz, at two wavelengths 1.047 and 1.053 µm with orthogonal polarizations. DWO was achieved by adjustment of cavity length. The mechanism and conditions for the achievement of DWO in Nd: YLF laser with an inhomogeneous diode end pumping were investigated by us in – Bezotosnyi et al. (2011 a), Bezotosnyi et al. (2011 b). Details of DWO realization are discussed below. In the experiment, dual-wavelength laser radiation is modulated by opto-mechanical chopper with a repetition rate of 12 Hz in order to a synchronous detector for use, and then is focused by a lens with a focal length of 150 mm a nonlinear crystal GaSe of 3 and 5mm lengths.

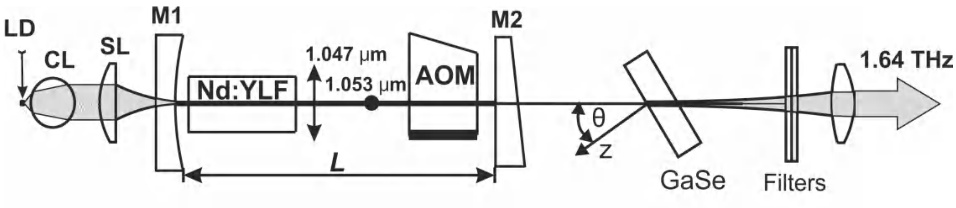

Fig.1. THz generation scheme.

The generated THz radiation is collimated by a TPX lens with a focal length of 50 mm from a polymeric material TPX on photodetectors - Golay cell or cooled superconducting HEB-bolometer (RS 0.4-4T, "SKONTEL") with a frequency range (0.4-4) THz, response time <1 ns – Seliverstov et al. (2015). Before photodetector filters are installed (plate from Si and polymer) which transmit terahertz radiation and cut off thermal and near-infrared laser radiation. THz signal is recorded by Golay cell with signal/noise ratio of at least 10. The angular synchronism of the DFG in GaSe crystal (Fig. 2 a) and the degree of polarization of the THz radiation (Fig. 2 b) were measured.

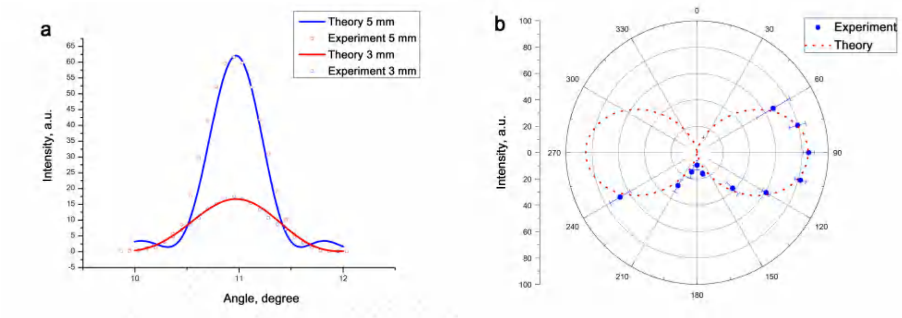

Fig. 2. (a) angular phase-matching synchronisms GaSe crystals 3mm-red curve, 5 mm-blue curve;
(b) degree THz of polarization.

Phase-matching angle was θ = 10.9 ° with a half-width of 0.6 ° for the 5 mm GaSe crystal length, the degree of polarization of THz radiation is not less than 1:100. Durations of the laser and THz pulses were also recorded using fast photodiode and Tektronix oscilloscope TDS 4032 with a bandwidth of 350 MHz. At the repetition rate of 7 kHz, by selecting the appropriate configuration of the resonator we have managed to get DWO of giant pulses of 13 ns duration, Fig. 3. The pulse duration of the THz radiation was 10 ns.

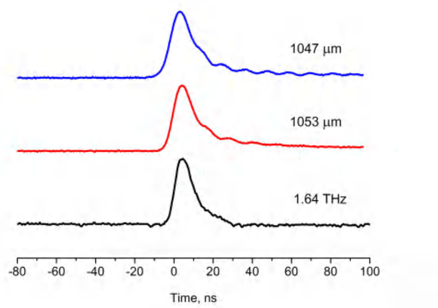

Fig. 3. Oscilloscope traces of dual-wavelength and THz pulses.

The measured average power of the THz radiation was 50 nW, pulse power - 0.8 mW, the conversion efficiency of about 10^{-7}. THz radiation was focused on the receiving area of 12 mm in diameter of the HEB-bolometer situated from GaSe crystal at a distance of 4 m. By displacement of the bolometer, it was shown that the diameter of the THz radiation beam is smaller than 12 mm.

The spectrum of the THz radiation was measured by Fourier transform infrared spectrometer (FTIR), described in – Gorbatsevich et al. (2015). The FTIR spectrometer scheme is presented in Fig.4. To suppress infrared laser and thermal radiations, special filters (Teflon, etc.) were used at the output of DFG THz source. The THz beam was collimated using polymer lens (PL) onto the inlet the interferometer. The movable mirror was displaced by a step motor (SM). Outlet radiation was registered by HEB-bolometer. Signal from HEB preamplifier was accumulated in the gated integrator/boxcar averager SR250, digitized by ADC and recorded to the computer (PC), where the obtained interferograms were the spectra were restored by FFT algorithm.

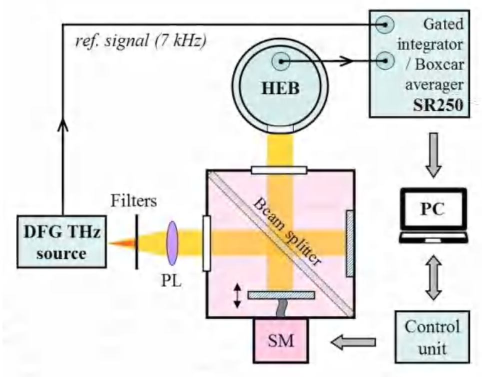

Fig. 4. The Fourier transform infrared spectrometer.

The spectrum of THz radiation is shown in Fig. 5. The maximum intensity of the spectrum corresponds to 53.8 cm^{-1} with the half width of 0.6 cm^{-1}.

To study the mechanism of dual-wavelength operation of solid state lasers with diode end pumping near degenerate cavity configurations, the dependences of the lasing thresholds on the cavity length was investigated in – Bezotosnyi et al. (2015). It was shown that the thresholds are substantially no monotonic. A substantial decrease of the lasing threshold is observed in degenerate cavity lengths where synchronization of the transverse modes occurs. Taking into account that the threshold determines the effective gain of the gain medium, this gain can be controlled in certain limits by choosing a specific length of the cavity.

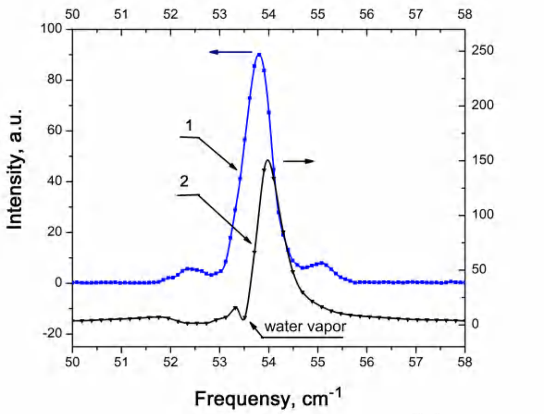

Fig. 5. THz radiation spectrum. Spectrum 1 was measured in the case of the interferometer evacuated to a pressure of 1 Torr, 2-under normal conditions. The difference between 1 and 2 is caused by the absorption of water vapor.

In the experiments we have measured the dependences of the threshold pump power for π (1.047 μm) and σ (1.053 μm) polarizations on the cavity length Nd:YLF laser near the semiconfocal cavity configuration. The experimental scheme is shown in Fig. 6.

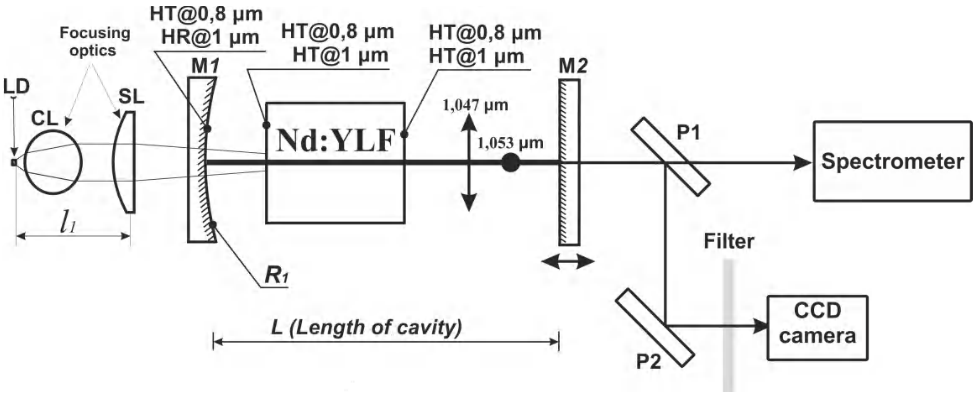

Fig.6. The measurement scheme of Nd:YLF laser threshold. LD - laser diode, CL – cylindrical lens, SL - spherical lens, M1 and M2 - cavity mirrors, P1 and P2 – plates from glass BK7.

To investigate the dependence of the Nd:YLF laser threshold, a plane-parallel plate from Russian glass TF 10 was placed in the cavity at the Brewster angle to the selected polarization. It was found that increasing of the cavity length from the semiconfocal length is accompanied by the increase of lasing threshold for the wavelength of 1.047 µm in the manner shown by blue triangles in Fig. 7 a, so that it exceeds at some lengths the threshold for the wavelength of 1.053 µm (red points). In the case of pulsed mode with duty cycle of less than 0.1, corresponding increase of the threshold at a wavelength of 1.047 µm (black triangles) was not observed. In our opinion, this behavior is due to the thermo-optical distortions of the active medium. Detailed consideration of this effect is beyond the scope of this paper and will be elaborated in subsequent publications. Without the polarizer plate the lasing occurs mainly in π-polarization (1.047 µm) because gain cross section at this wavelength is 1.5 times greater than the cross section of σ-polarization (1.053 µm), Fig. 7 b.

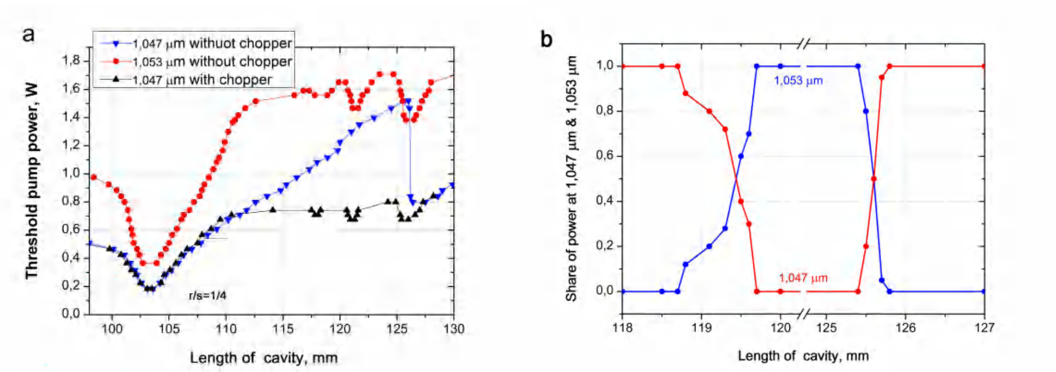

Fig.7. (a) lasing threshold dependence from on the cavity length; (b) the proportions of the radiation power at wavelengths 1,047 and 1,053 µm from on the cavity length at pump power 1.75 W.

At the cavity length of about 125 mm, lasing wavelength is switched from 1.047 to 1.053 µm. By increasing the pump power a switching range expanded, Fig. 7 b. We are currently exploring this mechanism for obtaining DWO in solid-state lasers based on composite media.

In the Q-mode this switching from one wavelength to another is still in effect, which makes it possible to obtain giant pulses DWO.

The presented method of producing dual-wavelength generation looks like to be the simplest and effective, and the generation of the THz radiation by difference frequency of the dual-wavelength laser in a nonlinear crystal is promising for practical use in various systems of THz vision and diagnostics.

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References

Zerike, F. Jr., Berman, P.R., 1965, Generation of far infrared as a difference frequency, Physical Review Letters, 15, p. 999.

Shi, W., Ding, Y.J., Fernelius, N., Vodopyanov, K., 2002, Efficient, tunable and coherent, 0.18–5.27-THz source based on GaSe crystal, Optics Letters, 27, 1454.

Shi, W., Ding, Y.J., Schunemann, P.G., 2004, Coherent terahertz waves based on difference-frequency generation in an annealed zinc–germanium phosphide crystal: improvements on tuning ranges and peak powers. Optics Communications, 233, pp. 183-189.

Vlasov, V.I., Garnov, S.V., Zavartsev, Yu.D., Zagumennyi, A.I., Kutovoi, S.A., Sirotkin, A.A., Shcherbakov, I.A., 2007, New possibilities of neodymium-doped vanadate crystals as active media for diode-pumped lasers, Quantum Electronics, 37(10), pp. 938-940.

Bezotosnyi, V.V., Gorbunkov, M.V., Kostryukov, P.V., Krivonos, M.S., Popov, Yu.M., Tunkin, V.G., Cheshev, E.A., 2011, Collection of reports of the 5th All-Russian School of Laser Physics and Laser Technologies, pp. 183-190.

Ashkinazi, E.E., Bezotosnyi, V.V., Bondarev, V.Yu., Kovalenko, V.I., Konov, V.I., Krokhin, O.N., Oleshchenko, V.A., Pevtsov, V.F., Popov, Yu.M., Popovich, A.F., Ral'chenko, V.G., Cheshev, E.A., 2012, Increasing the output power of single 808-nm laser diodes using diamond submounts produced by microwave plasma chemical vapour deposition. Quantum Electronics, 42 (11), pp. 959–960.

Bezotosnyi, V.V., Krokhin, O.N., Oleshchenko, V.A., Pevtsov, V.F., Popov, Yu.M., Cheshev, E.A., 2014, Emission parameters and thermal management of single high-power 980-nm laser diodes. Quantum Electronics, 44 (2), pp. 145–148.

Bezotosnyi, V.V., Krokhin, O.N., Oleshchenko, V.A., Pevtsov, V.F., Popov, Yu.M., Cheshev, E.A., 2014, Thermal modelling of high-power laser diodes mounted using various types of submounts. Quantum Electronics, 44 (10), pp. 899-902.

Bezotosnyi, V.V., Gorbunkov, M.V., Kostryukov, P.V., Krivonos, M.S., Popov, Yu.M., Tunkin, V.G., Cheshev, E.A., 2011, Two-frequency lasing in the Nd:YLF laser with a lens-shaped active element and longitudinal diode pumping, Bulletin of the Lebedev Physics Institute, 38 (10), pp 311-316.

Seliverstov, S., Maslennikov, S., Ryabchun, S., Finkel, M., Klapwijk, T.M., Kaurova, N., Vachtomin, Y., Smirnov, K., Voronov, B., Goltsman, G., 2015, Fast and Sensitive Terahertz Direct Detector Based on Superconducting Antenna-Coupled Hot Electron Bolometer, IEEE Transactions on Applied Superconductivity, 25(3), 2300304.

Gorbatsevich, A.A., Egorkin, V.I., Kazakov, I.P., Klimenko, O.A., Klokov, A.Yu., Mityagin, Yu.A., Murzin, V.N., Savinov, S.A., Tsvetkov, V.A., 2015, The dynamic characteristics of "low-temperature" gallium arsenide for terahertz-range generators and detectors, Bulletin of the Lebedev Physics Institute, 42(5), pp.121-126.

Bezotosnyi, V.V., Cheshev, E.A., Gorbunkov, M.V., Koromyslov, A.L., Kostryukov, P.V., Krivonos, M.S., Popov, Yu.M., Tunkin, V.G., 2015 Behavior of threshold pump power of diode end-pumped solid-state lasers in critical cavity configurations, Laser Physics Letters, 12 (2), 025001.