*NONLINEAR OPTICAL PHENOMENA AND DEVICES*

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# A $HgGa_2S_4$ optical parametric oscillator

V.V. Badikov, A.K. Don, K.V. Mitin, A.M. Seregin, V.V. Sinaiskii, N.I. Shchebetova

*Abstract*. **Parametric generation in a $HgGa_2S_4$ crystal pumped by a nanosecond Nd : YAG laser is obtained and investigated for the first time. The experimental results demonstrate the outlook for using $HgGa_2S_4$ crystals for the development of efficient optical parametric oscillators in the mid-IR range.**

***Keywords***: *optical parametric oscillator, nonlinear crystals.*

An important direction in the development of quantum electronics is the designing of tunable lasers emitting in the mid-IR range (2.5 – 11 μm). The designing and development of optical parametric oscillators (OPOs) is one of the possible solutions of this problem. At present, only a few nonlinear crystals are known that can be used in OPOs emitting in this spectral range. These include the $ZnGeP_2$, $AgGaSe_2$, and $AgGaS_2$ crystals [1 – 5]. However, these crystals have various drawbacks which limit their application in OPOs. For this reason, a persistent quest is being made for new nonlinear optical media, and the techniques for synthesising the known crystals is being refined continuously.

The efficient parametric generation of light upon pumping by widely used neodymium lasers is a problem of practical importance. Unfortunately, upon pumping by radiation at $\sim 1$ μm, the $ZnGeP_2$ and $AgGaSe_2$ crystals, which have the best nonlinear optical and technological parameters, do not exhibit phase matching. At present, an $AgGaS_2$ crystal is most often used in the mid-IR OPOs pumped at $\sim 1$ μm [5]. The nonlinear optical characteristics of this crystal (in particular, the figure of merit) are much worse than those of the above-mentioned crystals. An $HgGa_2S_4$ crystal studied in this work, which has a higher nonlinearity than the $AgGaS_2$ crystal, seems to be quite promising for the development of IR OPOs pumped by micrometer radiation. This crystal can also compete with $ZnGeP_2$ and $AgGaSe_2$ crystals in the development of OPOs pumped at a longer wavelength ($\lambda > 1.5$ μm).

**V.V. Badikov** Laboratory of New Technologies, Kuban State University, ul. Stavropolskaya 149, 350058 Krasnodar, Russia; Tel.:(8612) 658 549; fax: (8612) 658 549; e-mail: ntlab@mail.kubsu.ru;
**A.K. Don, K.V. Mitin, A.M. Seregin, V.V. Sinaiskii, N.I. Shchebetova** 'Astrofizika' Research and Production Association, Volokolamskoe shosse 95, 125424 Moscow, Russia;
Tel.: 490 9179; fax: 491 2121; e-mail: aphysica@aha.ru

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Mercury thiogallate was known long ago as a promising nonlinear optical material [6 – 10], but the low optical quality of the crystals allowed it to be used only for second-harmonic generation in a $CO_2$-laser, for frequency mixing, as well as for obtaining pico- and femtosecond parametric superluminescence.

Owing to the advancement of the technology for growing $HgGa_2S_4$ single crystals at the Laboratory of New Technologies, Kuban State University, it has now become possible to obtain crystals of high optical quality that are suitable for developing a single-cavity OPO.

In this paper, we obtained and studied for the first time parametric generation in a mercury thiogallate crystal pumped by a repetitively pulsed, electrooptically *Q*-switched, 1.064-μm Nd : YAG laser.

The maximum output-pulse energy was 15 mJ for a pulse duration of 30 ns. A 2-mm intracavity diaphragm ensured lasing at the fundamental transverse $TEM_{00}$ mode.

The OPO cavity was formed by two plane mirrors. The reflectance of the input and output mirrors was 90 % – 99 % in the wavelength range 1.4 – 1.9 μm. This provided the highest *Q*-factor in the cavity for the signal wave. The idler wave was coupled out of the cavity with minimum losses ($\sim 10$ %). The transmittance of the input mirror at the pump wavelength was 90 %, while the reflectance of the output mirror was 30 %. The separation between the cavity mirrors was 2 cm.

The $HgGa_2S_4$ crystal was cut at an angle of 52° to the axis and had an azimuthal angle of 45°. The length of the crystal was 6 mm and the cross section was $6.5 \times 6$ mm. An antireflection coating was deposited on the optical surface of the crystal. The reflectance at each surface was 0.2 % – 0.8 % in the spectral range 1 – 2 μm.

The OPO was placed in the focal plane of a focusing mirror of radius 3 m, and the diameter of the pump beam waist in the interaction region was 2 mm. The crystal was oriented according to the type I phase-matching (oo – e).

We obtained parametric generation in the wavelength range 1.4 – 2.0 and 2.3 – 4.4 μm. The tuning range was limited by the spectral region of reflection of the resonator mirrors. By replacing resonator mirrors in the OPO, we performed studies in a longer wavelength region as well. The lasing frequency was tuned by rotating the crystal in the phase-matching plane. Fig. 1 shows the dependence of the output wavelength on the phase-matching angle. A satisfactory agreement between the experimental and theoretical results is observed. The theoretical dependence was calculated by using Sellmeir equations [9].

By measuring the OPO radiation pulse energies, we obtained the threshold values of the pump energy at various

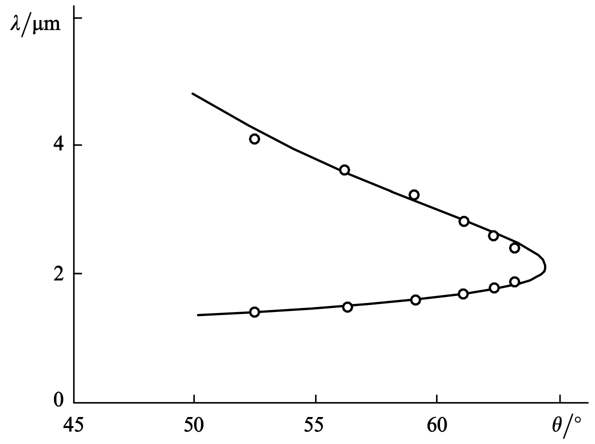


**Figure 1.** Dependence of the emission wavelength of an $HgGa_2S_4$ optical parametric oscillator on the phase-matching angle.

wavelengths and found the dependences of the output energy of OPO pulses on the pump pulse energy. The value 5–8 mJ obtained for the threshold pump energy is in good agreement with the results of calculations performed by the method used in Ref. [11]. Our calculations showed that if $HgGa_2S_4$ is replaced by $AgGaS_2$, the above-mentioned values of the threshold energy can be obtained only if the crystal is at least 1.5 cm-long, which clearly confirms the advantage of a mercury thiogallate crystal.

The experimental dependences of the OPO output pulse energy on the pump pulse energy are almost linear. A typical dependence for the 1.93-μm signal wave and the 2.37-μm idler wave is shown in Fig. 2. The maximum energy of OPO pulses was achieved at 1.93 μm, and the total energy of the pulse for signal and idler waves was 0.8 mJ, corresponding to the conversion efficiency of 6.7 %.

Therefore, we have shown that an $HgGa_2S_4$ crystal is a promising nonlinear optical material used in OPOs emitting in the mid-IR region. It is especially important to note that this material provides efficient parametric generation upon pumping by an Nd : YAG laser.

At present, OPOs based on $HgGa_2S_4$ crystals are being actively studied and the crystal-growth technique is being improved; in addition, the parameters of the crystals are also being investigated [12].

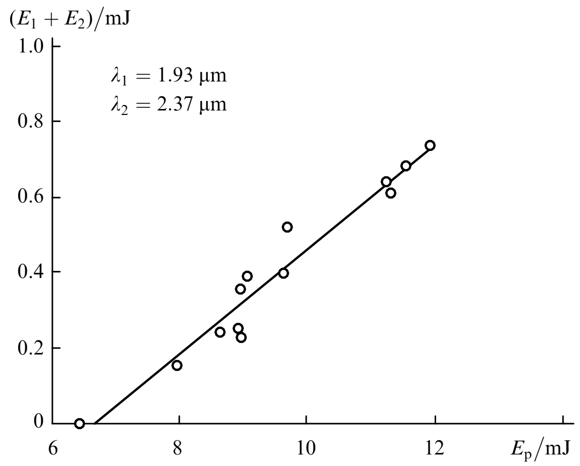


**Figure 2.** Dependence of the OPO output pulse energy on the pump pulse energy.

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## References

1. Budni P.A., Ezzo K., Schunemann P.G., Minnigh S., McCarthy J.C., Pollak T.M. *OSA Proc. Adv. Solid-State Lasers*, **10**, 335 (1992).
2. Budni P.A., Pomeranz L.A., Lemons M.L., Schunemann P.G., Pollak T.M., Chicklis E.P. *Adv. Solid-State Lasers Tech. Digest* (Washington, DC: OSA, 1998) p. 90.
3. Eckardt R.C., Fan Y.X., Byer R.L., Marquardt C.L., Storm M.E., Esterowitz L. *Appl. Phys. Lett.*, **49**, 608 (1986).
4. Budni P.A., Knights M.G., Chicklis E.P., Shepler K.L. *Opt. Lett.*, **18**, 1068 (1993).
5. Vodopyanov K.L., Maffetone J.P., Zwieback I., Ruderman W. *Appl. Phys. Lett.*, **75**, 1204 (1999).
6. Levine B.F. et al. *IEEE J. Quantum Electron.*, **12**, 367 (1976).
7. Badikov V.V., Matveev I.N., Panyutin V.L., et al. *Kvantovaya Elektron.*, **6**, 1807 (1979) [*Sov. J. Quantum Electron.*, **9**, 1068 (1979)].
8. Badikov V.V., Matveev I.N., Pshenichnikov S.N., et al. *Kvantovaya Elektron.*, **7**, 2235 (1980) [*Sov. J. Quantum Electron.*, **10**, 1300 (1980)].
9. Andreev S.A., Andreeva N.P., Badikov V.V., et al. *Kvantovaya Elektron.*, **7**, 2003 (1980) [*Sov. J. Quantum Electron.*, **10**, 1157 (1980)].
10. Rotermund F., Petrov V. *Opt. Lett.*, **25**, 1 (2000).
11. Brosnan S.J., Byer R.L. *IEEE J. Quantum Electron.*, **15**, 415 (1979).
12. Badikov V.V., Laptev V.B., Malinovsky A.L., et. al. *Proc. SPIE Int. Soc. Opt. Eng.*, **4972**, 131 (2003).