Nanosecond optical parametric oscillator in the mid IR range with a two-pass pumping is based on the crystal $AgGaS_2$

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Abstract — **The optical parametric oscillator based on the bulk crystal $AgGaS_2$ with a two-pass pumping is created. Optical parametric oscillator pumped by the fixed wavelength 1.053 µm a compact nanosecond Nd:YAG laser. Pulse duration is 5-7 ns, a maximum pulse energy was 500 µJ at a frequency of 1-7 kHz. Lasing threshold from 12 to 20 mJ were obtained using an $AgGaS_2$ crystal.**

Keywords-optical parametric oscillator, nonlinear optical crystals, silver thiogallate, photo-acoustic spectroscopy

I. INTRODUCTION

At the present time the creation of universal coherent sources of infrared radiation is of great interest. Registration and determination of the concentrations of various gases in the atmosphere plays an important role in biology, atmospheric chemistry and medical diagnostics. Hydrocarbons, aldehydes, alcohols, and a couple other chemical compounds have pronounced absorption lines in the near infrared [1].

Optical parametric oscillation (OPO) is today one of the most widespread ways to produce tunable coherent radiation. The main part of OPO is a nonlinear crystal. Single crystals, such as proustite Ag_3AsS_3, silver thio- and selenogallates ($AgGaS_2$, $AgGaSe_2$), mercury thiogallate $HgGa_2S_4$, zink phosphatogermanate $ZnGeP_2$, gallium and cadmium selenides (GaSe, CdSe) etc., are used as nonlinear elements [2].

$AgGaS_2$ (AGS) was chosen for OPO over other familiar nonlinear crystals for several reasons. Cadmium selenide CdSe does not phase match over the entire 8–12 mm wavelength band when pumped at 1.57 mm. Zinc germanium phosphide ($ZnGeP_2$) and cadmium germanium arsenide ($CdGeAs_2$) absorb at the 1.57 mm pump wavelength, while $ZnGeP_2$ are not transparent at wavelengths greater than 10 mm.

AGS crystal has high nonlinear optical coefficient and high optical transmission from 0.5–12.0 µm, which makes it realistic to generate infrared parametric radiation. That is why numerous experiments with one or multistage OPO/OPG pumped by ns and ps IR dye, Nd:YLF and another near IR solid state lasers.

By far, commercial negative silver thiogallate crystal is one of the few crystals which can be pumped by commercially available 1.053 µm Nd:YLF laser to achieve phase-matched down-conversion into the $\lambda > 5$ µm region.

The properties of this crystal is shown in Table 1.

TABLEI. The Properties Of $AgGaS_2$ Crystal.

Crystal/parameter	**$AgGaS_2$ (AGS)**
Point group	$\bar{4}2m$
Space group	$I\bar{4}2md$
Band gap, eV (300 K)	2.73
Transparency range (µm)	0.48-11.4
Shortwave transparency edge in the far-IR (µm)	346
Birefringence, Δn	-0.054
Nonlinear coefficient, Pm/V	d_{36}=13.9±0.5
Nonlinear merit, Pm^2/V^2	11.5
Two-photon absorption at 820 nm, cm/GW	~4
Fundamental wavelengths for SHG (µm)	2.5-12.0
Thermal conductivity, W/m K	1.5
Thermo-optic coefficient $\beta_i = dn_i/dT$, $10^{-5}K^{-1}$ at 3 µm	β_x=15.31 β_y=15.31 β_z=16.07

The laser photo-acoustic spectroscopy (LOAS) is simply method to achieved high reliability, high sensitivity in the ppb and ppt levels. LOAS allows to measure the concentration of analyzing gas mixture in real time with a minimum volume of gas sample with continuous pumping. For medical use, the patient exhaled air is collected in a cell sample preparation and analyzed by the photo-acoustic detector.

Unlike the cavity ring-down spectroscopy (CRDS) LOAS detectors do not require the use of expensive mirrors with very high reflectance [1]. Since photo-acoustic signal is proportional to the absorbed optical power in the detector, the limiting parameters LOAS sensors generally increased with an increase in energy use of lasers.

The aim of our work is to develop a widely tunable source of coherent optical radiation in the mid-IR band as a basis for the gas analyzer [3, 4]. We propose to use parametric oscillator (OPO), which can provide sufficient power at high single wave (1-10 mW).

II. EXPERIMENTAL SETUP

In our experiment, $AgGaS_2$ crystal used with 5× 5 mm^2 in cross section, 15 mm in length, θ = 67° and φ = 0° cut for

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type-II phase-matching centered around 3.5 µm. For the calculation we used the following values of the coefficients of refraction for the crystal AGS: $n_p = 2.4$, $n_s = 2.39$, $n_i=2.39$. In order to reduce the loss so as to the oscillation threshold, both cross sections were well antireflection AR coated: high transparent HT 1.053 > 98% at pump wavelength 1.053 µm, and also at signal and idler wavelengths HT@1.15–1.7 ~ 97.5–99%, HT@3–5 ~ 97–98.5%, respectively.

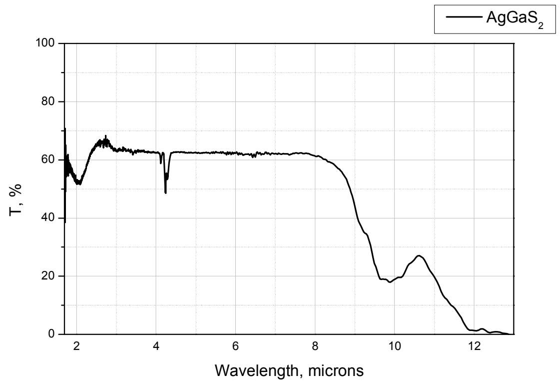

Figure 1. Transmission spectrum of $AgGaS_2$

The pump source was chosen as a single-mode Nd:YLF laser with a wavelength λ = 1053 nm and a maximum pulse energy of 540 µJ (model DTL-429QT). The laser operates in the nanosecond pulse regime with a length of 10.5 ns and a pulse repetition frequency f = 100-5000 Hz.

In this paper, the scheme has been demonstrated with different resonator mirrors OPO.

The parameters of the resonator OPO with different mirrors are shown in Table 2.

Fabry-Perot OPO resonator was formed by two flat mirrors, the mirror M4 by firm Layertech with coatings of (AR (0 °, 1064nm) <1.0% + AR (0 °, 4.0-6.0µm) <2%, HRr (0-15 °, 1310 -1470 ± 10nm)> 99.9%) was injected into the cavity OPO pump radiation and the radiation is excreted in the idler and signal wavelengths. The second resonator mirror M5 - flat with a silver-plated. Pulse duration τ = 5-10 ns 1000 Hz. Losses in a single pass for the signal wave were $\alpha_s = 0.04$, the ratio of transmitted to incident pump field amplitude in the crystal γ = 0.1. In this configuration, the energy density of the lasing threshold was $J_T = 13$ mJ/sm^2 beam diameter d = 1 mm, the minimum pump energy at which lasing was observed in 103µJ.

The cavity length of AGS OPO was minimized to around 25 mm, just at the minimal distance allowed to rotate the 15 mm length of AGS crystal.

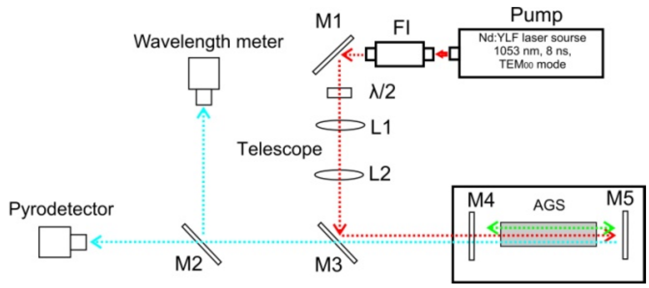

Figure 2. Experimental setup of $AgGaS_2$ OPO: M1 - rotating mirror, M2 – mirror with a partial reflection (angle of 45 °), M3 – dichroic mirror , M4, M5 – mirror resonator, Pump – pumping laser, FI – Faraday Isolator, L1, L2 – lens telescope, AGS - silver thiogallate.

Quasi-hemispherical resonator OPO, where the input mirror M4 was spherical (ZnS), the company Laseroptics with radius of curvature 2000 mm, with coatings of (HT 1064 HT3000-10000 HR1200-1650). Second resonator mirror M5 - flat with a silver-plated. Pump pulse duration τ = 5-10 ns (1000 Hz). loss in a single pass for the signal wave were α_s = 0.34, the ratio of transmitted to incident pump field amplitude in the crystal γ = 0.1. In this configuration, the energy density of the lasing threshold was

The energy density of laser threshold J_T = 18.72 mJ/cm^2 with a beam diameter d = 1 mm and at minimum pump energy E = 147 µJ was observed.

Fabry-Perot OPO resonator, which found the input mirror M4 (ZnSe) firms Laseroptics with coatings of (HT1053nm HR1150-1650nm HT2000-12000nm/0°) was injected into the cavity OPO pump radiation and the radiation is excreted in the idler and signal wavelengths. The second resonator mirror M5 - flat with a silver-plated. Pulse duration τ = 5-10 ns (1000 Hz). The loss per pass for the signal wave were $\alpha_s = 0.04$, the ratio of transmitted to incident pump field amplitude in the crystal γ = 0.1. The density of the laser threshold was at a beam diameter of 1 mm. In this configuration, the energy density of the lasing threshold was J_T = 11.59 mJ/cm^2 at a beam diameter d = 1 mm, the minimum pump energy at which the observed generation was 91 µJ.

TABLEII. The Technical Parameters Of Mirror's Resonator.

Specification of M4	Energy density of laser threshold, mJ/cm^2	Minimum pump energy, μJ
Layertech with coatings of (AR (0°, 1064nm) < 1.0% + AR (0°, 4.0-6.0μm) < 2%, HRr (0-15°, 1310-1470±10nm) > 99.9%)	**13**	**103**
Mirror ZnS (Laseroptics), R=2000 mm with coatings of (HT 1064 HT3000-10000 HR1200-1650)	**18.72**	**147**
Mirror ZnSe (Laseroptics) with coatings of (HT1053nm HR1150-1650nm HT2000-12000nm/0°)	**11.59**	**91**

III. CONCLUSIONS

In conclusion, nanosecond singly resonant type-II $AgGaS_2$ optical parametric oscillator pumped by a 1.053 μm Nd:YLF laser was demonstrated experimentally.

Pulse duration is 5-7 ns, a maximum pulse energy was 500 μJ at a frequency of 1-7 kHz.

Lasing in the region of 3.5 micron was observed. Currently, experiments are being conducted to study the tuning characteristics on different crystals with different orientations.

Created mock-compact optical parametric oscillator based on a nonlinear crystal thiogallate silver ($AgGaS_2$). On the basis of which will be further created a compact device for different applications, e.g. diagnosis of various diseases (diabetes, tuberculosis, bronchial asthma, etc.) and detection of trace explosive and toxic substances in the atmosphere.

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