OPO-LASER SYSTEM FOR ATMOSPHERIC SOUNDING IN THE MID-IR RANGE

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ABSTRACT

A laser system is designed that provides for tunable generation of nanosecond radiation pulses in the 3–4 μm range. Optical block-diagram and specifications of the system are presented. The laser system as a part of a differential absorption lidar designed can be used for remote control of pollutant concentrations along surface atmospheric paths.

Keywords: laser, OPO, nonlinear crystal, mid-infrared, trace atmospheric gases, atmosphere.

1. INTRODUCTION

New effective sources of laser radiation designed on the basis of molecular IR wide-band lasers and parametric frequency converters based on nonlinear crystals allow the spectral range from 2 to 18 μm to be overlapped due to generations of overtones, harmonics, and sum and difference radiation frequencies of the lasers [1]. In this work, we consider a laser system with a KTA-based optical parametric oscillator (OPO), which overlaps the 3–4 μm spectral range, which is of the highest information content from the viewpoint of sounding trace atmospheric gases (TAGs) (H_2O, CO_2, N_2O, NO_2, etc.), pollutants, and toxic gases.

2. LASER SYSTEM DESCRIPTION

Figure 1 shows the optical diagram of the laser system.

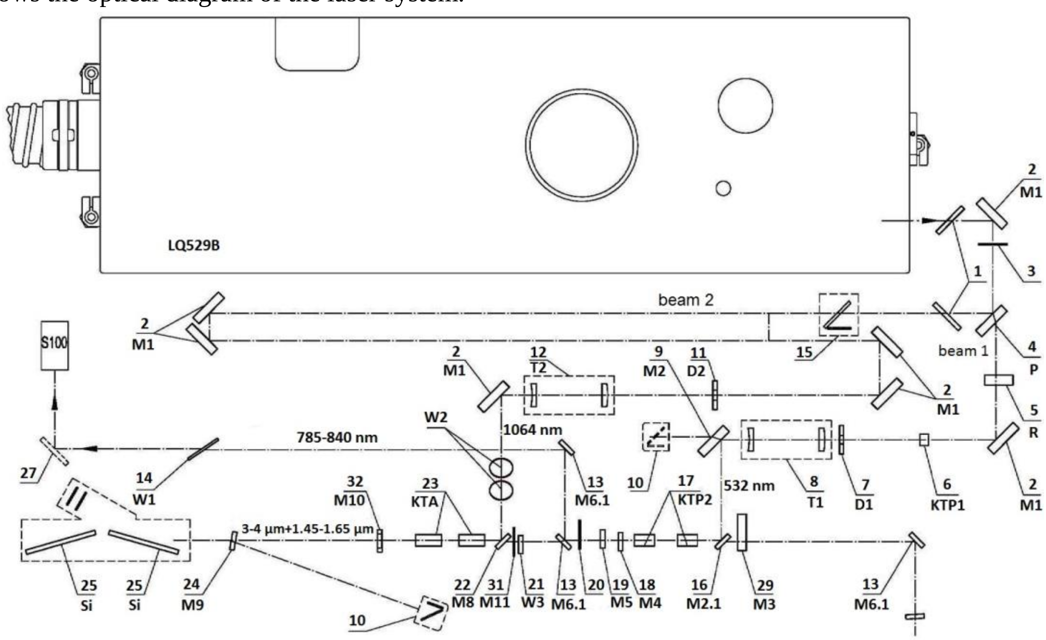

Fig.1. Optical diagram of the laser system

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The system includes: temporary mirror (removable) for controlling the pulse energy at 1064 nm (1), rotating mirror M1 with high reflectivity for radiation at 1064 nm (2), λ/2 retarder for 1064 nm (3), polarizer P (4), 45° quartz rotator R of radiation at 1064 nm (5), KTP1 crystal for the 2nd harmonic generation (6), aperture diaphragm D1, Ø 6 mm (7), telescope T1, ×1.8 (8), dichroic mirror M2 with high reflectivity for radiation at 532 nm (9), laser radiation trap (10), aperture diaphragm D2, Ø 7 mm (11), telescope T2, ×1.5 (12), dichroic mirror M6.1 with high reflectivity for radiation at 785–840 nm (13), shielding window (14), (removable) laser radiation trap (15), dichroic mirror M2.1 with high reflectivity for radiation at 532 nm (16), KTP2 crystals for OPO (17), output mirror M4 semitransparent for radiation at 785–840 nm (18), return mirror M5 with high reflectivity for radiation at 532 nm (19), λ/2 retarder for the 1450–1650 nm range (20), IRS7 glass shielding window (21), dichroic mirror M8 with high reflectivity for radiation at 1064 nm (22), KTA crystals for the high-power OPO (23), dichroic mirror M9 with high reflectivity for radiation at 1064 nm (24), Si plate (25), glass plate (27), temporary dichroic mirror (removable) with high reflectivity for radiation at 1450–1650 nm (28), Ag-coated totally reflecting mirror M3 (29), totally reflecting mirror M11 with high reflectivity for radiation at 1450–1650 nm (31), and output mirror M10 semitransparent for radiation at 1450–1650 nm (32).

3. OPERATION PRINCIPLES OF RADIATION CONVERTER

The radiation converter is intended for generation of laser pulses with a tunable wavelength in the 3–4 μm range. It includes a driving narrow-band OPO based on KTP crystals pumped with 2nd harmonic 532-nm radiation and a high-power OPO based on KTA crystals pumped with 1064-nm radiation. The driving OPO is intended for generation of low-power radiation with tunable pumping wavelength in the 785–840 nm (signal wave λ_s) and 1.45–1.65 µm (idler wave λ_i) regions. The wavelengths are related as

$$1/\lambda i + 1/\lambda s = 1/\lambda p, \text{ where } \lambda p = 532.1 \text{ nm}.$$

The high-power KTA-based OPO is intended for generation and amplification of radiation with a tunable wavelength in the 3–4 μm range (idler wave λ_1). The wavelengths are related as

$$1/\lambda_1 = 1/\lambda_3 - 1/\lambda 2, \text{ where } \lambda_3 = 1064.2 \text{ nm}, \lambda 2 = 1450\text{–}1650 \text{ nm}.$$

The output radiation wavelength is controlled by a S100 spectrometer. Using the spectrometer, the lasing wavelength of the signal wave λ_s of the driving narrow-band OPO based on KTP crystals is specified. The wavelength of the difference frequency λ_1 of the high-power OPO based on KTA crystals in the 3–4 µm region is calculated by the equation

$$\lambda_1 = 1.0642\lambda_s/(1.0642 - \lambda_s).$$

The converter design provides a possibility of mounting a diffraction grating in the cavity of the KTP crystal-based OPO for narrowing the lasing line to 1 cm^{-1} and a possibility of mounting a narrow-band injection laser diode with optical insulators for generation of radiation with the line width lower than 0.1 cm^{-1}. In this case, another single-frequency Nd:YAG pumping laser with the 1064-nm radiation line width lower than 0.1 cm^{-1} should be used.

Figure 2 shows the optical diagram of pumping radiation distribution. The same elements in Figs. 1–3 are designated by the same numbers. Vertically polarized 1064-nm radiation is divided to two beams with controllable ratio of pulse energies:

– the first beam with pulse energy of ~ 100 mJ is doubled and used for pumping driving KTP-crystal based OPO **KTP2**;

– the second beam with pulse energy of up to 230 mJ is used for pumping high-power KTA-crystal based OPO **KTA**.

The polarizer **P** and a λ/2 retarder for 1064-nm radiation are used for spatial division of a 1064-nm radiation beam to two beams 1 and 2.

The 45° quartz rotator **R** and nonlinear crystal **KTP1** with type II synchronism eoe in the XY plane are used in the first beam for 532-nm radiation generation. The **KTP1** crystal is mounted in a thermostat. The synchronism in the **KTP1** crystal is controlled in a vertical plane during the 2nd harmonic generation.

Vertically polarized 532-nm radiation passes through aperture diaphragm **D1** and telescope **T1** with 1.8 magnification, reflects from mirror **M2**, and is used for pumping driving OPO **KTP2**. The 532-nm radiation pulse energy is ~ 50 mJ, length is ~ 10 ns, and beam diameter is ~ 4 mm. The pumping pulse intensity is ~ 40 MW/смcm^2 (~ 0.4 J/cm^2) at the entrance faces of **KTP2** crystals of the driving OPO. Untransformed 2014-nm radiation is blocked by trap 10 after mirror **M2**. The second pumping 1064-nm radiation beam passes through a delay line formed by mirrors **M1**. The delay time range is chosen experimentally during the adjustment stage and is within 1–3 ns (the delay line length is 30–90 ns).

Vertically polarized 1064-nm radiation passes through aperture diaphragm **D2** and telescope **T2** with 1.5 magnification, reflects from mirror **M1**, and is used for pumping the high-power OPO based on **KTA** crystals. The 1064-nm radiation pulse energy is ~ 210 mJ, length is ~ 10 ns, and beam diameter is ~ 4.3 mm. The pumping pulse energy at the entrance faces of the **KTA** crystals of the high-power OPO is ~ 130 MW/cm^2 (~ 1.3 J/cm^2). To control the radiation pulse energy of the LQ529B pumping laser, temporary mirror 1 (see Fig. 1) can be used.
A possibility of blocking radiation using trap 15 (see Fig. 1) is provided in beam 2.

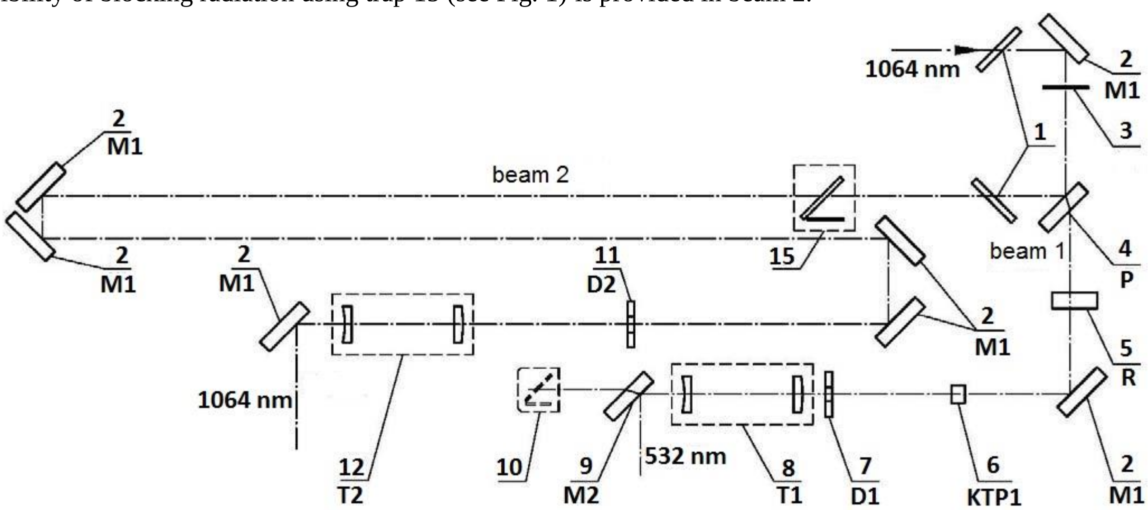

Fig. 2. Optical diagram of the pumping radiation distribution

Figure 3 shows the optical diagram of the radiation converter with tunable wavelength. A pair of KTP2 crystals with type II synchronism oe-o in the XZ plane is used in the driving narrow-band OPO; the crystals are fixed in the birefringence compensation position. The synchronism in KTP2 crystals is controlled in a horizontal plane. The pumping radiation at 532 nm and idler wave radiation in the 1450–1650 nm range are polarized in a vertical plane, and the signal wave radiation in the 785–840 nm range, in a horizontal plane.

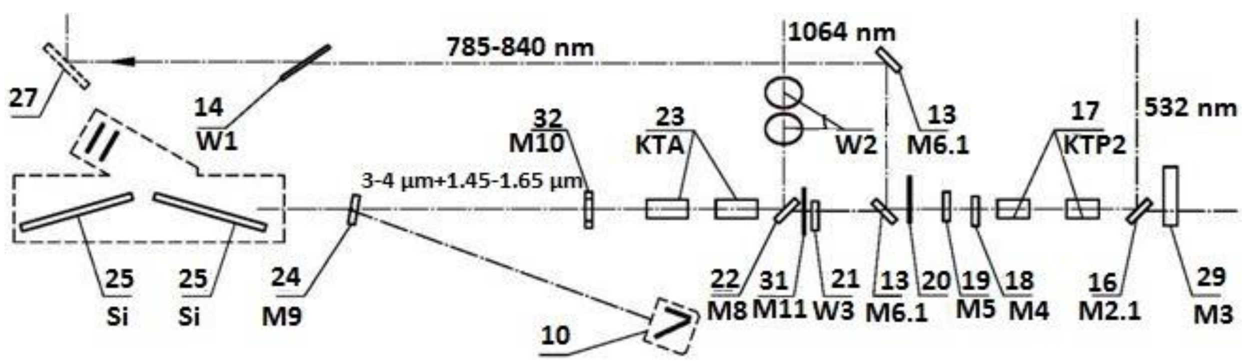

Fig.3. Optical diagram of the radiation converter

A cavity with the length L = 86 mm is formed by two mirrors **M3** and **M4**. Ag concave mirror **M3** is a totally reflecting mirror in the 785–1650 nm range. Output mirror **M4** transparent in the 785–840 nm range is of high transmittance in the 1450–1650 nm range and at 532 nm.
The 532-nm pumping radiation is leaded into the cavity of the driving OPO with dichroic mirror **M2.1**. Mirror **M5** reflects the pumping radiation back into the cavity, thus implementing the two-pass pumping circuit.
The vertically polarized radiation at 1450–1650 nm passes through the λ/2 retarder and becomes horizontally polarized.
Mirror **M6.1** is used for the spatial division of signal and idle wave beams. The signal wave radiation in the 785–840 nm range reflects from second mirror **M6.1** and is directed to the S100 spectrometer.
A pair of **KTA** crystals with type II synchronism oe-o in the XZ plane, set to the birefringence compensation position, is

used in the high-power OPO. The synchronism in the KTA crystals is controlled in a horizontal plane. The pumping radiation at λ_3 = 1.0642 µm with the difference frequency λ_1 = 3–4 µm is vertically polarized, and the radiation of an injected wave with c λ_2 = 1.45–1.65 µm, horizontally. A cavity with the length L = 86 mm is formed by two mirrors **M10** and **M11**. Totally reflecting mirror **M11** partly transmits the injected radiation in the 1.45…1.65 µm range. Output mirror **M10** semitransparent in the 1.45…1.65 µm range is of high transmittance in the 3–4 µm range and at 1.064 nm. A single-pass pumping circuit is implemented in the OPO.

Mirror **M9** is used to cut off 1.064 µm pumping radiation. Si plates are used for the spatial division of beams with tunable wavelength in the 3–4 µm (λ_1) and 1.45–1.65 µm (λ_2) ranges. The output radiation in the 3–4 µm range is vertically polarized.

The KTA crystal-based OPO is placed inside a dust-proof casing, the inner chamber of which is nitrogen purged.

Shielding glass windows **W2** are mounted in the pumping radiation input hole; IRG7 glass filter **W3** is fixed in the hole for injected 1.45–1.65 µm radiation input.

Figure 4 shows the tuning curve of the KTA crystal-based OPO. A quite high pulse energy at the system exit is seen in the 3–4 µm wavelength range (attain values higher 6 mJ at the tuning curve peak).

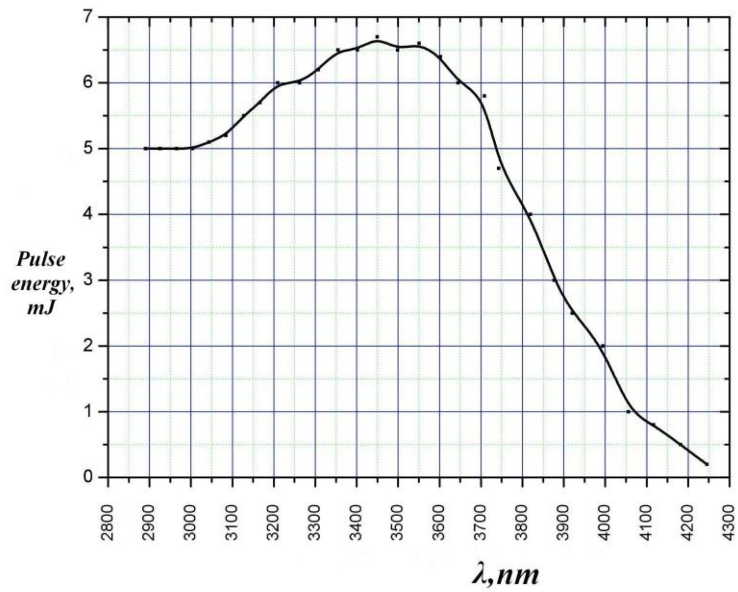

Figure 4. Tuning curve of the KTA crystal-based OPO

Main specifications of the pumping laser and radiation converter are given in Tables 1 and 2.

Table 1. Specifications of LQ529B pumping laser

Pulse frequency	10 Hz
Output energy: at 1064 nm	350 mJ
Pulse length at 1064 nm, FWHM	10...13 ns
Beam diameter at 1064 nm	≤ 6 mm
Divergence angle at 1064 nm	~ 1.5 mrad
Stability of pulse energy at 1064 nm, better than	± 2.5 %

Table 2. Specifications of radiation converter

Wavelength tuning range	3…4 µm
Radiation line width	< 5 cm^{-1}
Pulse energy, in the tuning curve peak	> 5
Pulse frequency	10 Hz
Radiation divergence angle	</= 2 mrad
Wavelength tuning control	by 3 SMs

4. CONCLUSIONS

The laser source considered is a part of the optical diagram of the differential absorption lidar designed for the study of TAGs along surface tropospheric paths. The laser is currently calibrated along with the lidar for laboratory experiments planned.

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