INTRACAVITY PHOSPHATE–NEODYMIUM - GLASS LASER SPECTROMETER IN THE 1.3 μm REGION

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Line structure of the phosphate–neodymium-glass laser generation spectrum within the 1.3 μm *region is investigated. It is shown that the structure is determined by the presence of atmospheric air in the laser cavity. Its elimination has made it possible to create an intracavity laser spectrometer with the threshold sensitivity of* $3 \cdot 10^{-8}$ cm^{-1}. *The spectrum is recorded using a vacuum spectrograph by the method of nonlinear frequency conversion (doubling and mixing frequencies) as well as by direct recording of the spectrum on a film.*

1.INTRODUCTION

A neodymium glass is a promising active medium for creating highly sensitive intracavity (IC) laser spectrometers. Precisely on the basis of the neodymium laser the first IC spectrometer has been created.[1] The neodymium-glass lasers can generate the radiation within 0.9, 1.06, 1.3, and 1.8 μm regions. At present the generation region at a wavelength of 1.06 μm is most extensively studied. In the other regions the generation is possible under specific conditions, namely, at low temperature and when suppressing generation at the main band. The glass composition plays also an important role. In the silicate glasses the 1.3 μm generation is difficult because of essential quenching of the luminescence due to the processes of multiphoton relaxation,[2] while in the phosphate neodymium glasses, where the processes of nonradiative relaxation are essential, it is easier to provide lasing.

As was shown in Ref. 3, the phosphate–neodymium-glass laser emission spectrum (λ = 1.3 μm) consists of narrow lines, whose occurrence is due to inhomogeneous broadening of the luminescence spectrum. That structure of the spectrum was described in Ref. 4, however, there that was explained by the presence of strong water vapor absorption lines. The availability of the structure in the emission spectrum does not allow one to use a laser at the 1.3 μm band for the intracavity spectroscopy.

This paper describes the results of investigation of the neodymium laser aimed at elucidating the origin of line structure of the phosphate–neodymium-glass laser emission spectrum and for creation of an intracavity (IC) spectrometer gas analyzer in the 1.3 μm region.

2. EXPERIMENTAL SETUP

There are several possible reasons for appearing the line spectrum of a multimode laser emission:

a) intracavity absorption of light by the atmospheric air;

b) "parasitic" selection due to the interference of reflected and scattered radiation inside the laser cavity;

c) condensation of emission spectrum[5];

d) fluctuation character of spontaneous emission;

e) inhomogeneous broadening of luminescence band of the active laser medium.

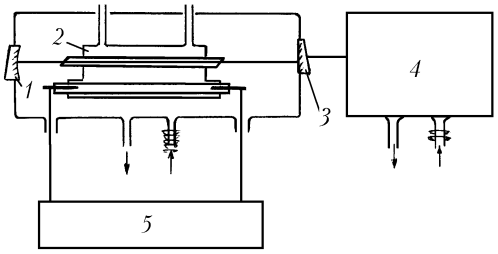

FIG. 1. Block diagram of the experimental setup: the cavity mirrors 1 and 3, the laser head 2 with an active element and a flashlamp, the vacuum diffraction spectrometer 4, the laser power supply unit 5.

To elucidate the reasons, causing the laser emission spectrum discreteness, we have designed an experimental setup, whose block diagram is shown in Fig. 1. The active elements used are GTSS–1621, GLS–22P, $\varnothing$ = 6 mm, L = 10 cm with the ends cut at 3° angle. The pumping was made using one IFP–800 lamp. A nondisperse cavity was formed by a spherical

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mirror *1* with a curvature radius of 100 mm and the 100% reflection coefficient and a plane mirror *3* with the 95% reflection coefficient. The pumping system provided a twofold excess of the pump over the threshold value (E_{thresh} = 350 J).

The laser radiation was directed to the diffraction spectrograph with a focal length of 900 mm. The diffraction spectrograph contained a diffraction grating, 300 grooves/mm, operating in the sixth order.

An important problem when developing the IC spectrometer in the 1.3–1.4 μm region is the recording of the laser emission spectrum. A commercially available silicon photodiode and a linear CCD have the operation range of 0.2 to 1 μm and do not permit recording of IR radiation in the 1.3 μm region. We used the commercially available film with the maximum sensitivity in the 1.06 μm region. Owing to high spectral power of laser radiation, its recording turns out to be possible during 1–3 pulses far beyond the boundary of the standard spectral sensitivity of the photographic films.

3. RESULTS OF INVESTIGATIONS

1. When recording the laser emission spectrum in the presence of the atmospheric air at 50% humidity and T ~ 295 K, we observed, as in Refs. 3 and 4, the line spectrum (Fig. 2*a*) at the intracavity air gap length l_{air} = 20 cm. The decrease of the l_{air} to 0.05 cm (Fig. 2*b*) results in a qualitative changes in the laser emission spectrum, namely, the spectrum is observed, which is typical of an IC spectrometer: relatively smooth, with the marked depth of emission intensity dips (the cavity construction enables us to remove a conventional "parasitic" selection). The IC spectrum generation is not characterized by the frequency autolockin (the spectrum condensation near the strong absorption lines, as it takes place in Ref. 5, in the IC spectrum near the Na absorption lines). The value of the water vapor spectral absorption coefficient is insufficient for the spectrum condensation to occur.

2. In the subsequent research we recorded the emission spectrum of a laser, whose cavity was evacuated up to the pressure of 10^{-5} mm Hg and then the cavity was filled with dried air through a nitrogen catcher. In this case we observed the laser emission spectrum with the structure analogous to that given in Fig. 2*b*.

A comparison of the spectrum obtained with the H_2O vapor absorption spectrum[6] has shown that the depth of the emission intensity dips in the laser emission spectrum is determined by the water vapor absorption lines in the space out of the laser cavity. In this case, the laser emission spectrum is significantly shifted toward longer waves, as compared to the spectrum given in Ref. 3, and practically falls on the H_2O $\nu_1 + \nu_3$ band center, where the strongest absorption lines of this band are located.

3. The use of a vacuum spectrometer pumped out to the pressure 10^{-3} mm Hg enabled us to get rid of the absorption outside the cavity. However, the generation spectrum contained a weak structure varying from pulse to pulse. The structure was washed off with the pulses accumulated on the photofilm. We assume that this structure in the spectrum is due to mode fluctuations, which greatly increase when going to the neodymium laser with spherical mirrors.[7] Forced smoothing of spatial inhomogeneity of the inversion of active medium by means of a rotating plane–parallel plate inside the cavity resulted in the total removal of the intensity modulation.

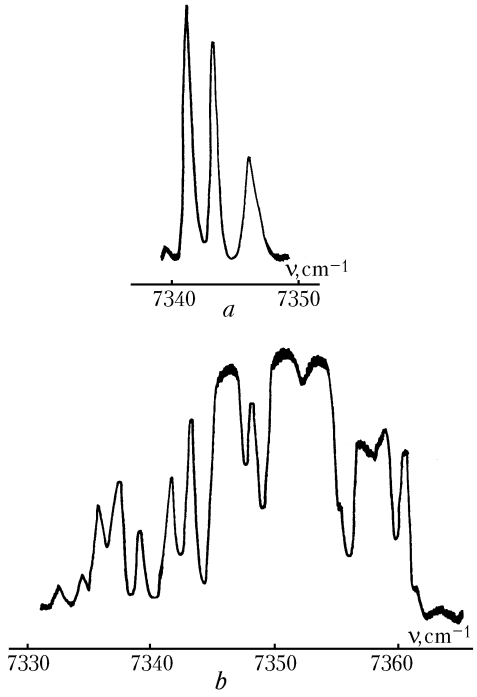

FIG. 2. The phosphate–neodymium-glass laser emission spectrum with the cavity air gap being equal to 20 *(a) and* 0.05 cm *(b).*

4. PERFORMANCE OF NONLINEAR FREQUENCY CONVERSION FOR RECORDING THE IC SPECTRUM

The performance of methods of nonlinear frequency conversion (doubling and mixing of frequencies) makes possible the recording of laser emission in the visible spectral range, namely, the range of maximum sensitivity of films, photodiode, and linear CCDs.

Frequency doubling

Frequency doubling of laser radiation is commonly used for conversion of a high–power pulse with a narrow spectral line of a nanosecond duration. When doubling the emission frequency with a broad spectrum, every spectral interval $\Delta 2\omega_i$ of a transformed

spectrum involves contributions from the emission with the frequency ω_2 and the emission with the frequencies $(\omega_i \pm \delta)$ symmetric relative to ω_i, being within the angular synchronism region. In this case the converted spectrum is the result of summation of all frequencies of the initial spectral profile of radiation. Therefore in the spectrum of second harmonic not only the broadened lines at doubled frequencies appear but also the lines at sum frequencies (Figs. 3*a*, *b*).

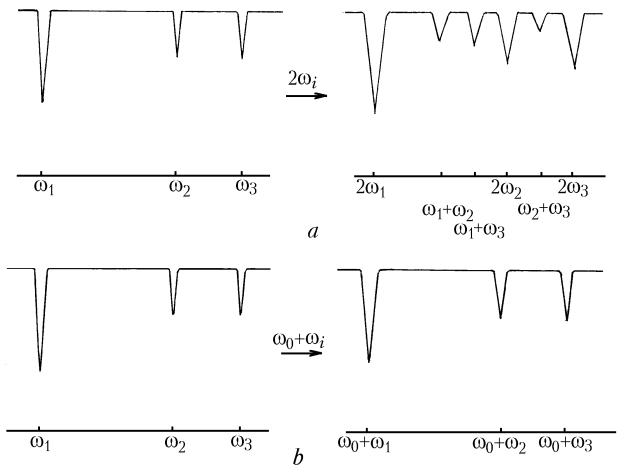

FIG. 3. Conversion of the broadband emission with the frequency doubling (a) and frequency mixing (b).

Hence, if we have the IC spectrum (the laser emission spectrum of the IC spectrometer) with dips due to absorption lines, then in the transformed spectrum the strong distortion of the original spectrum will occur.

Frequency mixing

In the case of mixing of a broad IC spectrum and the frequency ω_0 of a single-frequency laser emission, when using the parallel beams, the transformed spectrum will possess all the peculiarities of the original IC spectrum since in this case the convolution of the IC spectrum with the single-frequency radiation (Figs. 3*c*, *d*) takes place.

The experimental study of the possibility of recording the IC spectrum using the methods of nonlinear frequency conversion was carried out using the $LiIO_3$ crystal that enables one to perform frequency doubling and mixing. At doubling of frequency of a broad laser emission, the radiation converted is recorded in the 0.68 μm range. The spectral structure of the above radiation is shown in Fig. 4*a*. A comparison of the obtained spectrum with the original one (Fig. 4*b*) shows that depth of emission intensity dips in the original spectrum is not washed off completely although they are strongly distorted. The additional dips occur also, whose identification is difficult.

When using the frequency mixing regime, we mixed the frequencies of a narrowband neodymium laser ($\nu = 9434$ cm^{-1}, $\gamma = 0.05$ cm^{-1}, $\tau = 40$ ns) and those of the IC spectrum ($\nu = 7353$ cm^{-1}, $\gamma = 20$ cm^{-1}, $\tau = 500$ μs), and we obtained the laser emission spectrum with the frequency $\nu = 16787$ cm^{-1} ($\lambda = 0.595$ μm) (Fig. 4*c*). The variation of the generation spectral composition of occurs during a generation pulse of a multimode laser and the spectral narrowing is observed. Therefore, when using a single-frequency laser of nanosecond duration, the nonlinear radiation conversions are performed only for an instantaneous IC spectrum at an instant of generation of the single frequency laser, and the recorded IC spectrum turned out to be strongly narrowed.

Because the depth of the emission intensity dips in the IC spectrum increases by the exponential law, the use of the IC spectrum frequency mixing with that of the narrowband laser of nanosecond duration enables one to vary the IC spectrometer sensitivity when converting frequencies at different moments of the long pulse generation, thus increasing the sensitivity and the dynamic range of the IC spectrometer.

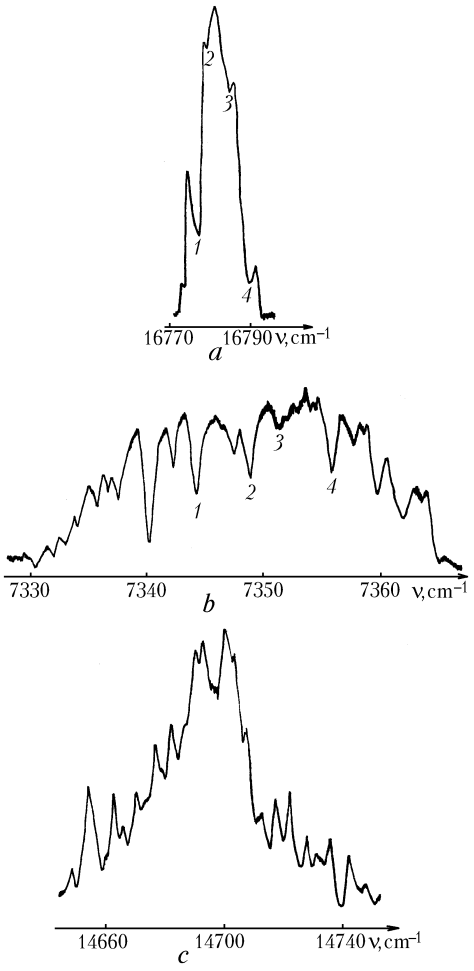

FIG. 4. The phosphate-glass laser emission spectra when mixing with the single frequency radiation (a), at a basic frequency (b), and when converting by frequency doubling (c).

5. CONCLUSION

As a result of the investigations performed, the IC phosphate–neodymium-glass laser spectrometer in the 1.36 μm region has been created and the water vapor absorption lines have been recorded. The IC spectrometer can be used to control the water vapors in a gaseous medium.

Below we estimate the concentration sensitivity of the spectrometer gas analyzer.

The recorded depth of the emission intensity dips in the intracavity spectroscopy is $J(\nu, t)/J(\nu, 0) = 0.8$ (here $J(\nu, 0)$ and $J(\nu, t)$ are the laser emission spectra at the beginning and at the end of generation, respectively). Hence it follows that one can easily obtain the value of the recorded absorption coefficient

$$K_{ab}(\nu) = [\ln J(\nu, t)/J(\nu, 0)] / (ct\,\mu),$$

where c is the light speed; t is the generation duration; μ is the cavity space factor. Assuming that $t = 0.5 \cdot 10^{-3}$ s, $\mu = 0.5$, we obtain $K_{ab}(\nu) < 2.9 \cdot 10^{-8}$ cm^{-1}.

In the generation range of the phosphate–neodymium-glass laser, the H_2O line 7339.846 cm^{-1} of the $\nu_1 + \nu_3$ band has the intensity 0.422 cm^{-2} atm^{-1} (Ref.8). Taking into account the fact that under atmospheric conditions the H_2O line halfwidth is about 0.1 cm^{-1}, the water vapor concentration, that can be recorded by a given spectrometer, is $2.2 \cdot 10^{-8}$.

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