The influence of OH groups on laser performance in phosphate glasses

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Because of the influence of OH groups in phosphate glasses on the radiation of rare-earth ions, the laser performance is degraded. The laser efficiency and the small signal gain experiment of several phosphate glass samples have been done, the concentration of OH groups in glasses was calculated from the measured absorption coefficient at 3.47 μm. It is shown that the concentration of OH groups in phosphate glasses can seriously influence the laser output characteristics, and the OH groups have worse influence on the laser amplifier than laser oscillator.

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Nd^{3+} phosphate laser glasses which have been main material instead of silicate laser glasses in high power laser because of its excellent properties have strong hydrophilicity. Although water has been removed in melting, a little water remains in glasses as OH groups[1], which influences sharply the spectral properties of laser glasses and laser output.

The influence of OH groups on physical characteristics and spectral properties has been investigated[2−5], but the research that the OH groups influence the laser output has been reported rarely[6,7]. In this letter, N_{21} and N_{31} phosphate laser glasses which have approximate absorption coefficient at 1053 nm and different concentrations of OH groups are chosen, the quantitative relations about OH groups with the small signal gain coefficient and laser efficiency at free oscillation are measured respectively. The results show that the small signal gain coefficient is inverse proportional to the concentration of OH groups, improving the Nd^{3+} fluorescence lifetime can decrease the need of the glass absorption coefficient. A method about improving the glasses laser properties is discussed.

The experimental setup measuring laser conversion efficiency is shown in Fig. 1. The Fox-Li parallel plane cavity is made up of high reflective (HR) film and half-reflection film. The half-reflection film reflectivity is 40%, the size of laser stick and the flashlamp are $\phi 8\times 200$ mm, the pulse pumping energy is 200 J, and the work frequency is 1 Hz. When the setup keeps thermal stability, the maximum laser output energy and the laser electricity-photon conversion efficiency are obtained by adjusting cavity.

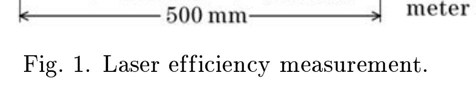

Fig. 1. Laser efficiency measurement.

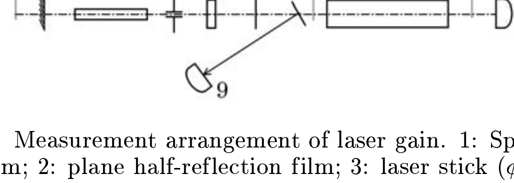

Fig. 2. Measurement arrangement of laser gain. 1: Spherical HR film; 2: plane half-reflection film; 3: laser stick ($\phi 4 \times 80$ mm); 4: diaphragm ($\phi 0.5$ mm); 5: Q-switch crystal; 6: 1-mm beam splitter; 7: laser stick ($\phi 8\times 200$ mm); 8, 9: energy meter.

In laser gain measurement the signal laser is single mode laser whose energy and pulse width are 1 mJ and 30 ns, respectively, the delay time between the oscillator and amplifier is 300 μs, the pumping pulse half-width is 400 μs. The equipment is shown in Fig. 2. When the amplifier does not work, the ratio E_{80}/E_{90} of energy meter's reading number is measured, when the amplifier works, the ratio E_8/E_9 is measured. The laser small signal gain is

$$G = \frac{E_8/E_9}{E_{80}/E_{90}}. \qquad (1)$$

The influence of absorption of beam splitter, laser stick and reflection of the two ends is eliminated by this way.

In this experiment the circular sticks made by Nd^{3+}, 2.2 wt.-% N_{21} and N_{31} phosphate glasses, whose two ends' obliquity is 2°, are chosen. Because the Nd^{3+} phosphate glasses are polluted by impurities in raw material and melting, in general the absorption coefficients of glasses are different. In this experiment all sample must have almost the same absorption coefficient, so the errors of the absorption coefficients are $< 2 \times 10^{-4}$ cm^{-1} (see Table 1).

The infrared absorption of OH groups in phosphate glasses caused by the flex and vibration of OH groups shows that the glasses have strong absorption from 2500 to 3600 cm^{-1} (2.7—4 μm) at infrared spectra. The concentration of OH groups in glasses C is calculated by[4]

$$C = 0.419\alpha_{\mathrm{OH}} \times 10^{20}, \qquad (2)$$

where $\alpha_{\mathrm{OH}} = \lg(T_0/T)/d$ is the absorption coefficient of sample at 2880 cm^{-1} (3.47 μm), T_0, T are the transmissivity at 3.47 μm of the fundamental glasses and the glasses in which OH groups exist, respectively, d is the sample thickness.

The laser efficiency and the small signal gain in free oscillation and amplifier modulated by Q switch are shown in Table 1. In Table 1 the absorption coefficients at 1053 nm in Nd^{3+} phosphate glasses are measured by the self-made laser loss measurement device. Under this experiment condition, when the concentrations of OH groups in N_{21} and N_{31} glasses are 5 and 24 times of the minimum concentration of OH groups, the laser energy conversion efficiencies at free oscillation decrease 15% and 19% respectively, and the small signal gains decrease 2.8 and 3.4 times.

Because the signal amplified is weak and the glasses' losses are by far less than the laser gain, the small signal gain coefficient approximates is $\beta = \frac{\ln G}{L}$ (cm^{-1}). The influence of the concentration of OH groups in two sorts of glasses on the small signal gain is shown in Fig. 3.

The concentration of OH groups does not influence on the Nd^{3+} stimulated emission cross section because the fluorescence effective line-width and the absorption spectra of glasses of different concentrations of OH groups keep the same.

From the experimental results, OH groups do not influence seriously on the energy conversion efficiency at free oscillation, because laser comes into being when the population reaches the threshold, and the oscillation remains and the laser exists when the pumping rate is bigger than the population consumption rate. But the population in amplifier deciding the deposited energy is different from the oscillation. The influence of fluorescence lifetime on laser amplifier can be analyzed independently because OH groups in glasses do not influence on the stimulated emission cross section.

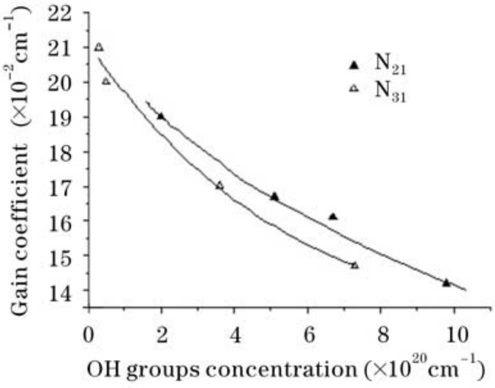

Fig. 3. The influence of OH^- concentration on laser gain.

If laser losses are by far less than the laser gain, the small signal gain coefficient is

$$\beta \propto \sigma_{\mathrm{em}} R \tau, \tag{3}$$

where β is the small gain coefficient, σ_{em} is the stimulated emission cross section, and R is a constant. In stable amplifier, because the small signal gain coefficient is approximately direct proportion to the fluorescence lifetime and $1/\tau$ rise linearly with the concentration of OH groups, the small signal gain coefficient should be inverse proportional to the concentration of OH groups, as shown in Fig. 3. The population at metastable-level returns to the elementary level by non-radioactive transition due to the muti-phonons relaxation caused by OH groups in glasses. Because the deposited energy is direct proportion to $\sigma_{\mathrm{abs}}\tau$, where σ_{abs} is the absorption cross section in laser glasses, the laser gain decreases with the decrease of deposited energy at metastable-level. The fluorescence lifetime and the small signal gain coefficient in phosphate laser glasses which do not remove water are under 100 μs and 0.1 cm^{-1}, respectively. The further experiments (see Table 2) prove that at the same fluorescence lifetime, when the absorption coefficient increases from 0.001 to 0.002 cm^{-1}, the gain coefficient descends 5%. At the same absorption coefficient, the gain coefficient increase 5% when the fluorescence lifetime increase from 330 to 350 μs (approximate 6%), so both can be counteracted. Now it is easy for improving the laser gain by eliminating water in glasses to increase the fluorescence lifetime, but it is difficult for improving the laser gain to decrease the laser losses.

Table 1. The Influence on Laser Performance of OH^- in Phosphate Glasses

Sample	Absorption Coefficient ($\times 10^{-4}$ cm^{-1})	OH^- Concentration ($\times 10^{20}$ cm^{-3})	Laser Efficiency (%)	Gain
N_{21}-1	14	9.8	2.3	17
N_{21}-2	14	6.7	2.4	25
N_{21}-3	13	5.1	2.4	28
N_{21}-4	13	2.0	2.7	48
N_{31}-1	12	7.3	2.6	19
N_{31}-2	13	3.6	2.8	30
N_{31}-3	12	0.5	3.1	60
N_{31}-4	11	0.3	3.2	65

Table 2. The Influence of Fluorescence Lifetime and Absorption in N_{31} on Gain

Sample	Fluorescence Lifetime (μs)	Absorption Coefficient ($\times 10^{-2}$ cm^{-1})	Small Signal Gain Coefficient
N_{31}-5	350	0.10	60
N_{31}-6	350	0.20	57
N_{31}-7	330	0.10	57

At present the absorption coefficients at laser wavelength of the Nd^{3+} glasses finished product are required under 0.0015 cm^{-1}, the fluorescence lifetime at laser wavelength of Nd^{3+} 2.2.-wt% glasses is 340 μs above. Because it is difficult to control the impurities in raw material and melting process, quite a few glasses whose absorption coefficient exceeds 0.0015 cm^{-1} are thrown. For removing water in glasses can be simultaneously monitored, keeping laser amplified properties by increasing fluorescence lifetime and decreasing the request of the absorption coefficient in glasses can increase the finished product probability.

In this letter two domestic phosphate laser glasses (N_{21} and N_{31}) are experimented. The results show that laser gain decreases seriously with increasing OH groups, the small signal gain coefficient is inverse proportional to the concentration of OH groups in glasses. OH groups should be kept under control by real-time monitoring removing water in glasses. It is the direction to improve the laser amplified properties by decreasing the concentration of OH groups.

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