Development of Nd-doped Silica glass with High Thermal Shock Properties for High-average-power Laser

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INTRODUCTION

High-average-power lasers are widely used for material processing, thin film fabrication with ablation, the generation of extreme ultraviolet (EUV) light sources for lithography, and for various scientific research purposes such as plasma physics, high energy physics and an inertial fusion energy. Since there are so many applications for high-power lasers, demand is growing rapidly for more powerful lasers. Laser media used for high average power operation require sustaining heat accumulation generated by high power and repetitive pumping, resulting in thermal stress in a medium and degradation of laser performances.

Nd:YAG laser has very good properties for thermal condition. It, however, has a large stimulated emission cross section, which can induce parasitic oscillations in the medium. Therefore, output energy of Nd:YAG laser is limited to several joules at maximum. On the other hand, phosphate glass laser is able to store large energy (~kJ), but doesn't work at high average power operation because it is very weak on thermal stress. Therefore we have been developing laser medium based on silica glass. Silica glass has high transmittance from near-ultraviolet to near-infrared, high thermo mechanical properties, chemical durability and large scalability in size.

A strong concentration quenching on rare earth ion doping in silica glass has been disturbing to make a laser medium based on silica glass. To reduce this problem, Fujimoto et al. used zeolite as a precursor which assists Nd ions doping homogeneously, and they succeeded reducing concentration quenching [1]. We demonstrated gain characteristics, high stored energy (0.81 J/cm^3) and laser oscillation (154 mJ) in bulk type of Nd doped silica glass (NdSG) for the first time [2, 3].

In this paper, we show the 30 J class laser operation of NdSG for high average power laser.

EXPERIMENTAL

Experimental setup

The sample, NdSG is fabricated by using zeolite method to reduce clustering of Nd ions [1]. The final composition of the sample was measured to be Nd_2O_3: 1.34wt%, Al_2O_3: 2.13wt%, SiO_2: 96.53wt% by X-ray fluorescence analysis. Its thermal shock parameter is calculated to be 12.0 W/cm. This is 1.5 times larger than that of Nd:YAG and 20 times larger than that of phosphate glass [4, 5]. The sample was cut and polished to a rod shape of ϕ30 mm × 300 mm. Both end surfaces were set parallel. The transmittance loss was 27% (0.0105/cm) at 1064 nm, which includes surface reflection because the end surfaces were not coated. A pumping system consists of six flash lamps whose arc lengths were 30 cm.

Gain measurement

A 24-mW Nd:YAG laser (1.06-μm in wavelength) was used as the probe beam. The gain characteristics are shown in Fig.1. The maximum gain of 3.75 was obtained at the electrical input to flash lamp of 18.8 kJ, and the gain coefficient was 0.046 cm^{-1}. The stored energy in the NdSG was calculated to be 124 J, corresponding to the stored energy per unit volume of 0.60 J/cm^3. Since parasitic oscillation was not observed, it is expected that higher stored energy density can be obtained with more energy pumping. Therefore, we can design a compact and a high stored energy density repetitive laser system.

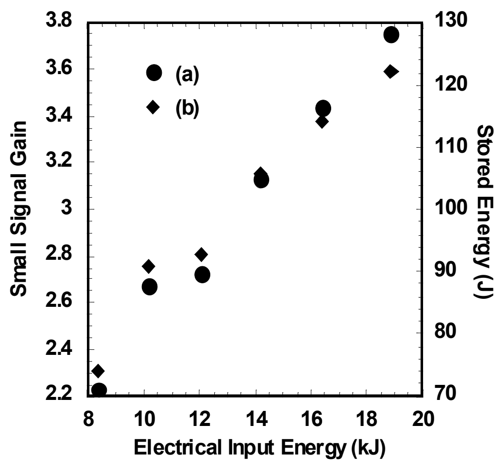

Fig. 1 Gain and stored energy characteristics

(a) Small signal gain, (b) Stored energy

Laser oscillation experiment

We also demonstrated input-output characteristics of laser oscillation as preparing high energy operation (Fig.2). The transmittance of the output mirror was 30%. The maximum output pulse energy was 29 J at 18.8 kJ pumping, oscillation threshold was 6.3 kJ. The extract efficiency was 23.7%

DISCUSSION

We showed that the gain characteristics and the input-output characteristics of NdSG. The stored energy density of this time is smaller than one in Ref.2. It is considered that this is because the pumping energy density is smaller than one in Ref.1, considering the medium volume of this time and one of Ref.2. The stored energy density will be more than 1 J by optimization of medium geometry and concentration of Nd ions, and matching of pumping system. Although the laser rod without AR coatings has the absorption loss coefficient of 0.009/cm at 1064 nm, the maximum output energy of 29 J was obtained. This is 200 times larger than one in Ref. 3.

The obtained output energy of 29 J is small compared with the stored energy of 120 J. The extraction efficiency (laser output/stored energy) is estimated to be 23.7%, by calculation using the following expression [6].

$$\eta = \left(1 - \sqrt{\alpha / g}\right)^2 \qquad (1)$$

where, α is loss coefficient and g is gain coefficient. The calculated value is agreed with the experimental value. Therefore, we can predict laser output energy with loss decreasing in the medium. Figure 3 shows estimation of loss coefficient vs. output energy (@18.8 kJ pumping). The estimated values of laser oscillation energy were calculated using the obtained stored energy and the above expression Eq. (1). As result, the laser output energy of 70 ~ 90 J will be expected with the same pumping energy of this laser oscillation experiment.

It is considered that NdSG is also effective as a high-average-power laser amplifier system, such as an optical booster amplifier for Nd:YAG (10 Hz/ 50 J/ 500 W). Since a high-power Nd:YAG laser with an NdSG booster amplifier can also be adapted for an excitation of a $Ti{:}Al_2O_3$ amplifier and an optical parametric chirped pulse amplification system, it is expected that the realization of a high repetitive sub PW-class table-top laser system will be possible in the future.

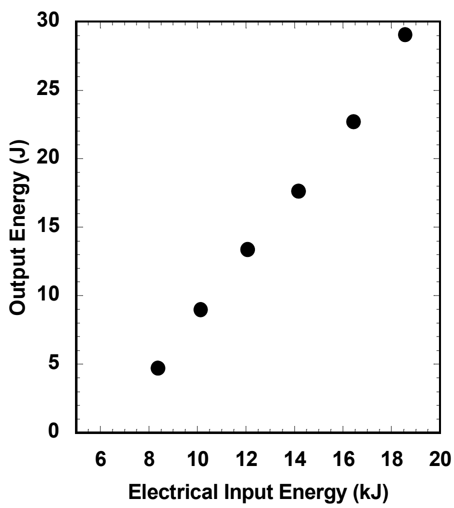

Fig. 2 Input-output characteristics

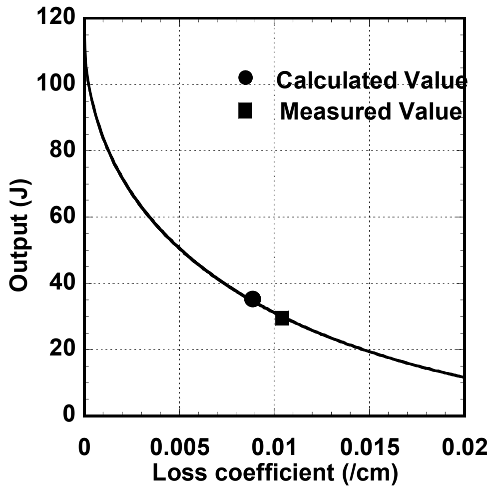

Fig. 3 Loss coefficient vs. output characteristics

CONCLUSION

We demonstrated the gain characteristics (3.75@ 18.8 kJ pumping) and the input-output characteristics of laser oscillation (29 J@ 18.8 kJ pumping) in a bulk-type NdSG with high thermal shock parameter (12.0 W/cm) for repetitive high energy laser operation. Our results encourage to produce a compact, high repetitive, high-energy storage, and high-average-power laser using NdSG.

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