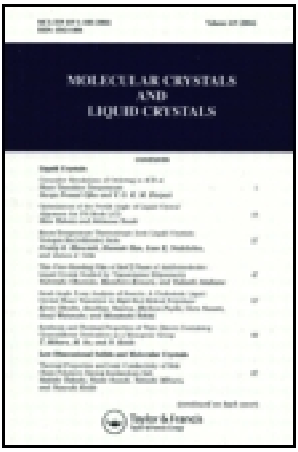

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Laser Action of Nd-Complex-Doped Polymer Laser Based on Liquid

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Laser Action of Nd-Complex-Doped Polymer Laser Based on Liquid

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Nd^{3+} complex doped polymer liquid laser have been demonstrated and the threshold of the laser was also calculated. The calculation results that a laser media with 2 mm length is suitable for low threshold laser oscillation. We obtained the slope efficiency of 20% and the maximum output energy of 5.3 mJ at the pumping energy of 31 mJ by the method of the side pumping. To the best of knowledge, this is the highest slope efficiency of the bulky laser using Nd^{3+} complex.

Keywords Complex; high power; Nd ion; polymer

1. Introduction

Organic materials are promising candidates for integrated optical waveguide with their ease of fabrication, flexible, compatibility with many kinds of photonic and electronic functional molecules. However, materials with low optical loss in visible and near-infrared wavelength region have been combined with fluorescent dyes, and short durability and low-temperature-tolerant. On the other hand, rare-earth-ion-doped oxide materials are currently dominant solid-state laser material due to robust, high optical conversion efficient and high-temperature-tolerant. Thus, rare-earth-ion-complex can be expected as a higher efficient organic laser material than traditional dye. Relatively longer fluorescent lifetime can decrease threshold for continuouswave (cw) laser oscillations. Some works on polymer-based rare-earth-ion-doped planar optical waveguides has resulted in an optical gain [1,2]. Therefore, Er^{3+}-doped [3,4] and Nd^{3+}-doped [5–9] polymer waveguide amplifiers were also reported. However, it is imposing a requirement for high pump powers because of the large fluorescence quenching of the dopant ions. It occurs by coupling of their excited state to high-energy vibrational modes of C-H and O-H bonds in the polymer host. Recently, C. Grivas reported first laser operation of a Nd^{3+}-complex

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doped polymeric laser with a slope efficiency of 2.15% [10]. In the report, a polymer channel waveguide doped with a Nd^{3+}-complex [$Nd(TTA)_3$ phen (TTA = thenoyl trifluoro-acetone, phen = 1,10-phen anthroline)] was used.

In this work, we found novel Nd^{3+}-complex that can demonstrated relatively higher lasing efficiency as high as 20% in slope efficiency. The optical properties and lasing threshold was also evaluated. The laser oscillation was confirmed from organic solutions and polymer blended viscous fluid. The theoretically calculation was also performed. Experimentally, the slope efficiency of 20% and the maximum output energy of 5.3 mJ at the pumping energy of 31 mJ were obtained from a traditional side pumping scheme. To the best of knowledge, this is the highest slope efficiency of the bulky laser using Nd^{3+} complex.

2. Investigation of Optical Properties and Calculation of Laser Threshold

We firstly measured the absorption of Nd^{3+} complex in Figure 1. The absorption is mainly composed of three strong bands around 580, 750 and 800 nm. The absorption around 800 nm is suitable for pumping because the absorption at 800 nm is suitable for high efficiency diode-pumped operation. Additionally, the lifetime of emission was measured, and a lifetime of 25 μs was obtained.

Figure 2 shows the simulation model of laser threshold. This is a Fabry-Perot cavity, and a gain medium is inserted in the cavity without space. Cavity mirrors are used a high-reflectivity mirror and a output coupler with 70% reflectance. The gain medium has 3% reflectance loss. A 802 nm cw (continuous wave) laser is used as a pumping source. The output beam is at the wavelength of 1064 nm. These beams transmit the gain medium in Gaussian mode with the beam waist of 200 μm. The gain medium length (cavity length) and dopant are used for the parameters.

Figure 3 shows the laser threshold simulation result of Nd^{3+}-complex doped polymer laser. Figure (a) shows the laser threshold of Nd^{3+}-complex doped polymer laser versus the concentration of Nd^{3+} complex and the gain medium length. Figure (b) shows the 3D illustration of Figure 2(a). These figures indicated a laser media with 2 mm length is suitable for low threshold laser oscillation. The minimum

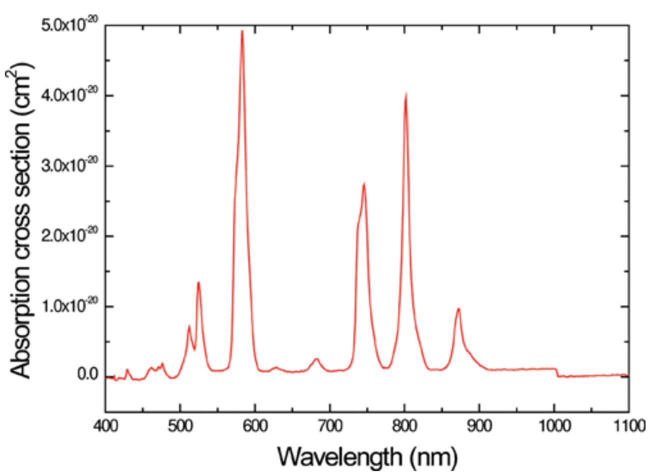

Figure 1. Absorption cross section of Nd^{3+} complex.

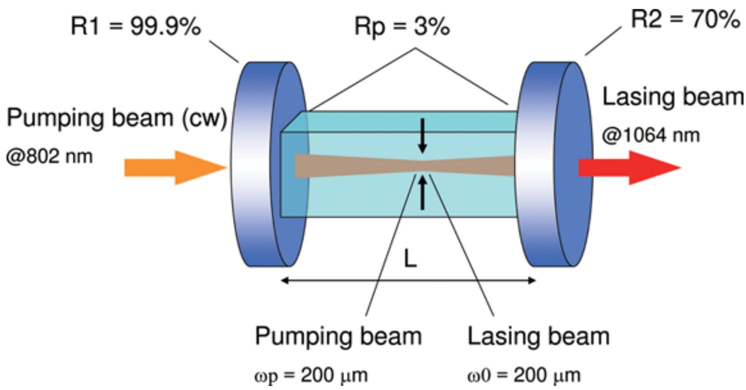

Figure 2. Simulation model of laser threshold.

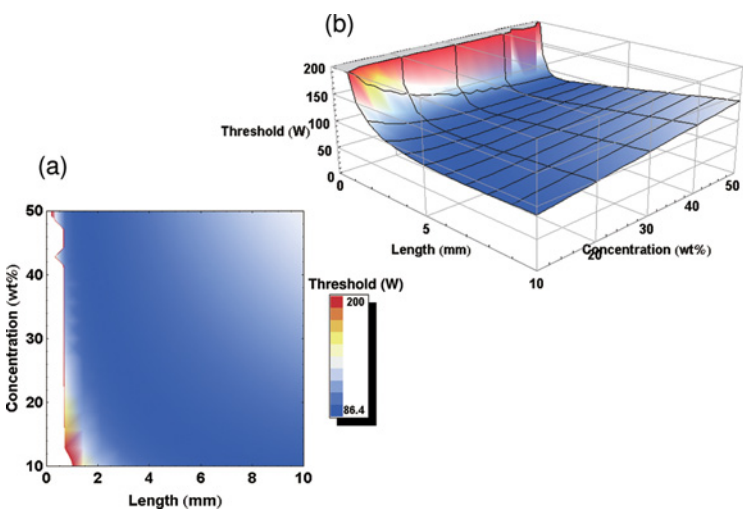

Figure 3. Laser threshold power as function of Nd^{3+} complex concentration and gain medium length.

threshold was 86.4 W. Therefore, it is possible that a laser media more than the concentration of 30 wt% make laser oscillation with low threshold. In this study, we prepared the Nd^{3+} complex in DMAc (N,N-Dimethylacetamide) with the concentration of 30 wt%. Then, the Nd^{3+}-complex doped DMAc was set in a silica cell of 10 mm × 10 mm because the side pumping method was used for easy laser oscillation. In this case, the laser threshold is expected a cw pump power of 103 W or a pumping pulse energy of 2.6 mJ.

3. Experimental Setup

Figure 4 shows the experimental setup of Nd^{3+}-complex doped polymer laser. The polymer host of the Nd ions was produced by TFA (Trifluoroacetic acid). Nd-TFA complex consists of three TFA for one Nd^{3+} ion, and describes as $Nd(OCOCF_3)_3$.

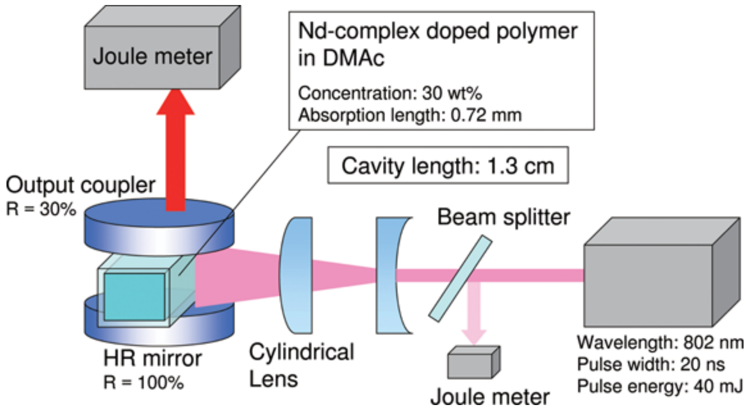

Figure 4. Experimental setup for Nd^{3+}-complex doped polymer laser.

Nd-TFA complex is possible to increase concentration because TFA is smaller than another ligand. Nd^{3+} complex was dissolved into DMAc with the concentration of 30 wt%. The Nd^{3+}-complex doped DMAc was set in a silica cell of 10 mm × 10 mm. The silica cell was placed between a high-reflectivity mirror and a 30% output coupler. The high-reflectivity mirror was antireflection (AR)-coated at 802 nm and had a high reflectivity at 1064 nm. The cavity length was 13 mm. A 802 nm pulsed Ti:sapphire laser pumped by SHG (Second harmonic generation) of Q-switching Nd:YAG laser was used as a pumping source. The maximum pump pulse energy and pulse width was 40 mJ and 20 ns, respectively. The pumping beam was focused onto the silica cell with a beam size of 10 mm × 1 mm using a expandable lens and a cylindrical lens ($f = 60$ mm). A beam splitter was inserted between the expandable lens and the Ti:sapphire laser to monitor pumping beam energy.

4. Experimental Results

Figure 5 shows the dependence of the output energy on the pump energy with the cavity length of 30 mm and 13 mm. When the cavity length was 30 mm, the maximum output energy of 3.7 mJ was obtained at the pumping energy of 43 mJ. However, input and output characteristics were saturated in high pump energy. Therefore, the laser oscillation was not operated below 15 mJ pump energy. When the cavity length was 13 mm, the output energy of 5.3 mJ was obtained at the pumping energy of 31 mJ and the slope efficiency of 20% was obtained. This slope efficiency of 20% is higher than the slope efficiency of 2.15% in ref [10]. The saturation of input and output characteristics was improved in high pump energy using a short cavity from 30 mm to 13 mm. This results that the short cavity of 13 mm reduced the strong thermal lens effect in high pump energy region. Additionally, the laser threshold of the 13 mm cavity was 2.9 mJ pulse energy. This laser threshold energy of 2.9 mJ is close to the simulation laser threshold of 2.6 mJ. However, the lasing threshold of 13 mm was still high with 2.9 mJ. Assuming to pump by pulsed LD (laser diode), output power more than 116 W is required by the relation of $E_p = t_p \times P_p$. E_p, t_p, and P_p are pulse energy, pulse width (lifetime), and peak power (pump power), respectively. The threshold energy is required to be under the 250 μJ

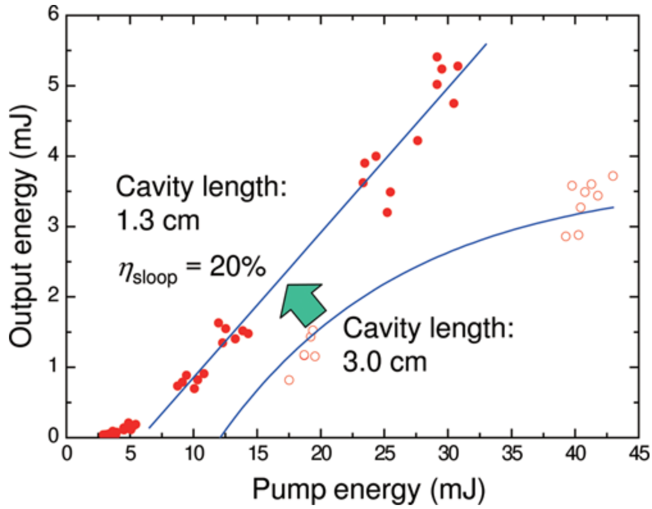

Figure 5. Input-output energy dependence of Nd^{3+}-complex doped polymer laser with the cavity length of 30 mm and 13 mm.

because compact and reusable LDs around the wavelength of 800 nm have maximum output power of 10 W. By the simulation of laser threshold, a laser cavity with Nd^{3+} complex (gain medium) and cavity length of 2 mm is possible to be low threshold under the 250 µJ pump energy.

5. Summary

Nd^{3+}-TFA-complex doped polymer liquid laser have been demonstrated and the threshold of the laser was also calculated. The calculation results that a laser media with 2 mm length is suitable for low threshold laser oscillation. Therefore, it is possible that a laser media more than the concentration of 30 wt% make laser oscillation with low threshold. In the experiment of laser oscillation, we obtained the slope efficiency of 20% and the maximum output energy of 5.3 mJ at the pumping energy of 31 mJ by the method of the side pumping. To the best of knowledge, this is the highest slope efficiency of the bulky laser using Nd^{3+} complex

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