Medium performance effect on the high output energy from a xenon lamp-pumped pyrromethene-567 solid-state dye laser

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In order to obtain a high output energy from a xenon lamp-pumped solid-state dye laser, homogeneities of laser mediums and flatnesses of medium faces with different processing treatments are discussed in the paper. The mediums without aging treatment, which are prepared by using a prepolymer process and have diamond-machined end faces to produce the required optical finish, give a highest laser output of 281.9 mJ with 0.215% slope efficiency at 2.0×10^{-4} mol/L. The best medium lifetime is 21 shots to 50% of original output equating 74.6 kJ/liter.

Keywords: solid dye laser, pyrroinethene-567, xenon lamp excitation, end flatness

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1. Introduction

From the mid-1960s, dye lasers have been found to have various applications in many fields.[1] Solid-state dye lasers, which overcome the disadvantage of liquid ones have developed greatly due to their advantages such as non-toxicity, flammability, low cost, and compactness.[2,3]

To achieve high energy output, the choices of polymer matrices and dyes are very important for lamp-pumped solid-state dye lasers. Polymethylmethacrylate (PMMA) is one of the most commonly used polymeric hosts, which have characteristics of high transparency, being lightweight, easy machining, and high mechanical strength.[4−6] 1, 3, 5, 7, 8 pentamethyl-2, 6-diethylpyrromethene-BF2 (PM567) is a kind of very efficient dye with a high quantum efficiency of 99.5% and a triplet excitation coefficient that is one-fifth that of rhodamine560's.[7]

By far, most of the reported studies relate to a coaxial xenon lamp serving as a pumping source which has low inductance, short rise time and high current density.[8−10] However, a large size of medium needs a special order coaxial xenon lamp, which leads to high prices and going against the miniaturization of dye lasers. In the meantime, a laser without a cavity makes its practicality poor, as it is limited to laboratory usage. Considering the deficiencies of these devices, a tubular xenon flash-lamp is adopted in the experiment, which has advantages such as low cost and high availability over a coaxial one. Fast charge power systems which are used for driving the xenon lamps are designed and built by us.

2. Experimental setup

Bulk polymerization was adopted in the experiment, polymethylmethacrylate (PMMA) and azobisisbutyronitrile (ABIN) were used as the polymer and the initiator, respectively.[11,12] In order to eliminate the bubbling and discoloring of mediums during the polymerizationprocess, prepolymerization was used in experiment, which has a lower volume shrinkage ratio (8%–12%), better uniformity, and a shorter polymerization time (1 day–2 day) than normal bulk polymerization (volume shrinkage 25%–40%, 5 day–7 day polymerization).

Laser testing of solid state dye was carried out by placing a solid-state medium inside 110-mm diffuse reflection compact cavity with polytetrafluoroethylene (PTFE). Two tubular xenon flashlamps each with an arc length of 100 mm, an inner diameter of 4 mm, gas pressure of 450 Torr (1 Torr=1.33322×10^2 Pa) were used as pumping sources. Each lamp was driven from a 0.5-μF capacitor charged to 20 kV–28 kV, giving an input energy of 100 J–196 J. The resonator was plane-plane with a 50% output coupler (500 nm–700 nm)

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and a 100% rear mirror (520 nm–680 nm), and the length measured between the mirrors was 320 mm. Alignment of the cavity was realized by the use of an auxiliary He–Ne laser beam (633 nm). Figure 1 shows the schematic diagram of the xenon lamp pumped dye laser.

A crystalline pyroelectric energy meter, Newport Model 818J-25B, was used to measure the output energy. The output voltage was measured by using a Tektronix digital oscilloscope, model DPO 4054. Molecular weight was measured by using an Aligent GPC, model 1100. Flatness of the medium face was measured by using a Sygo laser interferometer, model GPITM XP/D. A Pearson Rogowski coil (Model 101) was used to measure the discharge current waveform of the xenon lamp.

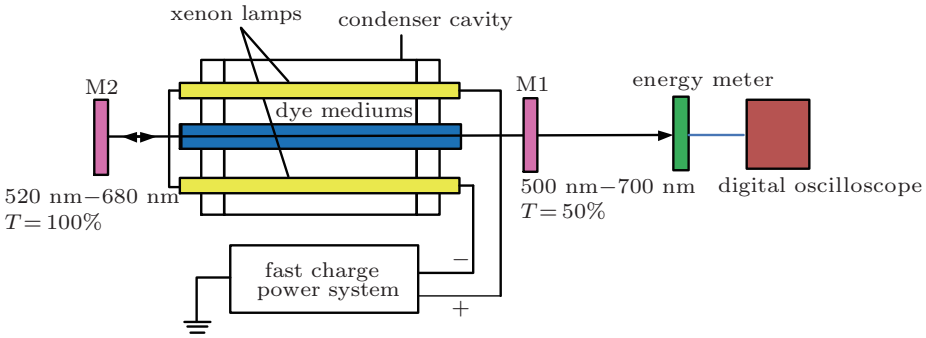


Fig. 1. (colour online) Schematic diagram of the xenon lamp pumped dye laser.

Figure 2 shows the discharge current waveforms of the xenon lamp at different input voltages. Their rise times are close to 1 μs and the waveforms are similar to the critical damping ones, so the requirement for an upper state lifetime of dye that can achieve high efficiency laser output can be satisfied.

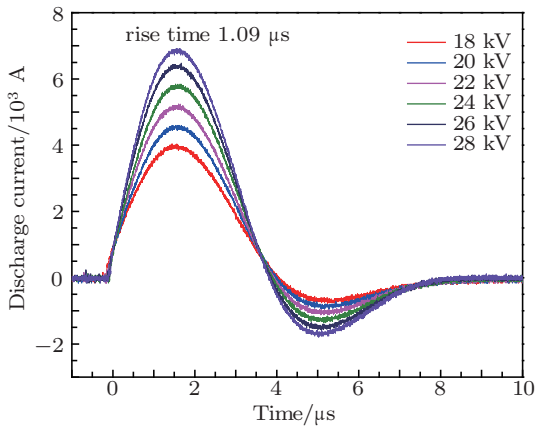


Fig. 2. (colour online) Discharge current waveforms of xenon lamp at different input voltages.

3. Experimental results and discussion

For the preparation of a medium usually an aging treatment and pre-polymerization are adopted. We discuss whether these two methods are suited for achieving a high output energy. Molecular weights of mediums with different processing treatments were studied first, which is important for high energy output. Molecular weights of different parts of medium are measured by using an Aligent GPC in order to obtain the molecular weight distribution. Tetrahydrofuran was selected as the mobile phase with the flow rate being 1 mL/min. Columns of Agilent 101 and 104 in series were used to separate the polymer solution according to molecular sizes, with the temperature maintained at 30 °C. The temperature of the differential refractometer, which was used for detecting the concentration of the liquid sample from the column, was 35 °C. Polystyrene was used as a standard sample. Agilent Addon software (version Rev.A02.02) was used to calculate the molecular weight of polystyrene with leaching time, and a standard calibration curve was obtained by taking the logarithm of the molecular weight. Figure 3 shows the standard calibration curve of a standard sample.

Peak values of samples, which were read from their gel permeation chromatograms, were taken to plot the standard calibration curve, molecular weights of samples were obtained by taking the antilog values. Molecular weights of laser mediums with different processing treatments were shown in Table 1 (PP Pre-polymer; Ag Aging).

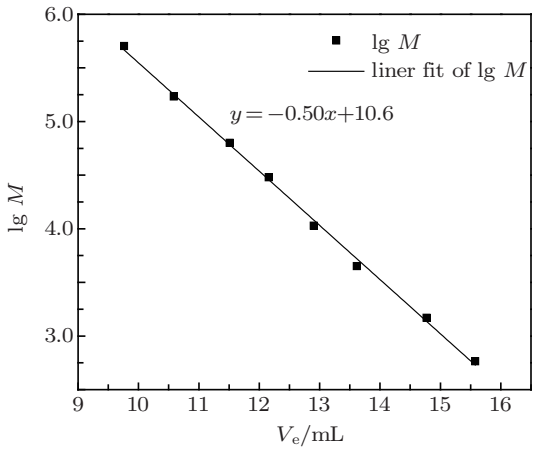


Fig. 3. Standard calibration curve.

Table 1. Molecular weights (MWs) of different parts of laser mediums with different processing treatments.

Sampling location	MW (PP, AG)	MW (PP, no-Ag,)	MW (no-PP, no-Ag)
Top	374311.25	750239.90	279188.34
Middle part	446132.89	894193.52	593146.10
Bottom	393452.08	603167.59	666954.06

A medium with an aging treatment has less fluctuation of molecular weight than that without the aging treatment, as indicated in Table 1; while the molecular weight of a medium with an aging treatment is much lower than that without an aging treatment. For the experiment with thermal-oxidative aging treated medium, the medium interacts with oxygen in high temperature conditions, which leads to the macromolecular chain being broken or crosslinked. So as the aging time increases, the molecular weight distribution becomes narrower, and the molecular weight becomes smaller at the same time. Although the purpose of the aging treatment is to eliminate the internal stress of medium, the mechanical strength of mediums is also additionally reduced. The most important thing is that the change of the internal structure of mediums is prone to a negative lens effect in the aging process which has an influence on laser output. Conclusively, aging treatment is not suitable for achieving high energy output.

The molecular weight of a laser medium without being processed by the pre-polymer method has bigger disparities of different parts (see Table 1) than that without being processed by the pre-polymer method. A broad molecular weight distribution of medium has better processability than a narrow one, but the lower the molecular weight of contained polymer, the more severe the stress cracking is. Meanwhile there exists an adverse effect on transparency of the medium, which is very important for laser high energy output. In summary, the pre-polymer method is important for improving the medium performance.

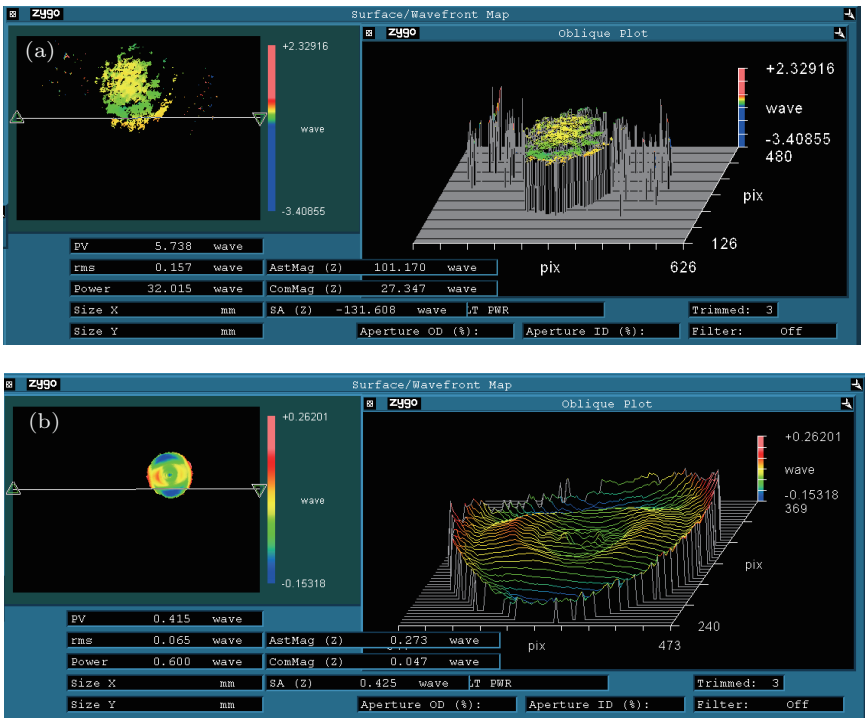


Fig. 4. (colour online) Influence of polishing device on the flatness of the medium face. (a) End face polished by common polishing equipment. (b) End face polished by using a diamond lathe.

Different polishing devices have different influences on the flatness of the medium face as shown in Fig. 4. It can be seen that the face flatness of a medium polished using a diamond lathe is much better than that by using the common polishing equipment.

Table 2 shows the end face flatness of different mediums. The rods were selected for highest output energy under different conditions. Rod 1 was prepared by a prepolymer process but not treated through aging, and its end faces were diamond machined; rod 2 was prepared by prepolymer process and treated through aging, and its end faces were diamond machined; rod 3 was prepared by a prepolymer process and not treated through aging, and its end faces were polished by using a common polish device; Rod 4 was prepared neither by prepolymer process nor by treatment through aging, and its end faces were diamond machined.

Table 2. Flatness of an end face with different mediums.

Polymer rods	Flatness of end Face 1 (PV)	Flatness of end Face 2 (PV)
1	0.368	0.796
2	0.316	0.482
3	6.896	5.491
4	0.487	0.553

The laser was operated in a single shot regime with an interval of 5 min between two shots to avoid accumulative radial thermal gradients. No correction for a thermal lens was introduced in the resonator. The variations of output energy with processing treatment under the same molar concentration (2×10^{-4} mol/L) and same diameter (7 mm) are shown in Fig. 5.

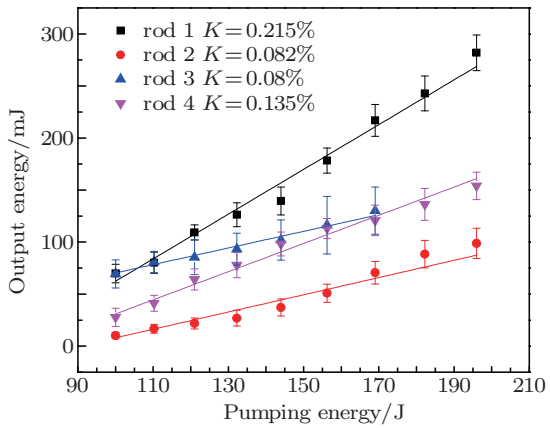


Fig. 5. (colour online) Plots of output energy versus flashlamp input energy for different rods.

The results show that rod 1 polished using diamond lathe obtains a higher output energy than rod 3 polished by a common polishing device. Compared with an ordinary polishing device, a diamond lathe can make a medium achieve high-dimensional accuracy and surface accuracy, which may reduce bulk loss and improve laser efficiency. Rod 2 has an aging treatment gas lower laser output than rod 1, which confirms the analysis of previous experimental data. The output energy of rod 4 is much lower than that of rod 1 under the same condition. Based on previous experiments, it is known that mediums without prepolymers have disadvantages: bad transparency and dye stratification which has an adverse effect on energy output. So, of those rods, rod 1 offers the highest laser output of 281.9 mJ with 0.215% slope efficiency.

The lifetime of a medium with a processing treatment was measured at an input energy of 196 J with an interval of 5 min between shots unless otherwise indicated. Figure 6 shows that the degradation in performance is due to both thermal effects and dye degradation, meanwhile the thermal effects are reversible. From this the lifetime to 50% of the original output was calculated to be 21 shots equating 74.6 kJ/liter. The lifetime is 21 shots to 50% of the original output.[9]

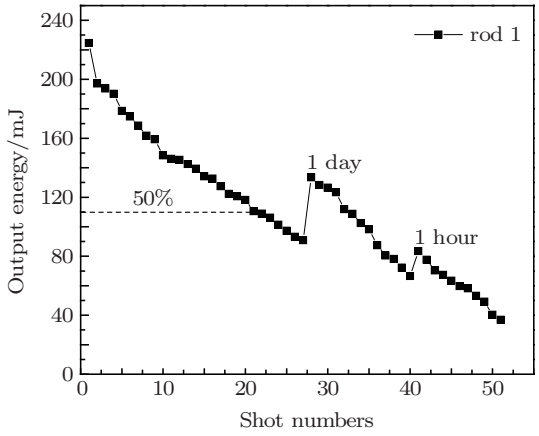


Fig. 6. Degradation of laser energy output.

4. Conclusion

This paper deals with the preparation, the characterisation, and the comparative laser testing of rods containing PM567 dyes. The experimental equipment is general industrial products, and a fast charge power system of xenon lamps is designed and built by ourselves. The mediums, which are prepared by prepolymer process without aging treatment and whose end faces were diamond machined to produce the required optical finish, can achieve a highest laser output of

281.9 mJ which is pumped with an input energy of 196 J with 0.215% slope efficiency at 2.0×10^{-4} mol/L. The lifetime is 21 shots to 50% of the original output equating 74.6 kJ/liter.

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