Characteristics of xenon-lamp pumped pyrromethene 567-doped dye laser based on polymethylmethacrylater

Wang Lei(王 磊), Chen De-Ying(陈德应)†, Xia Yuan-Qin(夏元钦)
Fan Rong-Wei(樊荣伟), and He Wei-Ming(何伟明)

National Key Laboratory of Tunable Laser Technology, Harbin Institute of Technology, Harbin 150001, *China*

(Received 15 April 2011; revised manuscript received 21 June 2011)

The solid-state medium containing pyrromethene 567 (PM567) in a polymethylmethacrylate polymer host is shown to lase under the flash lamp excitation. The experimental setup is an ordinary industrial product without special design. The bulk transmission losses, the output energy, and the other lasing properties are compared. The medium with the lowest transmission loss, measured to be 0.392 %/cm at 633 nm, gives a laser output of 130 mJ with a slope efficiency of 0.082%.

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

PACS: 42.55.Mv, 2.70.Jk, 42.60.Lh **DOI:** 10.1088/1674-1056/21/1/014206

1. Introduction

Since the mid-1960s, dye lasers have been found to have applications in a wide variety of fields.[1] The liquid dye laser is a coherent source of radiation with advantages such as wide tuning range, high power output, high pulse energy, and wide choice of pumping sources. Since the first realization of solid dye lasers by Soffer and Mcfarland[2] and Peterson and Snavely,[3] the solid dye lasers have developed greatly due to their advantages over liquid ones, such as easy handling, low cost, the elimination of flammable and toxic solutions, and the ability to engineer a compact and rugged laser system.[4−8]

A number of studies have been reported using a variety of different solid state hosts including polymers,[6−9] sol-gels,[10] ormosils,[11−12] inorganic glasses,[13] and so on. The polymer is a kind of attractive host for laser dyes, because it has some advantages over the other hosts, such as high transparency in pumping and lasing ranges, superior optical homogeneity, better chemical compatibility with organic dyes, and easy control of the chemical process. The polymethylmethacrylate (PMMA) is one of the most commonly used polymeric hosts, and it has high transparency in the visible region of electromagnetic spectrum. The 1, 3, 5, 7, 8 pentamethyl-2, 6-diethylpyrromethene-BF2 (PM567) is a kind of very efficient dye with a high quantum efficiency (99.5%) and a triplet excitation coefficient that is one-fifth of rhodamine560's.

Most of the previous studies are related to special ordered coaxial xenon lamps, thus the full width at half maximum (FWHM) of the discharge current waveform is relatively narrow (< 2 μs).[14−16] However, media of different sizes need different coaxial xenon lamps correspondingly, which leads to the high cost of the dye laser and requires much time to produce the components. Meanwhile, the structure with no cavity makes its usability poor. Considering the faults of those devices, in this paper, we use tubular xenon flash lamps, which can make up for disadvantages of the coaxial ones and have advantages such as easy assembling, low cost, and high availability. Our design can satisfy the operation requirements for the whole device and reduce the cost effectively.

2. Experimental setup

The methyl methacrylate (MMA) was purified by using the method mentioned in Ref. [4]. A proper amount of PM567, which was bought from Exciton, was dissolved under sonication into the freshly prepared PMMA, then we obtained a solution with an initial concentration of $1.5–3 \times 10^{-4}$ mol/L. Using the azoisobutyronitrile (AIBN) as the radical initiator, the mixture was again sonicated. Generally, the solution

†Corresponding author. E-mail: alonwang@yahoo.cn

© 2012 Chinese Physical Society and IOP Publishing Ltd

was filtered into a glass tube and then sealed within. The polymerization was performed in a thermostatic bath at 40–45 °C until solidification (5–7 days).[17−18] However, this polymerization has some disadvantages, such as long preparation time, heterogeneous polymerization, and uneven dye distribution. The pre-polymer method was adopted instead of the original method in this paper. First, the beaker with solution was placed in a thermostatic bath at 80 °C after the PM567 and the AIBN had been sonicated in the MMA solution. The solution was stirred constantly until the solution became viscous (when the string stick was taken out of the solution, the liquid flew down into the strip), which might take 20–30 min. Second, the beaker was cooled down to room temperature. Then solution was poured into a vacuum bottle, which was evacuated until there were no more bubbles in the solution (15–25 min). Finally, the solution was filtered into a silanized glass tube, which eliminated the carrier surface binding energy of the hydrogen bonds in order to avoid the absorption effect in the process of polymerization, then sealed and performed in a thermostatic bath at 40 °C until solidification (1–2 days). Figure 1 shows the unprocessed PM567 solid state dyes based on the polymers (pre-polymer and original methods with the same volume of PMMA solution before the polymerization). The polymers in the original method are 20% shorter than that in the pre-polymer method; meanwhile with the original method, there appears the phenomenon of dye stratification. The pre-polymer method reduces the volume shrinkage during polymerization for eliminating internal stress of the media and releases a mass of polymerization heat before solidification, thereby ensuring the quality of the products.

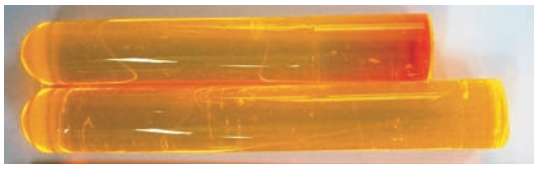


Fig. 1. (colour online) Unprocessed PM567 solid state dyes based on polymers (pre-polymer and original).

The laser test of the solid state dye was carried out by placing media in a 110 mm polytetrafluoroethylene condensing cavity. We used two tubular xenon flash lamps, each with arc length 100 mm, internal diameter 4 mm, and inner gas pressure 200 torr (2.67×10^4 Pa). The lamps were located in an ellipsoidal condenser cavity and were power-supplied by 0.5 μF capacitors charged to 18–26 kV with the energy of 81–169 J. The resonator was plane–plane with a 50% output coupler (500–700 nm) and a 100% rear mirror (520–680 nm), and the length measured between the mirrors was 320 mm. The alignment of the cavity was aided by the use of an auxiliary He–Ne laser beam (633 nm). A crystalline pyroelectrics 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. Figure 2 shows the schematic diagram of the flashlamp pumped dye laser (FPDL).

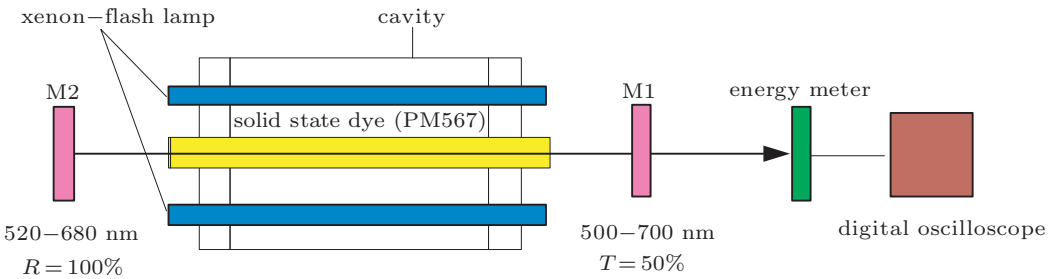


Fig. 2. (colour online) Schematic diagram of FPDL.

3. Experimental results and discussion

Bulk transmission losses are the key to obtain a high laser efficiency. It has been shown that bulk losses of less than 0.5 %/cm are required to obtain a good laser efficiency.[19] The formula is

$$\mu = 100 \ln\left(\frac{0.924}{T}\right)/L, \tag{1}$$

where T is the transmittance, and L is the length of the medium. In our case, the solid dye medium transmittance was measured by using the He–Ne laser as the transmitted light, as shown in Fig. 3. As the out-

put power of the He–Ne laser was unstable, we split the laser into two light beams with a spectroscope, one was used as the measurement light, the other as the reference light. The two beams had the same optical path lengths. The output power was measured with a coherent power meter, model PS19Q, which was connected to a display device (EMP2000). The mathematical expression of transmittance is

$$T = \frac{W_2 W_4}{W_3 W_1}, \tag{2}$$

where W_1 and W_2 are the powers of the measurement and the reference lights with the solid dye medium, W_3 and W_4 are the powers of the measurement and the reference lights without the solid dye medium. The T has been averaged over repetitive measurements.

Bulk transmission losses of the pre-polymer solid dye medium were measured by using the above method. The measurement results are shown in Table 1. All of the media are pre-polymerization. The medium at 1.5×10^{-4} mol/L has a similar bulk loss to that of the medium at 2.0×10^{-4} mol/L, which is measured to be about 0.5 %/cm as shown in Table 1. Medium 4 has the lowest transmission loss, measured to be 0.392 %/cm at 633 nm. The bulk loss increases with the growth of the molar concentration when the molar concentration is over 2.0×10^{-4} mol/L. The increased loss may lead the laser efficiency and the output energy to decrease, which has an adverse effect on the solid dye laser.

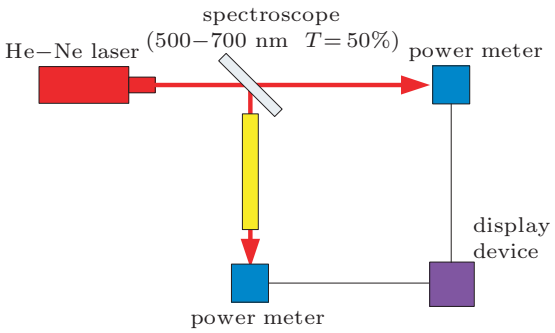


Fig. 3. (colour online) Schematic diagram of solid dye medium transmittance measurement.

Table 1. Measurements of PM567-doped laser medium bulk loss.

Medium	Concentration /10^{-4} mol L^{-1}	Length /cm	Transmittance at 633 nm /%	Bulk losses at 633 nm /% cm^{-1}
1	1.5	11	85.2	0.738
2	1.5	11	87.3	0.527
3	1.5	11	88.1	0.433
4	2.0	11	88.5	0.392
5	2.0	11	86.7	0.579
6	2.0	11	84.4	0.823
7	2.5	11	79.8	1.333
8	2.5	11	78.5	1.482
9	2.5	11	76.2	1.752
10	3.0	11	67.2	2.895
11	3.0	11	68.3	2.747
12	3.0	11	70.5	2.459

The laser was operated in the single shot regime at 5-min intervals to avoid the thermal effects. In order to obtain a higher output energy, a tight-type condenser was used in the experiment. It was close to the lamps and the medium, and its cross-sectional dimensions were slightly larger than the sum of the lamp and the medium diameters, which led to a high efficiency. A shot was taken at an input energy of 81 J and step by step increased to 169 J, which can be seen in Fig. 4. As the diameter decreases, the energy output increases. Particularly, when the diameter is 7 mm, the output energy is much higher than the others. When the diameter is smaller than 7 mm, there is serious negative lens effect, which causes the laser output energy to decrease dramatically.

Figure 5 shows the variation of the dye medium output energy with the molar concentration in the case of same inner diameters. These measurements, which were taken a number of shots after the initial energy measurements, show the highest output energy of 130.2 mJ and a slope efficiency of 0.082%. The output energy increases with the growth of the molar concentration up to 2.0×10^{-4} mol/L, and then decays if the molar concentration grows further. These data confirm the previous results obtained by the bulk loss experiment. As the molar concentration increases, the bulk loss turns higher, which leads to a lower laser efficiency.

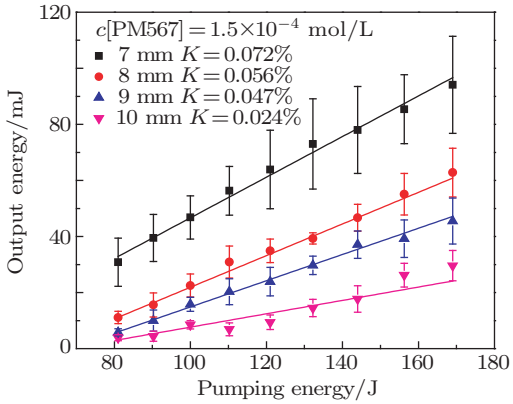


Fig. 4. (colour online) Output energies against input energy for different media.

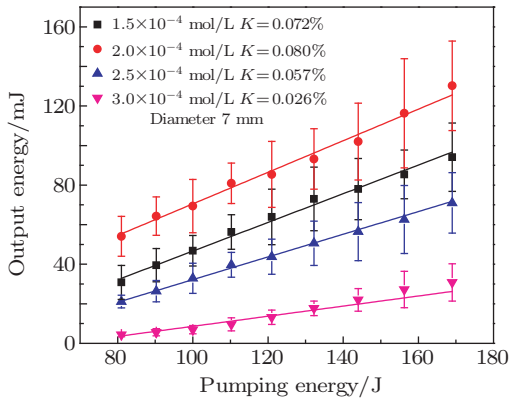


Fig. 5. (colour online) Output energies against input energy for different molar concentrations in the case of same diameter.

4. Conclusion

In this paper, we improve the process of solid state dye media and test their bulk losses and uniformity. A low-cost normal industrial product is used to implement the high energy output (130.2 mJ). The slope efficiency approximately reaches 0.082% in the case with 2.0×10^{-4} mol/L molar concentration, 7 mm diameter, tight-type diffuse reflection cavity, and plant–plant resonator. Meanwhile, we show that the output energy is dependent on the molar concentration and the medium diameter.

References

[1] Duarte F J and Hillman L W 1990 *Dye Laser Principles* (San Diego: Academic Press)

[2] Soffer B H and McFarland B B 1967 *Appl. Phys. Lett.* **10** 266

[3] Peterson O G and Snavely B B 1968 *Appl. Phys. Lett.* **12** 238

[4] Costela A, Garcia-Moreno I and Sastre R 2003 *Phys. Chem. Chem. Phys.* **5** 4745

[5] Susdorf T, del Agua D, Tyagi A, Penzkofer A, Garcí O, Sastre R, Costela A and García-Moreno I 2007 *Appl. Phys.* B **86** 537

[6] Costela A, Garcia-Moreno I and Figuere J M 1996 *Opt. Commun.* **130** 44

[7] Hermes R E, Allik T H and Hutchinson J A 1993 *Appl. Phys. Lett.* **63** 877

[8] Singh S, Kanetkar V R, Sridhar G, Muthuswamy V and Raja K 2003 *J. Luminescence* **101** 286

[9] Sastre R and Costela A 1995 *Adv. Mater.* **7** 198

[10] Salin F, Le Saux G, Georges P, Brum A, Bagnall C and Zarzycki J 1989 *Opt. Lett.* **14** 785

[11] Altman J C, Stone R E, Dunn B and Nishida F 1991 *IEEE Photonics Technol. Lett.* **3** 189

[12] Canva M, Georges P, Perelgritz J F, Brum A, Chaput F and Boilot J P 1995 *Appl. Opt.* **34** 428

[13] Costela A, Garcia-Moreno I, Gomez C, Carcia O and Sastre R 2003 *Chem. Phys. Lett.* **369** 656

[14] Finlayson A J, Peters N, Kolinsky P V and Venner M R W 1998 *Appl. Phys. Lett.* **72** 2153

[15] Finlayson A J, Peters N and Kolinsky P V 1999 *Appl. Phys. Lett.* **75** 457

[16] Finlayson A J and Venner M R W 2000 *Proc. SPIE* **3929** 154

[17] Li X H, Fan R W, Xia Y Q, Liu W and Chen D Y 2007 *Chin. Phys.* **16** 3681

[18] Liu W, Fan R W, Li X H, Chen H, Li X H and Chen D Y 2007 *Acta Phys. Sin.* **60** 024207 (in Chinese)

[19] Minnigh S W, Pacheco D P, Burke J G, Dunleavy P V, Aldag H R and Ehrlich J J 1996 *Proc. SPIE* **2698** 2