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Solid-state active media of tunable organic-compound lasers pumped with a laser. II. A copper vapor laser

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ABSTRACT The lasing properties of organic compounds in a polymethylmethacrylate matrix pumped by a copper vapor laser are studied. The results demonstrate that the transverse pumping scheme of solid-state laser-active media with the copper vapor laser is promising compared to the longitudinal pumping scheme from the viewpoint of the lifetime parameters.

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1 Introduction

In the last few years, there has been a remarkable surge of interest in the development and preparation of solid-state organic-compound laser-active media that substitute for liquid-compound media of tunable lasers, thereby making their application more convenient and safe. Much progress has been achieved by the investigators due to considerable recent advances in synthetic science. Thus, a new class of dyes (pyrromethenes) was synthesized late in the 1980s. These dyes pumped with the second harmonic of a Nd laser allowed one to excite efficient and stable generation of solid-state dye-active media in the visible range of the spectrum (from green-yellow to red), with the lasing parameters highly competitive with the corresponding parameters of liquid-dye media [1, 2]. To solve a number of applied problems (including laser sensing of the atmosphere and isotope separation), high-frequency tunable pulsed laser radiation must be used and, in this respect, a copper vapor laser (CVL) is the unique source for pumping of organic compounds.

However, only a few works were devoted to the feasibility of preparation of solid-state organic-compound laser active media pumped by the copper vapor laser. Here we mention some of these. Thus, in 1986, a solid-state active medium based on a $\Phi 1\backslash$ compound in polyurethane was excited with quasi-longitudinal pumping by the copper vapor laser (with an output power of 1.6 W and a pulse-repetition frequency of 12 kHz) with a lasing efficiency of 3.5%, $\lambda_{las} = 610$ nm, and an operating lifetime of 6×10^6 pulses [3]. In 2000, we obtained transverse excitation of phenalemine 512 in modified polymethylmethacrylate (MPMMA) pumped with the copper vapor laser ($\lambda_1 = 510.6$ nm, $\lambda_2 = 578.2$ nm, an average output power of 2 W, and a pulse-repetition frequency of 12 kHz) [4]. In the latest work [5] devoted to this problem, the feasibility of conversion of CVL radiation in a solid-state active medium based on pyrromethene 567 in polymer matrices of different compositions was studied. The longitudinal-excitation scheme was used, and only the green line was converted. The laser output power was 290 mW and the pulse-repetition frequency was 1 kHz. The maximum lasing efficiency was 37% and the operating lifetime (during which the laser output power halved) was 1.8×10^6 pulses. The element pumped with a radiation power of 1 W at a frequency of 6.2 kHz operated for a short time.

In the present work we continue our investigations started in [4] and aimed at the development and preparation of solid-state organic-compound laser-active media capable of operating with transverse pumping with the copper vapor laser. Transverse excitation of the laser element is primarily due to reduced radiation and heat loading of the active element of the dye laser. This is caused by the increasing area of focusing of the pump beam, which increases the operating lifetime of the active element. Of great importance is the dependence of the energy parameters of the dye laser on the relative energy content of the yellow line, which often falls within the dye amplification band, in the pump radiation. This effect is most strongly manifested for longitudinal excitation of the active medium [6]. In addition, the transverse-excitation scheme of dyes possessing high induced absorption is preferred compared to the longitudinal-excitation scheme. In the latter case, this effect influences significantly the energy parameters of the dye laser.

2 Experiment

We investigated phenalemine 512 (Ph-512), rhodamine 101 (Rh-101), rhodamine 11B (Rh-11B), and P-220 compounds in the MPMMA matrix (Fig. 1). The maximum of the Ph-512 absorption band was recorded at 540 nm, for Rh-101 it was at 575 nm, and for P-220 it was at 510 nm. The maximum of the Ph-512 fluorescence band was recorded at 590 nm, for Rh-101 it was at 620 nm, and for P-220 it was at 625 nm. The copper vapor laser emitted two lines (green and yellow); the output radiation power was 3 W, the pulse du-

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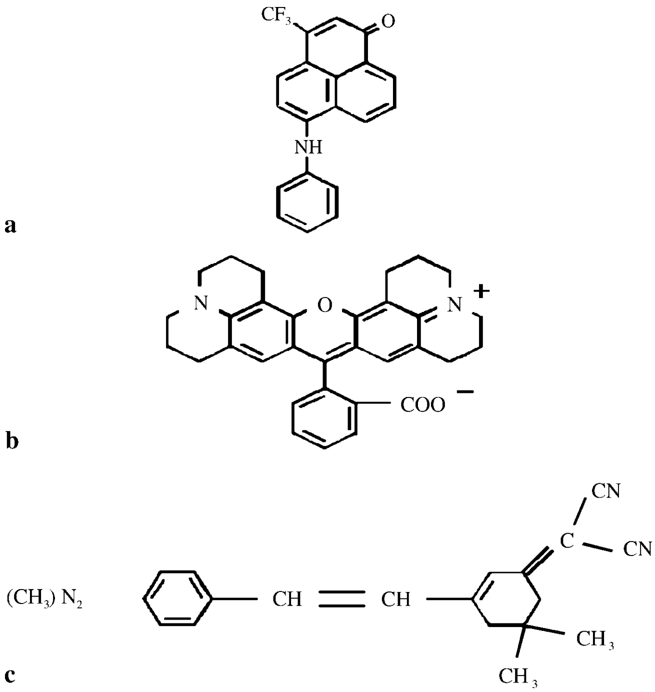

FIGURE 1 Structural formulas of the examined compounds: phenalemine 512 (**a**) , rhodamine 101 (**b**) , and P-220 (**c**)

ration at half-maximum was 35 ns, and the pulse-repetition frequency was 8–14 kHz. The transverse-pumping scheme (Fig. 2) was used. The solid-state laser-active element was shaped as a disc 30 mm in diameter with a thickness of 10 mm and with a central rotating shaft. The laser cavity consisted of a nontransparent spherical mirror ($r = 4$ cm), a spherical lens ($f = 4$ cm), and a flat output mirror ($R = 8\%$). The laser degree of purity of the sample surface was not reached. The energy and time radiation characteristics, emission spectra per pulse, and absorption and fluorescence spectra were recorded. The photostability of the active medium was estimated as the operating lifetime $P_{0.5}$, numerically equal to the energy absorbed by the active medium of unit volume before its efficiency halved, or to the number of CVL pulses generated before the lasing efficiency halved. The irradiated area of the element was $\sim 10\,\mathrm{cm}^2$. In this case, the excitation radiation power density was $3 \times 10^{-3}\,\mathrm{J/cm}^2$. To investigate the lifetime characteristics of the active element, we used a setup shown in

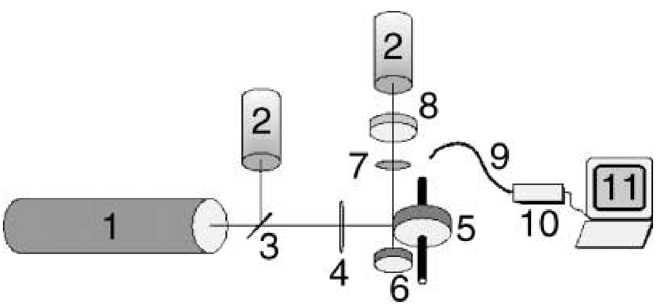

FIGURE 2 Block diagram of the experimental setup comprising pumping laser 1, IMO-2N calorimeter 2, light-dividing plate 3, cylindrical lens 4, active element 5 with the rotating central shaft, spherical mirror ($R_{\mathrm{nontr}} = 100\%$) 6, lens 7, flat output mirror ($R_{\mathrm{out}} = 8\%$) 8, light guide 9, laser spectrometer 10, and personal computer 11

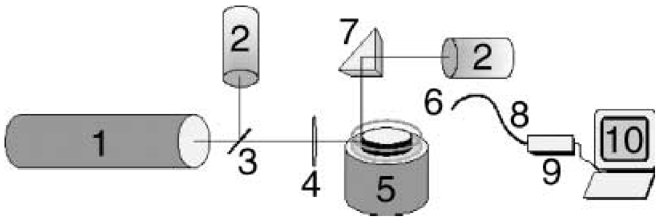

FIGURE 3 Block diagram of the experimental setup for investigating the operating lifetime comprising pumping laser 1, IMO-2N calorimeter 2, light-dividing plate 3, cylindrical lens 4, turntable 5, active element 6 in the plane-parallel cavity ($R_{\mathrm{nontr}} = 100\%$ and $R_{\mathrm{out}} = 8\%$), prism 7, light guide 8, laser spectrometer 9, and personal computer 10

Fig. 3. The sample was shaped as a washer 32 mm in diameter and 8 mm in thickness. The washer was inserted into a plane-parallel cavity and fixed in it so that the sample and the cavity form a unit mounted on a turntable. Beats of the turntable rotation shaft, inexact geometry of the washer, and insufficient purity of surface treatment led to partial misalignment of the cavity and decreased the lasing efficiency. Therefore, this experiment was aimed at investigating the lifetime of the material.

3 Discussion of results

The results obtained are tabulated in Table 1. Figure 4 shows the laser-induced fluorescence and emission spectra of Ph-512 pumped with a CVL. It can be seen that the maxima of the lasing and fluorescence bands remain virtually unchanged during the irradiation period, which indicates the stability of the dye-laser wavelength. Analogous results were also obtained for other compounds. The maximum efficiency of the conversion of pump radiation equal to 20% was recorded for phenalemine 512 ($C = 2.6$ mmol/L); it was 18% for rhodamine 11B ($C = 1$ mmol/L). For Ph-512, $\lambda_{\mathrm{las}} =$ 608–612 nm depending on its concentration, and for Rh-11B, $\lambda_{\mathrm{las}} = 598$–$600$ nm. In the experiment, the operating lifetime of solid-state laser active media based on phenalemine 512 and rhodamine 11B was $N = 9 \times 10^7$ pulses and considerably exceeded the well-known results ($N = 6 \times 10^6$ pulses [3] and $N = 1.2 \times 10^6$ pulses [5]).

The efficiency of radiation conversion in the P-220 compound was not optimized; the solid-state active medium gen-

Dye	C, mmol/L	Efficiency, %	$\lambda_{\mathrm{las}}^{\max}$, nm	Time, h:min	P_{50}, pulses
Ph-512	10	6.5	612	1:50	6.6×10^7
Ph-512	3.6	3	610	6:00	2×10^8
Ph-512	2.5	4.5	610	5:00	1.8×10^8
Ph-512*	2.6	20	608	2:30	9×10^7
П-220	2.5	1.6	655	0:16	10^7
П-220**	2.5	1.8	655	2:30	9×10^7
П-220**	1	0.45	655	0:25	1.5×10^7
Ph-101	2.3	12	650	3:00	10^8
Ph-101	1	7.2	650	2:30	9×10^7
Rh-11B*	0.75	0.73	598	1:30	5.4×10^7
Rh-11B*	1	18	–	2:30	9×10^7

* Setup No. 1 (Fig. 2)
** Air cooling of the sample was used

TABLE 1 Lasing characteristics and operating lifetimes of the examined compounds pumped with the CVL

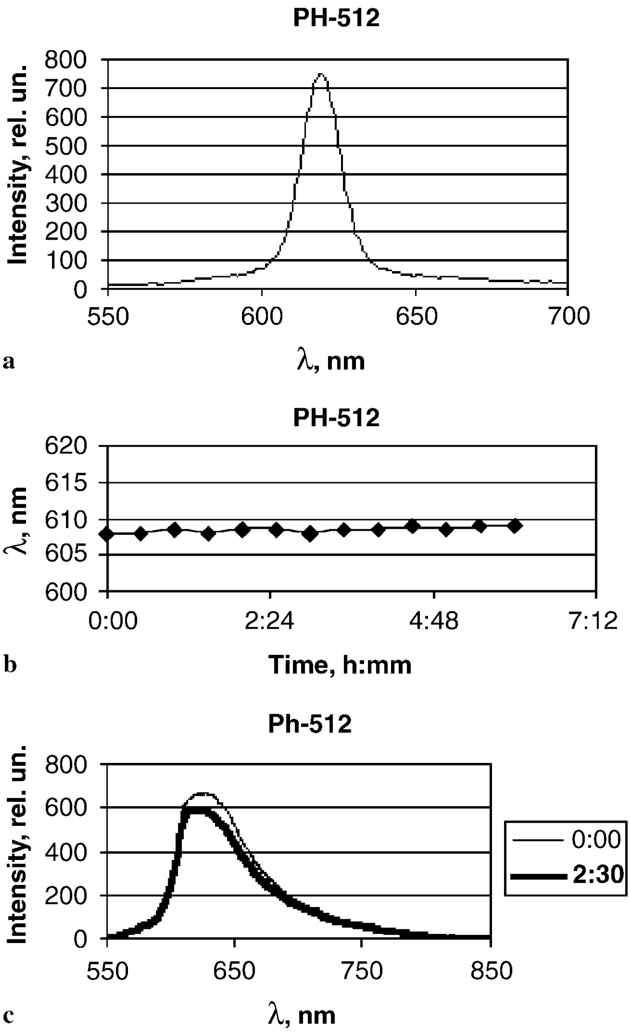

FIGURE 4 Spectral characteristics of Ph-512 pumped with the CVL: the emission spectrum (**a**), the dynamics of the maximum in the emission spectrum (**b**), and the dynamics of the fluorescence spectrum (**c**)

erates in the wavelength range centered at 655 nm and has a sufficiently long operating lifetime ($N = 8 \times 10^7$ pulses). This is also true for rhodamine 101 (the efficiency was 7.2%, $\lambda_{\text{las}} = 650$ nm, and $N = 10^8$ pulses). Figure 5 shows the dependences of the Ph-512 lasing efficiency on the irradiation time (the efficiency for the setup shown in Fig. 3 was not optimal) typical of all the examined compounds. A sufficiently long operating lifetime was obtained for the element with the lasing efficiency equal to 4.5%, when the phenalemine 512 concentration was 2.5 mmol/L: ~ 360 kJ/cm^3 was deposited into the sample for 8 h of its operation ($> 10^8$ pulses); the lasing efficiency halved during this period. Of interest is partial restoration of the efficiency after a pause during which the sample was not irradiated. As demonstrated in [7], this phenomenon may be due to changes in the electrical parameters of the MPMMA matrix on irradiation by the CVL. Phototransformation of dye molecules on irradiation by the CVL is also possible.

The operating lifetime of a solid-state medium based on phenalemine 512 in the MPMMA matrix pumped with the CVL exceeded the lifetime of the solid-state active medium obtained in [3] (10^8 and 6×10^6 pulses, respectively).

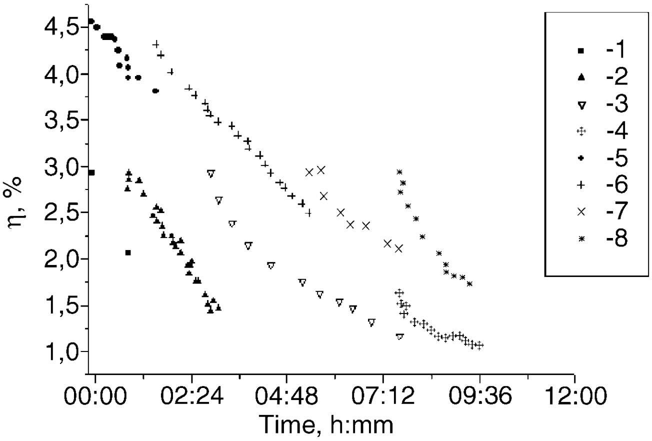

FIGURE 5 Operating lifetime of Ph-512 with $C = 3.6$ (1–4) and 2.5 mmol/L (5–8) with pauses for 1 (6–7), 12 (1–2), 12 (5–6), and 48 h (7–8) and 11 days (3–4)

4 Conclusions

The above results demonstrate that the transverse-pumping scheme of solid-state laser-active media with the CVL is promising compared to the longitudinal-pumping scheme from the viewpoint of the lifetime parameters. For close values of the conversion efficiency, the operating lifetime of the active element increases by two orders of magnitude. We associate this effect with the reduced radiation and heat loading of the active element through the pumping channel (in our case, 3×10^{-3} J/cm^2, whereas for the longitudinal-pumping scheme [5] it was higher by two orders of magnitude). One more advantage of the transverse scheme of pumping with the CVL is low sensitivity of the energy characteristics of the dye laser to the relative content of the yellow line (578.2 nm), falling within the amplification band of dyes, in the pump radiation, whereas for the longitudinal-excitation scheme, pump radiation must be filtered (by analogy with liquid dyes [6]).

The results obtained demonstrate that, in the near future, mobile laser converters based on solid-state laser-active media, competitive with liquid-dye lasers, will be developed.

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