Amplified Spontaneous Emission of DCM Dye in PMMA Polymer Using Copper Metal Disks Mold

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Abstract

The effect of irradiation and exposure time of laser light on the fluorescence emission of DCM dye in PMMA polymer contained in the composition mold using different metals have been investigated. It was found that the fluorescence intensity decreases as the exposure time increases and then reaches stabilization at long times. The effect of the incident laser power on fluorescence intensity of DCM dye in PMMA polymer at 10^{-3} M and 20% mixing ratio, using copper disks of composition molds, has been studied too. It was observed that there is an upward knick in the curve at laser intensity of 19.2 W/cm^2, which may be associated with the threshold for amplified spontaneous emission (ASE) or laser action. And at intensity higher than about 88.8 W/cm^2 nearly saturation is reached.

Keywords
PMMA Polymer
Copper Metal Disks

Article info
Received: Mar. 2010
Accepted: Apr. 2010
Published: Dec. 2010

الانبعاث التلقائي المضخم لصبغة DCM بوسط بوليمر PMMA باستخدام حاوية دائرية نحاسية

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الخلاصة

تناولت الدراسة دراسة تأثير زمن التعرض لضوء الليزر على طيف انبعاث الفلورة لصبغة DCM بوسط صلب من بوليمر PMMA الموجود ضمن قوالب التحضير باستخدام معادن مختلفة. تبين ان شدة الفلورة تقل بزيادة زمن التعرض. ومن ثم تصل الى مرحلة ثبوت عند فترة زمنية طويلة. كما تم دراسة تأثير قدرة الليزر الساقطة على شدة الفلورة لصبغة DCM في بوليمر PMMA بتركيز 10^{-3}مولاري ونسبة مزج 20% صبغة الى بوليمر باستخدام قوالب التحضير لأقراص النحاس ,لوحظ ان هناك زيادة مفاجئة عند شدة الليزر19.2 واط/سم^2 والذي يمكن ان يعزى الى الانبعاث التلقائي المضخم أو الفعل الليزر ويصل الى حد الاستقرار عند شدة الليزر 88.8 واط/سم^2.

Introduction

Solid-state dye lasers, consisting of an organic dye dissolved in solid matrix, have been the subjects of much interest since their demonstration nearly four decades ago. The dyes, most commonly dissolved in sol gels [1] or polymers [2] or, have large absorption and emission cross-sections and are tunable from the UV to the near IR. Solid-state dye lasers offer practical advantages such as compactness as well as alleviating some disadvantages associated with the flammable and volatile organic solvents used in liquid dye lasers [3].

Amplified spontaneous emission (ASE) is a process by which spontaneously emitted light is amplified by stimulated emission as it travels down the waveguide [4, 5]. It has been observed at low pump intensities in a number of materials when photo-pumping in a planar waveguide configuration [4, 6, and 7]. Characterizing ASE is a useful way to demonstrate laser gain and to identify good laser materials [5, 8, and 12].

2-Materials and Method

In this study these materials were used: DCM dye (4-dicyanomethylene-2-methyl-6-p-dimethylaminostyryl-4-4H-pyran, (LC 6500), supplied by Lambda physiks, MMA (methyl methacrylate), (Fluka & Buchs, Switzerland), methyl chloroform (Philip Harris, England) and three disks (copper, brass and steel) which were oxygen and bubbles free. The disks have thermal conductivity of 401, 109 and 46 (W/m. K) [9]. Their diameters of 2.5 cm, 2.5 cm and 2 cm, and thickness of 0.8 cm, 1.1 cm and 0.4 cm respectively.

Two kinds of solutions were prepared: The first using methanol as solvent with 10^{-3}M primary concentrations of DCM dye. The second using a mixture of MMA and methyl chloroform of ratio (1:1) (to form PMMA polymer later), and then adding 2 ml of the first solution to 8 ml of this mixture (to get percentage of 20% by volume). Three pairs of disks were used: steel, copper and brass. Each pair consists of lower and upper solid disk; the upper disk has a hole in the center of 3 mm diameter. The gap between the two solid disks was covered from sides with aluminum foil to make a composition mold. 4 ml of DCM dye in PMMA polymer, of $2x10^{-4}$ M concentration was then poured into the composition mold. After that the composition mold was covered with the upper disk and then left for two days in order to make it homogenous. A small side hole in the aluminum foil was used to receive the fluorescence emission. Fig. (1) shows schematic diagram of ASE measurement. The study was performed using a diode pumped solid-state CW green laser of 531nm and 10mW power as a light source with neutral density filter to reduce the transmitted laser intensity. A quartz lens of 5cm focal length was used to focus the laser light on the sample and to increase its intensity by reducing the laser spot size. The beam diameter at the sample was 0.1mm.

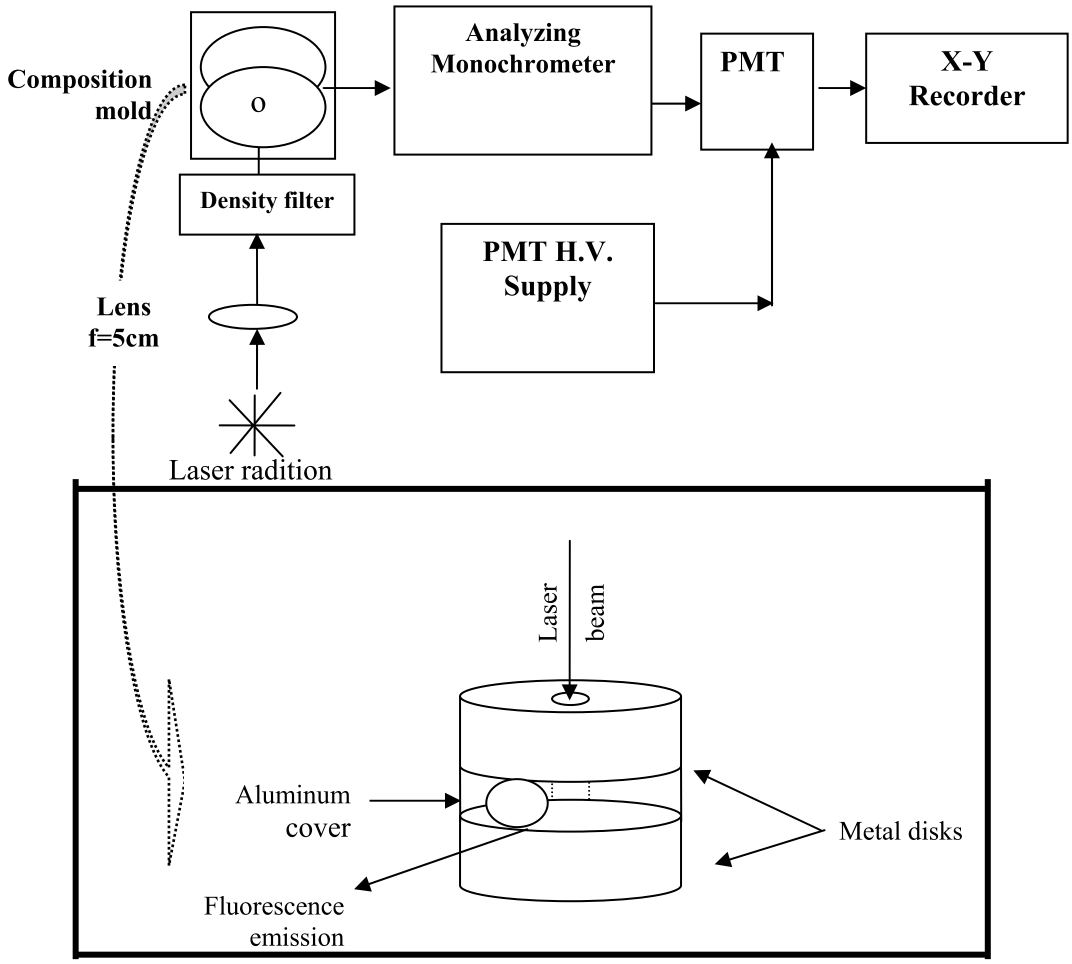

Fig.(1): Schematic diagram of ASE measurement

Resultes and Discussion

The effects of irradiation and exposure time of laser light (λ = 531 nm) on the fluorescence emission of DCM in PMMA polymer contained in the composition mold using steel, brass and copper disks have been studied. Fig. (2) shows the variation of peak fluorescence intensity of DCM dye with exposure time.

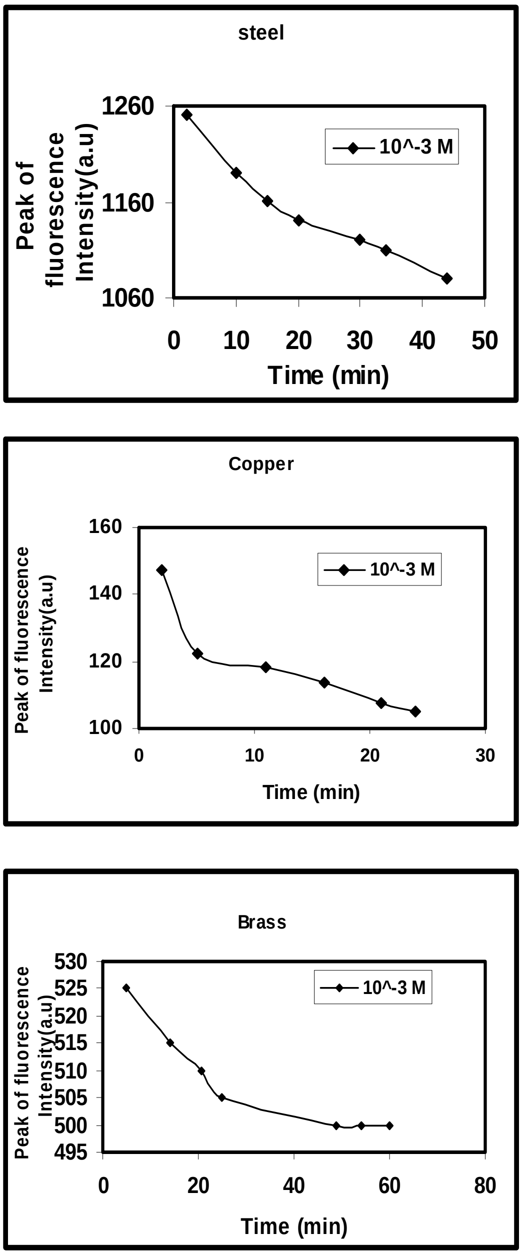

Fig.(2): Peak of fluorescence intensity vs. exposure time for DCM dye in PMMA polymer at 10^{-3} M and 20% dye mixing ratio, using different disks of composition molds.

One observes from the figure (2) that the peak fluorescence intensity decreases as the exposure time increases and then reaches stabilization at long times (e.g. 60 min. for brass disks). This may be explained as follows: When the absorbed light excites dye molecules from the lowest vibrational levels of the ground state S_{00} to higher vibrational levels of an excited singlet S_{1n} state, where n integer, the excited molecules then return to ground state by two processes: radiative or non-radiative. Since the polymer host is transparent to the pump radiation, the excited dye molecules heat up the host through the non-radiative thermal relaxation (because in non-radiative relaxation, the molecules lose the energy as heat). This heat is then transfered by conductivity of the surrounding medium. The increase of thermal conductivity thus, increases the photo-stability by reducing thermal degradation. If the medium is poor thermal conductor, the dye molecules will photodegrade because of the heat accumulation. This photodegradation reduces the number of absorbing dye molecules and may, also, produce quenching species and hence the fluorescence emission is reduced. This phenomenon is called bleaching. Additional experimental results such as: FWHM, peak fluorescence intensity, wavelength (λ_p) at peak fluorescence intensity etc. are listed in Table (1).

Table (1): Some related fluorescence parameters of DCM dye in PMMA polymer in composition molds at 10^{-3} M concentration, 20% mixing ratio and different metal disks.

Steel				Brass				Copper			
Time (min)	λ_P (nm)	Peak of fluorescence intensity (a.u)	FWHM (nm)	Time(min)	λ_P (nm)	Peak of fluorescence intensity (a.u)	FWHM (nm)	Time(min)	λ_P (nm)	Peak of fluorescence intensity	FWHM (nm)
2	571.2	1250	48.5	5	585	525	45	2	585.65	147.5	
10	571.5	1190	49.64	14	585	515	45.41	5	586.25	122.5	42
15	571.8	1160	50.2	20.5	586	510	45.07	11	587.16	118.5	42.4
20	570	1140	50.6	25	585.6	505	45.21	16	586.96	113.5	42.7
30	571.9	1120	50.2	49	585	500	45.7	21	585.55	107.5	42.7
34	571.9	1110	50.8	54	585	500	45.54	24	586.83	105	43.4
44	571.5	1080	50.8	60	585	500	45.11				

One can see from Table (1) that the wavelength, $\lambda_{p,}$ at maximum intensity is almost constant, and does not change with time. With regard to the FWHM of the fluorescence spectrum, we see that there is a slight increase of its value with the increase of the exposure time which may be attributed to photo-degradation.

Also we have studied the effect of the incident laser power on fluorescence intensity of DCM dye in PMMA polymer, using copper disks of composition molds. The copper disks are preferred in this study for two reasons:

a- The copper has high thermal conductivity (401 W/m.K) compared to those of brass(109 W/m.K) and steel(46 W/m.K) [9], which makes copper a better heat sink to get rid of the excessive heat that produced by the radiation less processes involved in the emission process.

b- The copper has high reflectivity (89% at λ=589.3 nm) compared to those of brass (76%) and steel (58%) [10, 11]. Fig. (3) Shows incident laser power (λ = 531 nm) effect on fluorescence intensity.

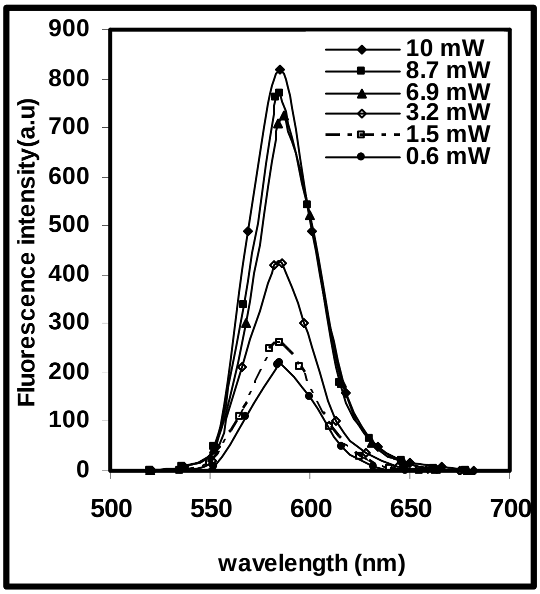

Fig.(3-a): Fluorescence intensity vs. wavelength for DCM dye in PMMA polymer at 10^{-3} M and 20% mixing ratio, using copper disks of composition molds.

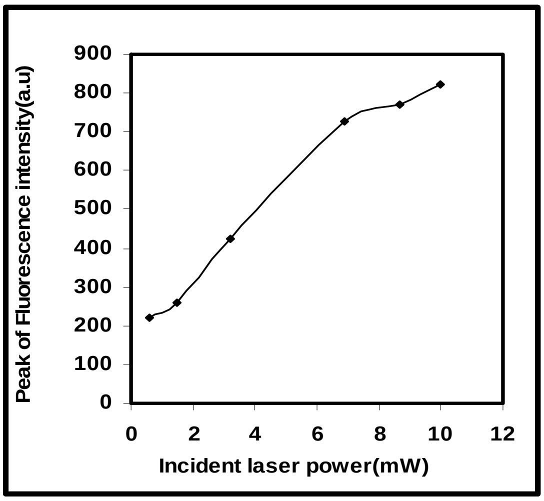

Fig.(3-b): Peak of fluorescence intensity vs. incident laser power for DCM dye in PMMA polymer at 10^{-3} M and 20% mixing ratio, using copper disks of composition molds.

Other related parameters such as λ_p, FWHM etc. are listed in table (2).

Table (2): Some other related parameters of DCM dye in PMMA polymer at 10^{-3} M and 20% mixing ratio, using copper disks of composition molds.

One can see from Table (2) that in general the fluorescence intensity increases with increasing of incident laser power. One can observe from Fig.(3) that there is an upward knick in the curve at incident laser power of 1.5mW (corresponding to laser intensity of 19.2 W/cm^2) which may be associated with the threshold for laser action or ASE. And at power higher than about 7mW (intensity≈ 88.8 W/cm^2 nearly) saturation is reached. From these results one can also conclude that copper disks, of the composition molds, are more suitable to be used as mirrors.

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