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Pumping scheme dependent multimode laser emission from free-standing cylindrical microcavity

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ABSTRACT

We report the observation of multimode laser emission from a free-standing microring cavity based on rhodamine 6G dye doped hollow poly(methyl methacrylate) optical fiber (DDHPOF) obtained by pulsed photo-excitation. Two different pumping schemes were employed to characterize DDHPOF; the stripe illumination and the spot illumination. By using spot illumination, the slope efficiency of system is enhanced by more than 3 times than that of the stripe illumination and also a red-shift in emission spectrum is observed with the pump power. When the pump power is increased beyond the threshold value, laser emission occurs with a multimode structure. From the relation between mode spacing and diameter of cylindrical cavity, the lasing action is considered to be formed by whispering gallery modes (WGMs).

1. Introduction

In the last decades, solid state dye gain media has attracted considerable research interest [1]. Solid state dye lasers have many advantages than their counterpart in liquid form, such as, reduced toxicity, easier and safer to handle, etc. PMMA (poly methyl mathacrylate), the most frequently used polymer host for dye lasers, shows best optical transparency in the visible spectral range [2] and is compatible with most of the organic dyes used as dopants [3]. Laser dye doped PMMA is found to be a highly efficient medium for laser source with narrow pulse width and wide tunable range as well as for optical amplifier with high gain, high power conversion and broad spectral bandwidth [4–6]. Rhodamine 6G (Rh6G), the best known of all laser dyes, has high quantum yield and a low intersystem crossing rate [2]. For Rh6G, there is also a spectral region of overlap between the absorption and emission bands.

Optical amplifiers and lasers made of dye doped fiber require much less pump power than in bulk material, because of the effective confinement and long interaction length available in the fiber [7]. These microcavities confine light into an interior region close to the surface of the resonator by resonant circulation due to the total internal reflection at the boundary [8]. Resonators having a diameter *s* from a few tens to several hundreds of micrometers can have a very large free spectral range of several nanometers. Generally, a microring cavity is realised by making a coating of a few micron thick conducting polymers [9] or dye doped transparent polymer over a glass fiber. The most important parameter for a solid-state dye laser system is the rate of dye photo-degradation. In all applications of a laser dye, the main concern is the photostability of the dye under irradiation by the pump light [10]. The bleaching of dye molecules could be assumed mainly due to the thermal effect. Also, the thin and long geometry of the fiber is ideal for good thermal relaxation to minimize the thermally induced photo-bleaching as well [11].

2. Experimental

In this paper, we are presenting the effect of pumping scheme on the multimode laser emission from a cylindrical microcavity structure fabricated by Rhodamine 6G dye (10^{-4} mol/l) doped hollow poly (methyl methacrylate (PMMA)) optical fiber (DDHPOF). The detailed fabrication process of DDHPOFs was already reported by kailasnath et al. [5]. In our study we used Rh6G doped DDHPOF, which is having a dye concentration of 10^{-4} mol/l, with an outer diameter of 280 μm, inner diameter of 120 μm and a length of 5 cm. DDHPOFs samples were transversely pumped using 8 ns pulses from a frequency doubled Nd:YAG laser (532 nm, 10 Hz). A set of calibrated neutral density filters were used for varying the pump power. The average pump power was varied from 2 mW to 40 mW and the emission from the sample was collected using a collecting fiber coupled to a monochromator-CCD system (SpectraPro) with a resolution of 0.03 nm.

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The pump beam was focused onto the DDHPOFs either by a convex lens (Fig. 1 left inset) or by a cylindrical lens (Fig. 2 left inset). Pumping scheme is very much significant in practical applications, especially for optimizing the life of solid state dye gain media [1].

3. Results and discussions

3.1. Spot illumination technique

When the pump beam is focused into the DDHPOF with the help of a convex lens, the entire light is concentrated on a single point (~0.1 mm). Hence the power density at the focused point is very high. This leads to the excitation of only a few dye molecules to higher energy bands which can de-excite with an emission. The emitted light from this point gets propagated to other regions of the fiber. As a result, the short wavelength emission from dye molecules gets absorbed by itself and is re-emitted at longer wavelength due to stokes shift. When the pump power is increased the emission spectrum shows a line narrowing (due to amplified spontaneous emission (ASE)) [12]. With an increase in pump power, the excited molecules absorb more energy and hence the emission from these molecules can excite more neighboring molecules which leads to a shift in the peak emission wavelength from 561 to 565 nm with pump power. That is, the red-shift is attributed to the absorption of shorter wavelength and emission from the neighboring dye molecules at longer wavelengths. The red-shift and line narrowing as a function of pump power are depicted in Figs. 3 and 4. A clear line narrowing from 30 nm to 4 nm is observed when the pump power is increased to 10 mW, above which no further line narrowing is observed due to gain saturation effect [12].

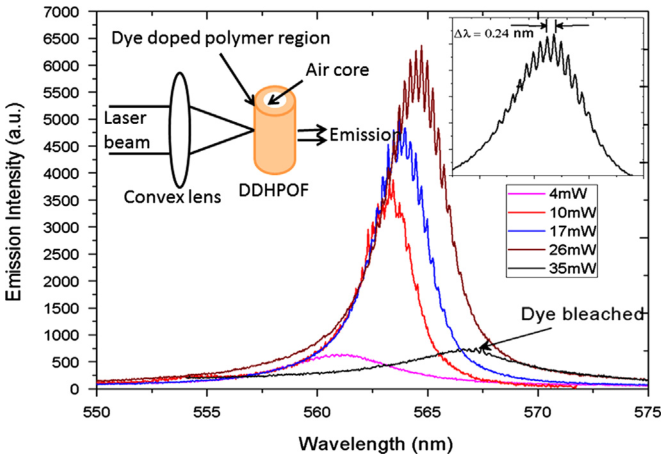

Fig. 1. Emission spectrum from DDHPOF as a function of pump power. Left inset shows the pumping scheme and right inset shows the expanded modes at 26 mW.

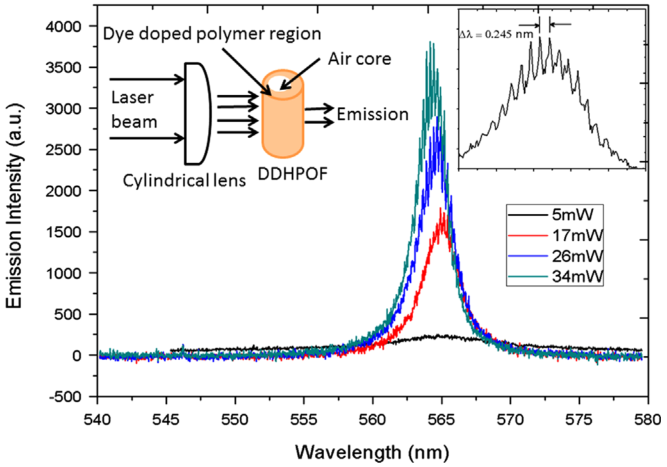

Fig. 2. Emission spectrum from DDHPOF as a function of pump power. Left inset shows the pumping scheme and right inset shows the expanded modes at 26 mW.

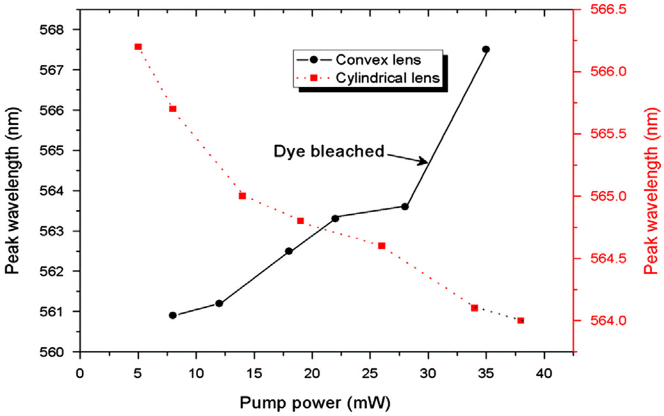

Fig. 3. Shift in peak wavelength as a function of pump power (when pump power is focused with convex and cylindrical lens).

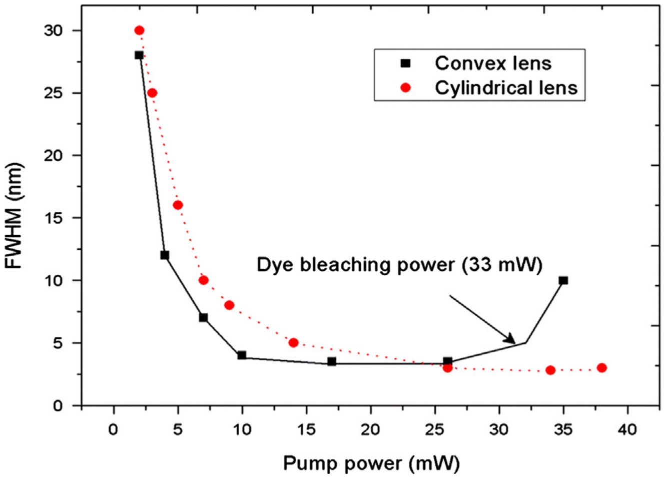

Fig. 4. Line narrowing as a function of pump power (when the pump beam is focussed with convex and cylindrical lens).

At higher pump powers a change in the spectral shape was observed. Fig. 5 shows the evolution of spectrally integrated emission intensity as a function of pump power for the multimode lasing from the DDHPOF. At a threshold pump power, P_{th} (~10 mW), laser emission with multimode structures emerges as depicted in Fig. 1. This threshold behavior of the laser peak intensity provides a clear signature of lasing. The expanded mode structure is clearly shown in Fig. 1 (right inset).

The DDHPOFs can be modeled as a number of serially connected microring cavities [3]. Thus the expected mode spacing $\Delta\lambda$ is given by

$$\Delta\lambda = \lambda_m - \lambda_{m-1} = \lambda^2/\pi D n_{eff}$$

where λ is the wavelength of strongest emission line, n is the refractive index of the fiber material, and D is the diameter of the fiber. From the equation we get the mode spacing as 0.24 nm,