PRAMANA
— journal of
physics

© Indian Academy of Sciences

Vol. 75, No. 5
November 2010
pp. 923–927

A microring multimode laser using hollow polymer optical fibre

M KAILASNATH*, V P N NAMPOORI and P RADHAKRISHNAN
International School of Photonics, Cochin University of Science and Technology,
Kochi 682 022, India
*Corresponding author. E-mail: kailas@cusat.ac.in

Abstract. We report the observation of multimode laser operation at wavelengths corresponding to whispering-gallery modes from a freestanding microring cavity based on rhodamine B dye-doped PMMA hollow optical fibre. Cylindrical microcavities with diameters 155, 340 and 615 μm were fabricated from a dye-doped hollow polymer optical fibre preform. An average mode spacing of 0.17 nm was observed for the 340 μm cavity. This shows that the laser mode intensity distribution is concentrated on the outer edge of the cavity.

Keywords. Dye-doped optical fibre; fibre laser; microcavity; whispering gallery mode.

PACS Nos 42.60.Da; 42.81.-i; 42.81.Wg

1. Introduction

Optical microcavities are natural candidates for very low threshold microlasers and for observing interesting quantum optical behaviour [1]. The simplest of the cavities from the viewpoint of semiconductor fabrication technology may be the planar dielectric Bragg mirror cavity. A disadvantage of the planar dielectric cavity is that, as there is no lateral confinement of the mode, the transverse modes of the cavity are poorly defined, and so is the spontaneous emission coupling factor [2]. High Q value optical microresonators with strong optical confinement to the gain region can be obtained using the whispering-gallery resonator modes propagating around the edge of a sphere, disk, cylinder or ring [3]. These techniques may be applicable to a wide range of material systems because low optical cavity loss is obtained from a simple curved surface instead of multiple layer dielectric mirrors.

The optically pumped polymer-based devices show lasing at relatively low excitation intensity threshold and are having superior polymer optical properties that allow high optical gain. Laser dye-doped poly(methyl methacrylate) 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]. Dye-doped optical fibres have also been fabricated in conjunction with fibre lasers and fibre amplifiers [5,6]. The first optical amplification in dye-doped optical fibre was demonstrated by researchers in Japan [7,8] in which they demonstrated that efficient conversion as well as long lifetime of the gain medium can be achieved in a rhodamine B dye-doped polymer optical fibre. Exceptionally thin microcavities can, in principle, exhibit threshold-less lasing even though ideal microcavities are difficult to fabricate. The usual method of fabrication of a cylindrical polymer microcavity is by making a coating of few microns thick conducting polymer or a dye-doped transparent polymer of high refractive index over a glass optical fibre [9]. In this letter we report the fabrication and observation of whispering-gallery mode (WGM) structure at room temperature from a hollow cylindrical cavity made up of rhodamine B dye-doped hollow poly(methyl methacrylate) optical fibre pumped by a frequency doubled Q-switched Nd:YAG laser.

2. Experiment

A typical procedure for the fabrication of dye-doped hollow polymer optical fibre is as follows: First we used a teflon rod of 6 mm diameter that was properly fixed on the centre of a glass tube of inner diameter 13 mm. One end of the tube was sealed and then it was filled with a mixture of monomer (MMA), 0.4 wt% of the polymerization initiator (benzoyl peroxide (BPO)), rhodamine B (10^{-4} m/l) and 0.1 wt% of the chain transfer agent (n-butyl mercaptan). The polymerization was carried out at 80°C for 48 h. The preform tube thus obtained was placed in an oven at 110°C for 24 h for the complete polymerization. Finally, the preform tube was heat-drawn into a fibre at 180°C [10]. The drawn fibre has the structure of a microring with 340 μm diameter and 157 μm hole diameter. 1 cm of the fibre was transversely pumped at 532 nm with a frequency-doubled Q-switched Nd:YAG laser (Spectra Physics) with 8 ns pulses at 10 Hz repetition rate. The pump beam was focussed by a cylindrical lens exciting a narrow stripe with 0.6 mm width on the hollow fibre surface. The emission was recorded by a CCD monochromator assembly of 0.03 nm resolution.

3. Results

Figure 1 shows the fluorescence emission from a 1 cm long 340 μm thick hollow fibre doped with rhodamine B for an excitation length 2 mm. As seen from the diagram, for an excitation length of 2 mm, up to a pump power, the fibre exhibits normal fluorescence up to an average pump power 0.049 W. The amplified spontaneous emission begins at 0.081 W and the FWHM decreases continuously up to 0.220 W where laser emission is also observed with a multimode structure. Beyond this pump power the fluorescence intensity is found to decrease with a blue shift in the spectrum. At these higher pump intensities, the multimode structure also starts disappearing. This result is attributed to the degradation of the dye molecule at higher pump powers. The hollow fibre acts as a waveguide forming a ring resonator

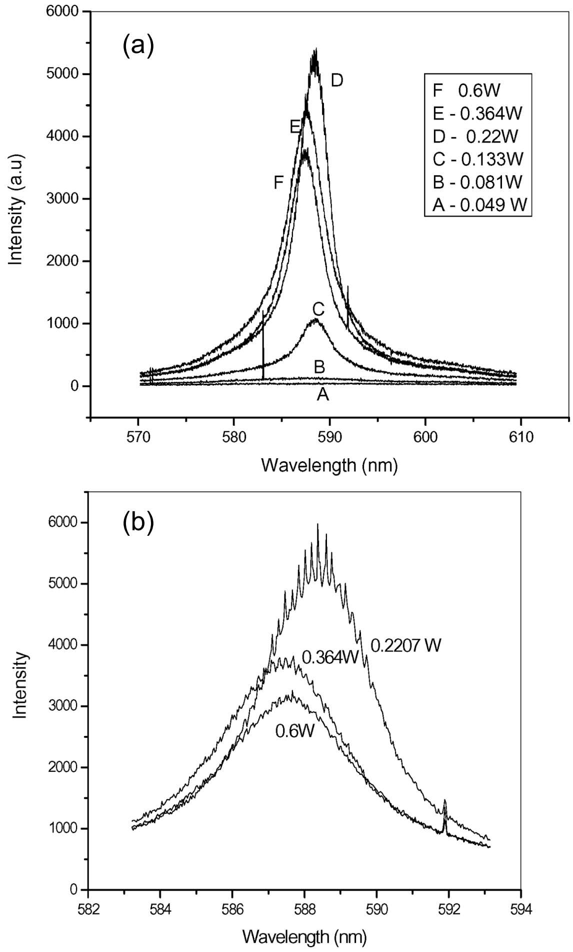

Figure 1. (**a**) Emission spectrum of a 1 cm long, 340 μm diameter rhodamine B-doped hollow polymer optical fibre for 2 mm excitation length. (**b**) Expanded modes in figure 1a for 2 mm excitation length.

similar to a polymer film on an optical fibre. The resonant frequencies ν_{m} for the wave-guided laser modes are given by [11],

$$\nu_{\mathrm{m}} = \frac{mc}{\pi D n_{\mathrm{eff}}}, \tag{1}$$

where m is an integer, c is the speed of light in vacuum, D is the outer diameter of the fibre and n is the effective index of refraction of the hollow waveguide.

Figure 1b shows the expanded peaks of the three curves in figure 1a for the highest three pump powers. At an average pump power of 0.22 W, the mode structure is clearly resolved. The wavelength spacing between the modes in the present observation at 0.22 W is in agreement with that of the whispering-gallery modes in the microcavity ring lasers given by eq. (1). The $\Delta\lambda$ in the present study

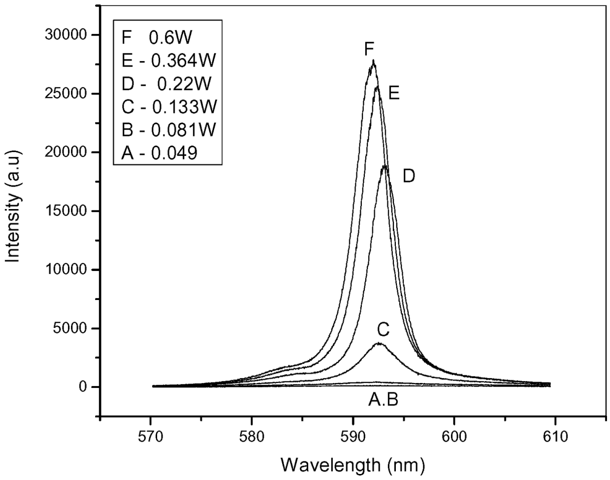

Figure 2. Emission spectrum of a 1 cm long, 340 μm diameter rhodamine B-doped hollow polymer optical fibre for 4 mm excitation length.

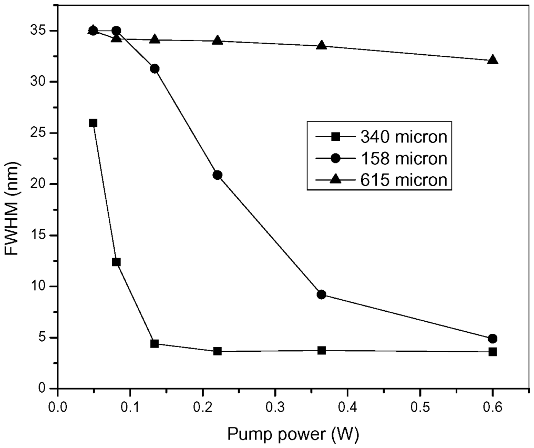

Figure 3. The pump power dependence of FWHM of 158, 340 and 615 μm diameter hollow fibres.

is found to be 0.176 nm which is in close agreement with the theoretical value of 0.172 nm. The longer round trip distance means that there are many longitudinal modes supported by the cavity. The feedback mechanism is also rather complicated with a combination of whispering-gallery modes confined at the outer surface plus the other waveguided modes in which light is trapped in the film by total internal reflection from both inner and outer air–polymer interfaces [9]. Each mechanism support a distinct set of resonant frequencies. These are superimposed to give complicated clusters of closely spaced modes within the polymer gain bandwidth. The dominance of WGM may be accounted for the considerably larger thickness of the polymer film (92 μm) [9].

The emission spectrum showed in figure 2 gives rise to an enhancement in the fluorescence intensity when the excitation length is increased to 4 mm but the mode structure is absent in this case. Also, no decrease in emission intensity with pump power is observed in this case resulting in a minimum FWHM of 3.6 nm at 0.6 W compared to 3.73 nm at 0.22 W for the 2 mm excitation. The variation in the FWHM with pump power for three different diameters of the fibre is presented in figure 3. The line narrowing effect is more predominant in a fibre with 340 μm diameter. The absence of ASE in the case of 615 μm fibre is attributed to the fact that most of the focussed stripe of light from the cylindrical lens is falling on the curved fibre surface resulting in an inefficient pumping. In the case of 158 μm fibre, even though the coupling efficiency of light into the fibre is poor, the threshold pump power for ASE is very small due to its low dimension.

4. Conclusions

Amplified spontaneous emission and multimode lasing from a freestanding polymer microcavity based on dye-doped hollow polymer optical fibre has been observed and the corresponding threshold pump power was determined. Multimode laser emission was observed when 2 mm of a 1 cm long fibre was excited with a cylindrical lens. Peak of the ASE is found to have a strong dependence on the length of the fibre and pump power. The lasing threshold may be further reduced and the dye degradation can be prevented by a smaller diameter fibre with an efficient pumping mechanism.

References

[1] Xiaomei Wang, R A Linke and G Devlin, *Phys. Rev.* **A47**, 4 (1993)

[2] Gunnar Bjork, *Phys. Rev.* **A47**, 5 (1993)

[3] M Kuwata Gonokami, R H Jordan, A Dodabalapur, H E Katz, M L Schilling, R E Slusher and S Ozawa, *Opt. Lett.* **20**, 20 (1995)

[4] G D Peng, Pak L Chu, Zhengjun Xiong, Trevor W Whitbread and Rod P Chaplin, *J. Light Wave Technol.* **14**, 10 (1996)

[5] Mitsunori Saito and Kazuto Kitagawa, *J. Light Wave Technol.* **19**, 7 (2001)

[6] M Rajesh, M Sheeba, K Geetha, C P G Vallabhan, P Radhakrishnan and V P N Nampoori, *Appl. Opt.* **46**, 1 (2007)

[7] A Tayaga, Y Koike, T Kinoshita, E Nihei, T Yamamoto and K Sasaki, *Appl. Phys. Lett.* **63**, 883 (1993)

[8] A Tayaga, Y Koike, E Nihei, S Teramoto, K Fujii, T Yamamoto and K Sasaki, *Appl. Opt.* **34**, 988 (1995)

[9] S V Frolov, M Shkunov and Z V Vardeny, *Phys. Rev.* **B56**, 8 (1997)

[10] M Kailasnath, T S Sreejaya, Rajeshkumar, V P N Nampoori, C P G Vallabhan and P Radhakrishnan, *J. Optics and Laser Technol.* **40**, 687 (2008)

[11] H P Weber and R Ulrich, *Appl. Phys. Lett.* **19**, 38 (1971)