Characterization of rhodamine 6G doped polymer optical fiber by side illumination fluorescence

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Abstract. The length-dependent tuning of the fluorescence spectra of a dye doped polymer fiber is reported. The fiber is pumped sideways and the fluorescence is measured from one of the ends. The excitation of a finite length of dye doped fiber is done by a diode pumped solid state laser at a wavelength of 532 nm. The fluorescence emission is measured at various positions of the fiber starting from a position closer to the pumping region and then progressing toward the other end of the fiber. We observe that the optical loss coefficients for shorter and longer distances of propagation through the dye doped fiber are different. At longer distances of propagation, a decrease in optical loss coefficient is observed. The fluorescence peaks exhibit a redshift of 12 nm from 589 to 610 nm as the point of illumination progresses toward the detector end. This is attributed to the self-absorption and re-emission of the laser dye in the fiber. © 2006 Society of Photo-Optical Instrumentation Engineers. [DOI: 10.1117/1.2221553]

1 Introduction

With the advent of low loss polymers in photonics, glass-based optical devices and fibers have been replaced by polymers for short-haul systems. The advantages of using polymeric materials in the fabrication of waveguides and other devices are that they are easier to fabricate, cost less, are lightweight, and enable us to carry out a variety of optical functions by incorporating organic dyes to the polymer system.[1] These advantages make them suitable for local area networks, data links, and multimode bus networks and as passive devices such as optical switches, lasers, amplifiers, and gratings. Polymer optical fibers are found to be more sensitive to temperature, strain, and pressure than silica fibers and hence are suitable for sensor applications.

Polymer fibers doped with organic dyes have proved to be potential candidates for use in fiber lasers and amplifiers in the visible region.[2-5] Dye doped fiber lasers are used extensively in a variety of fields depending on their emission wavelength in the visible spectrum. By choosing appropriate dyes, we can obtain laser emission from doped polymer fibers in the entire visible region.

The optical attenuation in polymer optical fibers (POF) is an important parameter of interest. There are different techniques for measuring the propagation losses in fiber structures. Usually the propagation loss in fibers and planar

fiber structures is measured by the cutback technique,[6,7] which consists of comparing the transmittance of several fibers with different lengths at a specific wavelength or extrapolating the loss from a bulk measurement. The disadvantage of the cutback technique is that it is a destructive method. Bulk measurements involve a broadband light source incident on a fixed length of material and a spectrometer to read the transmitted intensity. As an alternative to the above-mentioned techniques, a nondestructive side illumination fluorescence technique for measuring the optical attenuation in dye doped fibers has been developed by Kruhlak et al.[8,9] Geetha et al. have carried out similar studies in planar waveguides.[10] In this paper, we describe the use of this technique to characterize the loss mechanisms in dye doped polymer optical fibers. This measurement technique requires a pump source to illuminate the fiber from the side. The fluorescence collected from one end of the fiber is used to characterize the attenuation mechanisms in the fiber.

2 Experimental Procedure

The dye doped polymer fibers used for the studies are based on polymethylmethacrylate (PMMA). Because PMMA has good optical quality and is compatible with most of the organic dyes used as dopants, it is chosen as an ideal candidate. The dye used as the dopant is rhodamine 6G, which has a reasonably good photostability. Rhodamine 6G has an absorption at 532 nm and a fluorescence emission in the

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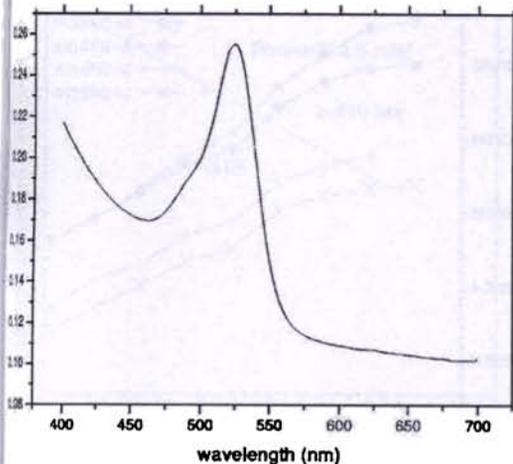
Absorption spectrum of rhodamine 6G doped PMMA bulk sample.

Fig. 2 Experimental setup to record the fluorescence emission from the fiber end. Pumping is done transversely.

length range of 580 to 610 nm. The core diameter of fiber used is 200 μm. The refractive index of methyl-methacrylate is about 1.41. When polymerized, the index of polymer will increases up to 1.48 to 1.49 due to the volume reduction during liquid-to-solid phase transition.

The preform for fiber fabrication[6] is made by polymer-izing the monomer methylmethacrylate (MMA). The monomer is mixed with benzoyl peroxide (0.01 mol l^{-1}) as initiator, n-butyl mercaptan (0.03 mol l^{-1}) as the chain transfer agent, and rhodamine 6G (0.001 mol l^{-1}) in sealed tubes. These tubes are then placed in a constant temperature bath for three days at a temperature of 80°C until it hard-ens and later they are kept in a furnace at 100°C for 24 h. The prepared preform is now ready for drawing the fiber in a custom-made fiber drawing tower. By using a preform holder, the preform is lowered into a furnace that is main-tained at a stable temperature of 180°C, and fiber is drawn at this temperature. The fiber diameter is fixed at 200 μm by adjusting the feed rate of the preform and draw rate of the fiber. Using a diffraction technique, the homogeneity in diameter of the fiber is tested. Variation in diameter is found to be less than 1% so that the effect of inhomogene-ity in the loss mechanism can be neglected.

The total length of the fiber used for the loss measure-ments is 8 cm with its ends cut and polished by conven-tional means. To select the pump beam for exciting the dye doped fiber, we recorded the absorption spectrum (Fig. 1) of the bulk sample using a spectrophotometer (JASCO UV/VNIR V-570). Based on the absorption spectrum, radia-tion at 532 nm (beam spot size 1.5 mm) from a diode pumped solid state (DPSS) laser neodymium doped yttrium vanadate or (Nd:YVO$_4$) is used as the pump source. A schematic diagram of the experimental setup is shown in Fig. 2.

The fiber is mounted normally on a translation stage with respect to the incident radiation. The side illumination of the dye doped fiber generates fluorescence emission. The emission from one end of the fiber is collected by an optical fiber that is coupled to a monochromator-photomultiplier tube assembly coupled with a lock-in am-

plifier (Stanford Research Systems SR830) for signal analysis. To measure the transmitted fluorescence as a func-tion of propagation distance through the fiber, the illumina-tion point on the fiber is varied by translating the fiber horizontally across the laser source. The direction of trans-lation is indicated by the arrow mark in Fig. 1. At each point of illumination, the fluorescence spectrum is re-corded. The experiment is repeated for three different pump powers. It is ensured that the sample is not bleached even at the highest pump power.
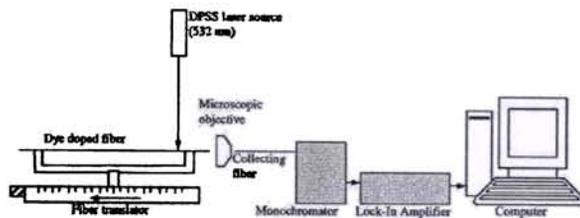
3 Results and Discussion

The side illumination fluorescence spectrum is recorded for various propagation distances of the dye doped fiber. Figure 3 shows the spectra of transmitted fluorescence light mea-sured as a function of the propagation distance through the fiber. As the propagation distance increases, the magnitude of the output intensity decreases due to loss mechanisms such as absorption and scattering of fluorescence emission. In addition, there is a redshift for the peak fluorescence emission as the illumination distance from one edge of the fiber is increased. A similar redshift in the fluorescence emission from a side illuminated dye doped fiber has also been observed by other workers.[8,9] The redshift of the fluo-rescence signal is produced by the self-absorption of the dye rhodamine 6G caused by the overlap of the absorption spectra with the fluorescence spectra over a certain wave-
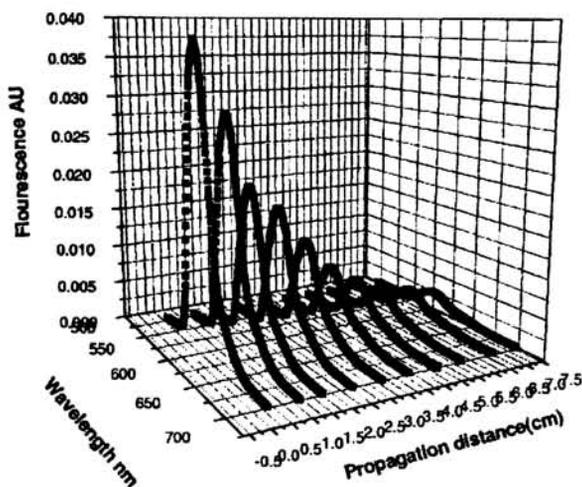
Fig. 3 Transmitted fluorescence spectra measured as a function of the propagation distance (Au = arbitrary units).

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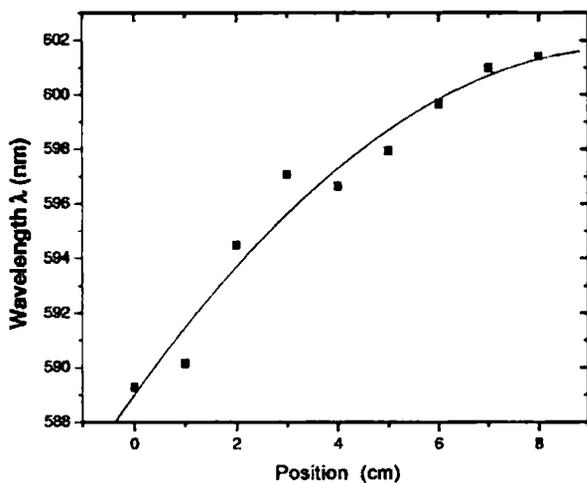
Fig. 4 The variation of the fluorescence peak with propagation distance.

Fig. 5 Plot of ln(I) versus z (z is the propagation distance through the fiber in centimeters).

length region.[11] As the fluorescence light is guided through the dye doped fiber, the effective path length is increased resulting in self-absorption and re-emission, causing a red-shift in the observed spectrum. The farther the point of illumination is from the observation end, the larger is the effective path length. This results in increased interaction between the dye molecules and beam propagating through the fiber causing enhanced fluorescence emission in comparison to that expected from Beer–Lambert's law. This results in an increased self-absorption of the fluorescence and thereby shifting the emitted fluorescence peak toward the longer wavelength region. Figure 4 shows the variation of the fluorescence peak wavelength as a function of propagation distance through the fiber. For shorter propagation distances in the fiber, the redshift shows a linear behavior, whereas at longer distances, the shift tends to exhibit saturation behavior. This mechanism is similar to the concentration-dependent redshift that is observed in dye solution.[12]

The fluorescence collected from the dye doped fiber has a spectral width of about 40 nm. The transmitted fluorescence is measured as a function of the propagation distance so as to characterize the attenuation in the fiber. From Beer–Lambert's law for linear optical attenuation in a medium, $I(\lambda,z)=I_0(\lambda)\exp(-\alpha(\lambda)z)$, where $I(\lambda,z)$ and $I_0(\lambda)$ represent the intensity of the transmitted light at wavelength λ at propagation distances z and $z=0$ (incident intensity), respectively, and $\alpha(\lambda)$ is the linear attenuation coefficient.

Figure 5 shows plots of the natural logarithm of the transmitted fluorescence intensity versus the propagation distance corresponding to various emission wavelengths. An interesting observation is the nonlinear behavior of these plots, which suggests that the loss coefficient is not a constant for the total length of propagation through the fiber. The nonlinear plot of ln I versus z can be fitted to a minimum number of straight lines (the method is known as peeling the curve), which will provide the corresponding loss coefficients. Figure 6 shows the application of this
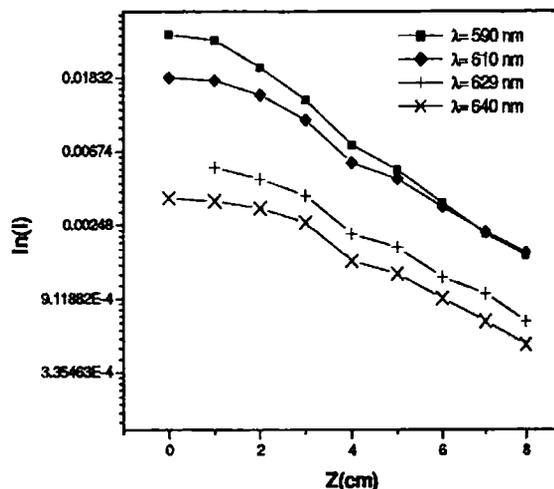
method to the semilogarithmic plot for a given wavelength (λ=610 nm). For the lowest pump power, the plot can be fitted to a single straight line [Fig. 6(a)], whereas for higher powers it has to be fitted to two straight lines [Figs. 6(b) and 6(c)]. These results clearly suggest that as light propagates through the fiber, there arise some mechanisms that tend to alter the optical attenuation inside the fiber especially for larger propagation distances. It is observed that the spatial dependence of attenuation decreases for longer distances of propagation.

One of the possible mechanisms for this behavior is re-absorption of fluorescent light on the shorter wavelength side of the absorption spectrum and subsequent emission in the longer wavelength region. This re-emission in the longer wavelength side generates increased emission in the longer wavelength region resulting in enhanced intensity. The increase in the path length also causes different attenuation rates for various emission intensities. This explains the observation of difference in attenuation values with respect to distance for a given power. This also supports the observation that z-dependent attenuation effect is more prominent in the longer wavelength region of the fluorescence spectrum. As the pump power is increased, the intensity of the fluorescence emission is also enhanced, which in turn causes increased probability of the reabsorption-emission process. This is exhibited as two linear parts in the ln I-z plots corresponding to higher pump powers.

4 Conclusion

Using a side illumination technique, position-dependent tuning of fluorescence light emitted from a rhodamine 6G doped polymer optical fiber is observed. The data from the fluorescence collected from the fiber are used to characterize the loss mechanisms of the fiber. It has been observed that at longer wavelengths, there is a lowering of attenuation toward larger distances of propagation in the fibers. This type of position-dependent loss coefficient in the dye doped fiber suggests the possibility of gain at the longer wavelength side of fluorescence emission. The mechanism

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Power@ 4.5 mW

λ=610 nm

-0.05

Z (cm)

Power @9.52mW

λ=610 nm

-0.40

-0.33

Z(cm)

Power @ 18 mw

λ=610 nm

-0.46

-0.34

Z(cm)
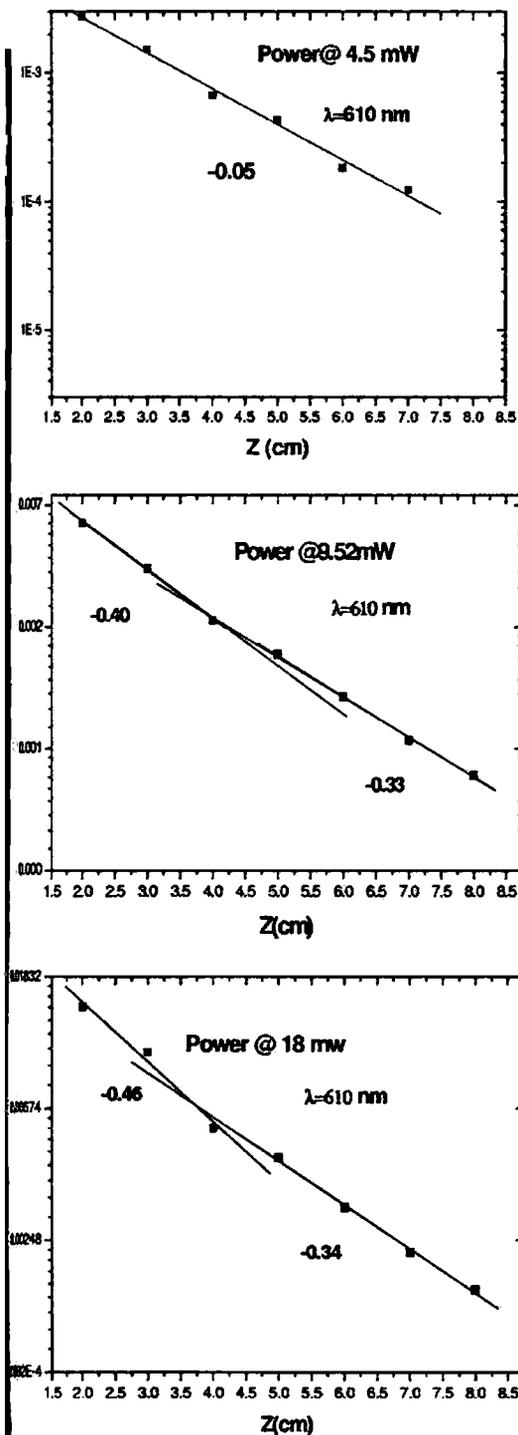
The "peeling the curve" method applied to ln(I) versus z plot at 610.064 nm at different powers. The solid lines represent the fits to the data.

for such a position-dependent loss parameter is attributed to the reabsorption and re-emission processes taking place along the length of the fiber. This suggests that appropriate design of the fiber will lead to a gain on the longer wavelength side.

Acknowledgments

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