



Polymer optical fiber with Rhodamine doped cladding for fiber light systems



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ABSTRACT

Both preform and polymer optical fiber with a Poly(methyl methacrylate) core and THV–Rhodamine 6G cladding were characterized. UV–vis absorbance, photoluminescence spectra and lifetime of the preform were measured. Axial and lateral photoluminescence spectra of the polymer optical fiber were studied under 404 nm excitation in order to study the illumination performance of the fiber. It was observed that the peak wavelength from the fiber photoluminescence spectra is higher than the peak wavelength from the fiber preform and that the peak wavelength from the fiber photoluminescence spectra is red shifted with the fiber length in the case of axial emission. The obtained results suggest the influence of self-absorption on the photoluminescence shape. Strong lateral emission along the fiber was observed with the naked eyes in all the cases. The lateral photoluminescence spectra show that the lateral emission is a combination between the pump laser and the Rh6G molecule photoluminescence. The results suggest that this polymer optical fiber could be a potential candidate for the development of fiber lighting systems.

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1. Introduction

Over the past decade, polymer optical fibers have found a new niche in the illumination field. Typically, a lighting fiber system is composed of a light source, a connector and a side emitting polymer optical fiber which is designed to promote leakage of the core-transmitted radiation through their side surfaces. Such fiber light systems offer several advantages; the light source can be placed in a convenient location for access and maintenance, and one source can be used to light several areas. With the appropriate filters, lighting fibers will not transmit infrared or ultraviolet light, making them well suited for museums and showcase lighting since they will not damage paintings, textiles, or other sensitive materials. Glass or plastic fibers are also nonconductive, making them good choices for wet environments such as gardens or swimming pools [1]. Additionally, fiber lighting systems are useful in hazardous and explosive environments where high-voltage tube devices can be replaced with side-emitting optical fibers.

Lateral light emission can be achieved in several ways: by increasing the refractive index of the fiber cladding material over

that of the core material; leaving fine particles inside the fiber core or cladding to scatter the light along the fiber [2–4], having a partially detached core region and leaving a gap between the core and the clad along the length [5]; by scratching the surface of the cladding or the core with angular cuts or discontinuities at intervals along the fiber [6–8]; creating asymmetries in the fiber core/cladding geometry; and adding fluorescent dyes into the core or cladding material.

In this work, we present the fabrication and characterization of a Rhodamine 6G (Rh6G) doped polymer optical fiber for lateral illumination. Rhodamine dyes and their derivatives are widely used and have been studied in diverse areas of research and for commercial purposes due to their good fluorescence properties. Compared to other dyes, the Rh6G has a high photostability, high fluorescence quantum yield (0.95), a low cost, and its lasing range has close proximity to its absorption maximum [9–12]. In order to study the illumination performance of the fiber, axial and lateral light emission was captured by exciting the dye doped fiber with a blue laser. The shape and intensity of the axial photoluminescence spectra were studied in dependence of the fiber length. Unlike conventional lateral fiber light systems in which the lateral emission comes only from the pump radiation, the multicolor lateral light emission of the presented fiber is a combination between the pump radiation and the dye molecule photoluminescence.

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2. Experimental procedure

2.1. Preform and fiber fabrication

Fibers were obtained by drawing at 200 °C, a 25 mm diameter preform, with Poly(methyl methacrylate) (PMMA) core and THV–Rhodamine 6G cladding, (THV: fluorothermoplastic containing tetrafluoroethylene, hexafluoropropylene and vinylidene fluoride from 3M-Dyneon) to a diameter of 0.4 mm. The chosen cladding provides a good solvent processing, thermal stability, high transparency and low refractive index. It has good weatherability and anti-soiling properties. The preform was obtained by multicoating a PMMA bar with a solution of Rhodamine and THV in ethyl acetate. The used PMMA bar, with a molecular weight of 98,000 Da, and a polydispersity of 2.1, was obtained by a method described elsewhere [13]. For the coating, Rhodamine 6G from Sigma Aldrich was first diluted to saturation in HPLC grade ethyl acetate from Baker. The saturated solution was then filtered with a 100 Rundfilter from Macherey-Nagel to separate not dissolved particles and then used to dissolve THV to make a concentrated solution of 150 g of this polymer per liter of solution. To make the preform, the obtained PMMA bar was machined to lower its diameter to 24 mm and then coated by applying several single coatings of the described solution over the bar mounted in a lathe at a speed of 200 rpm. Each coating was applied under a flow of filtered air and subsequent coatings were applied until the previous one was dried to touch. In this way, an estimated thickness of 0.5 mm was obtained. The coated bar was then further dried at 90 °C for 40 h. Fig. 1 shows a photograph of the final preform taken after drawing. It was observed the presence of bubbles in the surface of the preform which appeared during the drawing process. Bubbles are the result of incomplete solvent evaporation during the preform drying procedure and they are only observed during the drawing process. They could be reduced by vacuum evaporation of the solvent and/or by extended preform drying times; however a detailed characterization is necessary to understand this phenomenon.

Although the quality and efficiency to obtain thick cladding are relatively low compared to other preform fabrication methods [14], the described method allows, in a simple way, the combination of many compatible materials as well as the inclusion of any type of dyes soluble in the solvent and the hosting material. From this point of view, the proposed method is complementary to those used to produce thick cladding preforms.

2.2. Preform and fiber optical characterization

The UV–vis absorbance spectra (300–750 nm) of the samples were measured with a spectrometer (Perkin Elmer Lambda 35) with 1 nm resolution. Preform and fibers photoluminescence (PL) spectra were recorded by exciting the samples with a 404 nm

pulsed laser diode drove at 1 MHz with a pulse width of 5 ns and an average power of 200 μ W. The pump beam was focused at one end of the tested fibers using a convex lens with a focal length of 5 cm. The photoluminescence spectra from the end face (Fig. 2(a)) or side face (Fig. 2(b)) of the fiber were measured using a fluorometer in which the input signal is chopper modulated at the entrance of the monochromator (iHR320 from Horiba) and synchronously measured by introducing the output of a H9307-02 photomultiplier tube in a Lock-In amplifier (Fig. 2(c)). The spectral attenuation of the fiber was also measured by the standard cut-back method. In this measurement, a tungsten lamp was used to feed the fiber. In the case of lateral emission, the photoluminescence spectra were collected perpendicular to the optical fiber axis using a 1 mm plastic multimode optical fiber (MMOF). Lateral emission along the fiber was observed with the naked eyes in all the cases. Fig. 2(d) shows a photograph of the Rh6G doped plastic optical fiber under 404 nm excitation. Lateral image of the fiber under 632.8 nm and 404 nm excitation was acquired using a microscope (NZ-14T Iroscope) at 40 \times magnification and a CCD camera. It is worth to mention that the polymer optical fiber was kept straight or with bend radius higher than 15 cm in all the measurements.

Lifetime measurement was done on the surface of the preform. The excitation and emission wavelength was 404 nm and 580 nm, respectively. Intensity decay was collected by a time-domain technique using a single photon detection module (ID100 model from IDQ) and an advanced time to digital converter (ID800 model from IDQ).

3. Results and discussion

3.1. Preform characterization

As previously reported for the case of Rhodamine dissolved in Ethanol (RDE) [15], the absorbance spectrum of Rhodamine 6G doped THV film shows two absorption bands peaked at 350 nm and 535 nm and a small shoulder around 500 nm (Fig. 3). The main peak for RDE is 5 nm blue-shifted with respect to Rhodamine 6G doped THV presumably due to a larger dipole–dipole interaction between the polar groups of Ethanol and Rhodamine [16]. The band around 535 nm is attributed to the S_1 state and corresponds to absorption by the free Rhodamine 6G monomer [17]. The small shoulder around 500 nm has been attributed to dimer formation at high Rhodamine concentrations [18]. The weak band around 350 nm is assigned as S_2 state [19–20].

The photoluminescence spectra under 405 nm and 532 nm excitation show one intense and broad band in the visible region (Fig. 3). In agreement with Kasha's rule, the emission spectra are essentially the same for 405 and 532 nm pumping [21]. The full

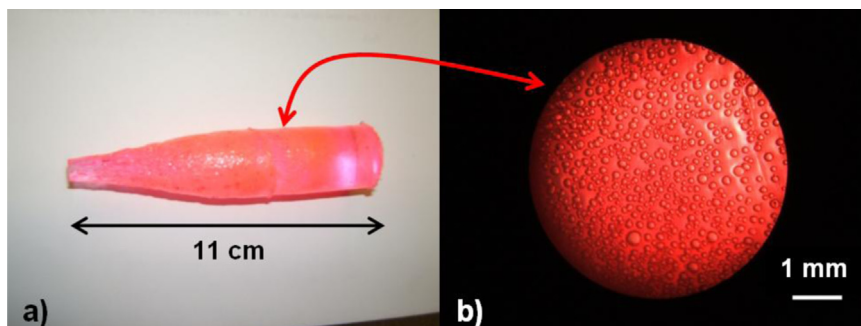


Fig. 1. (a) Preform photograph taken after the drawing process. (b) Surface image of the preform.

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