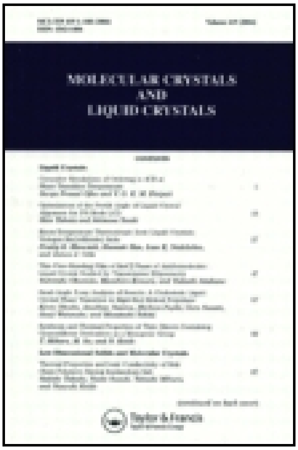

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Graded Index Polymer Optical Fiber Amplifiers

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Graded Index Polymer Optical Fiber Amplifiers

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Abstract Gain dynamics such as signal wavelength dependence and pump wavelength dependence for organic dye-doped graded index (GI) polymer optical fiber amplifiers (POFA) are characterized. A Rhodamine B-doped POFA, 1 m in length and 0.3 mm in core diameter, has exhibited more than 20 dB gain at signal wavelengths from 560 nm to 600 nm when optically pumped at 532 nm. The maximum gain of 37 dB was achieved with a Rhodamine B-doped POFA pumped at 550 nm, which was optimum pump wavelength. For an Oxazine 4-doped POFA, signal gain of 20 dB was obtained when pumped at 605 nm. It is shown that pumping at absorption maximum wavelengths optimizes amplifier performance.

Key words: graded index, polymer optical fiber, fiber amplifier, organic dye

INTRODUCTION

Coherent light sources in a fiber form have been generating a great deal of interest because of their potential use in the growing laser and optical-fiber communication industries. This interest has largely centered around rare earth-doped single-mode glass fiber lasers and amplifiers. However, polymer optical fibers have clear technical advantages over glass fibers, such as flexibility and a large core diameter, which enables efficient coupling and connection[1-3].

In pursuit of high-power, compact and coherent light sources in the visible, we incorporated organic dyes into the core region of polymer optical fibers[4,5]. Organic dyes were chosen as gain media based on the following features: a large emission cross section, which allows the achievement of high gains in a short length of fiber, and a broadband fluorescence spectrum that provides wide tunability. A large number of organic dyes are available over the entire range of the visible spectrum. Therefore it should be possible to design an organic dye-doped POFA that amplifies signal photons at any given visible wavelength. More remarkable is that each of these POFAs is individually tunable over a smaller range of wavelengths.

This paper reports an experimental analysis of the gain dynamics for the organic dye-doped POFAs operating as traveling-wave devices such as signal wavelength dependence and pump wavelength dependence.

SPECTROSCOPIC PROPERTIES OF ORGANIC DYES

Figure 1 shows the energy levels of an organic dye. Each electric level is a band composed of a continuum of vibrational and rotational levels. The absorption band of dyes is due to the transition from the electronic ground state S_0 to the first excited singlet state S_1. The reverse process, the transition between S_1 and S_0, is responsible for the spontaneous emission known as fluorescence and for the stimulated emission.

When the organic dye-doped POFA is pumped with an intense light source, the dye molecules are excited typically to some higher level in the singlet manifold, from which they relax within picoseconds to the lowest vibronic level of S_1, that is, the metastable level for stimulated emission. The allowed transition from the lowest vibronic level of the first excited singlet state to some higher vibronic level of the ground state will give a high amplification factor. However, there are several deleterious transitions such

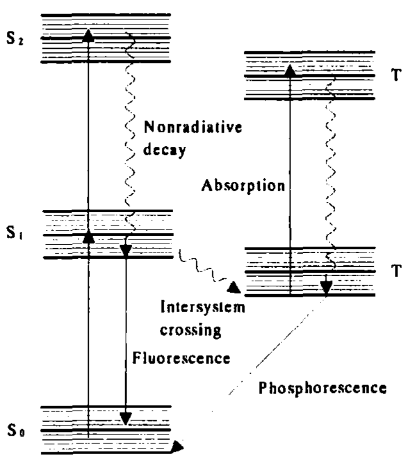

FIGURE 1 Schematic energy levels of a dye molecule.

as intersystem crossing to the triplet state, and absorption due to the allowed transition from the lowest triplet state to the higher triplet states. In the present study, we used light pulses in the nanosecond regime so that population of the triplet state was avoided.

Figs. 2 and 3 show the absorption and emission cross section spectra for Rhodamine B and Oxazine 4 in poly(methyl methacrylate) (PMMA). We determined absorption and emission cross sections based on quantum yield and absorbance measurements. The quantum yields for Rhodamine B, and Oxazine 4 in PMMA were measured to be 0.76, and 0.10, respectively. The smaller emission cross section of Oxazine 4 is due to the lower quantum yield compared with that of Rhodamine B. The broad absorption and emission spectra offer the wide variety of excitation sources and wide tunability, respectively.

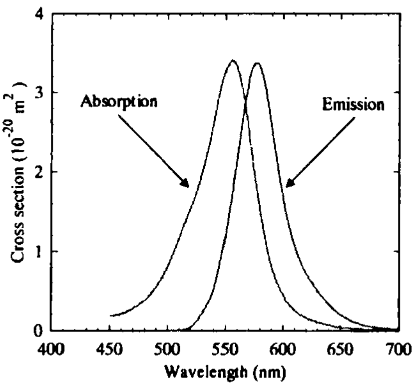

FIGURE 2 Absorption and emission cross section spectra of Rhodamine B in PMMA.

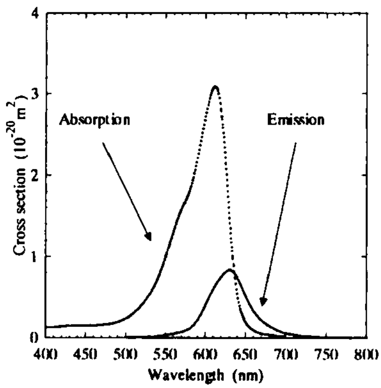

FIGURE 3 Absorption and emission cross section spectra of Oxazine 4 in PMMA.

FABRICATION OF POFA

We employed the interfacial gel polymerization technique to form the quadratic dye distribution as well as refractive index profile. Since the dyes in the low intensity portion of pump profile remain uninverted and reabsorb the signal, the overlap between the spatial modes of the pump light and the distribution of the dye molecules is crucial for efficient excitation. In what follows, we briefly describe the preparation of the fiber. We prepared a PMMA cylindrical tube with 6-mm inner diameter and 10-mm outer diameter. Then, a MMA monomer solution containing specified amounts of 1,1-bis(*t*-butylperoxy)3,3,5-trimethylcyclohexane (initiator), *n*-butyl mercaptan (chain transfer agent), triphenyl phosphate (low molecular weight dopant for a refractive index profile), and organic dye was poured into the tube. The polymerization was carried out at 90 ℃ for 24 hours. The preform rod obtained was heat treated at 110 ℃ to complete the polymerization. The preform rod was heat-drown into a fiber at 200 ℃. The fiber diameter and the core diameter were designed to be 500 μm and 300 μm, respectively.

GAIN DYNAMICS OF POFA

Signal wavelength dependence

A large gain bandwidth of organic dye-doped POFAs suggests that they can be tuned over a 20-50-nm range. We investigated signal wavelength dependence of a POFA fabricated from MMA solution containing 1 ppm-wt of Rhodamine B. The fiber was end-pumped with a frequency-doubled Nd: YAG laser at 532 nm (FWHM = 6 ns). A dye laser pumped at 532 nm with the frequency-doubled Nd: YAG laser was used as a signal source (FWHM = 3.5 ns). We used a spectroscope to separate the amplified output signal from any broad band spontaneous emission or remnant pump before detection with a photomultiplier. Figure 4 shows measured gain versus the signal wavelength for a Rhodamine B doped-POFA with 1-m length for 2.8 kW of pump power at 532 nm. Signal inputs were 0.3 W. Optical amplification over the range 560-600 nm has been achieved with a best observed gain of 33 dB at 580 nm.

The number of possible signal wavelengths and corresponding tunability range are greatly extended by the variety of organic dyes that can be used as dopants. The most important characteristic of POFAs for practical applications is their ability to provide high-power output tunable over a wide range.

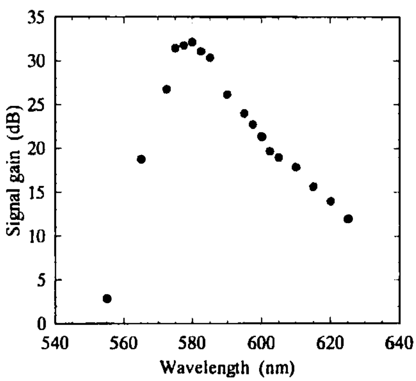

FIGURE 4 Measured signal gain against signal wavelength for a Rhodamine B-doped POFA with 1-m length. Launched pump power = 2.8 kW.

Pump wavelength dependence

We investigated pump wavelength dependence of organic dye-doped POFAs. The experimental setup employed was similar to that used in the previous section. We used an optical parametric oscillator as a pump source. The dye laser was pumped with a 532 nm output of the optical parametric oscillator.

Figure 5 shows pump wavelength dependence for a Rhodamine B-doped POFA with 1-m length. At the launched pump power of 600 W, the best observed gain was 22 dB for a Rhodamine B-doped POFA pumped at 550 nm. The optimum pump wavelength for a Rhodamine B-doped POFA was found to be 550 nm, which is absorption maximum wavelength of Rhodamine B in PMMA. The maximum gain of 37 dB was obtained for a Rhodamine B-doped POFA with 1-m length for 3 kW of pump power at 550 nm.

Figure 6 shows pump wavelength dependence for a POFA fabricated from MMA solution containing 10 ppm-wt of Oxazine 4. The optimum pump wavelength for an Oxazine 4-doped POFA was found to be 605 nm. The maximum gain of 20 dB was obtained for an Oxazine 4-doped POFA with 0.4-m length for 3 kW of pump power at 605 nm. It has been shown that the optimum pump wavelength optimizes the POFA performance. We assume that the lower gain for an Oxazine 4-doped POFA is due to the lower quantum yield compared with that of Rhodamine B.

The regions around 580 nm and 650 nm attract most attention because they coincide with the least-loss regions of PMMA-based polymer optical

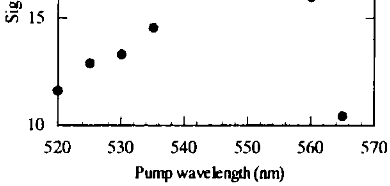

FIGURE 5 Measured signal gain against pump wavelength for a Rhodamine B-doped POFA with 1-m length. Launched pump power = 600 W. signal wavelength = 580 nm.

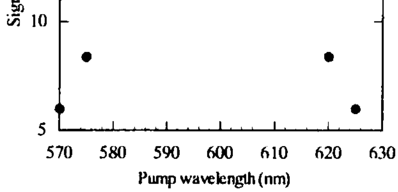

FIGURE 6 Measured signal gain against pump wavelength for an Oxazine 4-doped POFA with 0.4-m length. Launched pump power = 3 kW. Signal wavelength = 644 nm.

fibers. A Rhodamine B-doped POFA operates in the region around 580 nm, and an Oxazine 4-doped POFA in the region around 650 nm.

CONCLUSIONS

We studied signal wavelength dependence and pump wavelength dependence of organic dye-doped POFA. More than 20 dB gain has been obtained for signal wavelength spanning the 40 nm range between 560 nm and 600 nm with a Rhodamine B-doped POFA with 1-m length, pumped at 532 nm. Furthermore, the maximum gain of 37 dB was achieved with a Rhodamine B-doped POFA with 1-m length pumped at 550 nm. Also, signal gain of 20 dB was obtained with an Oxazine 4-doped POFA pumped at 605 nm. A remarkable advantage of organic dye-doped POFAs is the enormous selection of signal wavelengths for amplification due to the large variation in dye structure. Commercial dyes can be selected for output at wavelengths from visible well into the infrared. The broad spectral coverage demonstrates the versatility of the organic dye-doped POFAs.

We successfully combined the excellent properties of polymer optical fibers and organic dyes to generate high-power light pulses. The organic dye-doped polymer optical fiber amplifiers offer a high-power, and tunable coherent light source with minimum maintenance and an easy change of wavelengths, and are currently under further investigation with a view to applications in such diverse fields as medicine and industry.

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