

# Rhodamine 6G-doped polymer optical fiber amplifiers

Zhiqiang Zheng (郑志强)<sup>1,4</sup>, Hao Liang (梁浩)<sup>2</sup>, Hai Ming (明海)<sup>1</sup>, Qijin Zhang (张其锦)<sup>2</sup>, Yuanqin Yu (喻远琴)<sup>3</sup>, Shilin Liu (刘世林)<sup>3</sup>, Yunsheng Zhang (张运生)<sup>2</sup>, and Jianping Xie (谢建平)<sup>1</sup>

<sup>1</sup>Department of Physics; <sup>2</sup>Structure Research Laboratory and Department of Material Science and Engineering;

<sup>3</sup>Department of Chemical Physics, University of Science and Technology of China, Hefei 230026

<sup>4</sup>Department of Physics, Fujian Normal University, Fuzhou 350007

Received October 27, 2003

Rhodamine 6G-doped step-index polymer optical fiber is fabricated. The characteristics of the amplification of rhodamine 6G-doped step-index polymer optical fiber amplifier have been studied. The high-gain optical amplification with a tunable wavelength range from 585 to 613 nm is obtained in a step-index polymer optical fiber doped with rhodamine 6G at 10-ppm level, which can be used for broadband amplifiers and tunable lasers.

OCIS codes: 160.5470, 060.2320, 060.2280.

There has been considerable interest in the development of the polymer optical fiber (POF) for local networks, computer data links, optical sensors, etc.<sup>[1]</sup>. POFs offer many advantages over glass fibers, such as flexibility and a large core diameter, which enable efficient connection and coupling, resulting in lower installation and handing cost. Along with the development of POF systems, the corresponding laser and amplifier are necessary. Optical amplification in rhodamine B-doped POFs has been demonstrated<sup>[2,3]</sup>.

In this letter, we report the development of a novel technique for fabricating rhodamine 6G (R6G)-doped step-index (SI) POF and the experimental results of optical amplification using a R6G-doped SI POF made by our technique. To our knowledge, it is the first time to realize optical amplification of the R6G-doped SI POF.

In order to fabricate R6G-doped SI POF preforms, we use a thermal polymerization technique developed by our laboratory. First, 15-ml purified MMA, 0.02-g 2,2-azoisobutyronitrile (AIBN) as an initiator, 40- $\mu$ l 1-butanethiol as a chain-transfer agent, and a specified amount of R6G dimethyl sulfoxide (DMSO) solution were mixed in a vessel. The above solution was injected into a teflon tube, and then the thermal polymerization of the filled tube was carried out in a water bath at 50 °C for 48 h under 6-atm nitrogen and additionally heated at 75 °C until solidification was fulfilled. The preform with a diameter of 10 mm prepared by above process was then heat-drawn into an optical fiber at 170 °C by a taking up spool. The diameter of the R6G-doped SI POF can be controlled by adjusting the ratio of the preform moving velocity and driving roll velocity. The fiber was clad with silica resin whose refractive index is 1.411. The numerical aperture of the R6G-doped SI POF is 0.49 with a core refractive index of 1.496.

The pump source is an argon laser operating at 514.5-nm wavelength for fluorescence measurements. The coupling of the laser radiation into the fiber was achieved by 10 $\times$  microscope objective lens. The radiation from the other end of the fiber was directed to a spectrometer and detected by a photo-multiplier of silicon detector. To increase the signal-to-noise ratio, the phase sensitive detection scheme (lock-in) was employed by chopping the pumping beam. Figure 1 shows the emission spec-

tra of different length of R6G-doped fibers (10-ppm concentration). From this measurement, we know that the fluorescence intensity increases and the emission peak wavelength shift from 602 to 590 nm when the fiber length is shorten from 80 to 20 cm. Due to broad molecule energy, R6G possesses a large and broad overlapping between absorption and emission spectra<sup>[4,5]</sup>. Because R6G molecules absorb the emission spectrum on the short-wavelength, the emission from the front part of the fiber can be reabsorbed by the later part. The shorter the fiber length is, the smaller the absorption on short-wavelength is, which results in a blue shift of emission spectrum. It can also be seen from Fig. 1 that the emission band is very board (from 570 to 670 nm). Such a wide bandwidth emission can be used for tunable lasers and amplifiers.

The experimental setup of the amplification measurement is shown in Fig. 2. The pump source was a doubled Q-switched Nd:YAG laser (Spectra Physics PRO-190) at 532-nm wavelength and the signal source was a dye laser (Continuum ND6000). The full-width at half maximum of both signals and pump pulses is about 10 ns. The repetition rate of the pulses is 10 Hz. The pump and signal lights were combined by means of a beam splitter BS<sub>2</sub> and coaxially launched into the R6G-doped SI POF. After passing through a spectroscope, the output from the SI POF at signal peak power of 1.0 W launched into fiber was detected by a fast Si PIN detector connected with an oscilloscope. The core diameter and cladding of

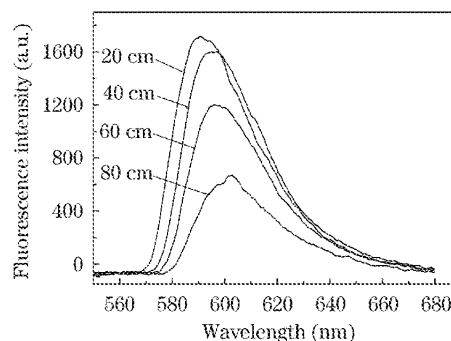


Fig. 1. Emission spectra of R6G-doped fibers (10-ppm concentration) with different length.

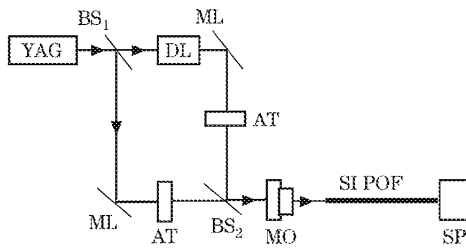


Fig. 2. Experimental setup of optical amplification. YAG: doubled  $Q$ -switched Nd:YAG laser; BS<sub>1</sub>, BS<sub>2</sub>: beam splitters; DL: dye laser; ML: mirror; AT: attenuator; MO: microscope objective; SP: spectroscopy.

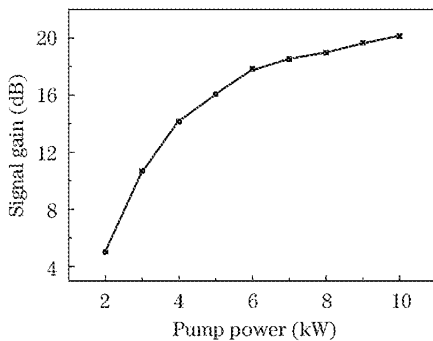


Fig. 3. Signal gain against pump peak power for R6G-doped POF (core diameter is 400  $\mu\text{m}$  and fiber length is 0.4 m).

R6G-doped SI POF used in this work were 400 and 700  $\mu\text{m}$ , respectively. Therefore it is multimoded for the wavelength interest. The pump power and signal power launched into fiber were estimated by the pump and signal coupling efficiencies to SI POF. To obtain optimal signal gain, first we adjusted the optical phase of the pump and signal beams from the beam splitter BS<sub>1</sub> to be the same (to ensure pump pulse to match in time with the signal pulse). Second we adjusted the position of the pump and signal beams to ensure them overlap and launch into fiber coaxially.

The signal gain of the SI POF at 595-nm wavelength against the pump peak power at 532-nm wavelength is shown in Fig. 3. In this case, we can see that the signal gain increases with the increase of pump peak power. Above 5 kW, there appears evidently a certain saturation of gain. The maximum output signal peak power of 102 W (the signal gain of 20 dB) was obtained with the pump peak power of 10 kW. The gain as a function of the signal peak power at input is shown in Fig. 4. The higher the small signal powers the gain is, the lower the energy conversion efficiency is. The region is useful for small signal amplification. With the increase of signal power, the gain drops significantly. When signal peak power is above 20 W, the gain becomes saturated. Nevertheless, the energy conversion efficiencies continue to increase. This is a useful region for high-efficiencies wavelength conversion. The gain as a function of signal wavelength is shown in Fig. 5. The signal peak power at the input is about the same as 1.0 W for different wavelength. From Fig. 5, we can see that a variation less than 3 dB is obtained over the range from 585 to 613 nm. A wide spectral band of high gain can be obtained using

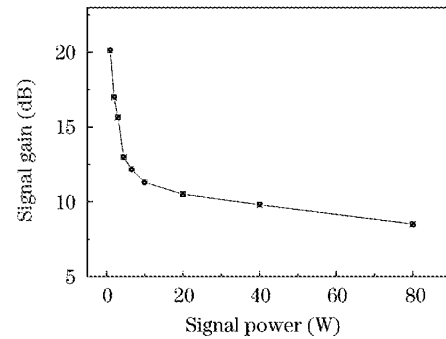


Fig. 4. Gain dependence on the signal peak power at input (fiber length is 0.4 m and the pump peak power at input is 10 kW).

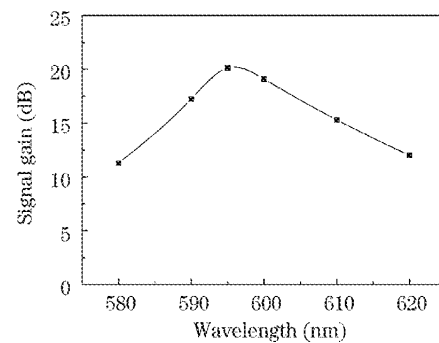


Fig. 5. Gain dependence on the signal wavelength at input (the fiber length is 0.4 m, the pump peak power is 10 kW and the signal peak power at the input is 1.0 W).

the R6G-doped polymer optical fiber, which can be used for broadband amplifiers and tunable lasers.

In conclusion, we have demonstrated that a R6G-doped SI POF can realize good optical amplification. From the experiment, we have achieved high optical gain of 20 dB and broad gain bandwidth. In the duration of experiment, no photodegradation has been observed. When the core of the fiber is decreased, the pump power can be further reduced.

This work was supported by the National Natural Science Foundation of China (No. 90201013 and 90201016), the Fujian Natural Science Foundation of China (No. A0110012), and the Fujian Educational Department Foundation of China (No. JA02169). H. Ming is the author to whom the correspondence should be addressed, his e-mail address is minghai@ustc.edu.cn.

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