Neodymium-complex-doped steady-state polymer waveguide lasers

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Channel waveguides based on a polymer, 6-fluorinated-dianhydride/epoxy, which is actively doped with a rare-earth-ion-doped complex, Nd(thenoyltrifluoroacetone)$_3$ 1,10-phenanthroline, have been fabricated. Luminescence and loss spectra of the channel waveguides have been experimentally investigated. By optimization of the fabrication procedure of both, host material and optical structure, steady-state laser emission has been demonstrated from a channel waveguide near 1060 nm, which provides up to 440 μW of output power from the waveguide structures developed.

Introduction

Polymer waveguides have emerged as a viable technology for integrated optical devices due to their high packaging density, low cost, capability of integration with other material systems, and ease of fabrication and modification of their chemical structure. This latter property offers enormous flexibility in the design of waveguide laser media.

Although laser action has been achieved in many optically pumped organic semiconductor and dye-doped polymer-based waveguides, reports on their rare-doped counterparts are limited to the observation of optical amplification, which was achieved in various Nd^{3+}, Er^{3+}, Eu^{3+}, and Er/Yb^{3+} doped polymers [1, 2]. Incorporation of rare-earth ions into polymers is challenging due to the immiscibility of their salt precursors with organic solvents. This problem can be overcome by encapsulating the ions with organic ligands to form complexes that can be easily dispersed in polymer solutions [3]. In addition to facilitating doping, the ligands can also function as antenna chromophores sensitizing the ion by intramolecular energy transfer, thereby enhancing the pump efficiency of the waveguide laser. Recently, 2 dB/cm gain at 1060 nm was obtained in channel waveguides using this approach [4].

Here, waveguide laser operation of Nd^{3+}-complex-doped polymer channel waveguides near 1060 nm is reported.

Waveguide fabrication

The fabrication process of channel waveguides has been detailed in Ref. [4]. In brief, a neodymium complex, $Nd(TTA)_3phen$, was synthesized and incorporated into the fluorinated host 6-FDA/epoxy. The fluorine ligands and the fluorination of the host material significantly decrease the luminescence quenching originating from high-energy vibrations of C-H and O-H bonds in the polymer host.

By spin-coating and subsequently photodefining a cycloaliphatic epoxy prepolymer (code name CHEP) [5, 6], inverted channels in the low-refractive-index CHEP polymer were obtained on a thermally oxidized silicon wafer. The core material, a $Nd(TTA)_3phen$ doped 6-FDA/epoxy solution, was then backfilled via spin-coating twice and 5×5 μm^2 Nd-complex-doped channel waveguides were realized after thermal curing. An additional 5-μm-thick CHEP layer was spin-coated on top of the channels as

the upper cladding layer. Figures 1(a) and (b) show the geometry of the Nd^{3+} doped 6FDA/epoxy channel waveguide and an optical microscope picture of a channel waveguide cross section, repectively. The channel waveguide loss at 1060 nm determined by the cut-back method at 1060 nm is ~0.1 dB/cm. The concentration of Nd^{3+} for the laser experiment is 1.03×10^{20} cm^{-3}.

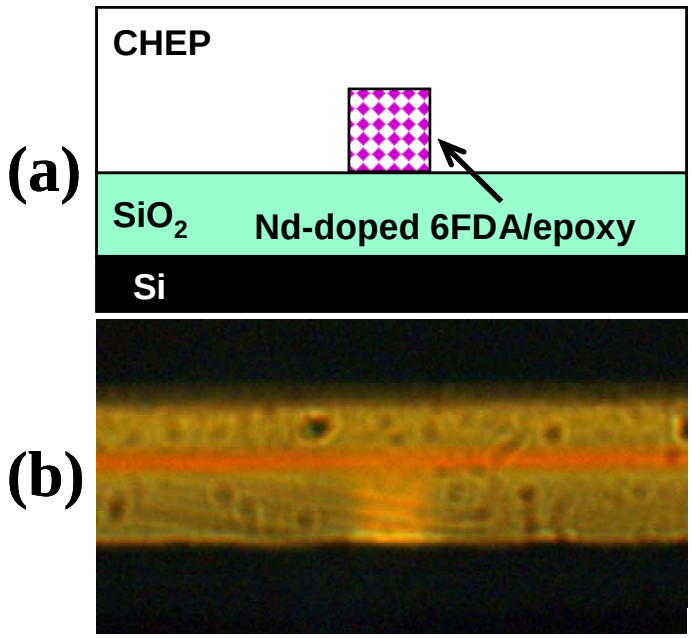

Fig. 1. (a) Geometry of the Nd^{3+} doped polymer channel waveguides and (b) optical microscope picture of a channel waveguide cross section

The photoluminescence of the Nd^{3+}-doped polymer channel waveguides was investigated by replacing the white-light source with coherent irradiation from a Ti:sapphire laser, operating at a wavelength of 800 nm. End-pumping of the sample in this way excited the Nd^{3+} ions in the polymer waveguides and the resulting fluorescence collected from the output face of the waveguide was measured by a spectrometer and an InGaAs detector. In the fluorescence spectrum measured under 800-nm excitation, three fluorescence bands near 880 nm, 1060 nm, and 1330 nm were identified, corresponding to the transitions between the metastable state $^4F_{3/2}$ and the lower lying $^4I_{9/2}$, $^4I_{11/2}$, and $^4I_{13/2}$ states of the Nd^{3+} ions, respectively. The luminescence lifetime of Nd^{3+} in the 6-FDA/epoxy host was measured to be 141 μs, thus demonstrating that the fluorination effectively diminishes non-radiative quenching of the luminescence.

Laser experiment

Figure 2 shows a schematic of the laser experiment. Laser operation was achieved by pumping with a continuous-wave Ti:sapphire pump laser emitting at 800 nm. The laser cavity was formed by attaching thin dielectric mirrors to the polished end-faces of the waveguide using the surface tension of a small amount of fluorinated liquid. The mirror used for incoupling was high-reflective (HR) at the lasing wavelength, while a transmission of 2% at the laser wavelength, respectively, was used as output coupler.

The pump beam was coupled into individual channel waveguides by a microscope objective with a magnification of ×6.3. Guided light from the waveguide was coupled out with a microscope objective with a magnification of ×10 and, after passing through a long-pass filter to block any residual transmitted pump irradiation, was directed onto a photodiode.

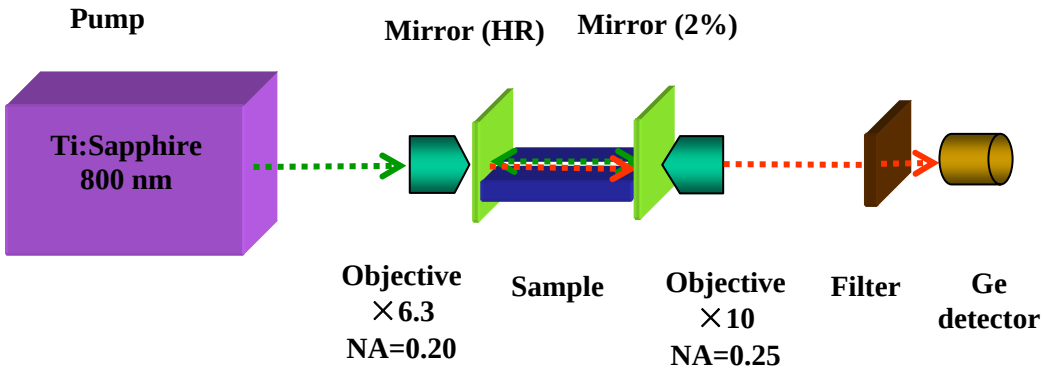

Fig. 2. Schematic of the laser experiment

Laser oscillation was obtained near 1060 nm. A laser threshold of 85 mW absorbed pump power was obtained. The maximum output power was 440 µW for 148 mW of absorbed pump power and a slope efficiency of 0.95% with respect to absorbed pump power was derived.

Conclusion

Laser operation at 1060 nm with an absorbed pump power threshold of 85 mW, a slope efficiency of 0.95%, and 440 µW output power for 2% outcoupling was successfully demonstrated in Nd-complex-doped FDA/epoxy channel waveguides.

Acknowledgement

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