Nd-complex-doped polymer channel waveguide laser

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Summary

Laser operation at 1060 nm with slope efficiency of 0.95% and 440 µW output power for 2% outcoupling was demonstrated in Nd-complex-doped FDA/epoxy channel waveguides, in what to our knowledge is the first report of a rare-earth-ion-doped polymer waveguide laser. The threshold was 45 mW of absorbed pump power.

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 Nd³⁺, Er³⁺, Eu³⁺, and Er/Yb³⁺ 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 Nd³⁺-complex-doped polymer channel waveguides near 1060 nm is reported, which is, to the best of our knowledge, the first demonstration of a rare-earth-ion-doped polymer waveguide laser.

Waveguide fabrication process

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 photodefining a cycloaliphatic epoxy prepolymer (CHEP), inverted channels in the low-refractive-index CHEP polymer were obtained on a thermally oxidized silicon wafer. The Nd³⁺-doped core material was backfilled in the inverted channels via spin-coating twice and then thermally cured, resulting in the formation of 5×5 µm² Nd-complex-doped channel waveguides. A 5-µm-thick CHEP overclad layer was spin-coated on top of the channels. The geometry of the resulting structure together with a microscope image of the cross section of a channel waveguide is shown in Fig. 1.
Channel waveguide laser

Laser operation was achieved 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 set of two mirrors, with high-reflectivity (HR mirror) and with transmission of 2% at the laser wavelength, respectively, were successively used as output couplers. The pump beam passed through an optical chopper operating with a 50% duty cycle to prevent potential photo-degradation effects in the polymer waveguide and was then 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.

Laser oscillation was obtained for all the channels investigated near 1060 nm. A laser threshold of 45 mW absorbed pump power was obtained when the cavity was formed using two HR mirrors. The laser output characteristics as a function of absorbed pump power for an output coupler with 2% transmission at the laser wavelength is shown in Fig. 2. 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.

Fig. 1. (a) Geometry of the Nd³⁺ doped polymer channel waveguides and (b) optical microscope picture of a channel waveguide cross section

Fig. 2. Laser output power as a function of absorbed pump power for an output coupler with 2% transmission at the lasing wavelength

Conclusion

Operation of Nd-complex-doped polymer channel waveguide lasers with a laser threshold of 45 mW, a maximum output power of 440 µW for 2% output coupling, and a slope efficiency of 0.95% was demonstrated. Further studies are ongoing to improve thermal management in order to allow efficient scaling to higher powers.

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References