

Continuous-wave Lasing in a Solid Polymer

J. Yang, C. Grivas, M.B.J. Diemeer, A. Driessen, and M. Pollnau*

*Integrated Optical Microsystems Group, MESA+ Institute for Nanotechnology, University of Twente,
P.O. Box 217, 7500 AE Enschede, The Netherlands*

* Corresponding author: m.pollnau@ewi.utwente.nl

Abstract

Channel waveguides with a Nd-complex-doped fluorinated polymer guiding core were fabricated. For the first time, continuous-wave lasing was demonstrated in a solid polymer. Lasers near 1060 nm and 878 nm were operated for 2 hours.

1. Introduction

Polymer waveguides have emerged as a viable technology for integrated optical devices due to their low cost, capability of integration with other material systems, and ease of fabrication and modification of their chemical structure. Here we report the first continuous-wave laser in a solid polymer.

2. Materials, fabrication, and characterization

To overcome the insolubility problem of the inorganic precursor salts of rare-earth dopant ions in the polymer host, the Nd^{3+} ions were encapsulated in a stable organic complex, $\text{Nd}(\text{TTA})_3\text{phen}$ (TTA = thenoyltrifluoroacetone, phen = 1,10-phenanthroline) (Fig. 1a). The Nd-complex was dissolved into the polymer waveguide material, a solution of 6-FDA/UVR (Fig. 1b). Lifetime quenching by the overtone vibrations of C-H and O-H bonds were diminished by fluorinating the complex and the polymer.

The functionalities of active doping and photo-definition were divided over the core and cladding polymers of the waveguide. The low-refractive-index cladding was a cycloaliphatic epoxy prepolymer (Fig. 1c). Channel waveguides of $5 \times 5 \mu\text{m}^2$ cross-section and up to several cm length were fabricated by spin-coating the cladding polymer onto a thermally oxidized silicon wafer, photo-defining inverted channel waveguides, back-filling these structures with the Nd-doped core material, and spin coating an upper cladding on top [1]. The measured propagation losses were $\sim 0.10\text{-}0.15$ dB/cm at 1064 nm.

When exciting the Nd^{3+} ions near 800 nm, the typical luminescence bands of Nd^{3+} were observed (Fig. 2a). Luminescence decay measurements near 1060 nm revealed a lifetime of 141 μs (Fig. 2b) [3].

3. Optical gain and lasing

In a pump- and probe-beam measurement, the continuous-wave optical gain achievable in the channel waveguide structures was investigated. In a 1-cm-long sample with a Nd^{3+} concentration of $1.03 \times 10^{20} \text{ cm}^{-3}$ a small-signal gain of 2.0 dB/cm and 5.7 dB/cm at 873 nm and 1064 nm (Fig. 3a), respectively, was obtained [2].

Channel waveguide lasers were demonstrated under pumping with a continuous-wave Ti:Sapphire laser at 800 nm, coupled into the channel waveguide with a microscope objective. The laser cavity was formed by two butt-coupled mirrors, which were highly reflective for the laser wavelength at the pumped side and with various outcoupling degrees at the other side. Continuous-wave laser emission (Fig. 3b) was obtained on the 4-level transition at 1062 nm [3] and the 3-level transition at 878 nm [4]. For an absorbed pump power of up to 130 mW, the laser was operated with an output power of up to 1 mW and a slope efficiency of up to 2% over 2 hours without degradation. Higher absorbed pump power caused permanent damage.

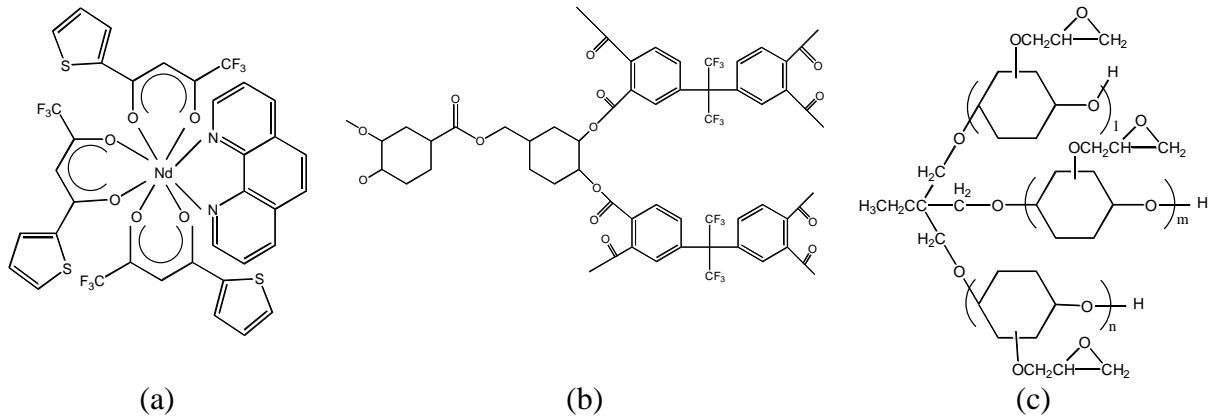


Figure 1. The chemical formulas of (a) Nd(TTA)₃phen, (b) 6FDA/UVR, and (c) EHPE [3].

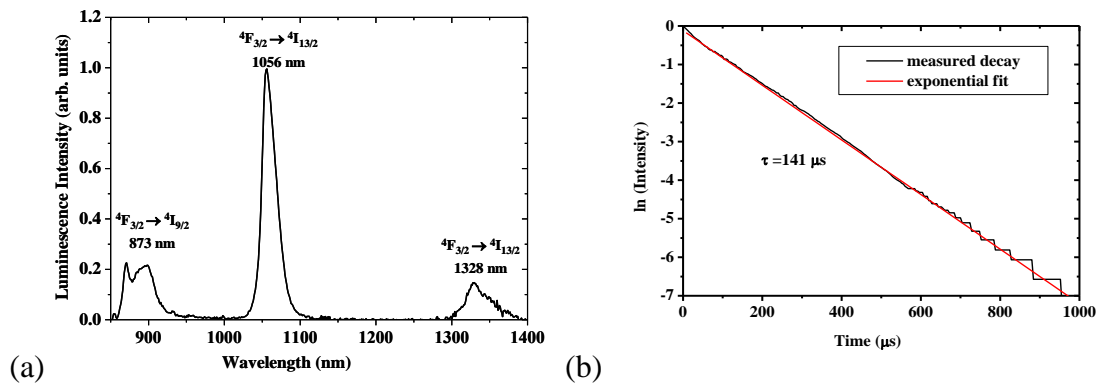


Figure 2. (a) Broadband luminescence spectrum of Nd³⁺-doped 6-FDA/UVR (corrected with respect to the detector response curve) measured in channel waveguides with a Nd³⁺ concentration of $0.30 \times 10^{20} \text{ cm}^{-3}$ [2]; (b) 1060-nm luminescence decay curve of Nd³⁺-doped 6-FDA/UVR [3].

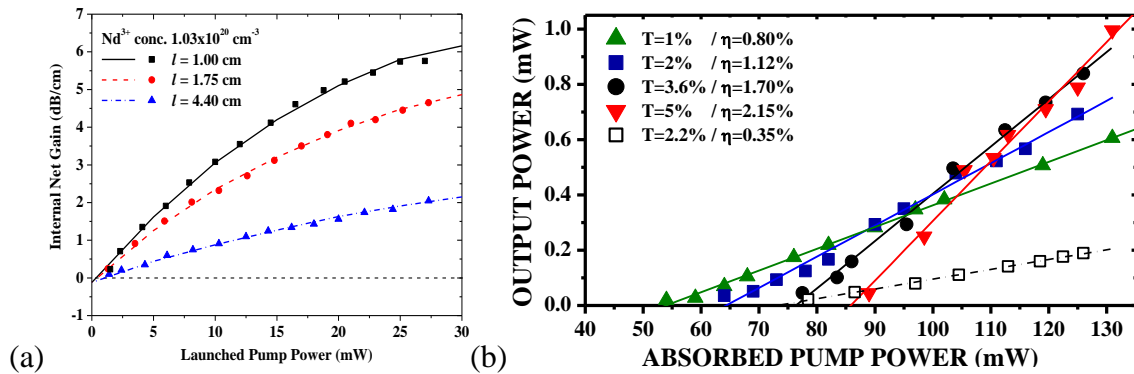


Figure 3. (a) Internal net gain at 1060 nm as a function of launched pump power at 800 nm for different waveguide lengths [2]; (b) Output power as a function of absorbed pump power for the four-level and quasi-three-level laser transitions at 1060.2 nm (filled symbols) and 878.0 nm (open symbols), respectively [4].

Acknowledgement

Support by the Dutch Technology Foundation STW (project TOE 6986) is acknowledged.

References

- [1] J. Yang, M.B.J. Diemeer, D. Geskus, G. Sengo, M. Pollnau, A. Driessen, *Opt. Lett.* **34**, 473 (2009).
- [2] J. Yang, M.B.J. Diemeer, G. Sengo, M. Pollnau, A. Driessen, *IEEE J. Quantum Electron.* **46**, 1043 (2010).
- [3] J. Yang, M.B.J. Diemeer, C. Grivas, G. Sengo, A. Driessen, M. Pollnau, *Laser Phys. Lett.* **7**, 650 (2010).
- [4] C. Grivas, J. Yang, M.B.J. Diemeer, A. Driessen, M. Pollnau, *Opt. Lett.* **35**, 1983 (2010).