Luminescence Study of the $Nd(TTA)_3Phen$-doped 6-FDA/Epoxy Waveguide

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The emission spectrum of the $Nd(TTA)_3Phen$-doped 6-FDA/Epoxy waveguide was measured at different pump powers. The result indicates that stimulated emission might take place at 890nm, 1060nm and 1330nm. The luminescent lifetime of this Nd complex doped waveguide was experimentally obtained and shows that this Nd complex is quite promising for amplification. Based on rate equations and experimentally determined parameters, optical gain of the Nd complex doped waveguide is expected.

Introduction

Our previous work demonstrated that the Nd complex doped 6-FDA/Epoxy is quite promising for optical amplification [1]. The spontaneous emission spectrum of the $Nd(TTA)_3Phen$-doped 6-FDA/Epoxy slab waveguide was observed and channel waveguides were fabricated [2]. In this paper, new results of luminescence spectra obtained with Nd complex doped waveguides are presented. Pump power dependent emission spectra of Nd complex doped channel waveguide were investigated. Luminescent lifetimes of Nd^{3+} ions within the polymer host were measured and discussed. With the experimental results and rate equations, a theoretical estimate is given of the optical gain of our Nd complex doped waveguides.

Emission spectrum of Nd doped polymer channel waveguides

The infrared fluorescence of the Nd complex doped channel waveguide was experimentally obtained by pumping at 800nm (Fig. 1). The emission peaks around 890, 1060 and 1330nm indicate that the Nd^{3+} ions in our polymer waveguide are active.

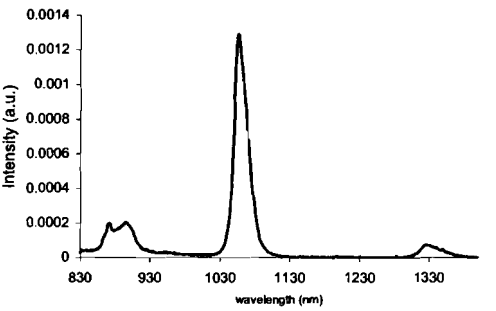


Fig. 1 Room temperature emission spectrum of the $Nd(TTA)_3Phen$ doped 6-FDA epoxy channel waveguide pumped by a Ti:Sapphire laser at 800nm.

Further study was focused on the emission spectrum around 1060nm with higher resolution. Fig. 2a shows the emission spectra of the Nd doped channel waveguide at different pump powers. Fig. 2b gives the intensity of the emission peak (1059nm) as the function of pump power. Comparing with pumping at low power, the emission peak increases faster at pump power higher than 50mW. The slope of the first three points

can be extrapolated, as expected, to the origin with zero intensity at zero pump power. The slope of the rest of the points at higher pump powers in Fig. 2b is much larger with much larger pumping efficiency. This nonlinear response observed in the emission spectrum at high pump powers is an indication of stimulated emission at 1060nm in this Nd complex doped sample. In literatures, similar results have been reported from pump power dependent measurements with similar materials and were attributed to amplified spontaneous emission (ASE) [3,4].

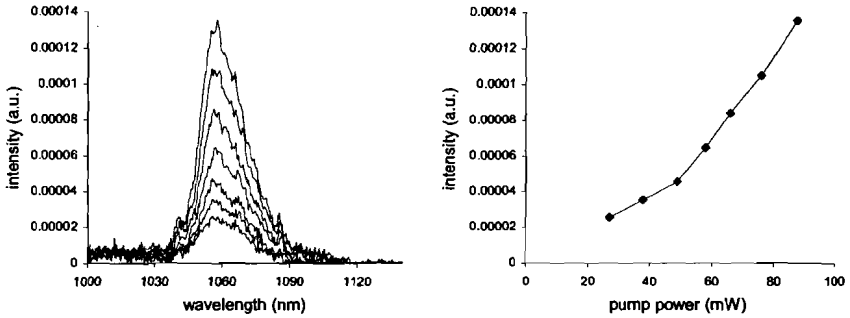


Fig. 2a The emission spectra of a Nd doped channel waveguide with different input powers. Fig. 2b The intensity of the maximum of the emission spectrum at 1059nm as function of input power.

Luminescence lifetime measurement

The lifetime of the metastable state can reveal information such as the quenching due to the interaction between the Nd^{3+} ions and their surroundings. In our $Nd(TTA)_3Phen$-doped 6-FDA/Epoxy, ligands with fluorine and fluorination of the host material were used to reduce the luminescent quenching from C-H bonds and water. Besides that, we replaced the water molecules of the Nd chelate with Phen to reduce the high-energy H-O vibration of H_2O.

In order to measure the luminescent lifetime of the Nd^{3+} ions in our polymer waveguide, we coupled pump pulses into the slab waveguide by a prism coupler. A mechanical chopper was used to modulate the pump beam (in a focal plane) with a 15 μs falltime and 10 ms repetition period. A monochromator operating at 1060nm with low resolution (40nm bandpath) was used to isolate the particular transition from $^4F_{3/2}$ to $^4I_{11/2}$. The signal generated by the photodiode was analysed with a digital oscilloscope.

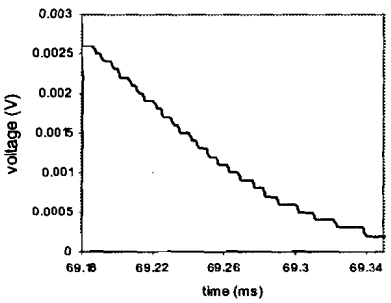


Fig 3. Decay curve of $Nd(TTA)_3Phen$ doped 6-FDA epoxy.

Fig. 3 gives the time dependence decay of the luminescent intensity recorded by the oscilloscope. The luminescent lifetime is 130μs obtained by an exponential fit. This value is of the same order of magnitude as the typical value (around 200 μs) and the value from our Judd-Ofelt analysis [1], which indicates that the transition properties of the Nd^{3+} ions within our polymer host is good.

Rate equations and small signal gain

With the parameters obtained from our experiments, we estimated the optical gain with the aid of the rate equations for Nd^{3+} ions. Theoretically Nd^{3+} can be described as a four level system as shown in Fig 4. The Nd^{3+} ions are excited from the ground state $^4I_{9/2}$ to the upper state $^4F_{5/2}$ followed by a fast decay to the excited state $^4F_{3/2}$.

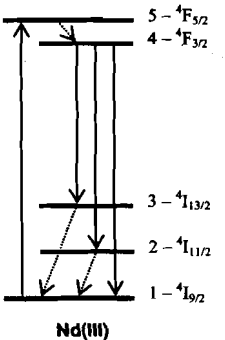


Fig. 4 Energy diagram of Nd^{3+} ions.

Table1 Simulation parameters for the Nd complex doped channel waveguides.

Parameter	Value
λ_p	800 *nm*
λ_s	1060 *nm*
P_p	100 *mW*
P_s	0.001 *mW*
σ_a	$5.92\times10^{-24} m^2$
σ_e	$7.54\times10^{-24} m^2$
τ	0.13 *ms*
N	$1.1\times10^{25} m^{-3}$

λ_p and λ_s are the wavelengths of pump and signal.
N is the concentration of Nd^{3+} in the waveguides.

The rate equations can be simplified as follows [5,6]:

$$\frac{dN_1}{dt} = -W_{15}N_1 + W_{42}N_4 + \frac{N_4}{\tau}$$

$$\frac{dN_4}{dt} = W_{15}N_1 - W_{42}N_4 - \frac{N_4}{\tau} = -\frac{dN_1}{dt}$$

$$N_1 + N_4 = N_{tot}$$

At steady state, we can solve the above equations and get the results:

$$N_1 = \left(\frac{W_{42} + \frac{1}{\tau}}{W_{42} + \frac{1}{\tau} + W_{15}} \right) N_{tot} \qquad N_4 = \left(\frac{W_{15}}{W_{42} + \frac{1}{\tau} + W_{15}} \right) N_{tot}$$

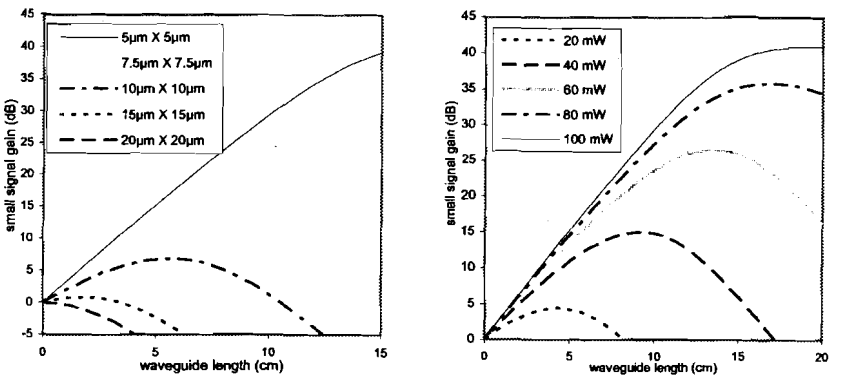
where τ is the lifetime of Nd^{3+} ions. W_{15} and W_{42} are the pump absorption and signal emission rates, which are defined as follows:

$$W_{15} = \frac{\sigma_a}{h\nu_p}\frac{P_p}{A} = \sigma_a \Phi_p \qquad W_{42} = \frac{\sigma_e}{h\nu_p}\frac{P_s}{A} = \sigma_e \Phi_s$$

A is the cross section of the waveguide. σ_a and σ_e are the absorption and emission cross section of Nd^{3+} ions. P_p and P_s are the powers of pump and signal. The change in photon flux and thus the power change of the signal and pump along the waveguide are given by:

$$d\Phi_s = W_{42} N_4 dz \qquad d\Phi_p = W_{15} N_1 dz$$

In this way, optical gain properties can be predicted. Results are presented in Fig.5 for varying waveguide cross section and pump power using the parameters listed in Table 1. The optical gain of multimode waveguides drops rapidly with increasing waveguide cross section. High pump power and waveguides with small cross sections are needed for gain measurement. A waveguide with a dimension of $5\mu m \times 5\mu m$ shows a gain of more than 2dB/cm at pump power of 40mW.



(a) (b)

Fig. 5 Small signal gain for Nd doped waveguides as a function of waveguide length; (a) for various cross sections when pumped at 100mW; (b) for a fixed cross section of 5μm X 5μm for various pump powers.

Conclusion

The pump power dependent measurement of emission spectra for Nd complex doped channel waveguide has been studied and results are quite promising. The measured luminescent lifetime demonstrate that the Nd^{3+} ions within our polymer host have good transition properties. Based on the experimental study and small signal gain model, we arrive at the conclusion that the Nd(TTA)$_3$Phen doped 6-FDA epoxy planar waveguides are well suited as gain media for optical amplification.

Reference

[1] J. Yang, M.B.J. Diemeer, L.T.H. Hilderink, R. Dekker, and A. Driessen, "Judd-Ofelt Analysis of Nd(TTA)$_3$Phen-doped 6-FDA/epoxy Planar Waveguides," in Proceedings of the Annual Symposium of the IEEE/LEOS Benelux Chapter, 2006, pp. 253-256.

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