Sm^{3+} doped polymers for planar optical waveguide amplifiers

L.H. Huang, K.C. Tsang, and E.Y.B. Pun

Department of Electronic Engineering, City University of Hong Kong
Tat Chee Avenue, Kowloon, Hong Kong

Abstract *Samarium (Sm^{3+}) doped SU8 polymer materials were synthesized and characterized. Intense red emission at 645nm was observed under 355nm laser light excitation. Spectroscopic investigations show that the doped materials are suitable for the realization of optical waveguide amplifiers.*

Introduction

Organic polymer materials have many advantages over inorganic materials in the fabrication of active and passive optical waveguide devices [1]. Moreover, many polymer materials are transparent across the low-loss visible wavelength windows of polymer optical fibers (POFs) which are being used in local area networks and short-haul communications [2]. These properties make polymer materials attractive for use in optical waveguide devices that can be readily deployed with POFs, e.g. planar waveguide amplifiers to compensate losses in splitters, multiplexers, switches, and so on. The first organic-dye-doped POF amplifier was reported in 1993, however, cw operation has not been demonstrated due to triplet losses [3]. On the contrary, rare earth ions as amplification media do not suffer from triplet loss and exhibit many advantates, such as steady fluorescence and longer metastable lifetimes, making them suitable for cw operations.

The optical properties of $Sm(BTF)_4P$-doped acetone-d_6 [4], $Sm(HFA)_4Net_4$ doped PMMA-d_8 and $Sm(BTF)_4P$ doped PMMA [5], and $Sm(DBM)_3(TPPO)_2$ doped PMMA [6] were studied. Numerical simulations showed that optical gain higher than 20dB can be realized [4,5].

In this paper, spectroscopic investigations on $Sm(TTFA)_3$ doped SU8 polymer films were carried out. Intense red emission at 645nm was observed in the doped polymer films under 355nm Nd:YAG laser light excitation, and doped polymer channel waveguides were fabricated using a simple UV exposure process.

Experimental

SU8 polymers are electron beam and UV light sensitive materials, and were chosen as the host materials due to their high sensitivities and negative tone properties [7]. $Sm(TTFA)_3$ doped polymers were prepared by adding $Sm(TTFA)_3$ organic complexes into SU8 polymers directly, and the complexes dissolve readily at room temperature. Polymers doped with 1, 2, 3, 4 and 6 wt% $Sm(TTFA)_3$ complexes were prepared and spin-coated on quartz substrates, and the film thicknesses were ~2μm. The absorption spectra were recorded using a UV-VIS-NIR Perkin-Elmer λ_{19} spectrophotometer. The emission spectrum and lifetime measurements were carried out using an Acton Research Corporation Spectra Pro 500i, and the excitation source used was a 355nm Nd:YAG 10Hz pulsed laser.

$Sm(TTFA)_3$ doped channel waveguides with a dimension of 2μm high and 50μm wide were also fabricated using simple UV exposure process, and thermally oxidized silicon wafers with ~7μm thick oxide layers were used as substrates.

Results and discussion

The absorption spectra of undoped and $Sm(TTFA)_3$ doped SU8 films are shown in Fig. 1. The absorption bands with peaks at 236nm and 278nm are attributed to the the absorptions of the SU8 polymers, and the absorption band with peak at 346nm corresponds to the ground state to excited state absorption of the organic ligand ($TTFA^{-1}$). The emission spectra of the doped SU8 films under 355nm Nd:YAG laser light excitation are shown in Fig. 2. Intense red emission was observable by naked eyes, and the spectra consist of four emissions, with peaks at 562, 598, 645, and 705nm wavelengths, corresponding to the transitions from the $^4G_{5/2}$ to the $^6H_{5/2}$, $^6H_{7/2}$, $^6H_{9/2}$ and $^6H_{11/2}$ levels, respectively, and the emission at 645nm is the most intense. The emission intensity increases monotonically with increasing $Sm(TTFA)_3$ concentration (up to the 4 wt%), and then decreases.

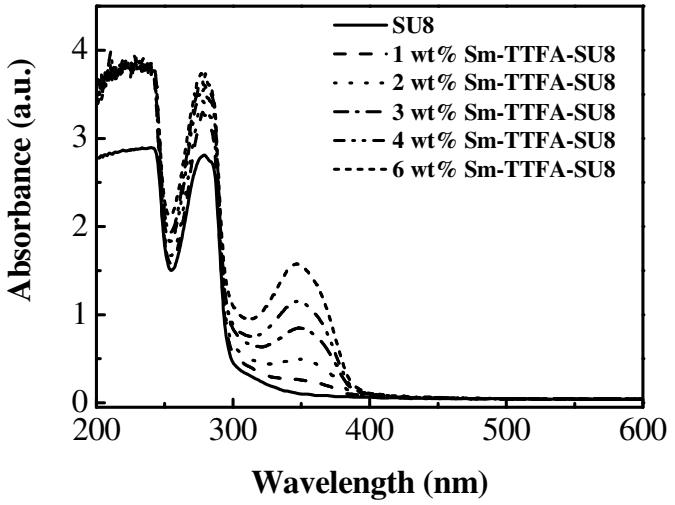

Fig. 1 Absorption spectra of undoped and $Sm(TTFA)_3$ doped SU8 films

From the absorption spectra, the emission spectra and the energy level diagram of Sm^{3+} ions, the luminescence mechanisms of $Sm(TTFA)_3$ doped SU8 films can be explained, as illustrated in Fig. 3. The excitation of the singlet state S_1 from the ground singlet state S_0 occurs in the TTFA ligand after the absorption of UV light. Then, the singlet state S_1 undergoes non-radiative intersystem crossing process to the triplet state T_1. The triplet state T_1 couples with the $^4G_{7/2}$, $^4I_{9/2}$ and $^4M_{15/2}$ energy levels, and transfers energy to these levels. These upper levels relax non-radiatively to the lowest level $^4G_{5/2}$. Finally, the ions in the $^4G_{5/4}$ level relax radiatively to the lower levels $^6H_{5/2}$, $^6H_{7/2}$, $^6H_{9/2}$ and $^6H_{11/2}$, respectively, thereby producing four emissions at 562, 598, 645 and 705nm wavelengths.

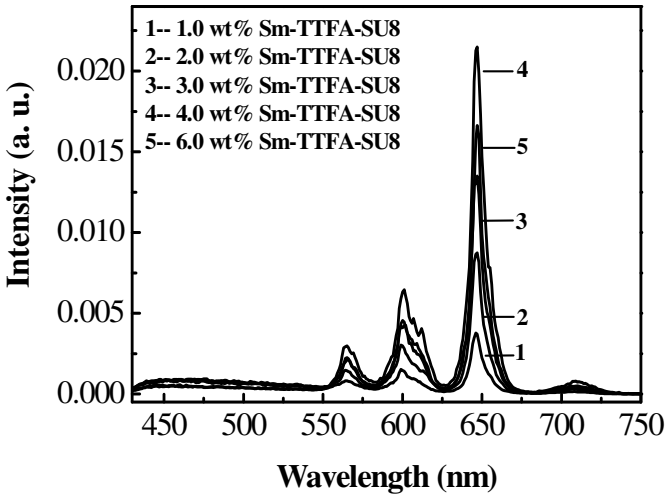

Fig.2 Emission spectra of $Sm(TTFA)_3$ doped SU8 polymer films

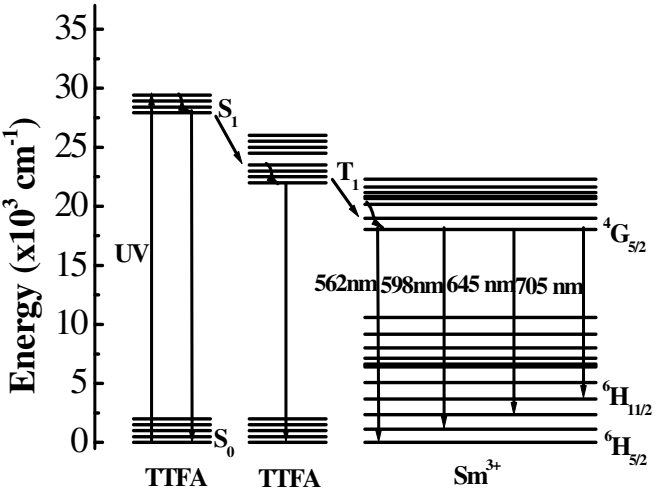

Fig.3 Luminescence mechanisms of $Sm(TTFA)_3$ doped SU8 polymer films under 355 nm UV laser light excitation

The spectroscopic properties of most rare earth ions in solids can be determined quantitatively by the Judd-Ofelt theory [8,9]. Since the waveguide films were only ~ 2μm thick, the absorptions attribute to the Sm^{3+} ions are too weak to be recorded, thus, a 1.47 mm thick 4 wt% $Sm(TTFA)_3$ doped SU8 film was prepared for this purpose. The Judd-Ofelt parameters calculated from the absorption spectra are $\Omega_2 = 14.96\times10^{-20}cm^2$, $\Omega_4 = 11\times10^{-20}cm^2$, and $\Omega_6 = 6.46\times10^{-20}cm^2$. The stimulated

emission cross section (σ_{em}) for the 645nm emission is calculated using the Fuchtbauer-Ladenburg relation [10] and is $2.75\times10^{-21}cm^2$. This value is comparable to reported values for $Sm(BTF)_4P$ doped Acetone-d_6 ($3.3\times10^{-21}cm^2$) [4], $Sm(HFA)_4Net_4$ doped PMMA-d_8 ($4.5\times10^{-21}cm^2$) [5], $Sm(DBM)_3(TPPO)_2$ doped PMMA ($1.58\times10^{-21}cm^2$) [6], and Er^{3+} doped silica optical fiber ($5\times10^{-21}cm^2$) [10]. Hence, $Sm(TTFA)_3$ doped SU8 materials can exhibit efficient amplification at 645nm wavelength under 355nm UV laser pumping. Channel waveguides have been fabricated using direct UV exposure process, and gain measurements are in progress.

Conclusions

Spectroscopic investigations on $Sm(TTFA)_3$ doped SU8 polymer films have been carried out. Intense red emission at 645 nm was observed in the doped polymer films under 355nm Nd:YAG pulsed laser excitation. The J-O parameters of 4 wt% $Sm(TTFA)_3$ doped SU8 film samples are $\Omega_2 = 14.96\times10^{-20}cm^2$, $\Omega_4 = 11\times10^{-20}cm^2$, and $\Omega_6 = 6.46\times10^{-20}cm^2$. The calculated stimulated emission cross section is $2.75\times10^{-21}cm^2$ and is comparable to values reported for Sm doped PMMA polymers. Channel waveguides have been fabricated in the doped materials using simple direct UV direct exposure, and the results indicate that $Sm(TTFA)_3$ doped SU8 polymers are suitable for the fabrication of polymer waveguide amplifiers and lasers in the visible spectrum.

Acknowledgments

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