Tm^{3+}/Yb^{3+} codoped aluminum germanate ion-exchanged glass waveguide amplifiers

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Abstract—**K^+–Na^+ ion-exchanged waveguide amplifiers have been fabricated in Tm^{3+}/Yb^{3+} aluminum germanate (NMAG) glasses. The quantum efficiency of the $^3H_4$ level is ~ 23.8%, and a relative gain of 3.47dB at 810nm wavelength has been obtained in a 2.20 cm long waveguide under 457mW 980 nm laser diode excitation.**

Keywords-component; Tm^{3+}/Yb^{3+} co-dopants; NMAG glasses; Waveguide amplifiers, Integrated optics

I. INTRODUCTION

In optical telecommunications, the first window wavelength (FWW) band (around 800-850 nm) which used multi-mode optical fibers has not been explored fully due to the high loss and large dispersion associated with the wavelength band. Recently, with the rapid expansion of the local area network (LAN) and intercity fiber-to-home net-work, FWW band has come into the focus for short-range communication. Thus, designing efficient optical amplifiers working at this wavelength region is highly desirable [1-3]. For signal amplification in FWW band, anti-Stokes upconversion emission plays an essential role. Up to now, rare-earth (RE) ions doped fibers have achieved effective signal gains in the first telecommunication window, and encourage researchers to re-examine the window again [4,5]. In addition, with the growing demand of compact and large capability communication systems, much of the research interest center on waveguide amplifiers owing to their potential applications in short-length, high-gain, and multi-channel signal amplification.

Recently, we have made high-quality and low phonon energy (~880cm^{-1}) aluminum germanate (NMAG) glasses, and have successfully demonstrated S-band and C-band ion-exchanged waveguide amplifiers [6,7]. In this work, we report the fabrication of high concentration Tm^{3+}/Yb^{3+} codoped NMAG glass waveguides, and obtain efficient integrated FWW band amplifiers. The results indicate that the Tm^{3+}/Yb^{3+} codoped NMAG waveguide amplifiers are suitable for short-range communications.

II. EXPERIMENTS

Tm^{3+}/Yb^{3+} codoped NMAG glasses, were prepared from high-purity Na_2CO_3, Al_2O_3, MgO, GeO_2, Tm_2O_3 and Yb_2O_3 powders, and followed the preparing procedures described in [6]. Considering the ion concentration dependence on upconversion efficiency, energy transfer rate and fluorescence quenching, 1wt% Tm_2O_3 and 2wt% Yb_2O_3 were used to dope the glasses. Yb^{3+} ions are used as an important sensitizer to produce efficient upconversion fluorescence under the 980nm laser excitation. Before preparing K^+–Na^+ ion-exchanged channel waveguide, Tm^{3+}/Yb^{3+} codoped NMAG glass substrates were optically polished and cleaned. A 200-nm-thick aluminum film was thermally deposited on the glass surfaces, and groups of 6-μm-wide channels were opened by standard micro-fabrication process and wet chemical etching method. The two end-faces of the waveguides were polished for further optical measurements.

The input end of an optical fiber was connected to the Tm^{3+}/Yb^{3+} co-doped NMAG glass channel waveguides, and under the excitation of a 980nm wavelength laser diode the ASE upconversion emission spectra were collected and recorded by a HORIBA Jobin Yvon FL3-21-iHR luminescence spectrometer. Gain measurements of the Tm^{3+}/Yb^{3+} codoped NMAG glass waveguide amplifiers were carried out as follows: Fiber-pigtailed 980nm and 810nm wavelength single-mode laser diodes were used as the pump and signal sources, respectively, and a wavelength division multiplexing (WDM) fiber coupler was used to combine both the pump and signal lights and lights were launched into the waveguide amplifer. The amplified light from the output facet of the waveguide amplifier was collected by a single-mode fiber connected to an HP86140B optical spectrum analyzer (OSA).

III. RESULTS AND DISCUSSION

Fig. 1 shows the ASE upconversion emission spectra of Tm^{3+}/Yb^{3+} co-doped NMAG glass channel waveguides under 980nm wavelength excitation.

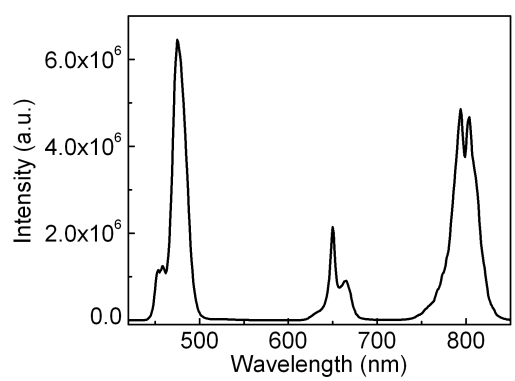

Fig. 1 The ASE upconversion emission spectra of Tm^{3+}/Yb^{3+} co-doped NMAG glass channel waveguides under 980nm wavelength laser diode excitation.

Three main ASE upconversion emission bands were observed at 475, 650, and 794 nm, corresponding to the radiative transitions of $^1G_4 \rightarrow ^3H_6$, $^1G_4 \rightarrow ^3F_4$, and $^3H_4 \rightarrow ^3H_6$, respectively. The excitation mechanism is similar to that in other RE doped glass substrates, and in Tm^{3+}/Yb^{3+} codoped NMAG glasses the blue and red emissions are due to a three-photon excitation process, and the NIR emission is due to a two-photon excitation process. The absorption σ_{abs} and stimulated emission cross-section σ_{em} of Yb^{3+} were calculated using the reciprocity method [8], and the maximum values are 1.51×10^{-20} and 1.44×10^{-20} cm^2 at 976.5 and 977.0nm, respectively. Both values are higher than those in fluoride, fluorophosphate and bismuth borate glasses, and close to that of tellurite-based glasses. Large absorption and emission cross-sections of Yb^{3+} are beneficial in absorbing enough pumping energy and transferring considerable energy to Tm^{3+} ions in codoped NMAG glass system. Based on the experimental analysis, the quantum efficiency of the $^3H_4$ level is derived to be ~23.8% from the ratio of the measured lifetime to the calculated radiative lifetime.

The devices were multimode waveguides, and the propagation losses were measured to be ~0.42dB/cm using the cut back method.

Fig.2 shows the OSA spectra recorded under 457mW pump power and presents the small signal enhancement in the first telecommunications window. The relative gain G_R is defined as

$$G_R = 10\log_{10}[(P_{Sig(PumpOn)} - P_{ASE})/P_{Sig(PumpOff)}], \quad (1)$$

where $P_{Sig(PumpOn)}$ and $P_{Sig(PumpOff)}$ are the signal powers from the output end of the waveguide amplifier with and without pump power, respectively, and P_{ASE} is the amplified spontaneous emission power. From the measured OSA spectra, the relative gain for the 810nm wavelength signal in a 2.20-cm-long waveguide is 3.47dB, hence the gain coefficient is 1.58dB/cm. The gain coefficient obtained in NMAG planar glass waveguide amplifiers is 2 orders of magnitude higher than those in long length silicate and alumino-germao-silicate glass fibers, and an order of magnitude or several times higher than the values in ZBLAN glass fibers [1,4,5]. This is due to the higher dopant concentration and the efficient upconversion emission of Tm^{3+} in the glasses. With further optimization of the glass composition and the dopant concentration higher gain value can be expected.

The dependence of G_R on pump power was also investigated. As expected, G_R increases with increasing pump power at the initial stage, and becomes saturated when the pump power exceeds 248mW.

IV. CONCLUSION

In conclusion, Tm^{3+}/Yb^{3+} co-doped NMAG ion-exchanged glass waveguide amplifiers have been fabricated and characterized. Efficient upconversion emission for $^3H_4 \rightarrow ^3H_6$ transition has been observed, and a relative gain of 3.47dB at 810 nm has been obtained in a 2.2cm long device. The value is higher that those reported for other glass hosts, and the broad near-IR emission band from 790 to 830nm indicate that Tm^{3+}/Yb^{3+} co-doped NMAG glass material is attractive for realizing compact efficient FWW band waveguide amplifiers.

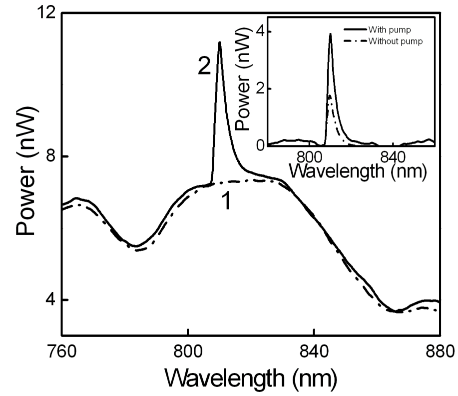

Fig.2 OSA spectra recorded from the output end-facet of 2.2 cm long Tm^{3+}/Yb^{3+} codoped NMAG glass waveguide amplifier. Curve 1: Amplified spontaneous emission (ASE). Curve 2: ASE together with amplified 810nm signal under 457mW 980nm wavelength laser diode excitation. Inset: 810nm signal without pumping and with 457mW 980nm laser pumping with removal of ASE.

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