Tellurite glass as a solid-state mid-infrared laser host material

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Abstract: We present recent results on the material, spectroscopic and laser properties of a range of Tm^{3+}, Tm^{3+}-Ho^{3+} and Dy^{3+} doped tellurium oxide (TeO_2) based glasses in the 2-4 µm wavelength region.

OCIS codes: (160.5690) Rare-earth-doped materials; (160.3380) Laser materials

1. Introduction

Lasers operating in the mid-infrared spectral region are of great importance for a range of applications such as medicine, chemical sensing, countermeasures and light detection and ranging (LIDAR) [1]. Lasers operating specifically in the 3-5 µm atmospheric transmission window of the mid-IR are especially useful for free-space, long range applications such as LIDAR and communications. Rare-earth doped solid-state lasers operating in this spectral region have so far mainly been limited to using host materials such as fluoride glasses and crystals which can have certain drawbacks such as being fragile, sensitive to corrosion from atmospheric moisture and relatively low operating temperatures. Therefore, there is great demand for new mid-IR host materials which may overcome some of these drawbacks. A requirement host materials for mid-IR solid-state lasers is that it has a low phonon energy to avoid absorption of light by the multiphonon absorption edge of the host medium. Silica fiber, for example, will therefore not support laser operation at wavelengths beyond around 2.3 µm due to its relatively high phonon energy of 1100 cm^{-1}.

A material of interest for potential future mid-IR lasers sources is tellurite glass. Tellurite glass has a phonon energy in the range 650-800 cm^{-1} depending on the exact composition and therefore has an infrared transmission range up to around 5-6 µm. Other advantages of tellurite glass are that it is more robust and more thermally, environmentally and chemically stable than standard fluoride (ZBLAN) mid-IR laser glass. Tellurite glass is also capable of dissolving a large concentration of rare-earth ions allowing the fabrication of compact laser gain elements such as waveguides and bulk rods/slabs [2].

This paper presents a review of research into the spectroscopic and lasing properties of a range of rare-earth doped tellurite glasses for the 2-4 µm spectral region. Tellurite fibers doped with Tm^{3+} and Tm^{3+}-Ho^{3+} were demonstrated to lase at around 1.9 µm and 2.1 µm, respectively, in CW and Q-switched modes. Dy^{3+} doped tellurite bulk glass and waveguide were shown to exhibit very broad fluorescence at 3.3 µm which was red-shifted when compared to the same transition in ZBLAN glass.

2. 2 µm Tm^{3+} and Tm^{3+}-Ho^{3+} doped tellurite fiber laser results

Tm^{3+} and Tm^{3+}-Ho^{3+} doped tellurite fibers were pumped using an Er^{3+}-Yb^{3+} silica fiber laser operating at 1.6 µm to directly in-band pump the Tm^{3+}: $^3F_4$ upper laser level. In-band pumping of Tm^{3+} has the benefit of very low quantum defect allowing high Stokes efficiency limit lasers. Figure 1 shows the laser performance of the in-band pumped Tm^{3+} doped tellurite fiber laser operating at 1.9 µm. A 32 cm long fiber yielded a maximum slope efficiency of 76% with respect to launched pump power and a maximum output power of 0.28 W which was limited only by the available pump power. Since this work was conducted, over 1 W of laser output has been demonstrated from a directly diode pumped Tm^{3+} tellurite fiber laser [3].

Figure 2 shows the laser performance of the in-band pumped Tm^{3+}-Ho^{3+} codoped tellurite fiber laser which yielded a maximum slope efficiency of 62% with respect to launched pump power and output power of 0.16 W, which was again only limited by the available pump power. The optimum fiber length for this set up was 76 cm. This fiber laser was also Q-switched using a rotating optical chopper placed in the laser cavity and 100 ns, 0.65 µJ laser pulses at 2.1 µm [4].

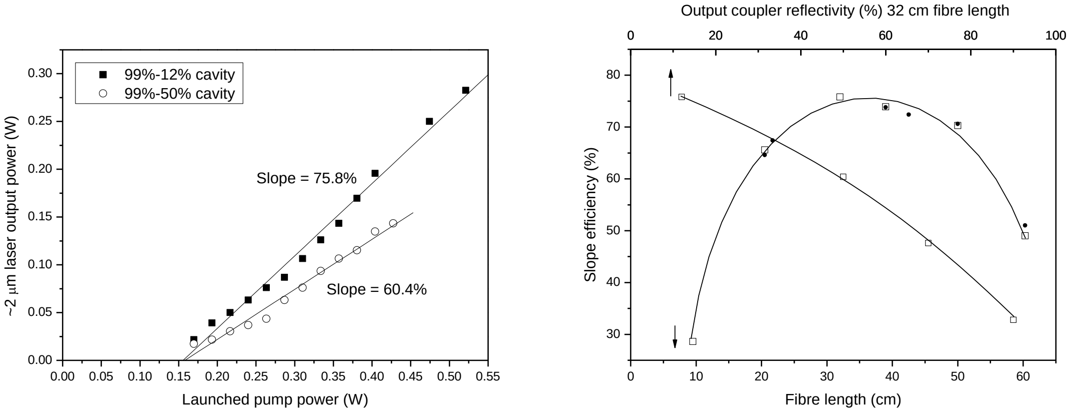

Fig. 1. Laser performance of 1.6 µm pumped Tm^{3+} doped tellurite fiber laser.

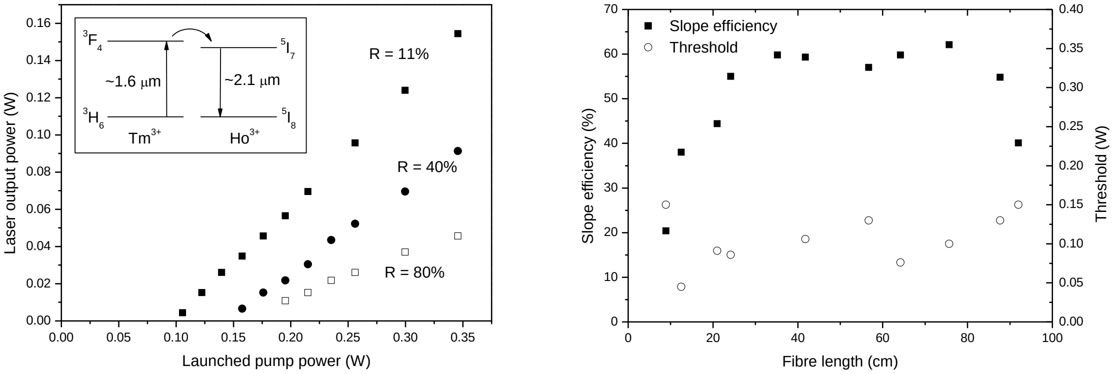

Fig. 2. Laser performance of 1.6 µm pumped Tm^{3+}-Ho^{3+} codoped tellurite fiber laser.

3. 3.3 µm Dy^{3+} doped tellurite bulk glass and waveguide fluorescence results

The spectroscopic properties of the $^6H_{13/2}$ – $^6H_{15/2}$ mid-IR transition of Dy^{3+} doped into a tellurite bulk glass sample was compared with that in a ZBLAN bulk glass sample when excited with an 808 nm laser diode. Dy^{3+} doped ZBLAN fiber lasers operating at ~2.95 µm have been demonstrated several times before [5], and fluorescence spectroscopy of Dy^{3+} doped ZBLAN glass matched by exhibiting a fluorescence peak at 2.95 µm (figure 3). However, when doped into tellurite glass, the Dy^{3+}: $^6H_{13/2}$ – $^6H_{15/2}$ transition is broadened and red-shifted to around 3.3 µm as shown in figure 3. The 2.95 µm output from Dy^{3+} doped ZBLAN fiber lasers coincides with the strong absorption of water in the atmosphere, making this laser unsuitable for long-range, free-space applications, whereas the red-shifted fluorescence in tellurite glass, peaked at 3.3 µm, falls within the atmospheric transmission window.

Using femtosecond laser inscription, a waveguide was written into this Dy^{3+} doped tellurite glass and the ASE spectrum recorded using the same 808 nm diode laser excitation source. The ASE spectrum is shown in figure 3b and shows enhancement in the fluorescence intensity at the short and long tails of the fluorescence peak, suggesting lasers resulting from this material may exhibit wide tunability in the mid-IR region.

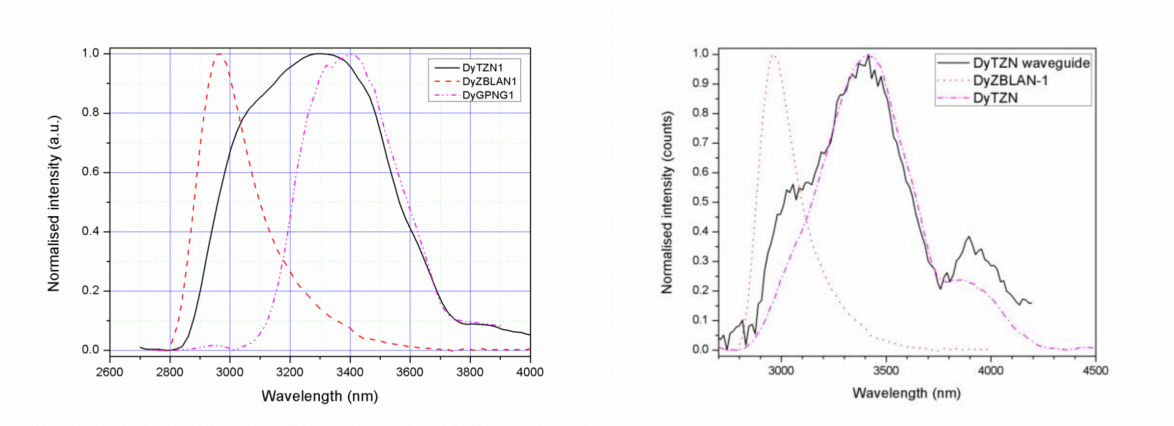

Fig. 3. a) The fluorescence spectra of Dy^{3+} doped ZBLAN, tellurite and germanate bulk glasses. b) The ASE spectrum of a Dy^{3+} doped tellurite waveguide compared to the bulk glass fluorescence spectra.

4. Conclusions

Tellurite glass is a promising host material for new rare-earth doped solid-state lasers, possessing a lower phonon energy than silica glass and greater stability than ZBLAN glass. High efficiency laser in short tellurite fibers have been demonstrated. The multiplicity of TeO_2 structural units results in broadening of rare-earth dopant fluorescence bands and in Dy^{3+} doped tellurite glass, the bottom level mid-IR transition which has a peak fluorescence wavelength of 2.95 µm in ZBLAN glass is red-shifted to 3.3 µm, as well as being significantly broader. 3.4 µm ASE from a Dy^{3+} doped, femtosecond laser inscribed tellurite waveguide has also been demonstrated.

5. References

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