Amplified spontaneous emission properties of a single mode Er^{3+}-doped tellurite fiber

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Spectral characteristics of the amplified spontaneous emission (ASE) from a novel single mode Er^{3+} doped tellurite fiber with D-type cladding is reported in this letter. When pumped at 980 nm, an ASE source that has nearly a 100-nm flat FWHM bandwidth is obtained with a fiber length of 30–60 cm. Variation of ASE spectra with pump powers and fiber lengths are measured. Output power up to 2.0 mW is obtained with a launched pump power of 660 mW.

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Because of their excellent optical and chemical properties rare-earth-doped tellurite fibers become promising candidates for novel optical amplifiers to extend the transmission bandwidth beyond the range available from conventional Er^{3+}-doped silica fiber. Examples include erbium-doped tellurite fiber amplifier (EDTFA) for C- and L-bands[1−3], thulium-doped fiber amplifier (TDFA) for S-band[4,5], and praseodymium-doped fiber amplifiers (PDFA) for the 1.3-μm band[6]. Efforts have been focused mostly on broadening and flattening of their amplification spectra[1−6] for applications in wavelength-division multiplexed (WDM) systems. On the other hand, erbium doped fibers (EDFs) are also good candidates as amplified spontaneous emission (ASE) sources. In order to obtain broadband ASE output covering C- and L-band using Er^{3+}-doped silica fiber, several approaches have been proposed[7−10] with the disadvantage of somewhat complicated structure based on dual-stage or dual-pump configurations. Furthermore, as EDTF has much better gain flatness and broader amplification range[1−3], it can be used as broad-band ASE source with much simpler structure[11]. For example, Thorlabs Co. has recently introduced an 80-nm-bandwidth ASE source constructed from a single piece of EDTF pumped by a single laser diode (LD). To our knowledge, few experimental investigations on the characteristics of ASE from EDTF are reported, wherein fiber cross-section and parameter optimization are critically important for effective coupling of pump light into erbium-doped tellurite fiber (EDTF).

In this letter, the successful fabrication of a novel single mode EDTF with D-type cladding is reported, while its ASE spectra are studied under various pump powers and fiber lengths. The core and cladding glass compositions of the proposed EDTF are based on TeO_2-ZnO-La_2O_3-Li_2O glass system. The Er^{3+}-doped tellurite glass is prepared by conventional melt-quenching method. Anhydrous powders of TeO_2, ZnO, La_2O_3, Li_2O,and Er_2O_3 with purity higher than 99.9% are used as starting materials. Accurately weighted 25-gram batches are thoroughly mixed and put into platinum crucibles, then melted between 800 and 850°C for 15 min in an electric furnace under air atmosphere. The melts are cast into preheated brass molds, and the obtained glasses are annealed at their glass-transition temperatures determined by differential thermal analysis (DTA).

EDTFs are fabricated from the same glass by the suction casting technology[12]. The core glass is surrounded by a similar tellurite glass having a lower refractive index. The core is uniformly doped with 5600-ppm Er_2O_3, resulting in a fluorescence decay time of 3.3 ms. The EDTF has a core diameter $D \approx 7$ μm, a cladding diameter of 125 μm, and a numerical aperture (NA) of 0.2. Figure 1 shows the cross-section of the EDTF. The cladding is coated with a low-refractive-index ($n = 1.52$) polymer (DSM) outer cladding. The average background loss is measured to be 3.5 dB/m at 1310 nm using the cutback method.

The experimental setup for ASE measurement is shown in Fig. 2. A diode laser (Limo Fb101c765) with up to

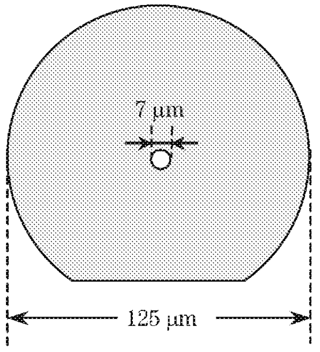

Fig. 1. Cross section of single mode Er^{3+}-doped tellurite fiber with D-type cladding.

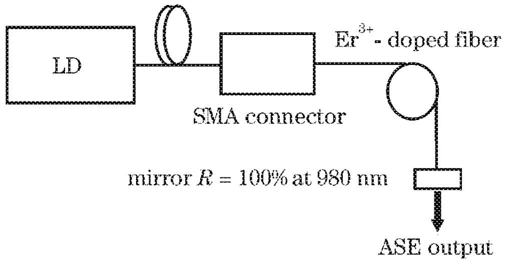

Fig. 2. Experimental setup for ASE measurement.

15-W pigtail output at 980 nm is employed as the pump source. The spot diameter at the fiber pigtail is 200 μm. The pump light is coupled into the EDTF using a precise positioning stage (Newport M-561D). A mirror with high reflectivity at 980 nm is located at the output end of the EDTF. The spectrum and total output power of the ASE are measured with a spectrometer (Jobin Yvon Triax550) and a power meter (Lxlightwave 0MM-681013), respectively.

Figure 3 shows the output ASE spectrum of a 30-cm-long EDTF compared with the fluorescence spectrum of Er^{3+}-doped core glass. The shape of ASE spectrum in the fiber is significantly broader and more flat than that in the glass, especially in L-band. The full-width at half-maximum (FWHM) bandwidth is about 100 nm in the fiber, nearly double the value in the core glass (55 nm). The ASE spectrum in the fiber shows a peak near 1557 nm, whereas the ASE peak in the glass appears at around 1530 nm which corresponds to the transition between the lowest Stark levels of $^4I_{13/2}$ and $^4I_{15/2}$.

From Fig. 3, one can see that ASE source with broad and flat bandwidths can be obtained by using EDTF with D-type cladding. The total ASE output power from the 30-cm-long EDTF is measured to be about 2.0 mW when the launched pump power is around 660 mW. Although this total ASE power is lower than that obtained from commercial ELED or rare earth doped silica-based fiber ASE sources, it should be noted that the pump power coupled into the EDTF is much lower than the launched pump power due to the low coupling efficiency between silica and tellurite fibers (~20%). Hence it is reasonable to anticipate that marked increase in ASE output power can be achieved through optimization of the pumping configuration as well as fiber parameters.

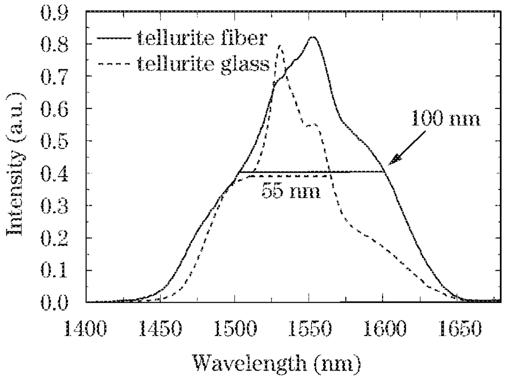

Fig. 3. Comparison of ASE spectrum of the EDTF and fluorescence spectrum of the core glass.

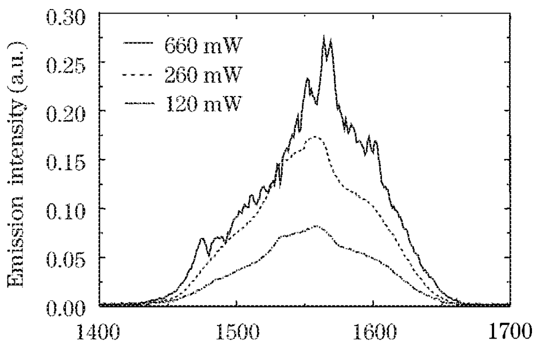

Fig. 4. ASE spectra of 50-cm-long EDTF under different launched pump powers.

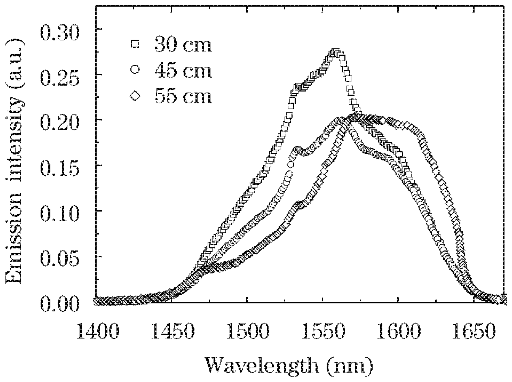

Fig. 5. ASE spectra EDTF with different fiber lengths. Launched pump power is 460 mW.

The ASE spectra of a 50-cm-long EDTF are measured at different pump powers as shown in Fig. 4. Three spectra exhibit similar features, while the peaks shift to longer wavelengths with increasing launched pump power. Meanwhile, resonance lines are observed when the launched pump power is 660 mW, and the ASE spectrum abruptly becomes narrower. This phenomenon is due clearly to the successive back reflections (Fresnel reflection) from the ends of tellurite fiber sample, which is formed by the large refractive index difference between the tellurite fiber ($\approx$ 1.9) and the spliced silica fiber[9].

Three EDTF samples with different lengths (from 30 to 55 cm) are measured under the same launched pump power of 460 mW. The results are shown in Fig. 5. With increasing fiber length, the ASE spectrum becomes broader and more flat, and the "rising" part shifts to longer wavelengths. This is attributed to the typical characteristics of a three-level system, mainly the reabsorption of emission by the ground state. One can expect that fibers with longer length at the proposed Er^{3+} doping concentration (and launched pump power) are more suitable to achieve a flat and wideband ASE source.

Room for EDTF performance improvement also exists by decreasing its background loss. In the case of rare-earth-doped silica fibers, the modified chemical-vapor deposition (MCVD) techique is employed, leading to very low background loss and the fiber length can be optimized for pump light absorption. On the contrary, because the oxides used in our experiments are not pure enough, and because the suction casting technique is unable to prevent the fiber from pollution during the fabrication process, it is not surprising that our EDTF has high background losses. Measures, such as using super-pure starting materials, are being applied to decrease the losses of the fiber. On the other hand, the coupling efficiency in our experiment was only about 20% between the laser diode and the fiber. We anticipate that the total loss of the fiber can be reduced from ~3.5 dB/m to 0.1−0.5 dB/m, and the coupling efficiency can reach 30−50%.

In conclusion, we have successfully fabricated single mode EDTF with D-type cladding, and observed a very broad amplification bandwidth when pumped with 980-nm LD. An ASE source that has nearly a flat FWHM bandwidth of 100 nm is realized with fiber length of 30−60 cm. The total ASE output power reaches 2 mW under a launched pump power of 660 mW. The very broad amplification bandwidth of the ASE spectra indicates that EDTF is also a very promising candidate for novel optical amplifiers.

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