Ultra-short wavelength operation of a thulium doped fiber laser in the 1620-1660nm wavelength band

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Abstract: We present a tunable thulium-doped fiber laser (TDFL) incorporating a Tm/Ge co-doped fiber capable of accessing the U-band wavelength region (1620-1660nm). These results represents by far the shortest laser wavelengths so far for a TDFL.

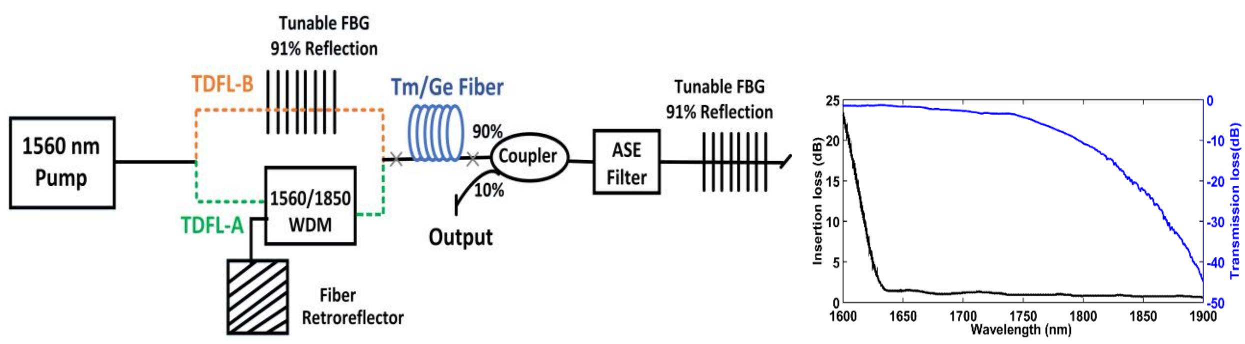
OCIS codes: (140.3600) Lasers, tunable; (140.3510) Lasers, fiber; (060.3735) Fiber Bragg gratings

1. Introduction

Thulium-doped silica fiber has recently emerged as a very attractive gain medium for optical amplification in the 2 µm transmission window [1], as well as for power scalable laser sources operating in this 'eye-safe' wavelength range. Broadband operation of tunable thulium doped fiber lasers (TDFL) has been extensively investigated over the past few years and efficient laser emission can readily be achieved in the 1700nm to 2050nm wavelength range [2-3]. However, it is challenging to achieve shorter wavelength operation of Tm-doped silica fiber, due to the fact that Tm exhibits a strong three-level behavior and as such requires a high population inversion (thus high pump power) and a low cavity loss to achieve reasonable lasing at this waveband. Recently, a tunable TDFL operable over the 1660 - 1750 nm has been demonstrated using a highly wavelength selective fiber Bragg grating (FBG) and a low loss all fiber laser cavity [4]. In addition, by suppressing the amplified spontaneous emission (ASE) at the longer wavelength region (1800-2000nm), Li et al have demonstrated a thulium-doped fiber amplifier (TDFA) working in the 1650-1700 nm range with a small signal gain of up to 29 dB [5]. Operation of Tm-doped fiber devices at or below 1650nm however remains a topic of great interest, not least as it could potentially provide for seamless silica based rare-earth doped amplifier solutions extending from the S-band (exploiting erbium doping) right up to the IR absorption edge of silica fiber.

Very recently, we have explored a new glass composition (specifically Tm/Ge co-doped silica fiber) and have successfully demonstrated a wideband tunable TDFL operable from 1679nm to 1992nm [6]. In this follow-on work, we focus on ultra-short wavelength operation of the TDFL and present the first demonstration of a tunable TDFL (based on an in-house fabricated Tm/Ge co-doped silica fiber) operating over the 1620-1660nm wavelength band, i.e. extending operation down to the long wavelength edge of the L-band. Our results represent by far the shortest laser wavelengths ever achieved for a TDFL.

2. Experimental setup



(a) (b)

Fig. 1 (a) Schematic of the TDF, showing the two laser configurations studied, hereafter referred to as TDFL-A (Green) and TDFL-B (Brown), and (b) the insertion loss of the WDM coupler (black) and transmission loss of the ASE filter (blue).

Fig. 1 (a) shows the experimental setup of the all-fiber tunable TDFL illustrating the two laser configurations studied. The setup comprises an in-house built Er/Yb fiber laser at 1565nm with maxmium output power of 5W as the pump source and a ~4.5m length of in-house fabricated Tm/Ge co-doped fiber with high Ge concentration (15 mol%). The core diameter and NA of the fiber was measured to be 4.4 µm and ~0.28. In TDFL-A, the pump light is coupled into the Tm/Ge co-doped fiber through a broadband, filter-based, 1560/1850 nm wavelength division multiplexer (WDM). In order to build the cavity, the signal port of the WDM was spliced to a silver coated fiber refro-reflector, whereas a highly wavlength selective compressible fiber Bragg grating (FBG) with a central wavelength of ~1675nm was spliced to the other end of the gain medium. The FBG could be tuned from 1620nm through to 1660nm by compression tuning [7]. The measured reflectivity and bandwidth of the FBG varied from 91% to 94% and from 0.67nm to 1 nm respectively, depending on the operating wavelength. The 10% port of the 90/10 tap coupler was used to extract the output from the TDFL. A coiled length of dispersion compensating fiber (DCF) was used as an ASE filter. The bend diameter was optimised to provide low transmission loss at wavelengths below 1700 nm, whilst exhibiting high transmission loss at longer wavelengths. Fig 1(b) shows the bend dependent loss of the coiled DCF for an optimised bend diameter of 5cm. The insertion loss of the WDM was also measured (see Fig. 1(b)), and it was found that the loss increases significantly at wavelengths shorter than 1640 nm. Therefore, for improved performance at wavelegnths below 1660 nm the TDFL-B configuration was used. Here the WDM and retro-reflector were replaced with a second compressible FBG thereby avoiding the insertion loss of the WDM. Given that the FBG is wavelength selective, it was possible to couple 1565nm pump power through the FBG without introducing additional cavity loss. Tuning of the laser cavity was realized by simultaneously compressing the two FBGs (mounted on mechanical stages) whilst ensuring wavelength sychronization between the two. Splicing the Tm/Ge co-doped fiber and the SMF-28 fiber pigtails of the passive components togther resulted in a high splice loss of ~3dB due to the large mode field diameter mismatch and this compromised the short wavelength operation of the cavity. To reduce this splice loss, a short section (~1cm) of OFS TmDF200 was used as an intermediate fiber between SMF-28 and Tm/Ge co-doped fiber and the optimized splice loss was reduced down to 0.8 dB. The 90/10 output coupler has an insertion loss of around 0.4 dB in the 1550-1750 nm waveband. The output characteristics of the tunable laser was measured by using a Yokogawa optical spectrum analyser (AQ6375) and a thermal power meter (Ophir 3A-FS).

3. Results and discussion

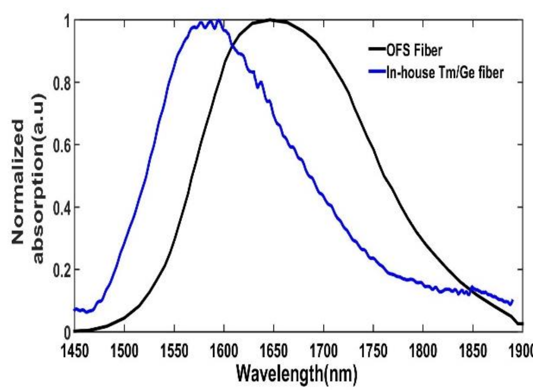
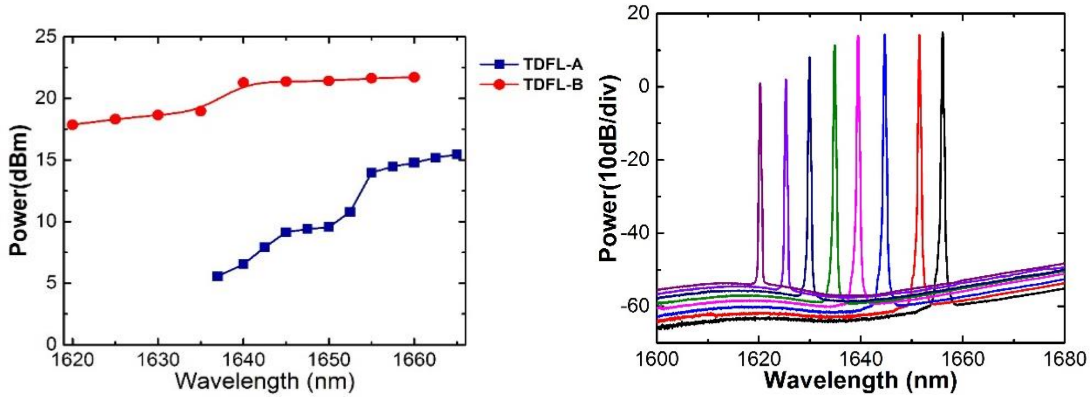


Fig. 2 Normalized absorption curves for OFS Tm-doped fiber (black) and in-house fabricated Tm/Ge co-doped fiber (blue).

As shown in Fig. 2, the in-house fabricated Tm/Ge co-doped fiber exhibits a blue-shifted absorption curve with a peak absorption of ~20 dB/m at 1580 nm, significantly shorther than the commerical Tm-doped aluminosilicate fiber. Moreover, according to McCumber theory, the emission profile of Tm/Ge co-doped fiber will also be blue-shifted, enabling shorter wavelength operation. In the TDFL-A configuration, the high insertion loss of the WDM coupler and ASE filter as well as the splice losses between SMF-28 and Tm/Ge co-doped fibers give an aggregate single pass cavity loss of 6 dB at 1650 nm, which increased further at shorter wavelengths. To achieve short wavelength operation, a short Tm/Ge co-doped fiber length is preferred in order to avoid signal reabsorption, with the minimum usable fiber length determined by the requirement to achieve sufficient total gain to overcome the large cavity loss. In our experiment, we found that the optimal fiber length was 4.5m (for a pump power of 3.5 W). The blue colored plot in Fig. 3(a) shows the output power as a function of operating wavelength for the maximum available pump power. A highest output power of ~15 mW was obtained at a wavelength of 1660 nm. The shortest lasing wavelength was measured to be 1637nm with an output power of ~5mW. The red colored plot in Fig. 3(a) shows the output power as a function of operating wavelength for the TDFL-B laser configuration. The same pump power and fiber length were used to ensure a fair comparison between the two laser configurations. We found that the lasing threshold for 1660nm operation decreased from 1.6W to 0.9 W, resulting in a much higher laser output power. Also, an almost constant output power was achieved over the entire tuning range from 1620nm to 1660nm which highlights the importance of avoiding passive components whose insertion loss varies with wavelength (i.e. the WDM coupler). The highest output power of about 22 dBm was recorded at 1660nm with a slope of efficiency of 5.8% with respect to the launched pump power, with an output power of 17 dBm measured at 1620nm, the shortest wavelength we could reach with the current tunable gratings.



(a) (b)

Fig. 3 (a) Output powers of TDFL-A and TDFL-B for different lasing wavelengths, and (b) Output optical spectra of the TDFL-B laser configuration (measured with 0.1nm OSA resolution).

Since the output from the laser cavities was extracted after reflection from FBG1, the out-of-band ASE was well suppressed, resulting in a high optical signal-to-noise ratio (OSNR) albeit at a slightly lower output power. Figure 3b plots the spectral characteristics of TDFL-B. An OSNR of more than 45 dB was successfully achieved across the full tuning range from 1620 nm to 1660nm (up to 60 dB OSNR from 1640nm to 1660nm). The 3dB bandwidth of the laser lines were measured to be <0.3nm. We believe that the output power and lasing efficiency could be further improved by optimizing the ASE filter to provide a much sharper wavelength cutoff and the Tm/Ge fiber glass composition.

4. Conclusion

We have successfully demonstrated an all-fiber tunable TDFL operating over the 1620 nm to 1660 nm range (communication U-band) by using Tm/Ge co-doped fiber. This unique glass composition effectively shifts the emission cross-section of the Tm ions to shorter wavelengths as compared to conventional Tm-doped fiber using an aluminosilicate host. This greatly improved short wavelength operation and allowed us to bridge the gap between Er^{3+} and Tm^{3+} ions in a silica based glass host. Using two FBGs as cavity mirrors and a long wavelength ASE filter, more than 17 dBm output power with >45dB OSNR was achieved over the entire tuning range.

Acknowledgement

This work was supported by Academic Research Fund Tier 1, Ministry of Education (Singapore) and by the EPSRC funded Hollow Core Fiber Photonics Programme Grant (EP/P030181/1).

5. References

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