Broadband Silica-Based Thulium Doped Fiber Amplifier Employing Dual-Wavelength Pumping

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Abstract: We report a broadband and gain-flattened silica-based thulium-doped fiber amplifier with dual-wavelength pumping (790 nm+ 1600 nm). 15dB gain bandwidth is more than 220 nm ranging from 1700 to 1920 nm with a maximum gain of 29dB and a noise figure of less than 5dB.
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1. Introduction

As a result of the growing demand for communication capacity the 2 μm wavelength region has been proposed as an attractive new transmission window for optical communications [1]. Thulium doped silica fiber amplifiers (TDFAs) can support amplification over a very broad bandwidth at 2 μm and several different TDFA configurations have been presented offering high gain and low noise performance across the wavelength range 1700 – 2050 nm [2]. Recently, the short-wavelength amplification edge has been further extended down to 1650 nm and opens the intriguing possibility of bridging the gap between the long wavelength edge of L-band erbium doped fiber amplifier and short wavelength edge of the TFDA [3]. The wide spectral coverage of TDFAs has attracted much attention in recent years and significant research has focused on further extension of the amplifier coverage. Despite this, it is to be appreciated that the wide spectral coverage of the TDFA has only been realized by concatenating several different TDFA configurations - individual amplifiers can only deliver a limited fraction of the full amplification bandwidth. Typical 15 dB bandwidths are ~100nm at wavelengths around 1750 – 1800 nm, slightly broader at longer wavelengths around 1900nm. Here we present a novel broadband TDFA operating in the 1680 – 1930 nm region, achieved by employing a dual-wavelength pumping scheme. Dual-wavelength pumping in TDFAs has previously been investigated in the S-band (1450 – 1520 nm) [4, 5], but no dual-wavelength pumped TDFAs working in 1.7 – 2 μm have been reported so far to the best of our knowledge. The proposed TDFA can extend gain to <1.7 μm whilst providing a much broader amplification window, a lower noise figure (NF) of <5 dB and a simpler implementation as compared to the prior art.

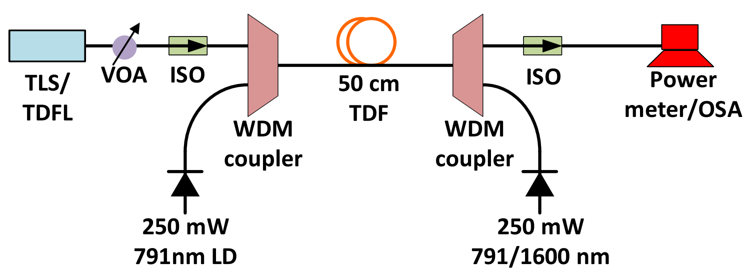

Fig. 1. Schematic of the 791 / 791 nm LD pumping and 791 / 1600 nm pumping TDFA. TLS: tunable laser source; TDFL: thulium doped fiber laser; VOA: variable optical attenuator; ISO: isolator; WDM: wavelength division multiplexer; TDF: thulium doped fiber; LD: laser diode.

2. Experimental setup

Figure 1 shows a schematic of the experimental setups. We compared two pumping schemes, including 791 / 791 nm pumping and 791 / 1600 nm pumping. All configurations were seeded by either a tunable laser source (TLS) provided by Yenista (Tunics T100S-HP) covering the wavelength range 1500 – 1680 nm, or an in-house built thulium doped fiber laser (TDFL) covering the range 1710 – 1950 nm. A variable optical attenuator (VOA) was used to adjust the power levels to -20 dBm and 0 dBm to exhibit small signal and saturated signal scenarios throughout the paper. Isolators were used at both the input and output to suppress parasitic lasing and any unwanted feedback into the seed lasers, thereby improving the stability of the amplifier. The single-mode TDF (OFS TmDF200) has a ~6.5 μm mode-field diameter at 2 μm and a core absorption of ~20 dB/m at 1.56 μm. We used a 50 cm length of TDF in our experiments which was core pumped in a bidirectional configuration by two laser diodes. We used laser diodes operating at 791 nm (Lumics) delivering up to 250 mW (24 dBm) of pump power. For 1600 nm pumping, we used a combination of TLS and L-band EDFA delivering 250 mW average power, as we were short of laser diodes operating at this wavelength. Two different WDM couplers were used to combine the signal and pumps at different wavelengths. An 800 / 1700 nm fused WDM coupler was used for 791 nm pumping and a 1550 / 2000 nm thin-film filter based WDM coupler was used for 1600 nm pumping. A power meter and an optical spectrum analyzer (Yokogawa AQ6375) were used to measure the gain and NF.

3. Results and discussion

Figure 2(a) shows the detailed characterization of both TDFA schemes, i.e. 791 / 791 nm LD pumping and 791 / 1600 nm pumping. The external small signal gain (measured with an input signal power of -20 dBm) and external saturated gain (measured with an input signal power of 0 dBm), along with the external NFs are shown for both pumping schemes. The total pump power launched into the TDF was fixed at 27 dBm in all cases. The 791 / 791 nm LD pumping provides a small-signal peak gain of 23 dB at 1800 nm and supports 15 dB gain over a 175 nm wide window from 1725 nm to 1900 nm. The spectral gain profile is flat over a 130 nm wide window spanning from 1740 – 1870 nm. The saturated gain has a similar amplification window and varies between 11 – 14.5 dB in the 1710 – 1930 nm waveband. The external NFs for both small and saturated signals are below 5 dB from 1710 – 1860 nm. Note that the NF increases at longer wavelengths are due to the fact that the insertion loss of our passive components (WDM couplers and isolators) increases at longer wavelength. Compared to 791 / 791 nm LD pumping, the 791 / 1600 nm pumping provides a 5 dB higher peak gain and a 35 nm broader 15 dB gain bandwidth spanning from 1700 – 1920 nm. There is no significant difference in NFs between the two pumping schemes.

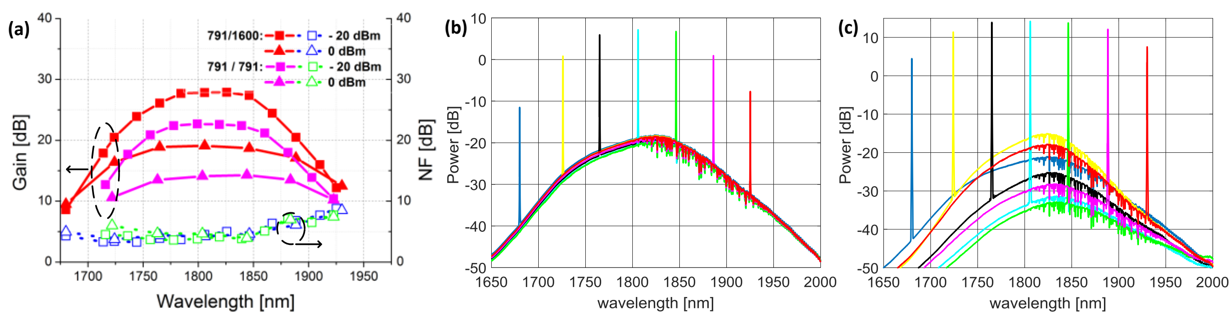

Fig. 2. (a) Detailed broadband performance of the 791 / 791 nm LD pumping and 791 / 1600 nm pumping TDFA. 791 / 791 nm LD pumping: red and blue; 791 / 1600 nm pumping: pink and green. Amplified (b) small and (c) saturated signals using dual-wavelength pumping. Measured with 0.5 nm optical spectrum analyzer resolution.

Figure 2(b-c) shows the amplified small and saturated signal spectrum for the 791 / 1600 nm pumped TDFA. The amplified small signal has 26 – 30 dB in-band optical signal-to-noise ratio (OSNR) across the entire amplification band. The amplified saturated signal has 48 – 50 dB in-band OSNR and up to 50 dB out-of-band OSNR.

4. Conclusions

We have shown that it is possible to implement a silica based TDFA employing a dual-wavelength pumping, thereby allowing us to obtain a low-noise broadband TDFA covering an amplification window of more than 220 nm with small signal gain as high as 29 dB and NF as low as 3.3 dB. The TDFA has a flat-top gain profile and high spectral quality should find use in various communication and sensing applications where optical bandwidth in this operating range is key.

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