S/S+ band tunable thulium-doped fiber laser anchored on 50-GHz ITU-T grid

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Abstract

We, for the first time, demonstrate a S/S+ band tunable thulium-doped fiber laser (TTDFL) anchored on 50-GHz ITU-T grid. The laser has a ring-type cavity where the gain medium (TDF) was pumped by dual wavelength light sources (1.4 and 1.5 μm). A fiber-pigtailed Fabry–Perot filter was introduced into the cavity to fit the laser wavelengths into 50 GHz grid. The tuning range was more than 57 nm (1454.9–1512.0 nm) covering most of the thulium bandwidth. The laser shows sufficient output power (higher than 0 dB) over the entire tuning range and SMSR of the lasing peak was measured to be more than 55 dB at 0.02 nm resolution bandwidth. The potential applications of this newly developed laser include the wavelength reference sources for S/S+ band DWDM in industries and laboratories.

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1. Introduction

Today there are basically three ways to maximize bandwidth per fiber in DWDM technology. The first method is the improvement of the channel efficiency up to 40 Gbps and the second is narrowing of the channel spacing as small as 25 GHz. These methods, however, have several issues such as PMD and fiber non-linearity that should be resolved for their broad implementation into the DWDM transmission systems. Therefore, another way, the exploitation of new transmission window, is still of great interest even though the size of the transmission bandwidth has been doubled rather lately through the progress in L-band technologies.

S and S+ bands, covering wavelength range from 1450 to 1530 nm became one of the strong
candidates for the new traffic window due to the recent developments on thulium-doped fiber amplifiers and Raman fiber amplifiers, in addition to the advances in DFB laser and high-power pump technology [1,2].

As it can be said that the expansion to the S/S+ band presumably assumes a channel spacing plan of the previous windows (C and L-band), the development of accurate wavelength reference sources in S/S+ band will be also very important for both industrial makers and research laboratories in the future. While there have been great advances in S/S+ band optical amplifiers like Raman or thulium-doped fiber amplifiers [1–6], relatively weaker efforts have been applied for this topic.

In this paper, we proposed and demonstrated S/ S+ band tunable thulium-doped fiber laser (TTDFL), anchored on 50-GHz ITU-T grid covering most S and S+ band. Since the laser has sufficient output power (higher than 0 dB) in the tuning range and SMSR of the lasing peak was measured to be more than 55 dB in 0.02 nm resolution bandwidth, it can be used as practical wavelength reference sources in S/S+ band.

2. Experiment and results

The experimental setup is described in Fig. 1. The thulium-doped fiber (TDF) was used as a gain medium that generates lasing seed photons in S/S+ band and amplifies them to overcome cavity loss. The TDF used was Zr-based thulium-doped fluoride fiber (NEL: FFM-Z Tm-2000-A) and the length was 20 m with a thulium concentration of 2000 ppm weight. The refractive index difference $\Delta n$ between core and cladding was 2.5%.

Combined with main pump laser diodes (LD) at 1.42 and 1.43 $\mu$m, a tunable external cavity laser at 1.56 $\mu$m was used as a subsidiary pumping source, to provide both high power conversion efficiency and functionality of gain clamping and tilt control [3,4,7].

An optical isolator (ISO) was placed inside the cavity both to provide a uni-directional lasing operation and to protect pump laser diodes from backward ASE out of the TDF gain medium. A polarization controller (PC) was used for the polarization control, and a fiber-pigtailed Fabry–Perot (FP) filter with free spectral range (FSR) of 50 GHz was inserted for the precise wavelength setting to ITU-T grid. Additional fiber FP tunable filter (FFPTF) with 100 GHz FWHM and 9 THz FSR was used for the selection of lasing line among 50-GHz spaced wavelength reference channels generated by the fine grid FP filter. The round trip loss from the cold cavity excluding gain medium was measured to be 6.75 dB at 1.47 $\mu$m. For the accurate measurement, the optical spectrum analyzer (OSA) has been calibrated against the spectrum of $^{13}$C$_2$H$_2$ acetylene absorption cell.

We first observed the laser operation without the fine-grid FP filter (50-GHz FSR) to verify the tuning range and operating pump conditions. Fig. 2 shows the output spectrum of the TTDFL lasing at 1.47 $\mu$m together with the spectra of the pump lasers. As mentioned earlier, tuned laser line (1.47 $\mu$m) in the figure was determined only by the fiber FP tunable filter in this case. The main pump powers supplied to the TDF were 69.6, 81 mW for 1.42 and 1.43 $\mu$m, respectively. The pumping power of the subsidiary laser (1.56 $\mu$m) was set to be 1.46 mW.

Fig. 3 shows the entire range of the laser spectrum obtained with maximum holding function of OSA while the wavelength of the laser was continuously scanned by using the fiber FP tunable filter.

As can be seen from the figure, wide tuning range of 52.66 nm (1457.92–1510.58 nm with output power of higher than 8 dBm) has been obtained with quite flat spectrum. If we are interested in the laser with output power more than...
0 dBm, then the available spectral width is increased by more than 4 nm, resulting in total 57-nm tuning range (1454.9–1512.0 nm). It is worth to mention that we were not able to observe any dependency on 1.56 μm subsidiary pump power in the laser output, in contrast to the case of amplifiers [4]. We attribute this to the saturated operation of TDFA inside the ring cavity.

To test the frequency locking capability of the TTDFL, we next inserted a fixed FP filter (50-GHz FSR, Insertion loss <1.5 dB) inside the cavity, and measured the output spectrum. Fig. 4 is the output spectrum of the laser obtained under the same condition with Fig. 3, that is, under the maximum hold mode of the OSA while the wavelength of the laser was continuously tuned. With a few mW increase of main pump power compensating the additional insertion loss of a fixed FP filter, almost same output power and spectral range has been obtained when compared to the case of no fixed FP filter.

In this case, however, a fixed FP filter generated a spectrum with periodic peaks separated by 50 GHz. As you can see in Fig. 4, frequency difference between the leftmost channel (marker \( \lambda \)001 in OSA screen) and rightmost channel was 1.000 THz (200.350–199.350 THz over 20 channel spacing).

The laser operation was stable over several hours, without any drift in the output power. SMSR of the lasing peak was measured to be more than 55 dB at 0.02-nm resolution bandwidth. As a comment, the unwanted pump signals in Fig. 2 can be easily removed by replacing the 3-dB coupler with a selective WDM coupler and changing its location between TDF and FFP. Other way is to use the backward pumping configuration. Then
the optical isolator cuts the unwanted signals and the S/S+ signals not so much different with those of forward pumping configuration can be obtained by tuning the several parameters properly.

3. Conclusions

We proposed and demonstrated S/S+ band tunable thulium-doped fiber laser (TTDFL) covering most of the thulium amplifier gain band. The output power of higher than 8 dB has been obtained over tuning range larger than 52 nm with quite flat spectrum. The spectral width of the laser with output power higher than 0 dB was 57 nm. When a fixed FP filter of 50-GHz FSR inserted into the cavity, the laser spectrum anchored on 50-GHz ITU-T grid. Since the laser has sufficient output power and SMSR of the lasing peak was measured to be more than 55 dB in 0.02-nm resolution bandwidth, the potential applications of this newly developed laser will include the wavelength reference sources of S/S+ band for both industrial makers and research laboratories. To authors’ knowledge, this is the first report of tunable laser source in S/S+ band that can be used at the same time as a wavelength reference satisfying 50-GHz ITU-T grid.

References