Intracavity Loss Optimization in Tunable Dual-Wavelength Erbium-Doped Fiber Laser

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ABSTRACT

A cost effective design of equal output power dual-wavelength laser is experimentally demonstrated. In this design, the two wavelength can be tuned simultaneously and cover 31.33 nm within C-band. Simultaneous equal power dual-wavelength laser are produced as the intracavity loss is optimized. We found that effective optimization is achieved by adjusting the cavity with lower loss. The power difference between the two wavelengths is less than ± 0.37 dB and flat within the tuning range.

1. INTRODUCTION

The development of multiwavelength fiber laser have received enormous attention due to its potential in various applications such as wavelength division multiplexed transmission and fiber sensors [1]-[5]. Erbium-doped fiber (EDF), the main components of the laser is a homogenous broadening medium under room temperature, which leads to fierce mode competition. Therefore, it is difficult to obtain simultaneous dual- or multiwavelength lasing at room temperature in an ordinary EDF based linear or ring laser cavity. There are many methods to generate simultaneous dual-wavelength lasing. For example, dual-wavelength fiber lasers based on FBG structures in a linear [6,7] or ring [8] cavity was reported. However, such laser can only offer fixed wavelength. Qian et al [9] successfully demonstrated a widely tunable dual-wavelength laser that propagates in opposite direction. However, the tuning range of the dual-output is limited within not more than 15 nm. In addition to that, the design is costly due to the use of polarization beam splitter (PBS) and polarization controller (PC). A tunable dual-wavelength and equal output power laser was reported in Abdullah et al. [10]. Although the wavelength of both outputs can be tuned over a wide tuning range, within the range, the output power of both wavelengths is not constant. The power keep increasing as the signal is tuned the longer wavelength. In previous years a dual ring dual-wavelength fiber laser was demonstrated [11]. However, costly polarization control system is necessary to stabilize the laser beam. In addition to that, the wavelengths are not tunable. This paper proposed and demonstrated a cost effective design of simultaneously tunable dual-wavelength fiber laser with wide tunability. By efficient loss optimization between the two ring cavities, the proposed fiber laser achieved equal output powers with wide tunability.

2. EXPERIMENTAL SETUP

Fig. 1 shows the experimental setup of tunable dual-wavelength erbium-doped fiber ring laser. In this setup, an 8 m long EDF is used (the forward and backward ASE of the EDF are nearly the same) as the gain medium, pumped by 1480 nm pump laser via a 1480/1550 nm WDM coupler. The EDF was characterized by 440 ppm of Er3+ ion concentration, numerical aperture of 0.27, a cutoff wavelength of 840 nm and the peak absorption of 6 dB/m at 1531 nm. The pump power was fixed at 130 mW.

![Fig. 1. Experimental setup of dual ring erbium-doped fiber laser.](image-url)
Two optical circulators (C1 and C2) were used to connect the dual-wavelength to the laser cavity and realize dual ring configuration. Furthermore, they serve as optical isolators to provide a unidirectional propagation of laser in clockwise and anti-clockwise directions. A variable optical attenuator (VOA) is installed in one of the ring to vary the cavity loss for the clockwise direction laser. Tunable band-pass filters (TBF) are used in both rings as in-line mode selector and suppress the amplifier spontaneous emission peak at 1530 nm. The operation wavelengths of the TBF’s are from 1534.28 nm to 1565.60 nm. The rings have laser propagating in both clockwise and anti-clockwise directions, resulting in bidirectional propagation in EDF. The two cavities have a free spectral range (FSR) of \( \frac{c}{nL} \), where \( c \) is the speed of light in vacuum, \( n \) is the average refractive index of the single mode fiber and \( L \) is the total cavity length. In the experiment, the ring cavity 1 (RC1) has a ring length of 30 m, corresponding to FSR of 6.8 MHz, while the ring cavity 2 (RC2) has a total length of 40 m, which gives a FSR of 5.12 MHz. No polarization controller was used, which simplify the setup. The laser output is taken from two 80/20 fiber couplers, which provide 20% for output and 80% for the feedback function. For laser output power measurement, a 3 dB coupler with 3.5 dB loss is used to combine both outputs and enable simultaneous monitoring of the lasing spectrum by Optical Spectrum Analyzer (OSA). For all measurement, the OSA resolution bandwidth of 0.05 nm was used. A variable optical attenuator with dynamic range of 80 dB in the 1550 nm region is inserted inside the RC1 to eliminate the differences of spectral gain characteristic and to act as a cavity loss controller. This will assure equal power level at the two laser outputs. The experiment is conducted for all possible combinations of output wavelength, from 1535 nm to 1565 nm.

Fig. 2 shows the setup of cavity loss measurement. The amplified spontaneous emission (ASE) signal is injected at port 1 of C2.

![Fig. 2. Schematic diagram of the cavity losses measurement setup.](image)

The circulator forces the signal to exit at port 2. Notice that the EDF has been taken out from the system. So there is no absorption of signal by EDF in this method. The two TBF’s have also been removed from the setup. This will allow the whole wavelength to pass through the cavity. This technique is called cold cavity loss measurement [10].

In order to measure the loss of the RC1, the measurement point is taken from the port 3 of the C1. The spectrum is taken by simply connecting ASE source to OSA. The loss experienced by the signal as it travels throughout the system is the cavity loss. The measurement is taken for one ring cavity at a time. Each time the measurement is taken; one loop will be totally disconnected from the system. The same steps are repeated for the RC2.

### 3. RESULTS AND DISCUSSION

From the experimental results, it found that the loss of the RC1 and the RC2 when the EDF and TBF’s are taken out from the setup is 5.7 dB and 6 dB respectively. These values are the amount of loss introduced by all components used in the proposed laser. Therefore, the difference of cavity loss is only 0.3 dB. The insertion loss TBF1 and TBF2 was also measured; TBF1 and TBF2 insertion loss is 3.8 dB and 4.6 dB at wavelength of 1550 nm respectively. Therefore, the cavity loss difference is around 1.1 dB. Fig. 3 shows that when the RC2 wavelength fixed at 1535 nm and RC1 wavelength tuned from 1536 nm to 1565 nm in 1 nm step, the RC1 loss should be adjusted by finely tune the attenuation value of VOA in RC1 whereas the loss of RC2 is remained constant. Thus, the output power of all dual wavelength lasing can be equalized by using just one VOA in the cavity with lower loss.

Fig. 3 shows the output power of this dual wavelength EDFL over the tuning range. The value of attenuation that is needed in the RC1 to equalize the output power of

![Fig. 3. The laser output powers and loss in RC1 (•) when TBF2 fixed at 1535 nm (□) and TBF1 tuned from 1536 to 1565 nm (△).](image)
the dual-wavelength laser increases as the TBF1 is tuned value at 1558 nm range and then decreased. This due to the fact that the spectral shape of RC1 loss is actually the reversed shape of the EDF gain.

In general, two independent lasers with equal power can be achieved from this new fiber laser design when lasing wavelength of the RC2 is fixed to certain value while the lasing wavelength of RC1 is tuned away from the fixed wavelength towards longer wavelength. However, when the TBF1 is fixed at 1535 nm while TBF2 is tuned to any position in C-band (from 1536 nm to 1565 nm), the different in output power between the two wavelengths were noticed. This only true when the loss difference between the two cavities is less than 0.5 dB. So it was difficult to obtain equal output power without the help of a VOA in the RC2. This is in-line with the previous reports [8].

In other paper [4, 10] the cavity that produces longer wavelength is the one to be optimized. While the wavelengths are tuned, by principle, we may need to change the cavity that need to be optimized. Therefore, this design requires VOA to be installed in both cavities. However, we found that by having the loss in the RC2 to be higher than that in the RC1 by more than 1 dB, the mentioned phenomenon is not relevant anymore. By using this setup, the optimization can be done regardless of the wavelength in the cavity. Only one VOA is needed, which should be installed in the lower loss cavity for optimization.

Fig. 4 shows the results of output power measurements of the dual-wavelength fiber laser and the corresponding losses in the RC1. Here, TBF1 is fixed at 1545 nm and the TBF2 is tuned from 1534.28 nm to 1565.61 nm in 1 nm step.

It is observed that as the wavelength of RC2 is tuned to be closer to the fixed wavelength of RC1, the difference in loss between the two cavities is small. It can also be to the longer wavelength, and reached the maximum seen that, when the TBF2 is detuned away to short wavelength, the total cavity loss in the RC1 is increased because the gain of the EDF at 1545 nm is higher than those at shorter wavelength. However, when the RC2 wavelength is detuned towards the longer wavelength the EDF gain is increased. So the loss in the RC1 should be reduced to achieve equal output power, and reached a minimum value at 1558 nm. From which it can seen that the loss of the RC1 increased slightly from 1558 nm to 1565.61 nm because the gain of the EDF at the fixed wavelength is higher than those at longer wavelength. The results have demonstrated a maximum tuning range of 31.33 nm within C-band, which correspond to the maximum tuning range of the TBF2, and a maximum output power variation of the laser is less than ± 0.37 dB and ± 0.33 dB for tuned and fixed wavelength respectively, and the maximum power variation between the two wavelength less than 0.35 dBm over the tuning range. Therefore, the power of the dual-wavelength over the tuning range is uniform and equal.

Notice that dual-wavelength EDFL with such equal output power can not be achieved at room temperature without adjusts the loss for both wavelengths [9, 10]. Since, in our configuration, the key component of the equal output power dual wavelength is loss optimization in the cavity with lower loss. So no need to install another VOA in the second cavity that leads towards reduction in cost compare to [9, 10].

1. CONCLUSION

We experimentally demonstrated a simple and cost effective dual-wavelength EDF ring laser with equal output power at room temperature. The dual-wavelength of the EDFL lased simultaneously as one of the cavity loss was carefully adjusted. The selection of cavity to be adjusted is based on the least amount of loss between these two cavities: clockwise and anti-clockwise directions. The dual lasing operation covers 31.33 nm of EDF spectral range within C-band from 1534.28 nm to 1565.61 nm. The power of the dual-wavelength is equal where the maximum output power variations of the RC1 wavelength and the RC2 wavelength was less than 0.35 dB over the tuning range. In order to obtain this significant result, the cavity loss optimization should be performed in the cavity with lower loss.

2. REFERENCES


