A New Design and Fabrication of Tapered Fiber-Based Loop Mirror as a Gain Flattened Erbium Doped Fiber Amplifier

Y. Ghorbani[1], Sh. Shahi[2]
1- Department of Electrical and Computer Engineering, Islamic Azad University Majlesi Branch, Isfahan, Iran.
Email: yalda_ieee19@yahoo.com (Corresponding author)
2- Dental Biophotonics and Laser Research Center (DBLRC), Islamic Azad University Khorasgan (Isfahan) Branch, Arghavanieh, Isfahan, Iran.
Email: shahilaser@khuisf.ac.ir

Received: April 2015 Revised: April 2016 Accepted: September 2016

ABSTRACT:
The purpose of this study is flattening the amplified spontaneous emission (ASE) spectrum based on an erbium-doped fiber (EDF) by using a standard fiber-based loop mirror (FLM) and tapered fiber. Subsequently, an over-coupled coupler is fabricated to realize the FLM, which is integrated to an EDF pumped by a 980-nm laser diode with a power level of 100 mW. By introducing an appropriate amount of bend-induced and inserting the optical tapered fiber in FLM, the ASE spectrum of the EDF was flattened within 0.9 dB over a wavelength range of 31 nm in the C-band (1525 nm-1556 nm).

KEYWORDS: ASE source, C-band, Erbium-Doped Fiber Amplifier (EDFA), Gain-flattening spectrum, Loop Mirror, Optical taper Fiber.

1. INTRODUCTION

optical communication is based on the optical signals which are transmitted over long distances via optical fibers. it is attenuated in optical fiber and it means that from time to time it is necessary to amplify the optical signals, so it can use the Erbium Doped Fiber Amplifier (EDFA) precisely at the spectral region applied in the optical fiber communication without any intermediate amplifying stage. Generally, Erbium-doped fiber amplifiers (EDFAs) have played a key role in long distance WDM transmission systems.

These fiber sources based on erbium doped fibers (EDFs) have also been widely investigated due to their advantages such as the higher power conversion efficiency and lower threshold powers [1-2]. However, the defect regarding communicating applications is that the gain range for such typical optical amplifiers at C-band is non-flat, in other words it is rugged, which is undesirable for such amplifiers reducing the transmission capacity and limiting the bandwidth.

Also, in the research demonstrated by M. K. Jazi et al., still the un-flatness gain backward spectrum around 1532nm was observed [3]. Hence, Gain Flattened Erbium Doped Fiber Amplifier (EDFA) is essential for these devices. Filters made of optical fiber have attracted significant study interest because of their low insertion loss and compressed size for optical fiber applications [4]. With the available technologies, band-pass filters based on optical fibers provide different range of bandwidth from less than 1 nm to more than 100 nm [4]. For example optical filters based on Long Period fiber Grating (LPG) using fabrication on unique fibers, or utilize photonic band gap fibers [5-7]. However, design and fabrication of some specific filters based on optical fibers such as tunable comb filters is difficult [4].

The purpose of this study is to design a new type of gain-flattening filters for EDFA using a kind of tapered optical fiber. Recently, use of a high-birefringence (Hi-Bi) fiber-based loop mirror (FLM) has been proposed for gain flattening of an EDFA [8].

Considering, use of a Hi-Bi fibers would lead to higher insertion loss, thereby designing and fabrication of Hi-Bi FLM as a gain Flattening perhaps somewhat is less attractive[8-9] as well as the design and fabrication of new kind of tapered fibers. In the past, tapered fibers were intensively used to wavelength-selective devices, resonators, interferometers [10], amplifiers, sensors [11] and filters [12], also in designing this kind of fiber considering the optimized parameters makes high-birefringence (Hi-Bi) so that the advantages will be low insertion loss, low dispersion and etc. The optical tapered fiber filters was first introduced by Ozeki et al. [13].

The purpose of this research, is to investigate the feasibility and design a new simple type of gain-flattening filters for EDFA using a FLM realized with a fiber coupler as a loop mirror and new design of tapered fiber on SMF-28.

This setup for gain flattening filter is fabricated in the Institute of optical and photonics, that eventually is one of the simple and affordable methods for gain flattening filter for ASE source.

2. EXPERIMENTAL SETUP

Figure 1 shows the simulation setup by Opt system software for a gain flattening C-band ASE source, that consists of 3 meters of EDF as a gain medium and length of EDF is one of the most important parameters, for this research, a 50:50 coupler, a 980/1480 WDM coupler as the coupling Pump power into the cavity, isolator and combination FLM filter are used.

The 3dB optical coupler is placed at the end of laser diode to transfer power to EDF. The fiber doping concentration is 1/9× 1025 ions/m3,and NA of 0.2, and its mode field diameter (MFD) is nearly 6.5 µm at 1550 nm..

The spectral output of SPB configurations are combined FLM filter inclusive a fiber coupler and a component with tapered fiber transmission spectrum.

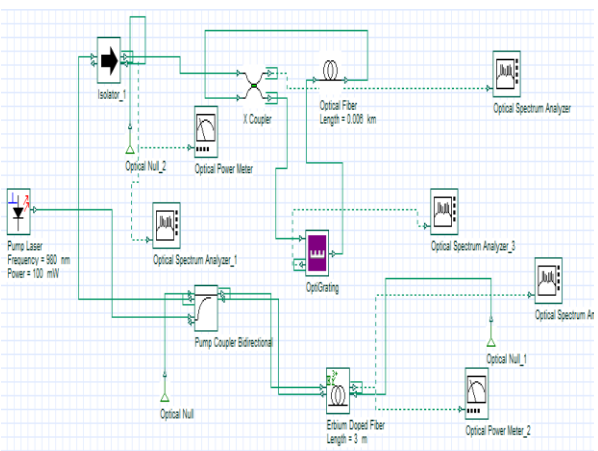

Fig.1. Schematic diagram by using the gain flattening filter for the ASE spectrum

2.1. Backward Un-Flat ASE Spectrum

Broadband ASE light source of EDF can be fabricated that is widely used in the field of sensors and optical communication. Figure 2 shows the spectrum light source output consists of the 980 nm laser diode, the coupler 980/1550 nm, Isolator and the appropriate length of EDF. The 12 meter lengths of the EDF and a power of 100 mW are used to demonstrate results based on simulation. Then, the simulation and experimental results of the backward un-flat ASE spectrum on 100 mW laser diode power are shown in figure 2.

By comparing, the un-flat backward spectrum to forward spectrum, it proposed the wider, flatter and more efficient power level.

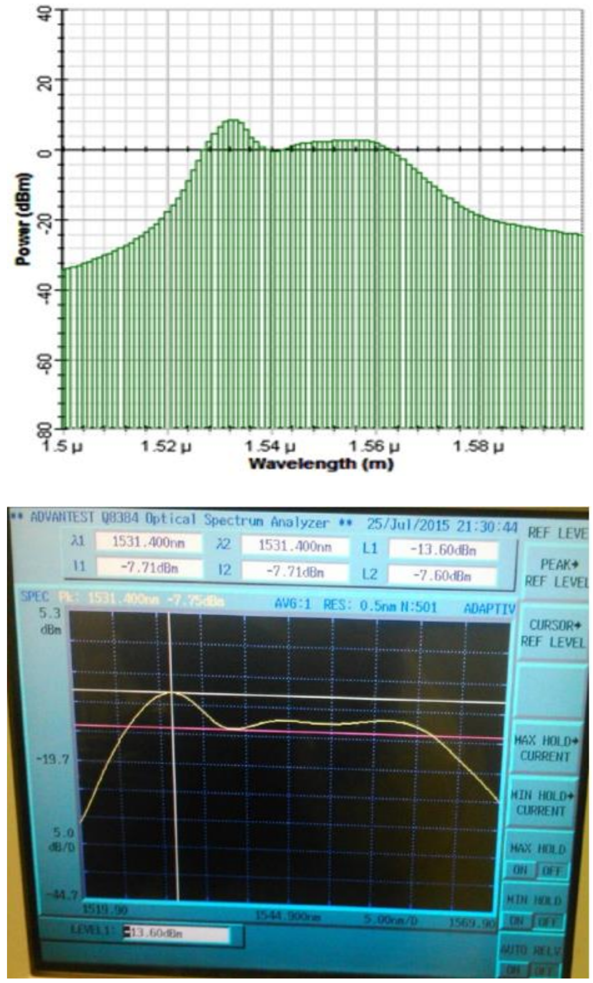

Fig. 2. The simulation and experimental output spectrum of backward ASE

2.2. Design of Filter Based on Tapered Fiber

There already exists matured technology for flattening the gain of fiber amplifiers as well as ASE spectrum, such as using dielectric filters, long period grating, which are so available, and provides flattened spectrum but in our design we used the simple method based tapered loop mirror filter.

The filter including the tapered fiber should be designed in a way that it would improve transfer backward ASE spectrum non-flatness. Hence, the various parameters for flattening spectrum must be considered for designing the tapered fiber. In this study, the available and simple single mode fiber-28 (SMF-28) is the choice of tapered fiber.

Other important parameters in this experimental setup are the pitch of taper, number of taper, length of tapered fiber and the effective refractive index of the clad and core. According to table 1, the effective refractive index of the clad and core depends on the wavelength.

Table 1. The applied numerical values in the software to design the tapered fiber

Parameter	Value
n2 clad (refractive index of the second clad)	1.470
neff-core (effective refractive index of the core)	1.473
Δneff(difference in refractive index)	0.00243
Λ (pitch of taper)	600
N (number of taper)	84
L (length of tapered fiber)	50 mm

2.3. Fabrication method of tapered fiber

A biconic tapered fiber was fabricated by UV radiation based arc splicing on single mode fiber (SMF 28, Corning) by the setup as shown in Figure 3. The reason of using this method is simplicity, availability and the reasonable price.

In this study, the quantity of tapering rate on the sample single-mode fiber is about 50 mm. The length of each stage arc (taper waist) is also an important parameter tuned on 1000 µm to be near the simulation parameters. Furthermore, the pitch of taper was 630 µm, and the number of taper on the optical fiber was selected more than 4 that was executed for simulation section too.

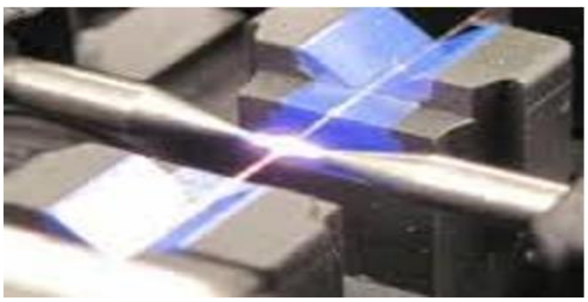

Fig. 3. Schematic of the tapered fiber fabrication setup

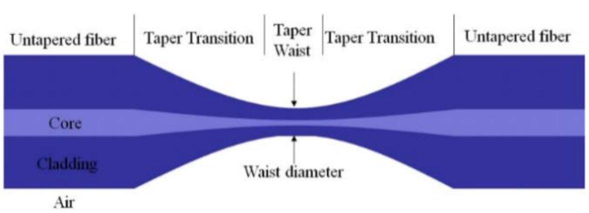

Fig. 4. Illustration of a tapered optical fiber

2.3. The Tapered Fiber Loop Mirror Filter

Birefringence properties of optical fibers can be obtained by geometric deformation, stress or a combination of two methods. The beams bending and compression leads to create linear birefringence due to elastic light effect. It is obvious that simple ring acts as a reflector where there is not any birefringence feature. The loop optical fiber with birefringence property makes a kind of filter. Principles loop mirror fiber inclusive non-linear or birefringence fiber (HiBi-FLM) in addition to the input signal that is split into two beams counter-propagation along the loop arm that after propagation in loop it is recombined at coupler. The interference effect depends on birefringence properties of cavity and reflectivity on this mirror filter that also depends on wavelength. The incident light is launched into the 3dB coupler (50:50) at the input port and splits into c1ockwise and counter clockwise beams of light by the 3-dB coupler as shown in figure 5.

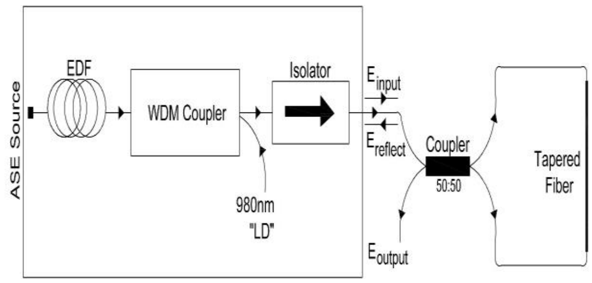

Fig. 5. Schematic diagram of the FLM combination with the tapered fiber after broadband light source of EDF

3. RESULTS AND DISCUSSIONS

The experimental and simulation results are divided based on three designs introduced as methods below:

1) The piece of tapered fiber was placed after broadband light source of EDF
2) The use of only simple FLM was placed after broadband light source of EDF.
3) The combination of tapered fiber in the FLM was placed after broadband light source of EDF.

By comparing the three methods above in figures (6-8), it can be observed that the combination of loop and taper fiber filter produces more flatness gain especially in right hand of gain spectrum. However, the figure 9 shows the comparison results of different taper segments on the fiber after using the ASE source as a filter.

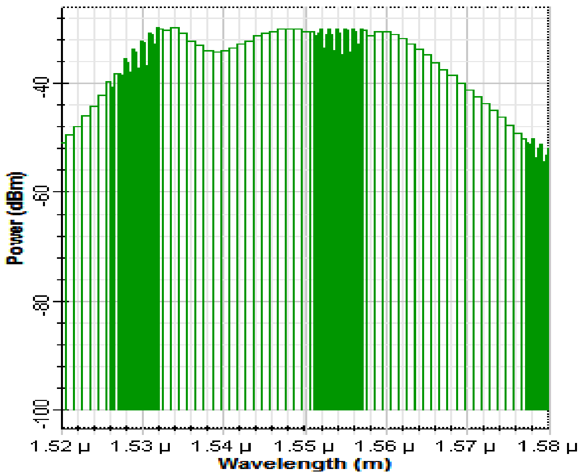

Fig. 6. Spectrum simulation inserting tapered fiber after ASE source

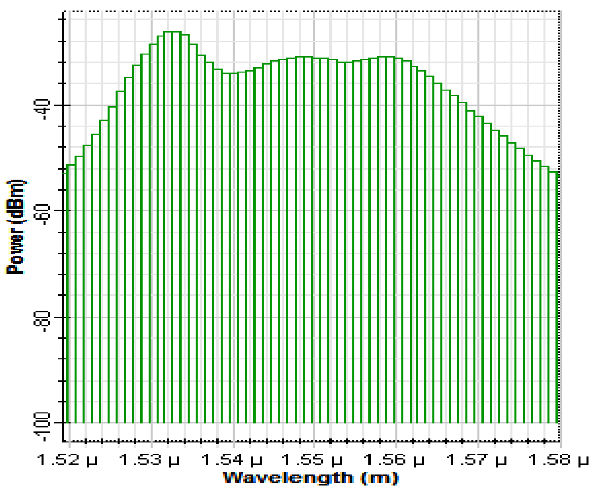

Fig.7. Spectrum simulation inserting loop mirror without tapered fiber after ASE source

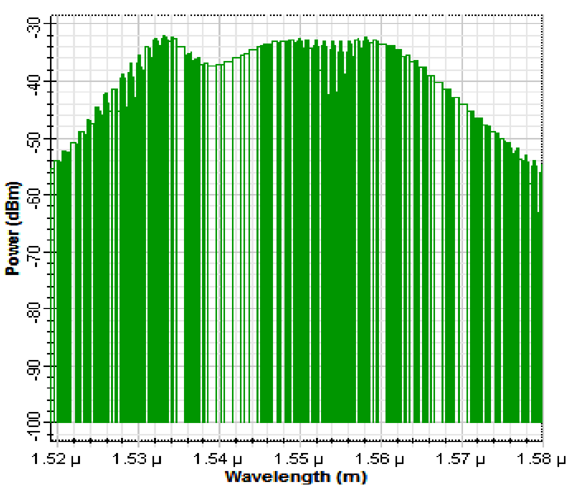

Fig. 8. Spectrum simulation inserting loop mirror component with tapered fiber after ASE source

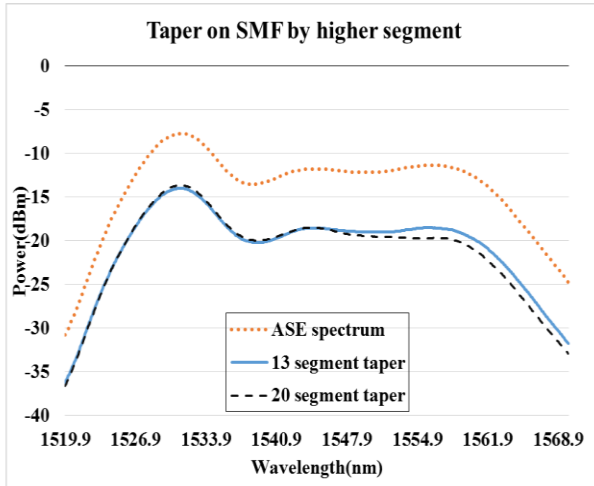

Fig. 9. A comparison of the number of taper segments as a filter

As shown in figure 9, by increasing the number of segment taper on fiber, the fluctuations of power decreased on right hand of spectrum. However, we cannot avoid decreasing the power level because of increasing the cavity loss in set up from 13 to 20 segment taper. Finally, we proposed the desired results of gain flattening filter designed by taper fiber in the loop as a compact filter in figure 10 and 11. Optical spectrum of an erbium-doped fiber ASE source exhibits strong peak near 1530nm, where the emission cross-section is the largest, and this peak still exists even in the presence of their tapered fiber loop mirror on the left hand of spectrum. However, we proposed the power fluctuation of less than 0.9 nm in extend range of 31 nm wavelength that can be useful for comparing sensing and filter devices.

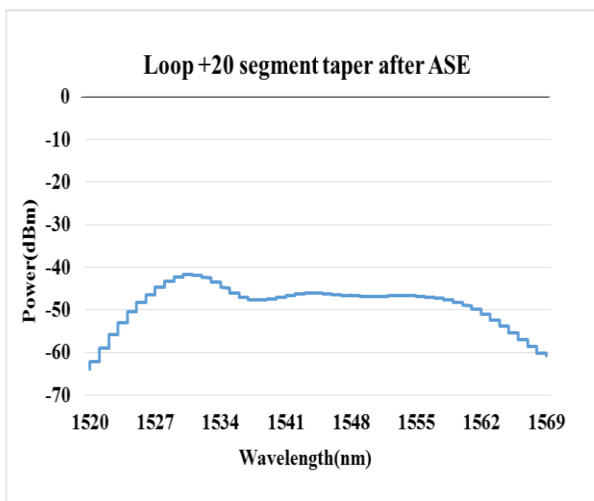

Fig. 10. The FLM filter spectrum within 20 pitch of taper on optical fiber after broadband light source of EDF

Fig. 11. Experimental output spectrum of tapered fiber loop mirror filter after broadband light source of EDF

The evaluation between results and choosing the best filter for the gain flattening of ASE source in this research are shown in table 2.

Table 2. Comparing the Difference of Level in the method of Gain flattening

Method of Flattening	Difference of Level(dB)	Optimum state
ASE without filter	6	
ASE+tapered fiber with 13 segment taper	2.5	
ASE+ tapered fiber with 20 segment taper	1.2	
ASE+ fiber loop mirror filter	1.9	
ASE+ tapered fiber loop mirror filter	0.9	✓

4. CONCLUSION

In summary, this research proposed the simple design for the gain flattening ASE spectrum. The gain flattening filter by using the loop mirror component and tapered fiber occurred around 21 nm wavelength range. In this way, the input power by this low level of power to combination FLM was only 100 mw, the relatively uniform gain in the telecommunication operating wavelengths or C-band (1525 nm-1556 nm) with 0.9 (±0.45) dB ripple was obtained. The flat ASE spectrum has many applications in sensors, WDM systems, filters and so on. The combination of inserted taper fiber in FLM makes a novel FLM filters which is simple, affordable to use, and compact. Also, telecommunication filters with high quality at competitive prices to meet the ever increasing wireless and fiber-to-the-home traffic is demanded.

REFERENCES

[1] H. Ahmad, S. Shahi, and W. Harun, **“Bismuth based erbium doped fiber as a gain medium for L-band amplification and Brillouin fiber laser,”** *Laser Physics*, Vol. 20, pp.716-719, 2010.

[2] S. Shahi, S.W. Harun, and H. Ahmad, **“Multi-wavelength Brillouin fiber laser using Brillouin-Rayleigh scatterings in distributed Raman amplifier”,** *Laser physics letters*, Vol. 6, pp.737-739, 2013.

[3] M. Kanani Jazi, S. Shahi, M. J. Hekmat, H. Saghafifar, A. T. Khuzani, H. and Khalilian, M. D. Baghi, **“The evaluation of various designs for a C and L band super fluorescent sources based Erbium Doped Fiber,”** *Laser Physics*, Vol. 23, 2013.

[4] K.-Chu. Hsu, N.-K. Chen, S.-Y. Chou, S.-K. Liaw, Y. Lai, and S. Chi,**” Bandpass Filter With Variable Bandwidth Based on a Tapered Fiber With External Polymer Cladding”**, *IEEE photonics technology letters*, Vol. 21, JULY 1, 2009.

[5] M. J. Kim, Y.M. Jung, B. H. Kim, W.-T. Han, and B. H. Lee**,” Ultra-wide bandpass filter based on long-period fiber gratings and the evanescent field coupling between two fibers”**, *Optics Express*, Vol. 15, pp. 10855-10862, 2007.

[6] B.W. Liu, M.L. Hu, Xiao-Hui Fang , Y.-F. Li , L. Chai , J.Y. Li , W. Chen , and Ch. Y. Wang**,” Tunable Bandpass Filter With Solid-Core Photonic Bandgap Fiber and Bragg Fiber”,** *IEEE photonics technology letters*., Vol. 20,pp. 581-583, 2008.

[7] S. K. Varshney, K. Saitoh, N. Saitoh, Y. Tsuchida, M. Koshiba, and R. K. Sinha, **“Strategies for realizing photonic crystal fiber bandpass filters”,** *Optics Express*, Vol. 16, pp. 9459-9467, 2008.

[8] N. Kumar, M. R. Shenoy, B. P. Pal, **“A Standard Fiber-Based Loop Mirror as a Gain Flattening Filter for Erbium-Doped Fiber Amplifiers,”** *IEEE photonics technology letters*, Vol. 17, pp.2056-2058, 2005.

[9] W. Jin, H. Xuan, and W. Jin, **“Birefringent microfiber-based fiber loop mirrors for tunable filters and refractive index sensors,”** *Fifth European Workshop on Optical Fibre Sensors*, 87943W, (May 20) 2013.

[10] Jie Li, Mengmei Geng, Li-Peng Sun, Pengcheng Fan, Bo Liu, and Bai-Ou Guan**,” Investigation on single taper-based all-solid photonic bandgap fiber modal interferometers”,** *Optics Express*, Vol. 24, pp. 8547-8554, 2016.

[11] K.Q. Kieu, M. Mansuripur, **“Biconical Fiber Taper Sensors,”** *IEEE photonics technology letters*, Vol. 18, pp.2239-2241, 2006.

[12] L. Huang, Jie Wang, W. Peng, W. Zhang, F. Bo, X. Yu, F. Gao, P. Chang, X. Song, G. Zhang, and J. Xu,**” Mode conversion in a tapered fiber via a whispering gallery mode resonator and its application as add/drop filter”**, *Optics Letters*, Vol. 41, pp. 638-641, 2016.

[13] T. Ozeki, T. Ito, T. Tamura, **“Tapered section of multimode cladded fibers as mode filters and mode analyzers,”** *Appl. Phys. Lett*., vol. 26, pp.386-388, 1975.