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ASYMMETRIC FIBER TAPER FOR NARROW LINEWIDTH COMB FILTER

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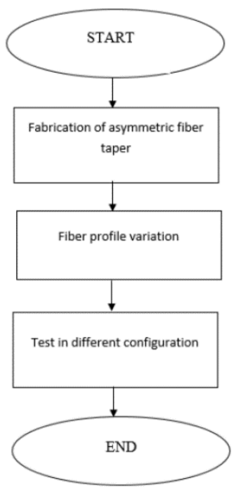
Graphical abstract



Abstract

The employment of asymmetric optical fiber taper as a means for producing narrow linewidth comb filter is proposed and demonstrated. Fiber taper with different values set for the up-taper and down-taper transition regions was used to produce narrow linewidth comb filter through coupling interaction of light in the asymmetric fiber. Two configurations; single-pass and bidirectional fiber taper filters were studied and analyzed in this project. Results showed narrower 3-dB linewidth for asymmetric taper compared with uniform taper for single pass configuration. The asymmetric taper linewidth was improved further in bidirectional configuration, narrowing down to 2 nm. Bidirectional asymmetric taper filter recorded extinction ratio of 27.14 dB, which was 18 dB and 3 dB better than single-pass asymmetric taper and bidirectional uniform taper respectively. The findings emphasize the attractiveness of bidirectional asymmetric taper as a high performance optical filter.

Keywords: Comb filter, linewidth, fiber taper, asymmetric

Abstrak

Salah satu cara untuk menghasilkan penapis garis lebar sisir yang tirus dengan menggunakan gentian optik tirus tak simetri telah ditunjukkan. Gentian optik tirus yang mempunyai nilai yang berbeza untuk bahagian peralihan tirus bawah dan tirus atas telah digunakan untuk menghasilkan garis lebar sisir yg tirus melalui gandingan interaksi cahaya dalam gentian optik tak simetri. Dua konfigurasi; laluan sehala and dwiarah penapis gentian optik tirus telah dikaji dan dianalisa dalam projek ini. Hasil kajian menunjukkan 3 dB garis lebar untuk gentian optik tirus tak simetri lebih tirus berbanding gentian optik tirus simetri. Garis lebar yang semakin tirus iaitu 2 nm diperolehi apabila gentian optik tak simetri digunakan didalam konfigurasi dwiarah. Dwiarah penapis gentian tirus tak simetri mencatatkan nisbah pupusan 27.14 dB, yang merupakan 18 dB dan 3 dB lebih baik daripada laluan sehala gentian tirus tak simetri and gentian tirus simetri. Penemuan ini menekankan kelebihan gentian tirus tak simetri dwiarah sebagai penapis optik berprestasi tinggi.

Kata kunci: Penapis sisir, garis lebar, gentian tirus, tak simetri

1.0 INTRODUCTION

Wavelength-division multiplexing (WDM) is a crucial technology for optical fiber communication since it is an efficient and cost-effective method to increase the transmission capability by orders of magnitude. It is always desirable to have multiple wavelengths laser source in a WDM system. In such situation, multiple wavelength fiber lasers draw much attention due to their all-fiber configuration and seamless integration.

The simplest technique for multiwavelength generation is through the use of comb filter in laser cavity. Several works were published on all- fiber comb filter, such as fiber grating [1], Fabry-Perot filter [2], Sagnac loop interferometer [3], Lyot filter [4], and Mach-Zehnder interferometer (MZI) [5]–[8]. Compared to other comb filters, MZI has more advantages such as simple fabrication at relatively low cost, high stability and reliability [9], insensitivity to environmental changes, as well as broad operating wavelength range [10].

In this work, we demonstrate and present an experimental investigation on producing a narrow linewidth comb filter by using asymmetric optical fiber taper. The linewidth, free spectral range (FSR), spectral profile and extinction ratio (ER) are obverse while varying the length of up-taper and down-taper transition regions. Additionally, by using two configurations; single-pass and bidirectional fiber taper filter, we are able to achieve different results.

2.0 EXPERIMENTAL

The experimental setup of the proposed narrow linewidth comb filter using asymmetric optical fiber taper is shown in Figure 1. Figure 1(a) is for the single pass study, which begins with the amplified spontaneous emission (ASE) light source connected to the circulator. The circulator is then connected to the tapered fiber. Finally, the performance of the comb filter was observed using an optical spectrum analyzer (OSA), which is connected to the other end of the tapered optical fiber. Subsequently, Figure 1(b) is the bidirectional fiber taper filter configuration. There are 2 circulators used in this setup with one functioning as a router for optical signals that travel in the opposite direction and the other circulator is connected at the end of the tapered fiber to act as a mirror to reflect the initial filter output

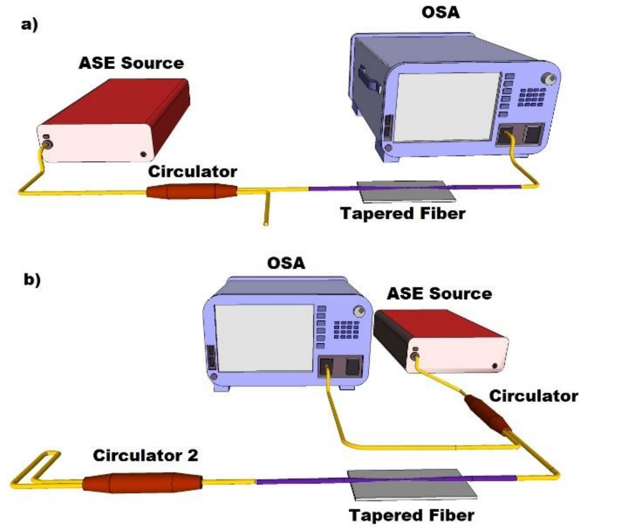


Figure 1 Experimental setup for a) single-pass and b) bi-directional fiber taper filter

Figure 2 shown the relevant geometry pertaining to a tapered fiber. In our work, we used the Vytran GPX-3000 Glass Processing and Fusion Splicing machine for the taper fabrication work. The machine can precisely control the waist length, transition length and waist diameter so that the uniformity of the tapered fiber can be guaranteed. For this experiment, we tested 3 taper profiles, which are listed in Table 1. The waist length and core diameter were fixed at 10 mm and 10 μm, respectively, to ensure the taper operates non-adiabatically for fringes generation [11]. The length of the transition regions was chosen to achieve equal summed value of both down-taper and up-taper lengths for all taper profiles. In all cases, the down-taper region was the initial entry point of light in this experiment.

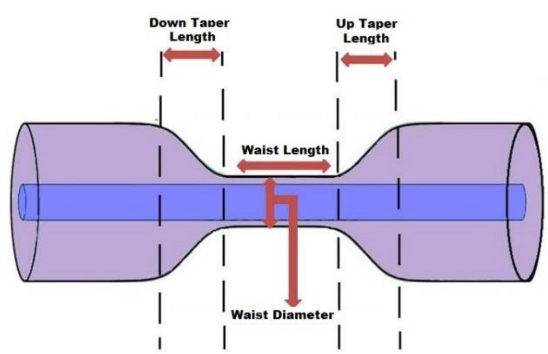


Figure 2 Dimensions of a tapered fiber

Table 1 Taper profiles used throughout the experiment

Type	Down-Taper Transition Length (mm)	Waist Length (mm)	Up-Taper Transition Length (mm)	Core Diameter (µm)
Uniform	5	10	5	10
Asymmetric	8	10	2	10
	2	10	8	10

3.0 RESULTS AND DISCUSSION

Figure 3 represents the transmission output spectra when the ASE source is injected into one end of the tested fiber and the output spectra are observed using OSA. The transmission output spectrum for the untapered fiber shows a smooth ASE spectral profile since no perturbation is induced to the light and only fundamental mode propagates within the fiber. Meanwhile, the orange line spectrum represents the transmission profile from a tapered fiber with taper profile of 2 mm – 10 mm - 8 mm (2 mm down-taper, 10 mm waist length, 8 mm up-taper), which depicts the presence of the comb-like fringes on the ASE spectrum. This result is due to the constructive and destructive interferences of light as it goes through the tapered region [6].

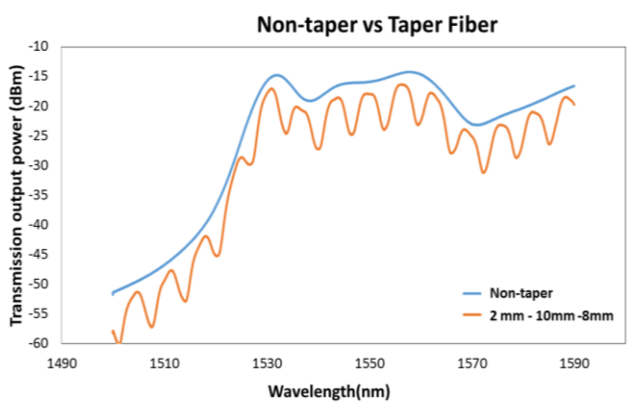


Figure 3 Transmission output spectrum of non-tapered fiber and tapered fiber.

The interferometry process occurs when the light passes through the down taper region into smaller waist region. Due to the tapering process, both cladding and core are now combined and act as the new core, with air acting as the cladding. Excitation of higher-order modes is induced with some parts continuing within the new core while the rest propagates near the boundary of the fiber, mostly leaking out as evanescent waves. The modes within the core travel with a different propagation constant and this induces phase difference between the modes, which will then recombine as they reach the down-taper region. The recombination of these phase-differentiated modes leads to interference that is represented as fringes as shown in Figure 3. Non-adiabatic taper is required to generate this effect since the abrupt taper angle allows excitation of higher order modes.

Equation 1 is the expression for resultant intensity interferences:

$$I_T = I_{co} + I_{cl} + 2\sqrt{I_{co}I_{cla}}\,COS\,(\Delta\Phi) \qquad (1)$$

I_{co} and I_{cl} are the intensities of two interference modes while ΔΦ is the phase shift, which is presented in Equation 2.

$$\Delta\Phi = \frac{2\pi(\Delta n_{eff})L}{\lambda} \qquad (2)$$

Where Δ_{neff}, is effective of reflective index and **L**, is the length of fiber. Similar effect can be observed in Mach-Zehnder interferometer where the interferometric pattern is formed due to different path delay introduced to its separate arms [12].

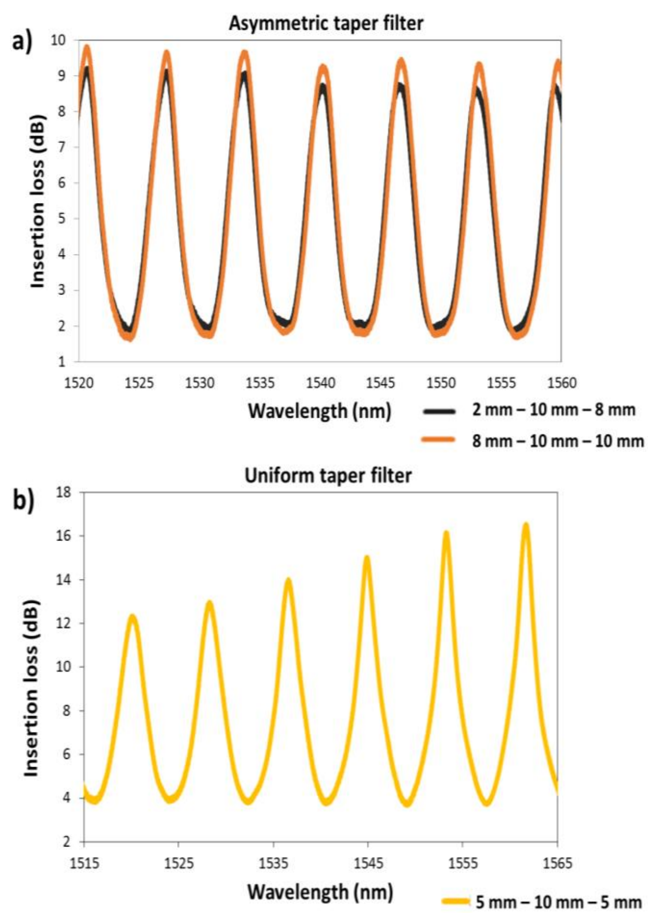


Figure 4 Loss spectrum in single pass configuration of a) asymmetric b) uniform fiber taper filters

Figure 4 shows the loss spectral profiles in single pass configuration with different transitions parameters for asymmetric tapered filter and uniform tapered filter. It is observed that uniform fiber taper shows higher insertion loss compared to asymmetric fiber taper. Uniform fiber taper with parameter 5 mm - 10 mm - 5 mm also recorded higher extinction ratio of 12.48 dB, which is 6 dB and 5 dB better than taper profile of 2 mm -10 mm – 8 mm and 8 mm -10 mm -2 mm, respectively. This shows that uniform fiber taper can achieve better extinction ratio in single pass configuration but will introduce high loss at the output.

Table 2 lists the linewidth, ER and FSR values obtained for the different tapers in single pass configuration. Taper profile with parameter 2-10-8 mm recorded the narrowest linewidth with only 3.70 dB linewidth. Meanwhile, the FSR of 2-10-8 mm and 8-10-2 mm have a difference of only 0.01 mm between the two. As shown in Figure 4(a), the distance between two adjacent peaks for these two taper profile spectrums are also quite similar. Therefore, only small variation can be seen between these two spectra. In contrast, large spacing between the two successive wavelengths are recorded in Table 2 for uniform fiber taper.

Table 2 Results for single pass configuration

Taper Profile (mm)	Linewidth (nm)	Extinction ratio (dB)	Free spectral range (nm)
2-10-8	3.70	6.77	6.42
8-10-2	3.77	7.61	6.41
5-10-5	4.40	12.48	8.38

Figure 5 exhibits the insertion loss spectra of three different spectral profiles when the light is injected into the bi-directional structure. When the light passes the tapered fiber twice, double interference effect is induced and the output spectrum observed at the output is basically the overlapped spectrum of each light pass. This concept is similar to the one observed in cascaded filter where a filtered light is filtered again as it passes through the second filter. In Figure 5, uniform taper filter shows higher insertion loss, which is around 2 dB more than asymmetric taper filter. Insertion loss spectrum above also shows that the bi-directional configuration has two times higher insertion loss than single-pass taper filter configuration in Figure 4. This is expected since the light goes through the tapered fiber twice thus inducing more loss. Moreover, as observed in Figure 5(a), the asymmetric taper filter shows the extinction ratio of about 27.14 dB at region 1550 nm, which is 3 dB better than bidirectional uniform taper filter. This indicates asymmetric fiber taper has better suppressions of unwanted wavelength compared to uniform taper filter. This extinction ratio values are measured by the difference between maximum and minimum power at the selected wavelength.

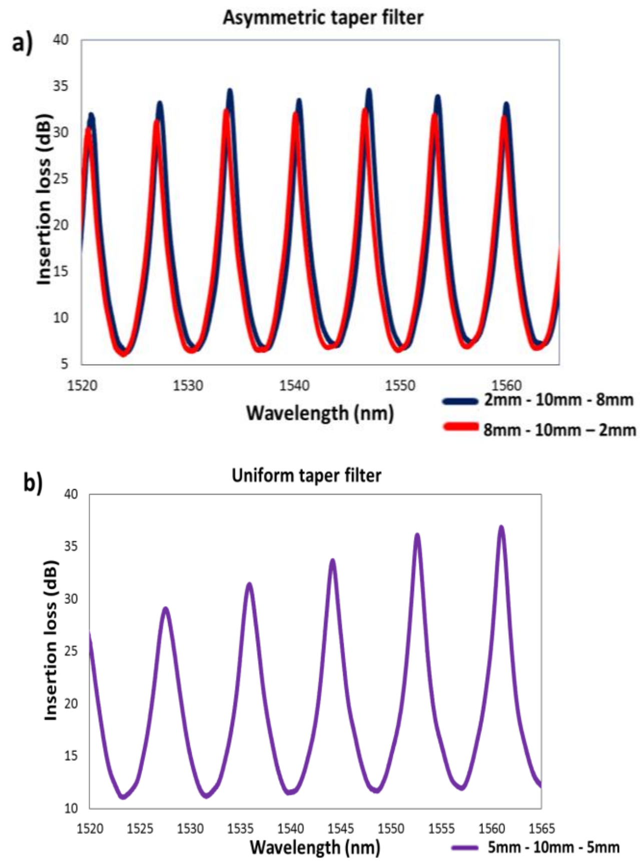


Figure 5 Loss spectrum in bidirectional pass configuration of a) asymmetric b) uniform fiber taper filter

Table 3, lists the linewidth ER and FSR values obtained for the different tapers in bidirectional pass configuration. Based on the results obtained, bidirectional asymmetric taper filters achieved better performance since it produces narrow linewidth output compared to uniform bidirectional taper filters. When light passes the asymmetric taper twice, different output spectrums will be obtained for each light pass since the light is reflected back and entered the tapered fiber at different transition length parameter. Therefore, the overlapping between the two different spectra results in narrower linewidth. In contrast, when the light passes uniform taper filter bidirectionally, the same output spectrums are obtained for each light pass since both transition lengths are similar. Therefore, the overlapping between each light pass in such case produces little variation at the output.

Table 3 Results for bidirectional pass configuration

Taper Profile (mm)	Linewidth (nm)	Extinction ratio (dB)	Free spectral range (nm)
2-10-8	2.00	27.14	6.48
8-10-2	2.49	25.43	6.56
5-10-5	3.10	24.48	8.70

4.0 CONCLUSION

In conclusion, we have successfully demonstrated the performance of optical fiber taper filter in single-pass configuration and directional configuration. For the single-pass configuration, asymmetric taper produce narrower 3-dB linewidth compared to uniform taper. With bidirectional configuration, we are able to achieve linewidth of 2 nm and extinction ratio of 27.12 dB using asymmetric taper. This result is much better compared to the bidirectional uniform taper and single pass asymmetric taper. The utilization of asymmetric tapered fiber as a comb filter has proven its feasibility as an integrated solution in producing a high performance optical filter.

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