Temperature Sensitive Wideband Spectrum-sliced ASE

X. S. Cheng, H. Ahmad, and S. W. Harun

***Abstract*—A wideband spectrum-sliced ASE source is demonstrated using a 1480nm pumped Bismuth-based Erbium-doped fiber and a thermal controlled fiber loop mirror. The spacing of output comb can be tuned by adjusting the birefringence and the effective length of the polarization maintaining fibers (PMFs) in the loop mirror. By changing the temperature of the PMF segments, the spacing can be tuned from 1.69nm to 4.35nm corresponding to a number of channels of 52 to 21 within a wavelength range from 1530nm to 1620nm as the birefringence axis for both PMFs is adjusted to be perpendicular to each other. The maximum 300 channels with 0.300nm comb spacing can be obtained when both PMFs are arranged in such a way that the beam orthogonal components of both PMF are parallel.**

***Index Terms*—Temperature sensor, bismuth-doped fiber, amplifier.**

I. Introduction

The tremendous growth of the internet and data traffic has created an enormous demand for transmission bandwidth of dense wavelength-division-multiplexed (DWDM) optical communication systems. Since the silica-based transmission fibers have a wide-band operating window ranging from 1400 to 1700 nm, optical light sources with a wider amplification bandwidth are required to cover the full range of the DWDM systems. The wide-band source is also needed for the wavelength division multiplexing passive optical network (WDM-PON), which is emerging as a promising solution for future broadband access networks. In WDM-PONs, there have been several approaches to implement low cost multi-wavelength sources [1-3]. Recently, the use of spectrum-sliced amplified spontaneous emission (ASE) source has been proposed and gained great attention [4].

To date, many comb-filter configurations have been proposed in accomplishing multi-wavelength lasers such as Fabry-Perot interferometer, fiber Bragg gratings (FBGs), Mach Zehnder interferometers and fiber loop mirrors [5-8]. Among all, polarization maintaining fiber loop mirror is one of the promising configurations in terms of simple fabrication process, low fabrication cost, low insertion loss to the system cavity and capable of creating large number of lasing numbers [8]. Recently, a novel temperature sensitive dual-segment loop mirror has been reported [9]. By exploiting the temperature dependent birefringence of the PMF, the wavelength spacing of the fiber loop mirror can be continuously increased or decreased by increasing the temperature of one of the segments.

Bismuth-based erbium-doped fibers (Bi-EDFs) have been extensively studied for use in compact amplifiers with a short piece of gain medium [10-11]. This fiber can also be used to produce a broadband amplified spontaneous emission (ASE) source. In this paper, a spectrum-sliced ASE source with wideband operation and adjustable spacing is proposed and demonstrated. It uses a Bi-EDF as the gain medium and a thermal controlled fiber loop mirror as the comb filter. To the best knowledge of the authors, this is the first experiment that reports on Bi-EDF based wide-band ASE source using temperature sensitive loop mirror.

II. Experiment

Fig. 1 is the experimental setup for the proposed spectrum-sliced ASE source using a piece of Bi-EDF and a loop mirror. The Bi-EDF has an erbium ion concentration of 3,250 ppm and a cut-off wavelength of 1440 nm as well as a pump absorption rate of 83dB/m at 1480nm. The 215cm long Bi-EDF is bi-directionally pumped by two 1480nm laser diodes to provide a broadband ASE covering from C-band to extended L-band regions. The ASE source was then spectrum sliced by a Sagnac loop mirror, which was formed by a 2x2 3-dB coupler and two segments of polarization maintaining fibers (PMF1 and PMF2). PMF1 and PMF2 have a length of 10.5m and 8.0m, respectively with a polarisation controller (PC) is incorporated in between them. The PC controls the relative phase difference between two orthogonal polarization modes within the PMF so that a comb filter can be generated with the spacing is depending on the effective length and birefringence of the two PMF segments. The wavelength spacing $\Delta\lambda$ of the adjustable PMF Sagnac loop mirror can be expressed as

$$\Delta\lambda = \frac{\lambda^2}{\Delta n \cdot L_{eff}} \quad (1)$$

where Δn is the effective birefringence between two orthogonal polarization modes and L_{eff} is the effective length of the two PMF segments. The L_{eff} can be varied between L_1 - L_2 and $L_1 + L_2$ by adjusting the PC that is incorporated in between the two segments. A rotation of 90^0 between the orthogonal components within the PMFs results a $L_{eff} = L_1 - L_2$ while a parallel orthogonal components gives a $L_{eff} = L_1 + L_2$.

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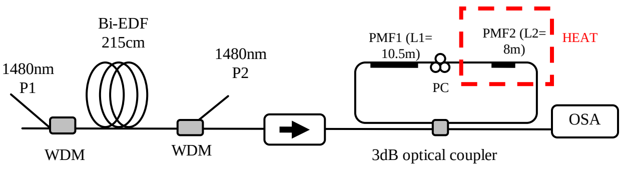


Fig. 1. Experiment set-up for spacing-adjustable wideband ASE source.

The birefringence as function of temperature, Δn(T) is given by;

$$\Delta n(T) = \Delta n(T_o) - b_1(T - T_o) - b_2(T - T_o)^2 \qquad (2)$$

where b_1 = 2.55 x 10^{-7} $^oC^{-1}$ and b_2 = 1.5 x 10^{-9} $^oC^{-1}$ [9]. Therefore the birefringence is estimated to be approximately 4.02 x 10^{-4} at 20^{o}C. The manipulating of the birefringence can be used to adjust the spectral spacing of the ASE comb. When the two PMFs are heated with different temperatures T_1 and T_2, thereby the spectral spacing can be written as

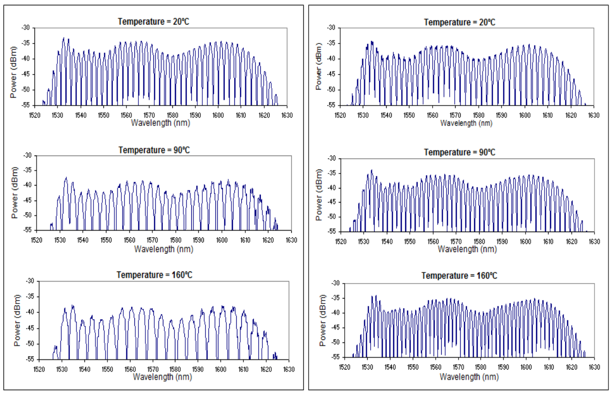
$$\Delta\lambda(T_1, T_2) = \frac{\lambda^2}{\Delta n(T_1)L_1 \pm \Delta n(T_2)L_2} \qquad (3)$$

In this experiment, one of the PMF segment is placed onto a hotplate and is wrapped with an insulator to ensure the uniform distribution of the temperature on the PMF. An isolator is placed in between the broad ASE source and Sagnac loop mirror to avoid internal reflection that can cause lasing in the system. An optical spectrum analyzer (OSA) is used to characterize the multi-wavelength source.

III. Results and Discussion

Wide-band ASE spectrum can be obtained by adjusting the powers of P1 and P2 to a suitable value. At the optimum values of P1 = 45mW and P2 = 160mW, a broadband ASE spectrum which cover 90nm bandwidth from 1530nm to 1620nm is produced. The power ripple ΔP is about ± 3dB which is measured as a half of the output variation from the valley power to the peak power of the spectrum. The broad ASE spectrum is used in conjunction with the Sagnac loop mirror to obtain a spacing adjustable wideband multi-wavelength source. The Sagnac loop mirror operates by splitting the input beam into two counter propagating beams and propagates through the PMFs with different velocity. Their individual polarization direction varies and the orthogonal components of travelling beam in the fast axis and slow axis may experience phase difference in the PMF. PC in between two PMFs sections rotates the beam orthogonal components in such a way that the interference of slow axis component and fast axis component occurs, therefore effect length of PMF, L_{eff} = L1 – L2. The PC can also be tuned so that the interference is achieved from the same component, which resulted in the effective length, L_{eff} = L1 + L2. The interference produces the multi-wavelength comb at output of the loop mirror, which the channel spacing can be controlled by the adjustment of the PC and temperature settings of PMF.

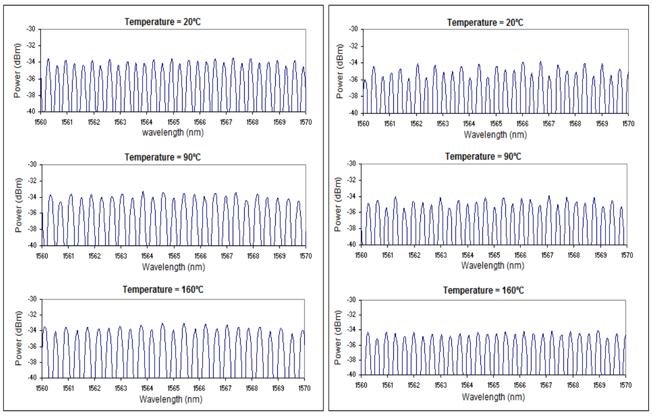
Fig. 2 shows the optical spectra of the spectrum sliced ASE output at various temperature settings of PMF1 and PMF2 when the PC is adjusted so that L_{eff} = L1 - L2. One of the PMF is set at a fixed temperature of 20^{o}C, while the temperature for another PMF is varied. The PMF was made from slightly different type of glasses thereby different thermal expansion rates induce a change in PMF birefringence when it detects a different temperature. Based on Eq. 2, the birefringence reduces as the temperature increases. Eq. (3) describes that the spacing increases with the reduction of birefringence. Therefore the spectrum comb spacing increases from 2.25nm to 4.35nm as the temperature of PMF1 (L1) is changed from 20^o to 160^o as shown in Fig. 2(a). By changing the temperature of the PMF segments, the spacing can also be tuned from 1.69nm to 4.35nm. This corresponds to a number of channels of 52 to 21 that covers a very broad bandwidth from 1530nm to 1620nm.



(a) (b)

Fig. 2. Optical spectra of the spectrum sliced ASE output when L_{eff} = L1 - L2 (a) L2 temperature is fixed at 20^{o}C and L1 temperature is varied (b) L1 temperature is fixed at 20^{o}C and L2 temperature is varied

Fig. 3 shows the enlarged comb spectrum at various temperature settings of PMF1 and PMF2. If the temperature changes, a small change in the comb spacing is also observed. Due to this small spacing, the number of channels in 90nm bandwidth goes up to 300 channels. Based on Eq. (3), increase the temperature of either L_1 or L_2 will reduce the denominator of the equation, which results a rise of the comb spacing. Heating L_1 from 20^{o}C to 160^{o}C will cause the spectra spacing to increase from 0.30nm to 0.38nm. However a smaller change from 0.32nm to 0.33nm is obtained for the case of heating L_2. This is because the longer length of L_1 reduce the denominator more that L_2 with a shorter length.

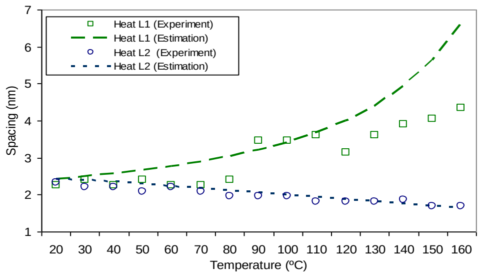


(a) (b)

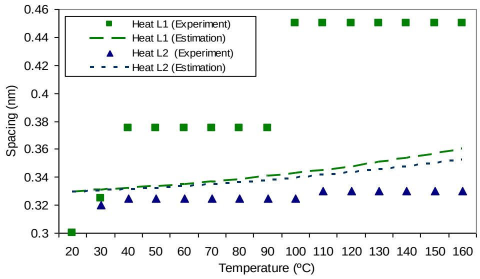
Fig. 3. Enlarged optical spectra of the ASE output when L_{eff} = L1 + L2 (a) L2 temperature is fixed at 20^{o}C and L1 temperature is varied (b) L1 temperature is fixed at 20^{o}C and L2 temperature is varied

The experimental comb spacing of the spectrum-sliced

ASE source against temperature is compared with the analytical estimation as shown in Fig. 4. Figs. 4(a) and (b) shows the comb spacing characteristics in the cases of L_{eff} = L1 - L2 and L_{eff} = L1 + L2 respectively. The experimental comb spacing is measured by taking the average spacing at around 1570nm region and the analytical estimation is calculated based on Eq. (3) using 1570nm as the operating wavelength. By rotating the orthogonal components 90^o between two PMFs (as in case of L_{eff} = L1 - L2), the spectra spacing can be increased (reduced) by heating the longer (shorter) PMF as shown in Fig. 4(a). Meanwhile, for the case when the orthogonal components of the PMF are parallel to each other (L_{eff} = L1 - L2), the comb spacing can only be increased slightly by heating either one of PMF. These results show that the birefringence axis of both PMFs should be perpendicular to each other in order to obtain the maximum tuning of the output comb spacing.



(a) $L_{eff} = L_1 - L_2$



(b) $L_{eff} = L_1 + L_2$

Fig. 4. Comb spacing against temperature increment for the case of (a) $L_{eff} = L_1 - L_2$ and (b) $L_{eff} = L_1 + L_2$

IV. Conclusion

A simple setup for a wideband multi-wavelength source with the adjustable comb spacing covering 90nm bandwidth has been proposed. It consists of a bi-directionally 1480nm pumped Bi-EDF and a thermal controlled fiber loop mirror. The spacing of output comb can be tuned by adjusting the temperature and the effective length parameter of PMFs in the loop mirror. By changing the temperature of the PMF segments, the spacing can be tuned from 1.69nm to 4.35nm corresponding to a number of channels of 52 to 21 as the birefringence axis of both PMFs is adjusted to be perpendicular to each other. The maximum 300 channels with 0.300nm comb spacing can be obtained when both PMFs are arranged in such a way that the beam orthogonal components of both PMFs are parallel to each other. This source is very useful to the future low cost DWDM applications.

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