Multi-wavelength fiber source using a reflection Mach-Zehnder filter and double-pass backward configuration

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ABSTRACT

A new spectrum sliced multi-wavelength fiber source (MWFS) with no power loss is presented in this paper. The source is composed by a reflection Mach-Zehnder filter (RMZF) with double-pass backward superfluorescent fiber source (DPB SFS) configuration. The RMZF not only provides spectrum filtering but also provides the double-pass function. Multi-wavelength source with extinction ratios larger than 15 dB can easily be obtained over the total conventional band gain region with appropriate erbium-doped fiber (EDF) length and pump power. There is no power loss with the MWFS as compared to the original DPB SFS owning to the RMZF also provides the double-pass function. More than 50 channels of 0.57nm wavelength spacing between 1530nm-1560nm are obtained.

Keywords: Multi-wavelength fiber source, reflection Mach-Zehnder filter.

I. Introduction

Wavelength division multiplexing (WDM) is an important technique for fiber optical communication since it can increase transmission capability by orders of magnitude. Among the multi-wavelength sources required for WDM system, the spectrum sliced sources have caused much attention because of only one broadband light source is needed, thus the cost and complexity may be relieved as compared with currently DFB lasers array [1,2]. Erbium-doped SFS has been widely used as the broadband light source for spectrum sliced source in the past years for it potential low spectral ripples and high spectral intensity. Fabry–Perot filters, arrayed-waveguide gratings and cascaded long period fiber gratings (LPFG's) have been used as the filter in the spectrum sliced fiber source [3,4,5]. Since the multi-peak filter is placed at the output end of a broadband light source for spectrum sliced fiber source, it inevitably incurs a considerable power loss. To reduce such a power loss, C.D.Su introduced a mechanism to cause power redistribution from the unwanted wavelength range to the wanted wavelength range. They have realized this idea by inserting cascaded LPFG's into a conventional DPB SFS, and the results show that output power of each channel is larger than that of the spectrum sliced fiber source [6]. However, the high extinction ratio wavelength channels are restricted due to the unequal peak transmittance of each channel of the cascaded LPFG's and to avoid other interference the fiber between the LPFG's and the fiber mirror must be coiled, which we believe to be the reason for the total power small reduced.

In this paper, we demonstrate a MWFS with obvious advantages by using RMZF and DPB configuration. More than 50 wavelength channels with extinction ratio larger than 15dB are obtained and there is no power loss as compared to the original DPB SFS with appropriate EDF lengths and pump power.

II. Operation Principle

The multi-wavelength fiber source arrangement is shown in Fig.1. The pump power is launched through a WDM into a section of erbium-doped fiber from a diode laser operating at 977 nm. Another WDM is used to separate the residual pump signal and the forward signal, and to avoid the feedback of pump power to the pump laser. We use a RMZF provide the filtering effect and the double-pass function. An isolator with ~60 dB isolation is used to prevent the formation of resonant cavity due to the optical feedback from the output end face. An ANDO6317B

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optical spectrum analyzer is used for spectrum measurement.

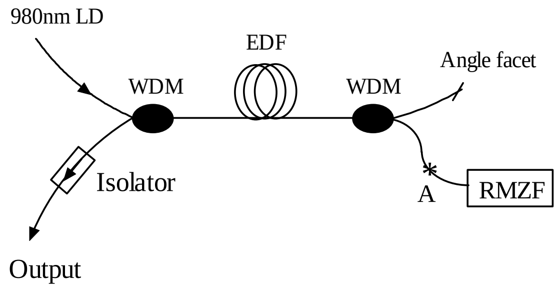

Fig.1. Experiment setup of the multi-wavelength fiber source

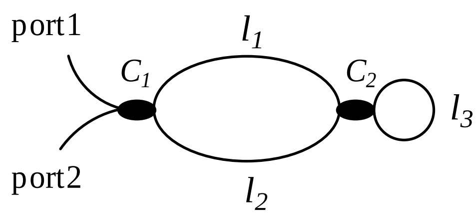

Fig.2. A reflection Mach-Zehnder filter made of two concatenated fiber couplers

The RMZF is formed by concatenating together the two output ports of a conventional single-pass M-Z, shown in Fig.2. For power launch into port1, and assume the electric field intensity of port1 is E_1, then the reflected back electric field intensity from port1 and port2 (E_1', E_2') can be calculated by the follow equation:

$$\begin{bmatrix} E_1' \\ E_2' \end{bmatrix} = \begin{bmatrix} \sqrt{1-C_1} & -j\sqrt{C_1} \\ -j\sqrt{C_1} & \sqrt{1-C_1} \end{bmatrix} \begin{bmatrix} \exp(-jk_0nl_1) & 0 \\ 0 & \exp(-jk_0nl_2) \end{bmatrix} \begin{bmatrix} \sqrt{1-C_2} & -j\sqrt{C_2} \\ -j\sqrt{C_2} & \sqrt{1-C_2} \end{bmatrix}$$
$$\begin{bmatrix} 0 & \exp(-jk_0nl_3) \\ \exp(-jk_0nl_3) & 0 \end{bmatrix} \begin{bmatrix} \sqrt{1-C_2} & -j\sqrt{C_2} \\ -j\sqrt{C_2} & \sqrt{1-C_2} \end{bmatrix} \quad (1)$$
$$\begin{bmatrix} \exp(-jk_0nl_1) & 0 \\ 0 & \exp(-jk_0nl_2) \end{bmatrix} \begin{bmatrix} \sqrt{1-C_1} & -j\sqrt{C_1} \\ -j\sqrt{C_1} & \sqrt{1-C_1} \end{bmatrix} \begin{bmatrix} E_1 \\ 0 \end{bmatrix}$$

Where, C_1 and C_2 are the couple coefficients of the two couples, n is the core refractive index of the fiber, l_1, l_2, l_3 is the length of the three sections fiber shown in Fig.2. We assume that C_1=C_2=0.5, then equation (1) simply as:

$$E_1' = 0.5j\exp(-jk_0nl_3)[\exp(-jk_0n2l_2) - \exp(-jk_0n2l_1)]E_1 \quad (2a)$$

$$E_2' = -0.5\exp(-jk_0nl_3)[\exp(-jk_0n2l_2) + \exp(-jk_0n2l_1)]E_1 \quad (2b)$$

According to the relations of $P_1=E_1E_1^*$、$P_1'=E_1'E_1'^*$、$P_2'=E_2'E_2'^*$, and define the $R_{11}= P_1'/P_1$, $R_{12}= P_2'/P_1$, then:

$$R_{11} = \sin^2 \frac{2\pi n\Delta l}{\lambda} \quad (3a)$$

$$R_{12} = \cos^2 \frac{2\pi n\Delta l}{\lambda} \quad (3b)$$

It can be seen that from Eq.(3) the reflection spectrum of a RMZF is characterized by a series of equally spaced reflection peaks. The wavelength spacing between the reflection peaks is given by:

$$\Delta\lambda = \frac{\lambda^2}{2n\Delta l} \quad (4)$$

The Eq.(4) notes that the wavelength spacing is determined by the Δl (length difference between the two arms $\Delta l = |l_1 - l_2|$). Therefore, the wavelength spacing can be turned by applying tension to one arm of the RMZF.

III. Results and Discussions

We first observe the output spectra of the MWFS against pump power, when the pump power is small, only in the long wavelength rang has MWFS generated. With the pump power increase, the MWFS will cover the total C-band and reach an almost same extinction ratio gradually. This is due to the change of the wavelength range and bandwidth of the forward ASE spectrum with the pump power. And the MWFS is caused by the ASE power redistribution according to the feeding back filtering signal.

Fig.3 show the output spectra of multi-wavelength fiber source and the original DPB SFS with the RMZF substituted by a fiber mirror of ~100% reflectivity. It notes that the power level for all channels is larger than that of the original DPB SFS in the same wavelength. This is caused by the RMZF not only filters the signal but also reflect the signal to the opposite direction and propagate through the EDF again which causes power redistribution. The total output power of the original DPB SFS and the multi-wavelength fiber source is 15.9mW and 16.2mW, respectively. Note that there is no power loss of the multi-wavelength compare to the DPB SFS. The power of the DPB SFS is slightly smaller than the MWFS due to the reflectivity of fiber mirror may be slightly less than the RMZF possibly. In ref [6], the MWFS using cascaded LPFG's has a power loss ~0.55dB. They think that is due to the weak forward ASE signal. However, the truly reason owning to the fiber between the LPFG's and the fiber mirror is coiled, therefore, the reflected signal is reduced. Notes that the power loss is inevitable because the fiber must be coiled to avoid other interference.

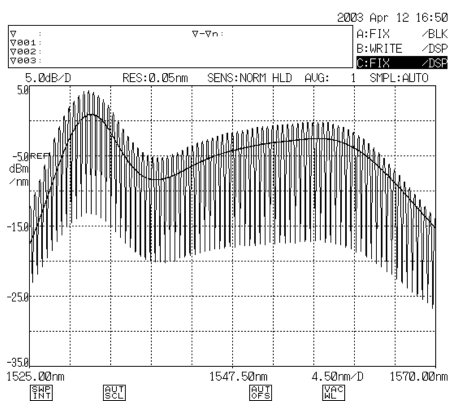

Fig.3. Output spectra of the MWFS and double-pass backward SFS.

The wavelength spacing is measured to be 0.57nm, which note that the arm difference of the RMZI is about 1.44mm. Therefore, between the 1530nm and 1561nm, there are more than 50 wavelength channels with extinction ratio larger than 15dB. As the peak position of MWFS corresponds to the peak wavelength of the RMZF, and its channel spacing is the same as the wavelength spacing of the RMZF, therefore, the channel spacing can be easily adjusted by varying the arms difference of the RMZF by applying tension to one arm of the RMZF (e.g. install a PZT on one are).

Fig.4 depicts the extinction ratio of the multi-wavelength fiber source against pump power, two channels centered at 1530nm and 1561nm are selected because all the channels between them have an almost same extinction ratio.

It notes that the extinction ratios of these two channels increase with pump power. If the pump power is not sufficient, little forward signal can reach the RMZF, and there is no multi-wavelength generation because there is no filtering effect. As the pump power increases, more forward signal is filtered by the RMZF, and the extinction ratio increases. And it need note that, the pump power is larger required to obtain an extinction ratio of >10dB for the 1530nm channel. This owns to the fact that the absorption coefficient of the EDF is larger at short wavelength. In fact, in the small pump power case, the forward ASE signal is small and its mean wavelength is longer, therefore, the feeding back filtering signal caused the power redistribution at the long wavelength range earlier. With the pump power increases, the extinction ratios of the two channels turn to be the same gradually, in our experiment case, the required pump power to obtain almost the same extinction ratio about 15dB for 1530nm and 1561nm is round 70mW.

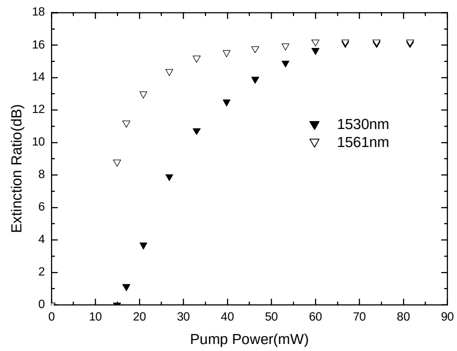

Fig.4. Extinction ratio of 1530nm and 1561nm channels against pump power

IV. Conclusion

We have demonstrated a new method for realizing a multi-wavelength fiber source by using reflection Mach-Zehnder filter and double-pass backward configuration. The reflection Mach-Zehnder filter not only provides spectrum filtering but also provides the double-pass function. More than 50 wavelength channels with extinction ratio larger than 15dB are obtained and there is no loss as compared to the original DPB.

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