Variable Attenuation and Wavelength Filter

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Abstract

A variable attenuation and wavelength filter using wavelength dependent birefringence crystal has been developed. The wide attenuation and wavelength tunable range operation was successfully demonstrated.

1. Introduction

Wavelength-division multiplexing (WDM) has enabled the realization of high capacity long-haul transmission systems using of erbium doped fiber amplifiers (EDFAs). Gain flattening filters (GFFs) are required to equalize a gain profile of EDFA in WDM system. Several GFFs are put into practice such as chirped fiber Bragg gratings, long-period fiber gratings, etalon filters, dielectric filters and so forth. It is, however, impossible to equalize completely due to its characteristic property. Therefore, second equalizers (EQL) are necessary to equalize the channel-power imbalance in plural EDFAs. They are required dynamic equalizing operation because it is not possible to estimate the gain profile in each EDFAs. And the gain profiles will change with numbers and power levels of input lasers and temperature in the EDFA.

Several dynamic gain equalizers are proposed [1-4]. In this report, we developed a new dynamic gain equalizer. A remarkable feature of this filter is to vary wavelength (free spectral range: FSR) and attenuation simultaneously.

2. Second EQL

Figure 1 shows the example of schematic diagram of second equalizer system. The relative gain in each EDFA is less than 0.35dB. However, because individual EDFA has different relative gain profile, the channel-power imbalance in plural EDFAs (n=10 in figure 1) is not pre-determined. Thus, the dynamic equalizer is available which is able to equalize arbitrary profile for the second EQL. And the optical performance monitor is used in order to feedback the change of profile to the EQL.

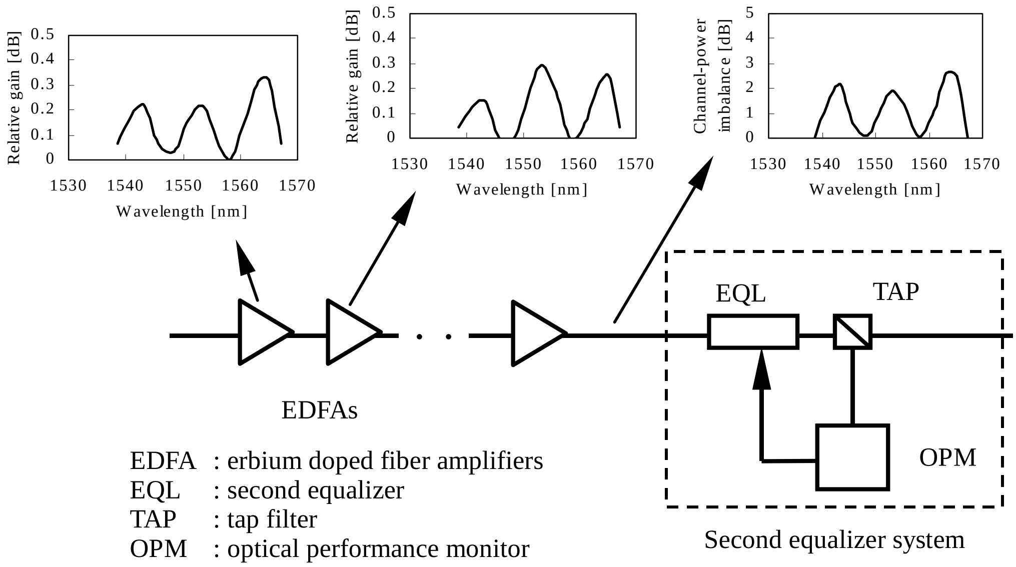
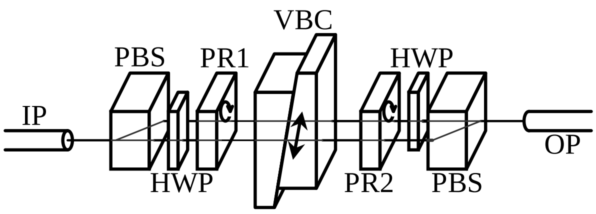


Figure 1: Example of schematic diagram of second equalizer system.

3. Variable filter

To realize simultaneous variable filter, we have applied an interleaver [5] using a wavelength dependent birefringence crystal, which has variable optical path length.



IP : input port
OP : output port
PBS : polarization beam splitter
HWP : half wave plate
PR : polarization rotator
VBC : optical path length variable birefringence crystal

Figure 2: Schematic diagram of variable filter.

Figure 2 shows a schematic diagram of this variable filter. A light from an input port is separated in a polarization beam splitter. One of them is rotated 90° by a half wave plate and they become same direction of polarization. A polarization rotator 1 rotates the direction of polarization of the light to vary an incident polarization angle from a crystal axis of an optical path length variable birefringence crystal, in order to vary transmittance at wavelength determined by a FSR. Adjusting the wedge type crystal thickness varies the optical path length in the birefringence crystal. Thus the FSR is varied. A polarization rotator 2 is used for compensating attenuation. After transmitting the polarization rotator 2, the light couples to an output port through the half wave plate and a polarization beam splitter.

The transmittance of this filter is calculated by equation (1) and (2).

$$\begin{pmatrix} E'_x \\ E'_y \end{pmatrix} = \begin{pmatrix} \cos(\alpha) & -\sin(\alpha) \\ \sin(\alpha) & \cos(\alpha) \end{pmatrix} \begin{pmatrix} \exp(i\delta) & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} \cos(-\alpha) & -\sin(-\alpha) \\ \sin(-\alpha) & \cos(-\alpha) \end{pmatrix} \begin{pmatrix} E_x \\ E_y \end{pmatrix} \qquad (1)$$

$$= \begin{pmatrix} \exp(i\delta)\cos^2(\alpha) + \sin^2(\alpha) & \sin(\alpha)\cos(\alpha)(\exp(i\delta) - 1) \\ \sin(\alpha)\cos(\alpha)(\exp(i\delta) - 1) & \exp(i\delta)\sin^2(\alpha) + \cos^2(\alpha) \end{pmatrix} \begin{pmatrix} E_x \\ E_y \end{pmatrix}$$

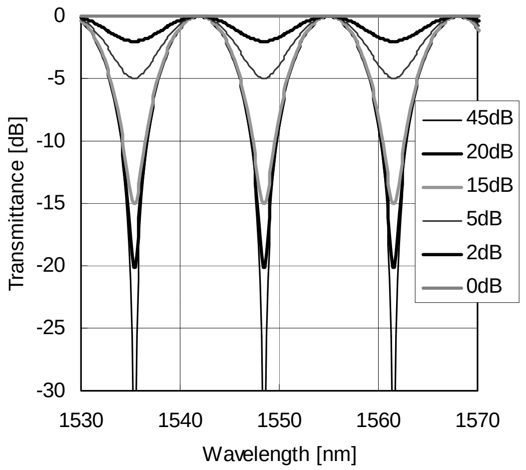
$$\delta = k(n_e - n_0)L \qquad (2)$$

where

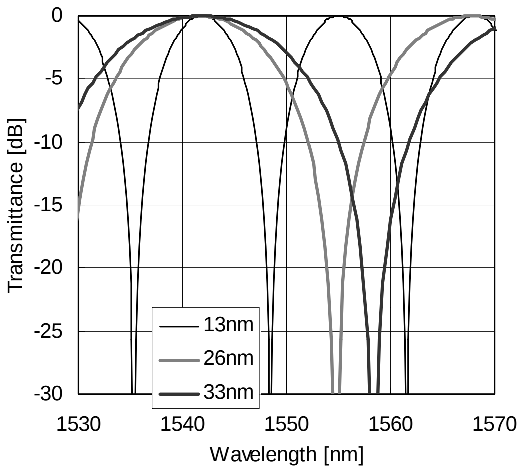
x, y : polarization state
α : angle of x-axis from birefringence crystal axis
L : length of birefringence crystal
k : wave number
n_e : refractive index of extraordinary ray
n_0 : refractive index of ordinary ray

α is determined by polarization rotator 1 to vary the attenuation and L is the thickness of the wedge type crystal.

Figure 3(a) and 3(b) show calculated transmission spectra, attenuation variation and wavelength (FSR) variation respectively. The parameter of the attenuation was 0, 2, 5, 15, 20, 45dB, and of the FSR was 13, 26, 33nm. The wide attenuation and wavelength tunable range are possible.



(a)

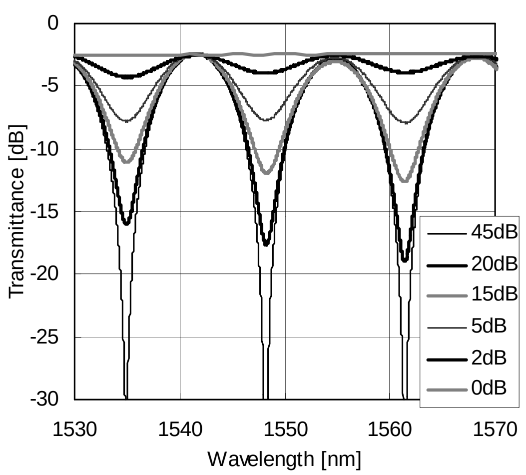


(b)

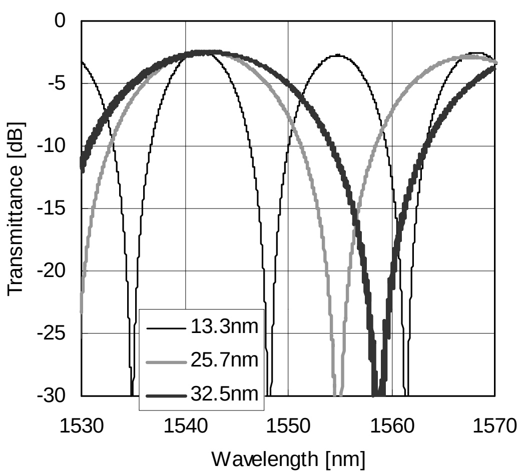
Figure 3: Calculated transmission spectra.
- (a) Attenuation variation-
- (b) Wavelength variation-

4. Experimental result

In our experiment, we have used rotational half wave plates as the polarization rotator, and quartz as the wedge type crystal. The refractive index of the quartz is n_0=1.52781 and n_e =1.53630 at 1.5424μm.



(a)



(b)

Figure 4: Measured transmission spectra.
- (a) Attenuation variation-
- (b) Wavelength variation-

Figure 4(a) and 4(b) show measured transmission spectra, attenuation variation and wavelength (FSR) variation respectively. The parameter was also same as the calculated result. The insertion loss was 2.4dB. In figure 4, the three-peak loss value is different in 40nm wavelength range. It may be the wavelength dependence of the half wave plate.

5. Conclusion

In conclusion, we have developed the attenuation and wavelength variable filter using wavelength dependent birefringence crystal. The wide attenuation and wavelength tunable range operation was successfully demonstrated.

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