Research on the Characteristics and Improvement of OADM that Uses 2 Steps FBG and MZI

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Abstract - WDM optical communication system requires wavelength division multiplexing, reverse multiplexing and optical filter. OADM is a device that can separate or combine specific wavelength of channel from the transmission line. This paper suggests OADM that uses 2 steps FBG based on MZI structure. The OADM that uses 2 steps FBG can minimize the system size and reduce the value of side lobe remarkably. The results obtained in this paper can be used for design and application of OADM that uses 2 steps FBG.

Keywords: FBG, MZI, OADM, 2 step FBG

1. Introduction

The need for information transmission channels is urgently required in modern information and communication systems as the demand for communication at every level of information transmission has greatly increased[1].

This paper shows the characteristics and improvement of the OADM(Optical Add/Drop Multiplexer) using the two steps of FBG and MZI for establishing an ideal optical communication system.

One optical fiber lattice has been added to the existing optical fiber to make it a 2 step process and the characteristics of optical fiber lattice and OADM have been analyzed to recommend ideal design data.

2. Theoretical consideration of optical fiber lattice

2.1 Optical fiber lattice

The optical signal passing through the core of the lattice is reflected or diffracted into a clad layer changing the optical signal. This means that a signal with specific wavelength is reflected by the lattice, thereby reversing its direction. Any unselected wavelength proceeds with its present way of direction. The wavelength selection filter, which handles and uses the characteristics, is widely used for many devices.

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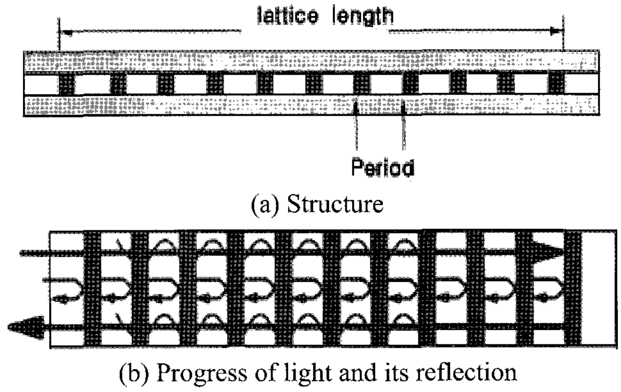
According to Fig. 1 The theory of optical bragg lattice is that the selected wavelength is reflected by the lattice that is configured with the resonance condition for a specific wavelength. The unselected wavelength proceeds on as before. In the case of optical fiber lattice, it includes the returning wave that goes on its way and that is reflected by the lattice. So the optical field can be expressed as the following formula.



(a) Structure

(b) Progress of light and its reflection

Fig. 1 Theory of optical bragg lattice

$$E(z) = A(z)\exp(iqz) + B(z)\exp(-iqz) \qquad (1)$$

A and B indicate the amplitudes of the wave. q is the electric wave constant. z indicates the path of direction.

The fluctuation equation for the propagation of light in optical fiber is shown in formula (2).

$$\frac{\partial^2}{\partial z^2}E + k^2E = 0 \qquad (2)$$

Applying the formula (1) into fluctuation equation (2) obtains the combined fluctuation equations (3a) and (3b)[4].

$$\frac{dA}{dz} = i\delta A + ikB \quad (3a)$$

$$\frac{dB}{dz} = -i\delta B - ik^* A \quad (3b)$$

δ is the tuning separation coefficient of mode at Bragg wavelength. k is the coefficient of coupling. According to the combined fluctuation equation, it can understand the relation between each progressing wave, which moves L in the direction of z and the wave in the input terminal. Solving the combined fluctuation equation and using the matrix analysis can lead to the following formula[2, 3].

$$\begin{bmatrix} A_{out} \\ B_{out} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} A_{in} \\ B_{in} \end{bmatrix} \quad (4)$$

S is the transmission matrix that shows the characteristics of optical fiber Bragg lattice. Using the combined mode theory, each S matrix component can be expressed as shown in the following formulas[4].

$$S_{11} = (1-r^2)^{-1}[\exp(iqh) - r^2\exp(-iqh)] \quad (5a)$$

$$S_{22} = (1-r^2)^{-1}[\exp(-iqh) - r^2\exp(iqh)] \quad (5b)$$

$$S_{21} = -S_{12} = (1-r^2)^{-1}r[\exp(iqh) - \exp(-iqh)] \quad (5c)$$

h is the length of the lattice.

The electric wave constant for the progressing wave and reflected wave is expressed as $q = \pm[(\delta\beta)^2 - k^2]^{\frac{1}{2}}$. The efficient reflective coefficient of the lattice is expressed as $r = (q - \delta\beta)/k$. The combined coefficient of the lattice (δn : difference of reflective index of the lattice) can be expressed as $k = \pi\delta n/\lambda_B$. The tuning separation coefficient at Bragg wavelength λ_B that is related to lattice cycle Λ can be expressed as $\delta\beta = 2\pi(\lambda^{-1} - \lambda_B^{-1})$.

The strength of wave that penetrates the optical fiber Bragg lattice and the reflected wave can be given according to boundary condition $B_{out} = 0$[5, 6].

$$T = \left|\frac{A_{out}}{A_{in}}\right|^2 = \left|S_{11} - \frac{S_{12}S_{21}}{S_{22}}\right|^2 \quad (6)$$

$$R = \left|\frac{B_{in}}{A_{in}}\right|^2 = \left|\frac{S_{21}}{S_{22}}\right|^2 \quad (7)$$

T is transmissivity. R is reflexibility.

3. Mach-Zehnder interference system

3.1 Transmission characteristics of MZI

The MZI coupler is composed of two 3dB couplers with a Mach-Zehnder interference system between them. Fig. 2 shows the MZI coupler.

In Fig. 2, the length of the first fiber is set up as $(L + \Delta L)_{eff}$. The length of the second fiber is set up as L_{eff}. It uses the theory of phase difference that occurs because of path difference ΔL. The two mixed waves λ_1 and λ_2 are input through $E_{in\,1}$. The waves progress separately through the two fibers. Then λ_1 is output at $E_{out\,1}$ and λ_2 is output at $E_{out\,2}$.

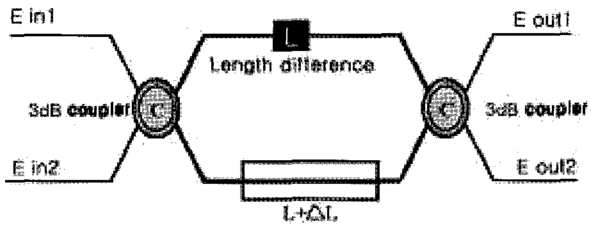


Fig. 2 Structure of Mach-Zehnder interference system

3.2 Determinant of Mach-Zehnder interference system

As indicated in Fig. 2, the transmission determinant of the Mach-Zehnder interference system can be expressed as the multiple of each 3dB coupler and phase shift.

$$\begin{bmatrix} E_{out1} \\ E_{out2} \end{bmatrix} = M_{3dB} \cdot M_{shift} \cdot M_{3dB} \begin{bmatrix} E_{in1} \\ E_{in2} \end{bmatrix} = M_{MZI} \begin{bmatrix} E_{in1} \\ E_{in2} \end{bmatrix} \quad (8)$$

Each 3dB coupler can be expressed as follows.

$$\begin{bmatrix} E_{out1} \\ E_{out2} \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} E_{in1} \\ E_{in2} \end{bmatrix} \equiv M_{3dB} \begin{bmatrix} E_{in1} \\ E_{in2} \end{bmatrix} \quad (9)$$

The transfer function of the 3dB coupler can be expressed as follows.

$$M_{3dB} \equiv \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \quad (10a)$$

The phase shift function can be expressed as follows.

$$M_{shift} \equiv \begin{bmatrix} e^{jk\frac{\Delta L_{eff}}{2}} & 0 \\ 0 & e^{-jk\frac{\Delta L_{eff}}{2}} \end{bmatrix} \quad (10b)$$

Phase difference $\Delta\phi$ can be defined as follows.

$$\Delta\phi = \frac{2\pi}{\lambda} n_1 L_1 - \frac{2\pi}{\lambda} n_2 L_2 \qquad (11)$$

n_1, n_2 : Refractive indexes of upper and lower arms,
L_1, L_2 : Length of upper and lower arms

4. Configuring the OADM that uses 2 step FBG

Optical Add-Drop Mux/Demux is a 4 terminal optical negative device. This paper presents an optical Add-Drop Mux/Demux that is composed of 3dB coupler and 2 step FBG as shown in Fig. 3.

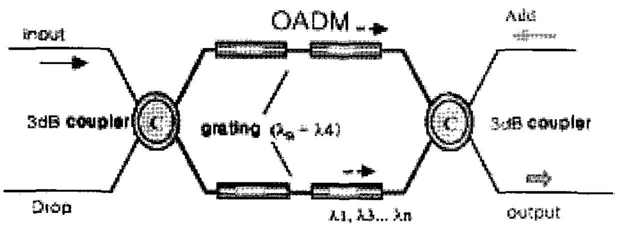


Fig. 3 OADM that uses 2 step FBG

Table 1 shows parameters to design OADM for DWDM.

Table 1 Design variables for numerical analysis

Design variables	Design value
Center wavelength (λ_B)	1548 [nm]
Difference of refractive index (δn)	3×10^{-4}
Length of lattice length (d)	10[mm]
Line width ($\Delta\lambda$)	0.6 [nm]
Valid refractive index (n_{eff})	1.44

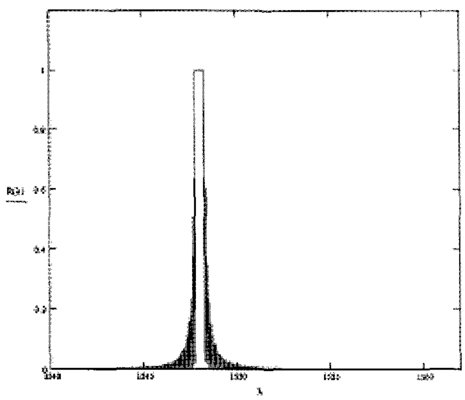


Fig. 4 (a) Output spectrum of MZI Drop terminal

If we input the light wave that has an optical wavelength between 1534.25[nm] - 1558.98[nm] to the input terminal of Fig. 3, some waves are reflected due to the characteristics of FBG and get out to the Drop terminal. The output wave is shown in Fig. 4(a).

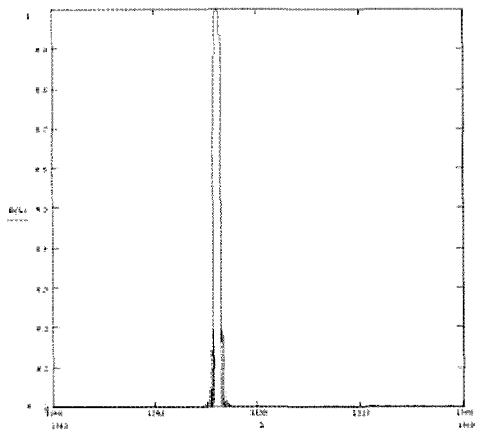


Fig. 4 (b) Output spectrum of MZI Drop terminal at 2 step FBG

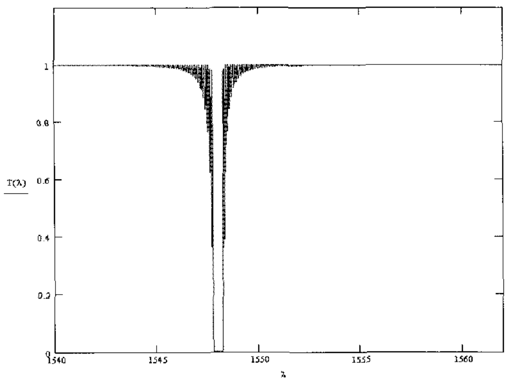


Fig. 5 (a) Output spectrum when there is no signal of MZI Add

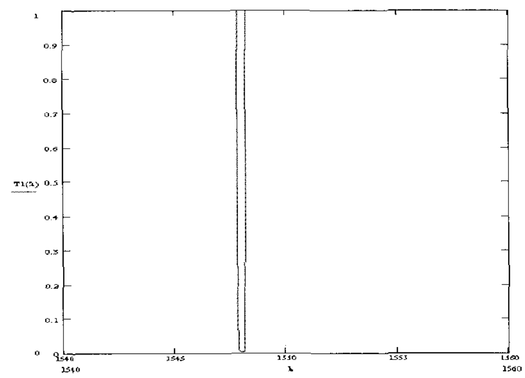


Fig. 5 (b) Output spectrum when there is no signal of MZI Add at 2 step FBG

Due to the characteristics of FBG designed for numerical analysis, the optical wave is reflected at the central wavelength of 1548[nm] as indicated in Fig. 4(a) and get out to the Drop terminal. If we input the optical wave into the input terminal of Fig. 3, some waves are reflected due to the characteristics of 2 steps of FBG and get out to the Drop terminal. The output wave improves as shown in Fig. 4(b).

The wave input through FBG gets out to the Output terminal. The output wave is illustrated in Fig. 5(a). FBG reflects the 1548nm wavelength of the optical wave and drops it. So the spectrum of the Output terminal as shown in Fig. 5(a) and 4-3(b) drops 1548nm of wave signal. The remaining wave signals are all output.

5. Simulation and test

5.1 OADM output characteristics at 2 step FBG

5.1.1 Output characteristics of input and output terminals

It reviews the characteristics of each terminal of Add-Drop Mux/Demux, which uses the 2 step FBG that this paper suggests.

$$T^2 = \left[\left| S_{11} - \frac{S_{12} S_{21}}{S_{22}} \right|^2 \right]^2 \quad (12)$$

$$R^2 = \left[\left| \frac{S_{21}}{S_{22}} \right|^2 \right]^2 \quad (13)$$

$$Output = \left| \frac{e^{j(\phi_A + \phi_C)} + e^{j(\phi_B + \phi_D)}}{S_{22}} \times \frac{1}{2} \right|^2 \quad (14)$$

$$Add = \left| \frac{e^{j(\phi_A + \phi_C)} + e^{j(\phi_B + \phi_D)}}{S_{22}} \times \frac{1}{2} \right|^2 \quad (15)$$

$$Drop = \left| \frac{S_{21}}{S_{22}} \times (e^{j2\phi_A} + e^{j2\phi_B}) \times \frac{1}{2} \right|^2 \quad (16)$$

Table 2 Result due to path difference at the OADM that uses 2 step FBG

Output terminal / Path length	add	drop	output
0	0%	100%	100%
$1\mu m$	80%	20%	20%
$5\mu m$	50%	5%	60%

Fig. 6(a) and Fig. 6(b) display the output characteristics of the output terminal and drop terminal using Equations 6(a) to 6(b) to review the operation characteristics of the Add-Drop Mux/Demux that uses 2 step FBG.

ϕ_A, ϕ_B, ϕ_C, ϕ_D are values of phase changes due to path difference.

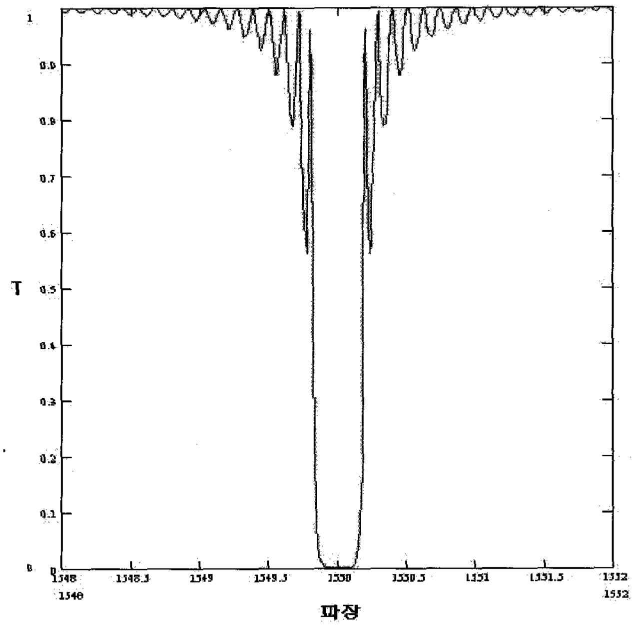


Fig. 6 (a) Transmission spectrum of output terminal of 2 step FBG OADM

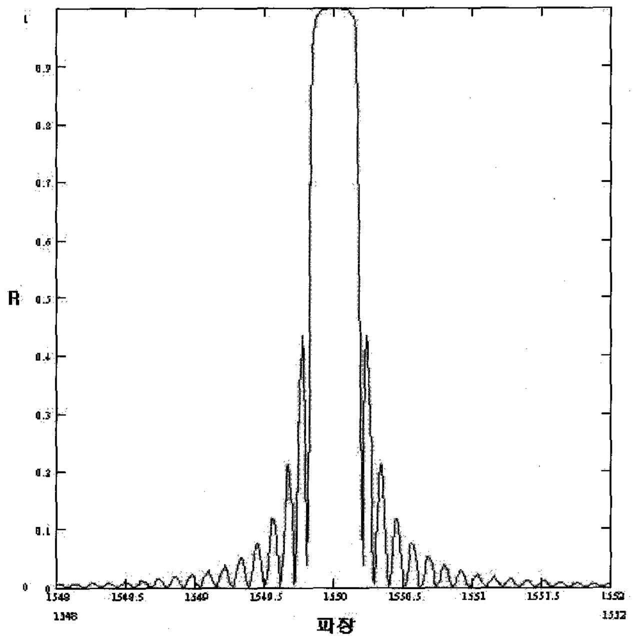


Fig. 6 (b) Reflective spectrum of drop terminal of 2 step FBG OADM

5.1.2 FBG measurement data

Fig. 7 shows the test structure for measuring the 2 step FBG characteristics. It utilized Broadband source (BBS-1550+1FP) from JDS as a light source to measure the characteristics of FBG as presented in Fig. 7. The scope of the wavelength is 1530[nm]-1559[nm]. An optical spectrum analyzer (AQ6317 from BANDO) measured the output at the *Output* terminal. Fig. 8 shows the measure-ment result. The characteristics of the FBG used in this paper has a central wavelength of 1548[*nm*]. It was found that it decreased by 26*dB*.

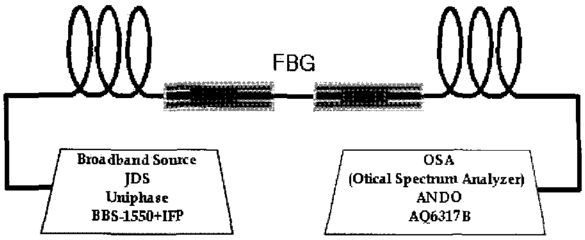


Fig. 7 Characteristics of 2 step FBG

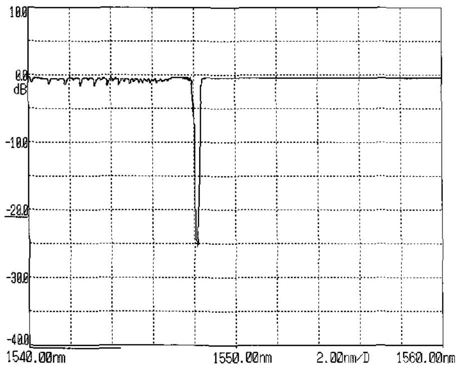


Fig. 8 Output spectrum of FBG

5.1.3 OADM measurement data that uses the 2 step FBG

Actual Mach-Zehnder Interference was designed with design variables. It measured the output spectrum of each terminal of OADM that uses 2 step FBG to discover the characteristics.

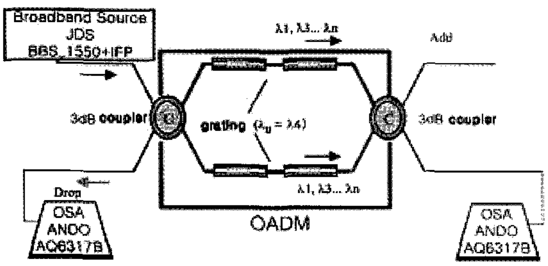


Fig. 9 Test structure of the OADM that uses 2 step FBG

As shown in Fig. 9, it connected the optical broadband source at the input terminal. It also connected the spectrum analyzer to the drop terminal to measure the output spectrum. The output spectrum wave at the drop terminal is indicated in Fig. 10.

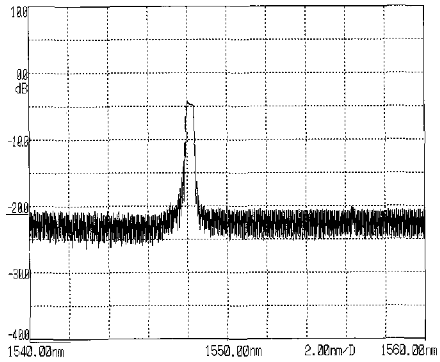


Fig. 10 Drop terminal spectrum of OADM

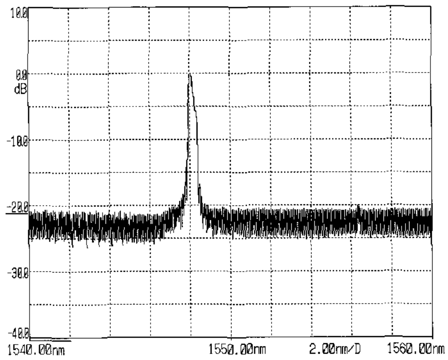


Fig. 11 Drop terminal spectrum of OADM that uses 2 step FBG

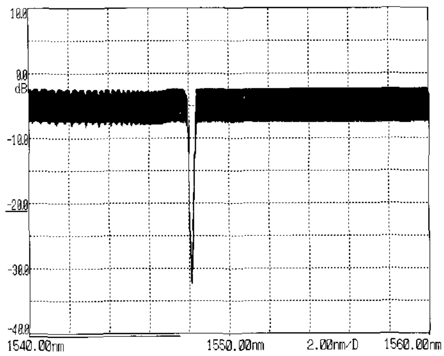


Fig. 12 Spectrum at ouput terminal when there is no input at Add terminal of OADM

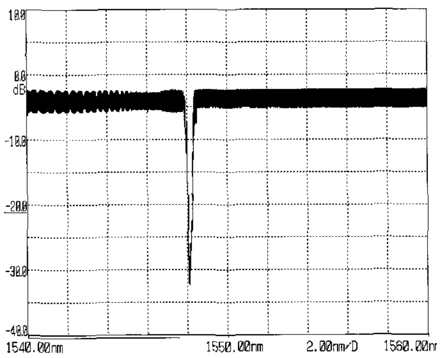


Fig. 13 Spectrum of output terminal when there is no input at Add terminal of OADM that uses 2 steps FBG

From Fig. 10 it is found that the central wavelength of the Drop terminal output wave is 1548[*nm*]. Except for the central wavelength, the other wavelength has decreased by 23*dB*. The oscillation at the spectrum is believed to be caused by the characteristics of FBG.

Fig. 11 indicates that the reflective spectrum of the Drop terminal of the OADM that uses 2 step FBG has improved compared with the one in which single FBG was used. The side lobe value has decreased. Fig. 12 presents the measurement result when the optical spectrum analyzer is connected to the output terminal to measure the output wave of the output terminal at Fig. 9. Fig. 12 indicates the measurement of output of the output terminal when there is no input at the Add terminal of the OADM. The central wavelength is 1548*nm* and there is 34*dB* of decrease at the central wavelength. Fig. 11 and Fig. 13 show that the transmission spectrum of the Drop terminal of the OADM that uses 2 step FBG has improved the transmission rate compared to single FBG. The side lobe value has decreased. Fig. 14 indicates the test structure to determine the operation characteristics of the Add terminal. When inputting the output spectrum of the Drop terminal of Fig. 14 into the Add terminal, it measured the output at the output terminal. Fig. 15 shows the result. Fig. 15 also shows that the spectrum includes 1548nm of spectrum, which is the central wavelength of the Drop terminal output spectrum with the operation of the Add terminal. However, with the loss of fiber length and connector, it didn't fill it completely, decreasing slightly at the central wave.

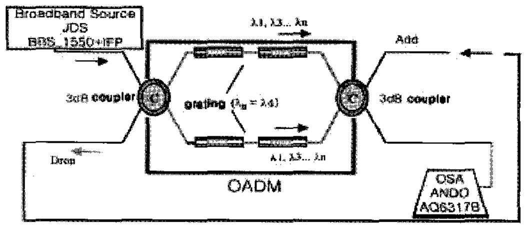


Fig. 14 Output measurement when inputting the output of the Drop terminal into Add

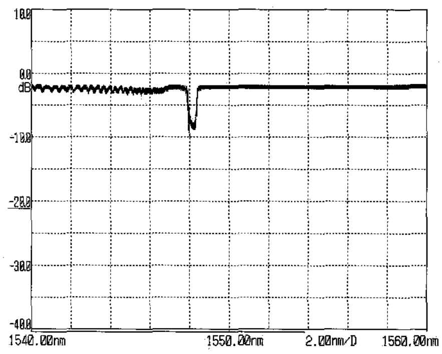


Fig. 15 Spectrum of output terminal when inputting the output of the Drop terminal of OADM to the Add terminal

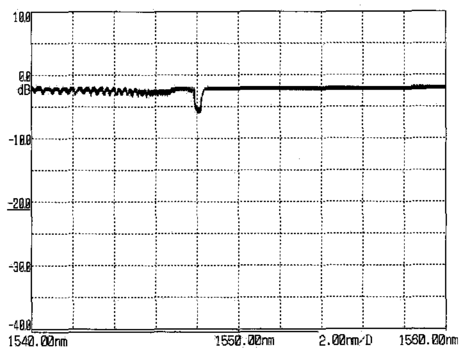


Fig. 16 Spectrum of output terminal when inputting the output of the Drop terminal of the OADM that uses 2 step FBG to the Add terminal

Fig. 16 shows inputting of the output of the Drop terminal to the Add terminal. It shows that the 2 steps of FBG have improved the transmission rate compared to the single FBG.

6. Conclusion

The OADM is established with 2 steps, FBG and MZI. To use it for DWDM, numerical analysis was performed with such parameters as wavelength $\lambda_B = 1548\,[nm]$, lattice length $d = 10 \cdot 10^{-3}$, refractive index difference $\delta n = 3 \cdot 10^{-4}$ and line width $\Delta\lambda = 0.6\,[nm]$. Two test methods were used to determine the characteristics of the OADM that uses 2 step FBG. Fig. 6(a) and 6(b) present the spectrum result of numerical analysis. Fig. 11 and 13 show output spectrum of OADM using actually manufactured multiple FBG. When that uses the 2 step FBG, it was found that the output terminal of the OADM improved the transmission rate and that the Add terminal improved the reflective rate. At all terminals the side lobe decreased obtaining overall improved performance. Fig. 16 shows the 2 step FBG. It reduces side lobe compared to single FBG minimizing the interference between nearby channels. So it is possible to obtain correct channel and transmission.

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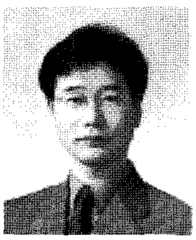

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