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Re-Configurable Low-Loss OADM Module Using 2×2 Port Optical Device

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We describe the optimal design and the fabrication of a 2 × 2 port optical device based on the thin film filter (TFF), and also propose a 4-channel OADM module using these devices. The optical performance of the proposed OADM module is evaluated theoretically and experimentally, and is compared to that of typical OADM modules using 1 × 2 port optical devices for 4, 8, 16 and 32 drop channels in optical transmission systems. Since the 2 × 2 port optical device accomplishes the function of wavelength multiplexing and demultiplexing simultaneously in the proposed OADM module, the insertion loss of through channels can be improved by 1.2 dB compare to that of typical OADM modules using 1 × 2 port optical devices. In addition, both the size and the price of the module can be reduced to 40 ∼ 50%.

OCIS codes : 060.1810, 230.4170, 060.4510.

I. INTRODUCTION

With to the rapid increase in data traffic, the necessity for the high capacity and the high speed of information networks is becoming larger. At present, the Wavelength Division Multiplexing (WDM) technique is believed to be the most efficient optical transmission system in the aspect of optical properties and economics. For the development of the optical transmission systems, the optical devices which have better optical performance, smaller size and lower cost by integration are needed. The Optical Add Drop Multiplexing (OADM) devices or modules, that aim the data flow with several optical paths in the local area, play an important role in the expansion of the functionality and flexibility of optical WDM transmission systems [1,2]. The OADM that includes a drop or an add function for an optical signal in the WDM optical transmission system has been developed to the re-configurable OADM from the fixed OADM [3]. The OADM module using the 1 × 2 port optical device based on the TFF was already proposed and applied in the system. The typical structure of a 4-channel re-configurable OADM module, shown in Fig. 1 [4], consists of two 1 × 2 port optical devices with the same optical characteristics needed for each channel in order to drop or add an optical signal on the local network. That is, the one of two optical devices has the function of wavelength demultiplexing (DEMUX) for an input signal, while the other does the function of wavelength multiplexing (MUX) for adding an optical signal from local networks. Therefore, 2n optical devices are needed for constructing the re-configurable

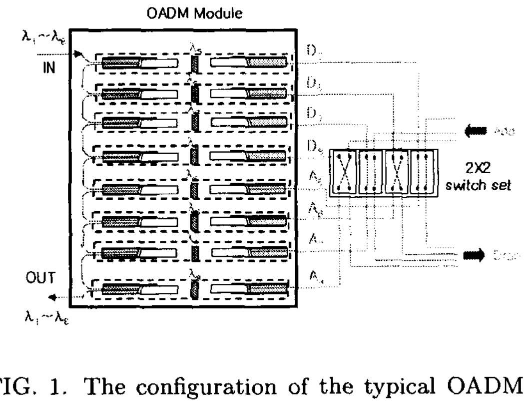

FIG. 1. The configuration of the typical OADM with 1 × 2 port devices.

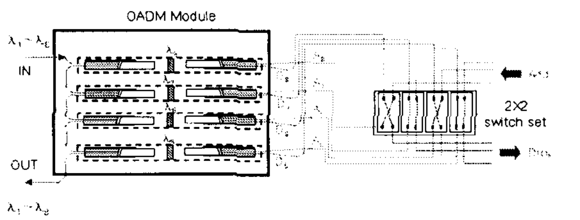

FIG. 2. The configuration of the proposed OADM with 2 × 2 port devices.

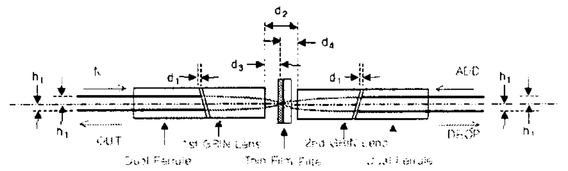

FIG. 3. The structure of 2 × 2 port devices with a thin film filter.

n-channel OADM module. However, the more the number of 1 × 2 port optical devices is increased, the more the number of reflections and the insertion loss is inevitably increased due to the number of reflections from the devices, resulting in increased cost and size. This is the limitation of a conventional OADM module using the 1 × 2 port optical device.

In this paper, we describe the 2 × 2 port optical devices with the function of MUX and DEMUX simultaneously contrary to the typical 1 × 2 port optical device, and propose the re-configurable OADM module with these optical devices as shown in Fig. 2. This new configuration may have merits in of insertion loss, cost and size. The 2 × 2 port device, however, is more seriously sensitive to the alignment tolerance among the elements, such as TFF, GRIN lens and ferrules, compared to the 1 × 2 port device, and consequently the characteristics of the proposed OADM module highly depend on those of the 2 × 2 port devices. Therefore, we present the procedure of optimal design by a ray tracing method in order to obtain the best optimal performance of the 2×2 port device, then fabricated the 2 × 2 port device and also analyzed the characteristics. And then we fabricated the proposed 4-channel OADM module using the 2 × 2 port device and analyzed the optical performance of the OADM module. We predicted the optical performance of 4, 8, 16 and 32-channel OADM modules with 2×2 port devices in the optical transmission system and compared the insertion loss and isolation of these OADM modules based on the proposed 2 × 2 port optical device based on the typical 1 × 2 port optical device.

II. THE 2 × 2 PORT DEVICE BASED ON A THIN FILM FILTER

As shown in Fig. 3, the 2 × 2 port device consists of four optical fibers(IN, OUT, ADD, DROP CHANNELS), two dual fiber ferrules, two GRIN lens and a thin film filter (TFF). TFF is an optical bandpass filter with dielectric materials such as SiO_2, TiO_2 and Ta_2O_5 deposited on glass substrate. While it is similar to the typical 1×2 port device, it uses dual ferrule instead of a single ferrule. In a 2 × 2 port device, a certain wavelength of optical signals entering into the IN port is reflected and the remainder is transmitted according to the characteristics of the TFF used. The reflected and transmitted signals come to the OUT and the DROP ports, respectively. On the other hand, the optical signal from the ADD port comes to the OUT port after passing through the TFF. Therefore a 2×2 port device can perform two functions of MUX and DEMUX simultaneously, while a 1 × 2 port device can perform only one function as the MUX or DEMUX. This means that the density of integration or package can be higher for modules using a 2×2 port device, so the size and the price of optical devices are reduced.

It is notable that the configuration design of the 2×2 port device is important to improve the coupling efficiency in the transmitted (IN DROP, ADD OUT) and reflected (IN OUT) direction. The coupling efficiency of the 2 × 2 port device varies according to the distances among optical fibers, lens and TFF more significantly than that of a typical 1×2 port device does. In order to understand their effects, we use the ray tracing method which traces the beam passing through the GRIN lens with the finite number of rays [5]. The SMF-28 (Corning) and GRIN lens (NSG; SLW, 0.23 pitch, 1560 nm) are used for the analysis. The optical fibers of IN and OUT ports are separated from each other by twice the distance of 62.56 μm (h_1) from the center of the optical axis respectively, as shown in Fig. 3. At first, the coupling efficiency between the IN port and the OUT port is simulated by varying the distance (d_1) between optical fiber and first lens and distance (d_3) between first lens and TFF. In the result of analysis, the coupling efficiency has the maximum value around d_1=0.25 and varies very little within d_3=1 . The coupling efficiency between the IN port and the OUT port is very sensitive to the distance d_1, but is insensitive to the distance d_3.

For the fabrication of the dual ferrule-lens assembly, it is necessary to align at the actual distance between optical fiber and first lens for efficient coupling. The fabrication includes the angle, spot size and filter alignment. First of all, the cross section of dual ferrule and first lens are made to contact each other in the glass tube, and then aligned with the 8-degree angled

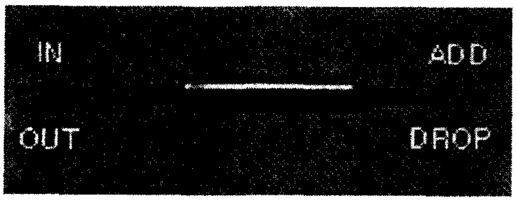

FIG. 4. The sample picture of 2 × 2 port device.

surfaces by the comparison of the fringes reflected from the angled surface of the GRIN lens with the aid of a CCD camera. The gap between the lens and dual ferrule is controlled by the high precision stage which is attached to the dual ferrule. The spot size alignment using a beam profiler has been reported by Kurt R. Francis. [6] After beam size alignment, the gap distance between the GRIN lens and the TFF is optimized by active alignment. We measured the power of light reflected from the TFF to find the optimum position between IN port fiber and OUT port fiber. The TFF is fixed in a metal cylinder filter holder by a thermal epoxy, and metal-coated. The lens and filter holder are soldered by a solder cream. One dual ferrule-lens-filter assembly attached on the TFF and other dual ferrule-lens assembly are automatically aligned and soldered to make maximum coupling efficiency by the high precision 12-axis stage including rotational and tilt stage.

Figs. 4 and 5 show the 2 × 2 port device sample and its optical characteristics. The center wavelengths at -0.5 dB and -25 dB are 1557.332 and 1557.352 nm respectively. Also, the passband from a IN port to a DROP port at -0.5 dB and -25 dB are 0.82 and 2.40 nm, and the passband from a ADD port to a OUT port are 0.85 and 2.39 nm respectively. The coupling efficiency of IN to DROP, ADD to OUT and IN to OUT are 0.86 dB, 0.88 dB and 0.29 dB, respectively. The ITU center wavelength of the four 2 × 2 port devices used in this report are 1560.61 , 1558.98 , 1557.36 and 1555.75 . And the bandwidth at -0.5 dB and -25 dB are 0.88 ~ 0.92 and 2.35 ~ 2.42 , respectively.

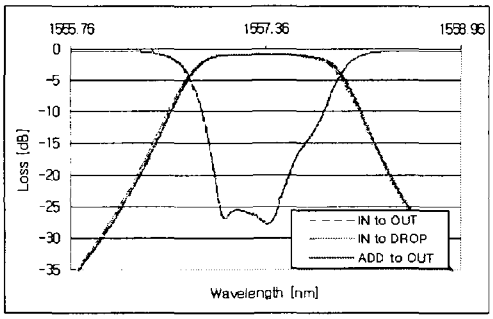

FIG. 5. The optical characteristics of 2 × 2 port device.

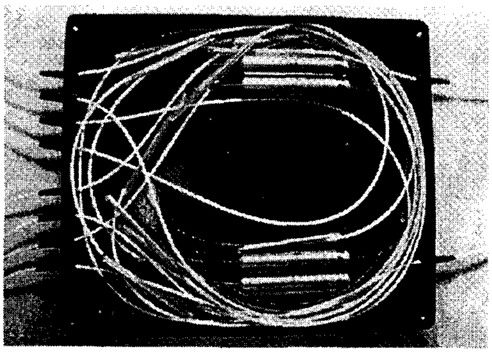

FIG. 6. The sample picture of the 4-channels OADM module with 2 × 2 port devices.

The coupling efficiency of IN to DROP, ADD to OUT and IN to OUT are 0.8 ~ 1.0 dB, 0.8 ~ 1.0 dB and 0.2 ~ 0.4 dB, respectively.

III. NEW RE-CONFIGURABLE OADM MODULE WITH THE 2 × 2 PROT DEVICES

Fig. 6 shows a sample of 4-channel OADM module which consists of four 2 × 2 port devices. The optical characteristics of drop channels($\lambda_5, \lambda_6, \lambda_7, \lambda_8$) at the DROP port and through channels($\lambda_1, \lambda_2, \lambda_3, \lambda_4$) at the OUT port are shown in Fig. 7 and also summarized in Table 1. The D_5, D_6, D_7, D_8 ports are used for drop channels. The insertion loss from input channel to drop channels are 0.9 dB, 1.3 dB, 1.5 dB and 1.9 dB, respectively, as shown in Fig. 7(a). The insertion loss from add channels to out channel are 1.8 dB, 1.4 dB, 1.2 dB, 1.0 dB , respectively, as shown in Fig. 7(b). Also, the insertion loss of through channels transmitted from IN port to OUT port are all 1.2 dB as shown in Fig. 7(c). The passband of λ_5 from the IN port to the D_5 port are 0.87 and 2.16 at -0.5 dB and -25.0 dB (Fig. 7(a)), and the passband of λ_5 from A_5 ADD port to OUT port are 0.891 and 2.43 at -0.5 dB and -25.0 dB (Fig. 7(b)). The inter-band isolation at a DROP port is 35.03 dB and the intra-band isolation among drop channels at OUT port is about 20 ~ 25 dB. The intra-band isolation is depended on

TABLE 1. The optical performance of the 4-Channels OADM module with 2 × 2 port devices.

IN	DROP 8 0.9 dB	DROP 7 1.3 dB	DROP 6 1.5 dB	DROP 5 1.9 dB	OUT 1.2 dB
ADD 8	-	-	-	-	1.8 dB
ADD 7	-	-	-	-	1.4 dB
ADD 6	-	-	-	-	1.2 dB
ADD 5	-	-	-	-	1.0 dB

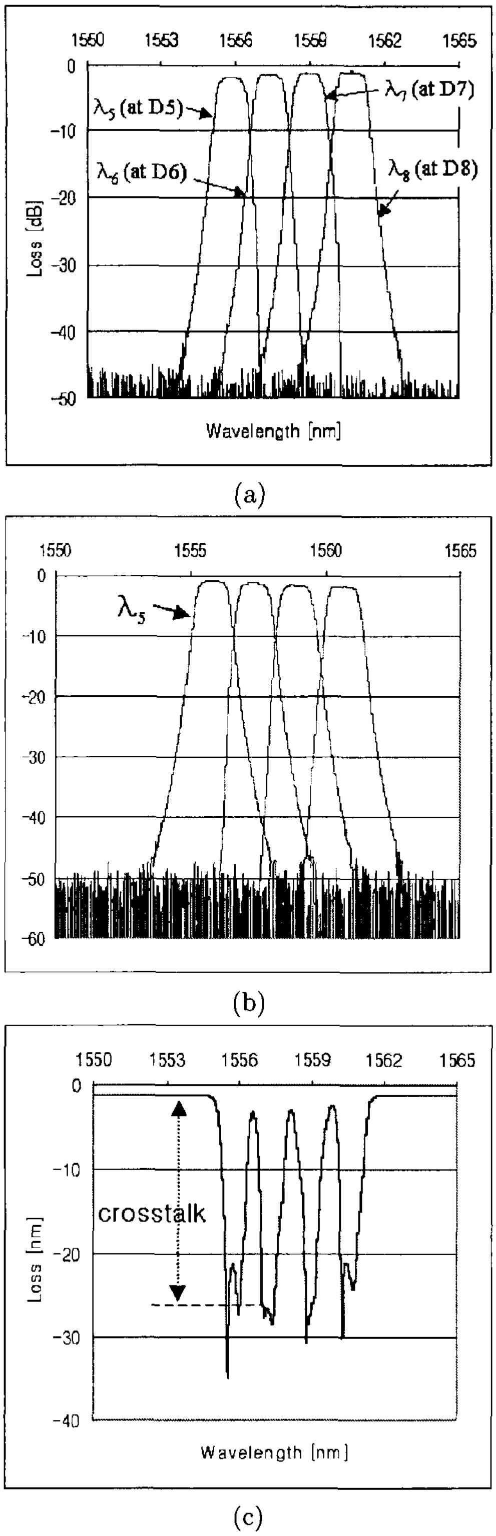

FIG. 7. The optical characteristics of the 4-channels OADM module.

the insertion loss and passband ripple of a TFF. The drop signals should perfectly transmitted through a TFF in idea case. However, the drop signals can not be transmitted perfectly in real device due to the optical performance of TFF. And then small amounts of drop signals are reflected to through channels and is transmitted finally to the OUT port of the OADM module. The TFF, reported in this paper, has the insertion loss and ripple under 0.1 dB (2.3%) and 0.2 dB(4.5%) including scattering, absorption, and alignment loss. However, the reflectance is about 0.3 ~ 1.0% excluding the scattering, absorption and alignment or packaging loss. Hence, the intra-band isolation can be improved by minimizing the reflectance of the TFF. For example, the intra-band isolation will be improved further by above 30 dB, when using the TFF with reflectance of 0.1% except for the scattering and absorption of TFF

As shown in Fig. 1, in the typical re-configurable n channel OADM module using 1 × 2 port device, the through channels inputted from IN port are transmitted through the OUT port by continuous reflection in the optical filter devices. And according to operation of an optical switch the arbitrary optical signal of the drop channels can be dropped through the DROP port to the local network, or can then be transmitted through the OUT port with through channels. Also, the add signals re-inputted into the ADD port are finally transmitted to the OUT port through sequential reflection and transmission of optical filters.

We compared the insertion loss of the proposed OADM module with that of the typical 1 × 2 OADM module. The transmission(IN DROP port, ADD OUT port) and the reflection(IN OUT port) in the optical filter device are denoted by T and R. Generally, the insertion loss of an optical filter device are 1.0 dB and 0.3 dB for T and R. The insertion loss of switch is 1.0 dB. At first, in the case of the n-channel re-configurable OADM module with the 1×2 port device, the through channels experience $2n$ times maximum reflections [$2n$R] in the WDM optical transmission system. An optical signal of drop channels, not dropped to the local network, goes through two times transmission and (n-1) times maximum reflections [2T, (n-1)R]. The drop and add channels go through one transmission and (n-1) times maximum reflection [1T, (n-1)R]. On the other hand, in the case of the proposed n-channel re-configurable OADM module with the 2 × 2 port device, the through channels experience only n times reflections [nR] contrary to [$2n$R] of the typical re-configuration OADM module. When the typical and the proposed re-configurable OADM modules are applied to the optical transmission system with 200 GHz channel spacing, the optical characteristics in terms of insertion loss are listed in table 2 and 3. The insertion loss of the n-channels OADM module can be summarized as follows. When the drop channels are transmitted to the OUT port or DROP port and the optical signals added to the ADD port are transmitted

TABLE 2. The theoretical insertion loss of the OADM module with 1 × 2 port devices.

drop channel	IN ⟶ OUT @exp. channel	IN ⟶ OUT @drop channel	IN ⟶ DROP	ADD ⟶ OUT	Remark (Insertion loss of MUX/DEMUX)
4	2.4 dB (8R)	3.9 dB (3R,2T)	2.9 dB (3R,T)	2.9 dB (3R,T)	
8	4.8 dB (16R)	5.1 dB (7R,2T)	4.1 dB (7R,T)	4.1 dB (7R,T)	IN ⟶ OUT : 0.3 dB
16	9.6 dB (32R)	7.5 dB (15R,2T)	6.5 dB (15R,T)	6.5 dB (15R,T)	IN ⟶ DROP : 1.0 dB ADD ⟶ OUT : 1.0 dB
32	19.2 dB (64R)	1 × 2.3 dB (31R,2T)	11.3 dB (31R,T)	11.3 dB (31R,T)	

* WDM transmission system with 200 GHz channel spacing,
* Insertion loss of optical switch : 1.0 dB, * R : Reflection, T : Transmission

to the OUT port, the insertion loss is the same for the OADM modules using either the 1 × 2 or 2 × 2 port device, which shows [2T, (n-1)R] and [1T, (n-1)R] respectively. However, the insertion loss of the through channel of the OADM module using the 1 × 2 or the 2 × 2 port device has $2n$R or nR at the OUT port respectively. According to the results of analysis for the re-configurable OADM module, the proposed OADM module with 2 × 2 port devices has a lower insertion than the typical OADM module with 1 × 2 port devices because the 2 × 2 port device has the function of both MUX and DEMUX, simultaneously.

As reported in the recent researches for OADM modules, the insertion loss of the through channels for a 16-channel re-configurable OADM module with an AWG is 6.6 ~ 10.3 dB [7,8]. In the case of the 8 channel re-configurable OADM module with both a FBG and an optical circulator, the insertion loss of the through channels is 3.5 dB [9]. As compared with these results, the proposed OADM module with a 2 × 2 port device has better optical characteristics than that of the typical OADM module using a FBG and an optical circulator. Also, the insertion loss of through and drop channels is better than that of the

TABLE 3. The theoretical insertion loss of the OADM module with 2 × 2 port devices.

drop channel	IN ⟶ OUT @exp. channel	IN ⟶ OUT @drop channel	IN ⟶ DROP	ADD ⟶ OUT	Remark (Insertion loss of MUX/DEMUX)
4	1.2 dB (4R)	3.9 dB (3R,2T)	2.9 dB (3R,T)	2.9 dB (3R,T)	
8	2.4 dB (8R)	5.1 dB (7R,2T)	4.1 dB (7R,T)	4.1 dB (7R,T)	IN ⟶ OUT : 0.3 dB
16	4.8 dB (16R)	7.5 dB (15R,2T)	6.5 dB (15R,T)	6.5 dB (15R,T)	IN ⟶ DROP : 1.0 dB ADD ⟶ OUT : 1.0 dB
32	9.6 dB (32R)	1 × 2.3 dB (31R,2T)	11.3 dB (31R,T)	11.3 dB (31R,T)	

* WDM transmission system with 200 GHz channel spacing,
* Insertion loss of optical switch : 1.0 dB, * R : Reflection, T : Transmission

OADM module using AWG below 16 drop channels. Especially, the insertion loss of through channels in the proposed OADM module is improved by 50% when compared with that of the typical OADM module with a 1×2 port device, and the price and size can also be reduced by 40 ~ 50% because both the function of MUX and DEMUX are done with one 2×2 port device simultaneously.

IV. CONCLUSION

In this paper we have presented the re-configurable OADM module with 2×2 port devices which showed low insertion loss, low price and small size. We analyzed the optical characteristics of the proposed OADM module and demonstrated the advantage of that by experiments. The insertion loss of the proposed OADM module was compared with that of the typical OADM module with the 1×2 port device. The insertion loss of through channels are improved by 50% as compared with the typical OADM module because the 2×2 port device performs both MUX and DEMUX functions, which resulted in reduction of the price and the size by 40 ~ 50% as compared with the typical OADM module. Also, the proposed module showed that the through and drop channels have an insertion loss lower than the AWG module below 16 drop channels. Consequently, the paper showed that the re-configurable OADM module with 2×2 port devices can remarkably improve, in respects of the performance, the price and the size, the typical OADM module below 16 drop channels in optical transmission systems.

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