A Reconfigurable Thin Film Filter-Based 2x2 Add-Drop Fiber-Optic Switch Structure

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ABSTRACT - A reconfigurable 2x2 add-drop fiber-optic switch structure is proposed by incorporating the independent mechanical control and alignment of the off-the-shelf thin-film filter with the reflective optical element. Cascading several 2x2 add-drop switches gives a low-cost polarization independent wavelength routing system with the limitation in optical loss that can be compensated by using optical amplifiers. The experimental result indicates a measured average optical loss of < 1.30 dB at the center wavelength. In addition, the measured optical coherent crosstalk values at the center wavelength are –15 and –22 dB when the thin film filter and the mirror are in the optical path, respectively. A very low polarization-dependent loss of < 0.07 dB is also investigated.

INDEX TERMS - Add-drop filters, fiber-optic switches, thin film filters, wavelength division multiplexing (WDM).

1. INTRODUCTION

Today large wavelength channel switching techniques for wavelength division multiplexed (WDM) lightwave systems can be implemented based on two well-known architectures. The first approach is the transmissive structure where there are two wavelength demultiplexers (DeMUXs) located at the main input port and at the add port, respectively. Additional two wavelength multiplexers (MUXs) are preferred if the system requires combining all wavelength channels into one optical fiber. In this structure, an array of 2x2 fiber optic switches is needed in order to direct the optical signals to the desired output ports. The second technique is the reflective type in which there are only two wavelength MUXs-DeMUXs incorporated with two fiber-optic circulators and the reflective fiber optic shutter array. Recently, several techniques have been employed to implement such fiber optic switches. These include the use of polarization sensitive components such as liquid crystal devices [1], [2] and acousto-optic tunable filters [3]. However, reliable low-cost polarization-insensitive fiber optic switches are based on mechanical movement of a reflective element that can be fabricated with bulk optics and microelectromechanical system technology [4]-[7].

To reduce the cost and the complexity of the WDM switching system, it would be desirable to eliminate the use of fiber-optic circulators and to have MUXs-DeMUXs as programmable routers. So far, a few wavelength selective devices have been implemented [8], [9]. Nonetheless, because they are not controllable, the transparent optical network cannot be realized. Hence, this letter proposes and experimentally demonstrates a reconfigurable thin-film filter-based 2x2 add-drop fiber-optic switch. Our key idea exploits the independent control of a movable wavelength thin-film filter (WTF) and a programmable reflective optical element.

2. PROPOSED STRUCTURE

Fig. 1 shows our proposed reconfigurable thin-film filter-based 2x2 add-drop fiber-optic switch structure. It composes of two dual fiber-optic collimators, one WTF, and one mirror. The use of dual fiber tip with the graded index (GRIN) lens offers a dual fiber-optic collimator where one optical fiber functions as the input port and another one acts as the output port. In this switch structure, the WTF and the mirror are operated in the opposite way. In addition, as the performance of the WTF can be different from its initial design process, the mirror and the WTF are sat on two separate actuators. As a result, these two active optical components are independently controlled and the free-space optical alignment for each component can be done easily.

This paper is reprinted from a paper published in IEEE Photonics Technology letters, vol. 15, pp. 930-932, July 2003.

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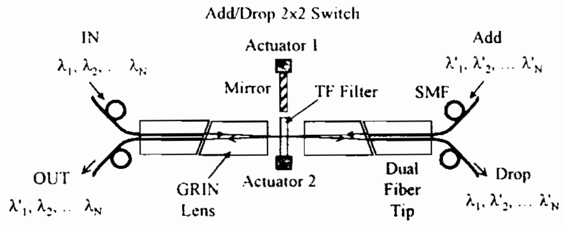


Figure 1. Illustrates Proposed reconfigurable thin film filter-based 2x2 add-drop fiber-optic switch structure. SMF: Single mode optical fiber.

From Fig. 1, the optical signals from IN and Add ports emerging from corresponding single mode optical fibers are collimated by associated GRIN lenses. When the mirror is programmed to move into the optical path by the actuator1 and the WTF is moved out of the optical path by the actuator2, all optical wavelength signals from IN and Add ports are directed to OUT and Drop ports, respectively. These two actuators can be based on motorized, piezoelectric, and solenoid techniques. This also implies that the response speed of the switch is limited by the choosen actuator technique and the weight of the mirror and the WTF. In addition, the required minimum movement as well as the size of WTF and mirror is $2w_0$, where w_0 is the Gaussian optical beam radius at the switching plane, in order to cover more than 99.96% of the incident optical power. On the other hand, the desired wavelength signals from IN (e.g., λ_1) and Add (e.g., λ'_1) ports are routed to Drop and OUT ports, respectively, when the desired WTF (e.g., λ_1) is moved into the optical path and at the same time the mirror is moved out of the optical path. Hence, these two settings indicate the operation of the 2x2 wavelength selective switch.

Based on the proposed switch architecture, cascading several 2x2 add-drop switches together as shown in Fig. 2 also leads to a large N wavelength switch system. For this serial configuration, if one wavelength selective switch module has an optical insertion loss of α dB, an optical loss of $N\alpha$ dB is accumulated. However, this optical loss value can be compensated by inserting optical amplifiers in the switch system.

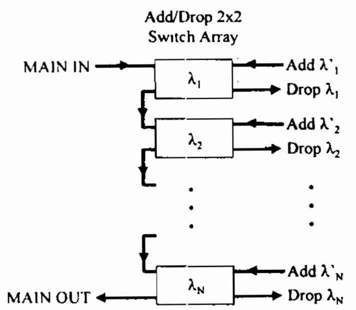


Figure 2. Illustrates an array of 2x2 add-drop fiber-optic switches is used to form a transparency multiwavelength routing system.

3. EXPERIMENTAL DEMONSTRATION

Based on the components available in our laboratory, the mirror is a 1-mm thick glass slide having a 50-nm gold layer on a 2-nm chromium layer coated on one side and it is positioned by a hand-operated mechanical translation stage. Fig.3 shows the closeup view of our experimental arrangement. Similarly, the WTF is controlled by another hand-operated mechanical translation stage. The WTF is a 1.4x1.4 mm^2 commercial 4-cavity WDM filter fabricated by Walsin THz, Inc., Taiwan and its designed center wavelength is 1546.12 nm with a 25-dB stopband of 1 nm. Note that each cavity in the WDM filter is a Fabry-Perot filter in which there are several dielectric thin-film layers. However, after aligning the WTF in the structure, the measured center wavelength is shifted to 1545.65 nm (λ_0). The tunable light source from Santec is directly connected to the switch structure via FC/APC adapter and the wavelength interval is set to 1.6 nm. The measured free-space dual fiber-optic collimator distance is 4 mm. The required minimum translation distance is 1.4 mm limited by the size of the WTF.

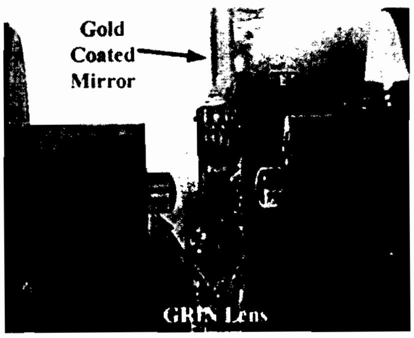
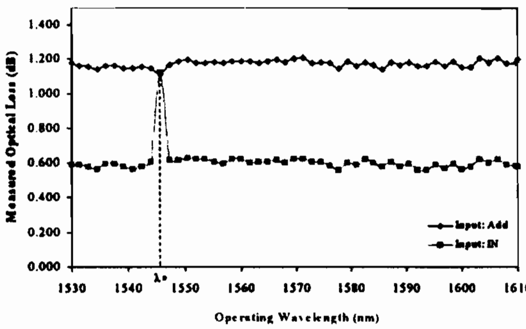
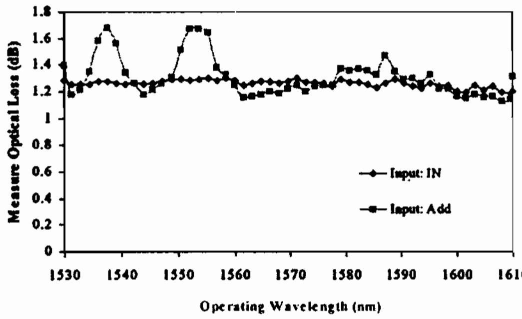


Figure 3. Illustrates Closeup view of experimental setup.

One important component issue is the optical loss which is the ratio of the input optical signal power to the corresponding output optical signal power. When the WTF is in the optical path, the measured optical loss at λ_0 is 1.12 dB. Optical loss variation over a 80-nm wavelength outside the passband of the WTF is also investigated as shown in Fig.4 (a). In this case, the measured average optical loss for IN as the input port is 0.60 dB with a + 0.03 dB optical loss variation. However, when the input port is the Add port, a higher measured average optical loss of 1.17 dB with a loss variation of +0.04 dB is obtained. This unbalanced optical loss values come from the fact that the free-space optical alignment and the optical beam deviation due to the beam refraction on both sides of the WTF are different.



(a)

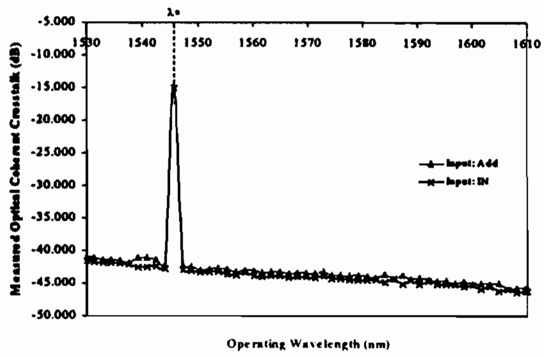


(b)

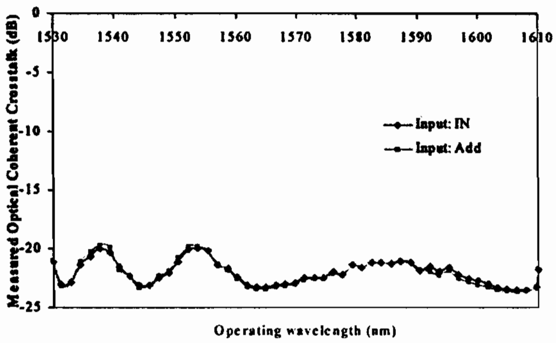
Figure 4. Illustrates Measured optical loss versus operating wavelength: (a) when the WTF is in the optical path (note that at 1545.65 nm, the output ports are OUT and Drop when the input ports are IN and Add, respectively) and (b) when the mirror is in the optical path.

When the mirror is in the optical path and the IN port acts as the input port, the measured average optical loss is 1.25 dB with an optical loss variation of +0.05 dB as shown in Fig.4 (b). However, when the Add port functions as the input port, a 1.30 dB measured average optical loss with a higher +0.28 dB loss variation is observed. This higher variation of optical loss is due to the Fabry-Perot interference effect generated from a single-side gold coated mirror.

Optical coherent crosstalk is also an important parameter for the wavelength selective switch. It is defined as the ratio of the wavelength optical signal power at the unwanted output power to the wavelength optical signal power at the desired port. When the WTF is in the optical path, the measured optical coherent crosstalk is shown in Fig.5, indicating an optical coherent crosstalk at λ_0 of < -15 dB. This optical crosstalk value is limited by the performance of the WTF. Optical coherent crosstalk of < -42 dB is also investigated outside the passband of the WTF. In addition, the measured average optical coherent crosstalk of –22 dB is measured when the mirror is moved into the optical path with a crosstalk variation of +1.88 dB over a 80-nm optical bandwidth which is again caused by the Fabry-Perot interference effect. Based on these two switch parameters, it is clear that lower optical loss variation and the improved optical coherent crosstalk can be accomplished by using thicker gold coated layer on both sides of the glass substrate and a lower-loss high-isolation WTF.



(a)



(b)

Figure 5. Illustrates Measured optical coherent crosstalks when (a) the WTF is in the optical path and (b) the mirror is in the optical path.

Another important system issue is the polarization dependent loss (PDL). In this case, a mechanical polarization controller is inserted between the tunable laser and the 2x2 add-drop fiber-optic switch structure in order to scramble the input state of polarization. The measured PDL when the mirror is in the optical path is 0.03 dB. When the WTF is in the optical path, the PDL of 0.07 dB is measured.

4. CONCLUSION

This letter proposes and experimentally demonstrates a novel reconfigurable 2x2 add-drop fiber-optic switch based on the combination of the independently controlled WTF and the mirror. This proposed 2x2 wavelength selective switch can be used to realize a large channel count polarization-insensitive wavelength routing system. Experimental results using a commercial 4-cavity WDM filter and a single-side gold coated mirror indicate a measured average optical loss of < 1.30 dB and a very low PDL of < 0.07 dB. The optical coherent crosstalk of < -15 dB is also investigated at the center operating wavelength. Limitation in optical loss and the optical coherent crosstalk can be overcome by utilizing optical amplifiers, a better WTF, and a double-sided gold coated mirror.

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