(1) Title of letter

Fast and stable wavelength selective switch using double-series coupled dielectric microring resonator

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(4) Running head

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high index contrast, optical waveguide, microring resonator, optical filter, optical switch, thermo-optic effect

(6) Abstract

We demonstrated a hitless wavelength channel selective switch (hitless tunable Add/Drop filter) using Thermo-Optic (TO) effect of double series coupled dielectric microring resonator. Using a dielectric material as the core, the response time was reduced to 105μs (rise time) and 15μs (fall time), which are fifteen-fold and hundred-fold faster than that of polymer material, and the reproducibility by the heat cycle test was also improved to less than 0.01nm. The tuning range of wavelength selective switch was expanded to 13.3nm using the Vernier effect, and a large extinction ratio of more than 20dB was realized.

I. Introduction

Reconfigurable optical Add/Drop multiplexer (ROADM) is a key component for the next generation photonic network [1],[2]. To realize an ROADM, tunable Add/Drop filters are needed, and some tunable ADM's have been reported using polymer core [3],[4],[5]. However, the conventional tunable filter blocks other wavelength channels during the tuning of resonant wavelength.

To solve this problem, two methods can be considered; one is the combination of conventional tunable Add/Drop filter and a channel selective switch with by-path route, and the other is the hitless wavelength-selective switch. There have been some reports on the microring channel switch using series coupling [6] and wavelength-selective switch using cascaded topology [7]. However, the former one analyzed only the ON-OFF switching characteristics and the latter one is difficult to realize the hitless operation, because the resonant wavelength dose not pass straight through the parallel port but is guided to the second (middle) output port.

Therefore, we proposed and demonstrated a hitless wavelength selective switch using a double series coupled microring resonator made of polymer material [8]. However, the reproducibility (0.16nm) and the switching time (∼2ms) were not satisfactorily good. Thus in this study, we fabricated a hitless wavelength selective switch using dielectric material. In addition, the tuning range was expanded using Vernier effect.

II. Principle

The series coupled microring resonator [9],[10] can realize a box-like spectrum response and an expansion of free spectrum range (FSR). In addition, by controlling individual resonant wavelengths of a series coupled microring resonator using TO effect, a hitless wavelength channel switch can be realized [8]. When resonant wavelengths of individual microrings in a series coupled microring resonator are not matched to each other, all wavelength channels are transmitted to the through port and no spectrum response appears in the drop port (OFF-state). After shifting all resonant wavelengths and adjusting these resonant wavelengths, a new spectrum peak in the drop port response appears at another wavelength channel. Therefore, the resonant wavelength can be shifted to another wavelength channel without blocking other wavelength channels.

III. Device fabrication

The structure of hitless wavelength selective switch is shown in Fig.1. Si was used as the substrate. The core material and the upper cladding material were sputtering deposited 17mol%Ta_2O_5-SiO_2 (n=1.657 @λ=1550nm) and SiO_2 (n=1.446 @λ=1550nm), respectively. The lower cladding material was thermally-grown SiO_2 (n=1.442 @λ=1550nm). To achieve high coupling efficiency, the resonator was shaped like a racetrack. The busline waveguide and microring resonator were laterally coupled with the gap width of 1.0μm. The coupling efficiency between busline and microring was designed to 0.25 and that between microrings was designed to 0.001$\sim$0.2 by changing the overlap length of the straight part of racetrack resonator. The core height and width were 1.2μm and 1.4μm, respectively. The round trip length of racetrack resonator was 700μm, which corresponds to the FSR of 2.1nm.

IV. Experiment

By applying electric current to each Cr thin film heater above individual ring resonators separately, we measured hitless tuning characteristics. When the electric current was changed according to the sequence shown in Table 1, the measured TE-mode drop port response varied as shown in Fig.2, and the through port response varied as shown in Fig.3, respectively. In the initial stage when no electric current was supplied, the resonant wavelengths of individual microrings were slightly different due to the fabrication error. When an electric current was supplied to the microheater above the Ring#2 according to step S1 in Table 1, the response reached ON-state. The change of TM-mode response was almost the same as that of TE-mode response except for the polarization dependance of center wavelength (1.25nm). The split of dip in the through port response at the ON-state was observed as shown in Fig.3. This is because the coupling coefficient between ring resonators was stronger than the critical coupling condition. In this device, the coupling coefficient between resonators was almost equal to the critical coupling condition for drop port response. However, the critical coupling condition for drop port is stronger than that for through port when the resonator suffers propagation loss [11].

OFF-state was realized by increasing the electric current supplied to the microheater above Ring#2 according to step S2 in Table 1. The ON-state in the TE-mode drop port response appeared again when an electric current of 21.4mA was supplied to Ring#1 and 22.5mA was supplied to Ring#2. The ON-state in the TM-mode drop port response appeared again under the same condition as for the TE-mode. Also by supplying an electric current of 23.8mA to Ring#1 and 24.8mA to Ring#2, a sharp drop appeared again at the wavelength of 1550.95nm in the TE-mode through port response and by supplying an electric current of 22.9mA to Ring#1 and 24.1mA to Ring#2, a sharp drop appeared again in the TM-mode through port response. The power consumption was evaluated to be 136mW. From these figures, it is seen that a hitless wavelength selective switch was successfully demonstrated.

In the drop port response, the extinction ratios were 38dB for TE-mode and 38.8dB for TM-mode, respectively. In the through port response, the extinction ratios were 14.7dB for TE-mode and 16.5dB for TM-mode, respectively. The switching crosstalk for drop port was -21.1dB for TE-mode and -20.3dB for TM-mode. However, the switching loss for through port at the OFF-state was -3dB. This loss can be reduced by optimizing the coupling efficiency between the busline and the ring resonator. In this measurement, fiber-to-fiber insertion loss was approximately -20dB due to the large spot size mismatch between the busline waveguide and single mode fiber.

In the drop port response, the tuning ranges were 1.21nm for TE-mode and 1.18nm for TM-mode, respectively. In the through port response, the tuning ranges were 1.47nm for TE-mode and 1.34nm for TM-mode, respectively. To increase the FSR and the tuning range, we fabricated a wavelength selective switch using two microrings with different curvature radii of racetrack resonator (105μm and 95μm). As a result, we successfully expanded the FSR to 23.2nm and the tuning range to 13.3nm in the TE-mode through port response due to the Vernier effect as shown in Fig.4. It should be noted that the center wavelength can be shifted to either longer or shorter wavelength side by changing the ring resonator for heating. Similar switching characteristics were also obtained for TM polarization. In this measurement, an LED was used as a light source and an EDFA was used to amplify the power.

Fig.5 shows the result of the thermal cycle test. The reproducibility of spectrum of the device made of dielectric material ($\leq$ 0.01nm) was much better than that made of polymer core device (0.16nm) [8]. The response shown in Fig.5 corresponds to that for the case of no eletric current shown in Fig.2. Therefore, the double peak is caused by the small difference of peak wavelength between two coupled resonators resulting from the fabrication error. On the other hand, the other small peak at λ=1550.6nm corresponds to the orthogonal polarization mode. In this measurement, the polarization state of input light was fixed using a polarization maintaining fiber. Since the peak power of orthogonal polarization is about -20dB smaller than that of the main peak, the polarization rotation in the ring resonator is very small.

Fig.6 shows the measured response time when the current was switched off. This time response was measured at the wavelength of 1548.45nm, which corresponds to the peak wavelenth of ON-state in the drop port response shown in Fig.2. After supplying an electric current of 20mA to the Ring#1, the output power from the drop port was switched to the OFF-state. The fall time was 15μs, which is hundred times faster than the TO tunable filter made of polymers [4],[9]. On the other hand, the rise time from 0mA (initial state) to 7.6mA (ON-state) at λ=1548.45nm was 0.105ms. This value was larger than the fall time of 15μs, because the wavelength shift (0.1nm) induced by the TO effect was smaller than that for the case from ON-state to OFF-state (0.96nm). If the wavelength shift is the same, the rise time must be the same as the fall time.

The accelaration of response time (fall time) compared with that of the polymer core device can be attributed to the following two reasons. The first one is the difference of thermal conductivity between dielectric and polymer materials. The thermal conductivity of polymer (polyimide) is 0.2[W/m·K] and that of dielectric material (SiO_2) is 1.4[W/m·K] which is about seven-fold greater than that of polymer material. The second reason is the difference of shifted wavelength range, which is the wavelength shift of one of two coupled resonators induced by TO effect to switch from ON state to OFF state. The wavelength shift of dielectric core device (0.96nm) was much wider than the FWHM bandwidth (~0.07nm). Therefore, the power transmission fell down very rapidly from ON-state to OFF-state. In contrast to this, the wavelength shift and FWHM bandwidth of polymer core device were 0.28nm and 0.2nm, respectively. The ratio of wavelength shift to FWHM was much smaller than that of the dielectric core device. Since the switching time (both rise and fall times) is determined by the ratio, the response time of dielectric device was much faster than that of polymer device. The difference of FWHM bandwidth between dielectric and polymer devices is not caused by the propagation loss but is attributed to the difference of the coupling efficiency between the busline waveguide and microring.

VI. Conclusion

The hitless wavelength selective switch made of dielectric material is much suitable for stable and fast switching than that made of polymer material [8]. The difference of switching current between through port and drop port responses is caused by the propagation loss in the ring resonator. This is because the maximum transmission condition for drop port and the maximum rejection condition for through port are different when the ring resonator suffers some amount of loss [11].

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Figure captions

Fig. 1 **Perspective view of hitless wavelength channel selective switch.**

Fig. 2 **Hitless wavelength switching of drop port response (TE-mode).**

Fig. 3 **Hitless wavelength switching of through port response (TE-mode).**

Fig. 4 **Wavelength switching of double series coupled ring with different ring radii (TE-mode, through port response).**

Fig. 5 **Thermal cycle test of drop port response.**

Fig. 6 **Time response of drop port switching.**

Table 1: Hitless tuning sequence of electric current (unit: mA)

	Step	S1	S2	S3
Drop port response (TE-mode)	Ring#1	0	0	23.8
	Ring#2	6.5	24.8	24.8
Drop port response (TM-mode)	Ring#1	0	0	22.9
	Ring#2	6.5	24.1	24.1
Through port response (TE-mode)	Ring#1	0	0	21.4
	Ring#2	7.8	22.5	22.5
Through port response (TM-mode)	Ring#1	0	0	21.4
	Ring#2	6.7	22.5	22.5