Wavelength-Selective Switch using Thermally Tunable Microring Resonators

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Abstract A novel wavelength-selective switch based on thermally tunable Si_3N_4 microring resonators has been designed, realized and characterized. The switch has an ON/OFF ratio of 7.5 dB and is made out of two rings which allow nearly full dropping (83%) and can thermally be tuned over 3 nm.

Introduction

In the metro and access networks an increase in the deployment of integrated optical techniques can be observed. In these short-haul networks the reduction of both cost and space is an important issue. Large scale integrated optics is able to satisfy this challenge, since low-cost high density integration of functional elements in mass-produced devices is feasible. For these integrated applications tunable wavelength switches are desired. A wavelength-selective switch based on thermally tunable microring resonator (MR) is analyzed and characterized.

Microring resonator based switch

MR's can be deployed as WDM filters, switches and modulators [1, 2]. Their small dimensions, area $<0.01 \text{ mm}^2$ are advantageous for densely integrated and cost-limited applications. The highly selective properties of the Lorentzian filter shape of the MR make it a good candidate for WDM filter applications. As proposed in [3, 4] the MR based switch shown in figure 1a can be used as a cost-limited wavelength dependent switch for the access network. By cascading rings in parallel even higher ON/OFF ratios can be obtained.

Figure 1. (a) Schematic view of MR based switch (b) Simulated response of second order switch

Design of MR based switch

For a proper functioning of a switch a key design parameter is that the individual MRs are full drop, i.e. at resonance all the power is transferred to the drop port. To achieve full drop the coupling to and from the ring resonator, denoted by κ_1 and κ_2 needs to be accurately defined. These coefficients, combined with the losses in the MR determine the Finesse and the fraction of the power that is dropped. According to [6] the maximum power dropped at resonance can be determined by maximizing M given by:

$$M = \frac{T_1 T_2 e^{-\alpha_0 2\pi R}}{(1 - \sqrt{\kappa_1 \kappa_2})^2}$$

$$T_i = \kappa_i (1 - \gamma_i)$$

$$X_i = (1 - \gamma_i)(1 - \kappa_i) e^{-\alpha_0 2\pi R}$$

where κ_i is the fraction of the power coupled to or from the ring respectively. γ_i is the coupling loss, R the radius of the ring and α_0 the total loss inside the ring. Figure 2 shows the dropped power as a function of the coupling coefficients at waveguide losses of 3 dB/cm. As can be seen the power is maximized for symmetric κ_1 and κ_2 and high coupling coefficients. High coupling means low Finesse so there is a trade-off between the maximization of the dropped power and the Finesse of the resonator.

Figure 2. Dropped power as a function of κ_1 and κ_2

Device fabrication

To achieve symmetric coupling coefficients the ring-waveguide alignment needs to be accurately controlled in the case of vertical coupling [5]. To reduce alignment errors during the different lithographic steps, different sets of MRs were designed with different predefined misalignments. The devices, fabricated using $\text{SiO}_2/\text{Si}_3\text{N}_4$ technology [5], showed a high reproducibility in resonance wavelength. Figure 3 shows the response of two MR's with a separation on the wafer of $950 \mu\text{m}$. The difference in resonance is $\approx 0.4 \text{ nm}$, translating to a 6.5 nm uncertainty in the resonator radius.

Figure 3. Resonance wavelength reproducibility of two identical resonators separated by 950 μm

Measurements on a single MR

The measured through- and drop- response of a thermally tunable MR (Fig. 4) shows a measured power at resonance in the drop port nearly equal to the off-resonance power in the through. Also shown are simulated curves drawn using fitted parameters. The fitted parameters are $\kappa_1 = 0.7$, $\kappa_2 = 0.6$ with ring losses of ≈ 90 dB/cm. Despite the high ring losses, caused by an error in the ring thickness during fabrication, around 83% of the power is still coupled to the drop port due to the high coupling constant. The high coupling is however also responsible for the low measured Finesse of 3.5.

Figure 4. Simulated and measured responses of nearly full drop MR

Measurements on a Thermally Tunable MR

A MR was heated using a chromium thin film heater [4]. Figure 5 shows the measured shift of the resonant peak as a function of the dissipated heater power for samples with 3 and 4 μm SiO_2 cladding layers. As can be seen from the figure both resonators could be tuned more than 3 nm. In the inlay the measured drop responses are shown for different tuning power.

Figure 5. Resonant peak shift for MR with 3 and 4 μm cladding; Inlay: measured response of drop port at 0 and 170 mW

Thermally Tunable Wavelength-Selective Switch

The measured drop response of a MR based switch with the geometry of Figure 1a is shown in Figure 6. The first stage was tuned to turn the switch from ON to OFF state using a switching power of 150 mW.

Figure 6. Measured response at the drop port of a MR based switch

Since the Finesse of the MRs is low and their peaks broad, a large shift is needed to turn the switch completely off. The measured ON/OFF ratio is 7.5 dB.

Conclusions

A wavelength dependent switch based on thermally tunable microring resonator is characterized. The switch has applications in low-cost small-area filter arrays for the access network.

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