# Thermally Tuneable, Wide FSR Switch based on Micro-ring Resonators

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*A thermally tuneable, wide FSR switch, based on integrated-optic micro-ring resonators is described. This wavelength-selective switch allows high ON/OFF ratios combined with small dimensions. Furthermore allows the structure for a wide Free Spectral Range, since multiple resonators are used. This switch can be used in WDM filter arrays for a transceiver in an access network. Measurements of the thermal behaviour of a single resonator confirm the switching capability of the switch.*

## Introduction

Optical access networks are gaining increasingly interest. Since the cost of the equipment of an access network is shared by only a few users, minimizing the cost is essential to compete with other access technologies like cable-access and ADSL. In a PON (Passive Optical Network) typically only several tens of users share the same equipment. Customer premises equipment is not even shared at all. Integrated optics will be able to satisfy the low-cost challenge, since mass production is feasible.

Integrated optic micro-ring resonators are promising to implement the different filtering and switching functionalities [1,6]. Their small dimensions are advantageous for large-scale integration -VLSI photonics - and cost-limited applications. In this paper a wavelength selective ON/OFF switch is described, based on thermally tuneable micro-ring resonators. The switch allows for a broad Free Spectral Range (FSR) and the selection of a single wavelength band within complete the third telecom window.

## Micro-Ring Resonator based Switch

Micro-ring resonators (MR) can be deployed as WDM filters, switches, and modulators [1-4]. The functional behaviour of a single MR is explained in [5,6]. A schematic view of a MR based switch is shown in Fig. 1a. The first stage of the switch selects the desired wavelength band. The second stage, which is thermally tuneable, can route the selected wavelength band to the drop port. The switch can be composed of higher order filter stages, see Fig. 1b, to broaden the pass-band and to increase the ON/OFF ratio [7]. The additional rings are added in parallel, meaning that the rings share the in and output waveguide. The distance between the rings is assumed sufficiently large so that a ring is only coupled to the other rings through the waveguides and not directly. The waveguide connecting the parallel cascaded rings must have the correct length to allow constructive interference between the different paths. In Fig. 2 the simulated response of a single switch is shown with second order stages based on MRs with a radius of 25 μm, a free spectral range of 10 nm, finesse 100 and propagation loss 2 dB/cm. The fraction of the field coupled between the MR and the straight waveguides is 10%. In this simulation the MR has a cladding with $\partial n/\partial T = -3.3 \cdot 10^{-4}\ K^{-1}$ (typical for a polymer). When increasing the temperature of the MR in the second stage by 50 degrees, a difference in effective refractive index ($N_{eff}$) of the ring of $4 \cdot 10^{-4}$ can be obtained, which leads to a shift in centre wavelength of 7 pm/°C. Figure 2 shows that this is sufficient to allow switching between the ON and OFF state.

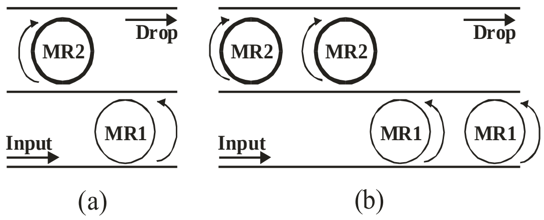


Fig. 1. First (a) and second order (b) wavelength selective switch, MR1: fixed wavelength MR; MR2: tunable MR

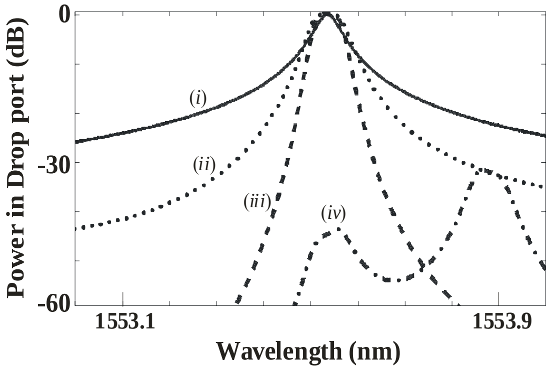


Fig. 2 Response of a MR based switch (*i*): response of the first stage in Fig. 1.a; (*ii*): response of the first stage in Fig. 1.b; (*iii*): response of complete switch in Fig. 1.b in ON-state; (*iv*): idem in OFF-state.

Line (*i*) in Fig. 2 represents the Lorentzian response of a single MR; by adding in parallel an identical MR the second order response (line (*ii*)) is obtained. The distance between the rings is assumed such that the different paths add up in phase. Lines (*iii*) and (*iv*) show the drop port of the complete second order switch in the ON and OFF state respectively. As can be seen in the figure the difference between the ON and OFF state can reach 30 dB, which is sufficient for applications in a WDM system.

For the higher order filter stages the parallel configuration has been chosen instead of a serial configuration for two reasons. The first is that differences in centre wavelength caused by technological imperfections affect the filter shape only slightly since an optical signal goes through all the rings simultaneously [8]. Furthermore the parallel configuration allows control of the bandwidth of the higher order filter stage, while maintaining the boxed-shape filter response [8, 9]. A broadening of the filter shape of a stage decreases the ON/OFF ratio of the switch at a given thermal shift. So by controlling the bandwidth of the stages the highest possible ON/OFF ratio can be reached for the lowest temperature changes.

## Wide FSR Switch

For application as wavelength selective device in WDM systems in which a single wavelength band has to be dropped, a wide FSR that spans the complete communication band is desirable. The MR based switch setup allows for a wide FSR by exploiting the Vernier effect through selecting different radii for the two stages. The total FSR of the switch can then expressed by:

$$FRS_{switch} = N \cdot FSR_{stage1} = M \cdot FSR_{stage2}$$

Where M and N are integers depending on the radii of the MRs. A parallel cascade of MRs can be designed such that the higher order stage itself extends the FSR. In this case the distance between the rings within one stage must be carefully designed [9,10]. However the proposed switch design (see Fig. 1) relaxes these criteria since the Vernier effect takes place over the two stages. The principle is suitable for applications where a single wavelength band has to be filtered out, for example a receiver at the customer premises in a PON. The first stage of the switch drops more than one wavelength band since its FSR is smaller than the span of the entire band. The wavelength bands filtered out by the first stage cannot be put back on the input bus for possible further use. So applications with a drop and through port (e.g. in Metro networks) cannot be handled by this wide FSR switch.

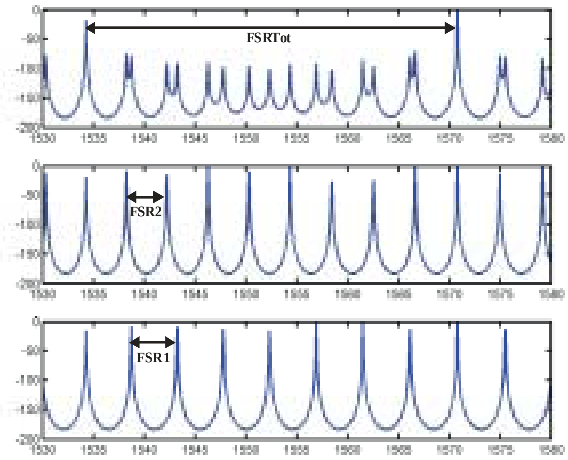


Figure 3. FSR of total switch; constructed of the two separate stages, FSR1 = 4 nm, FSR2=4.5 nm, FSRtot = 36 nm.

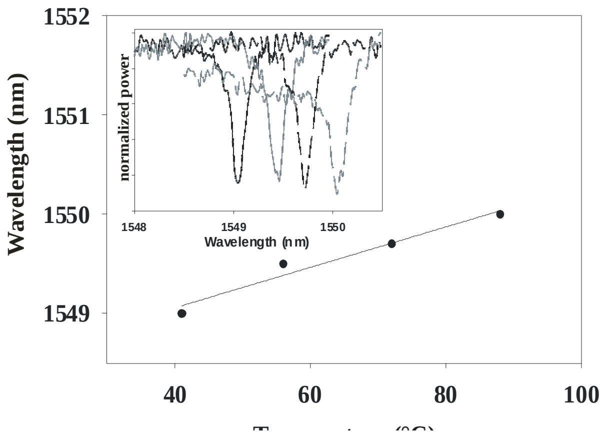


Fig. 4. Thermal dependency of trough- port response of a MR; $\partial\lambda/\partial T \approx 20$ pm/°C; inlay: measured wavelength response

The proposed wide FSR switch set-up allows to thermally tune the dropped wavelength band over the complete third telecom window. Since the total FSR is reached by cascading two stages with smaller FSR, any wavelength within the given band can now be addressed by only tuning across the smaller FSR's of the individual. In the example given in Figure 3 the total window of 35 nm can be spanned by tuning the different stages 4.5 nm. This shift can be achieved by thermal tuning as will be shown in the next paragraph. A single MR could not be tuned over the complete window without either using very large thermal shifts or very large FSR. This implies either very high temperature changes to achieve the desired shift, or very small rings, which will be more difficult to fabricate.

## Experimental results and feasibility

Siliconnitride MRs have been fabricated which are vertically coupled to $Si_3N_4$ waveguide channels embedded in $SiO_2$. The radius of the MRs is 25 µm. The SiON technology resulted in MRs with finesses as high as 180 around 1.55 µm and OFF resonance insertion losses smaller than 0.15 dB [6], [12]. The present devices have an air cladding. For thermal tuneability and switching a cladding layer is favourable since the cladding can be made of a material that has a high temperature dependent refractive index, e.g. a polymer. Furthermore this configuration allows the placement of heater structures.

For a MR with an air cladding and a Finesse of about 118 the thermal dependency of the power in the through port as a function of wavelength has been measured, see Fig. 4. For this device a difference in the effective index of the ring of around $1{\cdot}10^{-3}$ per 100 °C has been calculated by using a bend-mode solver. This implies a temperature dependency of the centre wavelength of 11 pm/°C. But not only the thermal effect on the index *n* of the ring influences the centre wavelength. By heating the entire device also the effect of thermal expansion of the complete device must be taken into account and consequently also the expansion of the diameter of the ring. Taking into account the thermal expansion of the Si substrate with a thermal expansion coefficient of 4.2 $10^{-6}$ $K^{-1}$ [14], an additional shift of the centre wavelength of 13 pm/°C can be expected. In these calculations it is assumed that the nitride ring follows the expansion of the substrate. Since the dimensions of the rings are very small compared to the substrate this can be done. Furthermore the effect of the increase in radius of the ring on the effective index is not taken into account, since this effect is very small (only a few percent of total difference in effective index). The measured response shown in figure 5 gives a shift of the spectral response with increasing temperature of $\partial\lambda/\partial T \approx 20$ pm/°C. As can be seen, the total predicted shift is in good agreement with the measured value. Preliminary results on rings with micro-heaters show a thermally induced shift of 20 pm/mW.

## Conclusion

A thermally tuneable switch with wide FSR is described which gives high ON/OFF ratios. It can be tuned over the complete third telecom window. The structures have an extremely small footprint (0.05 $mm^2$) allowing for large integration for and therefore low cost applications. Experiments show that thermo-optic switching even over the complete band is feasible. A wide FSR is reached by the Vernier effect over two stages in the switch. Future work is directed to the experimental verification of the concepts of multiple thermo-optically tuneable MR structures.

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