Integrated optical add-drop multiplexer using thermally tunable microring resonators.

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We present a four channel optical add-drop multiplexer based on vertically coupled microring resonators fabricated in Si_3N_4/SiO_2. The device with a Manhattan-like geometry has a footprint of 0.25 mm^2 and can find application in metro-networks. The individual micro-resonators have a 50 µm radius and are thermally tunable over a 4 nm range. The maximum power consumption per ring is 0.5 W. Measurements show that each microring has a bandwidth >10 Gbit and can be thermally tuned in less than 1 ms. The measured on-off resonance in the drop ports of each micro-resonator is 10 dB.

Introduction

As computer applications become more and more powerful the demand for network bandwidth is growing rapidly year on year. In order to satisfy this demand the deployment of optical networks is moving more and more towards the home-user's premises. Since deployment costs are a major issue in these access networks, low-cost optical filtering and switching functions need to be devised. Integrated optical Microring Resonators (MRs) are viable candidates for these functions as they combine a small footprint with a highly selective filters function[1,2,3]. Furthermore they can be readily combined into more complex structures such as a switch [4,5].

An important component which can be devised using MRs is a WDM router as presented in figure 1.

In this router, based on the Manhattan layout [6], an incoming WDM signal is split into separate channels by an initial row of MRs. Single or multiple of these channels can then be switched [4,5] to the outputs (O_x) by the other MRs. In addition it is possible to split a single wavelength across several outputs by tuning individual MRs such that each output receives the power required.

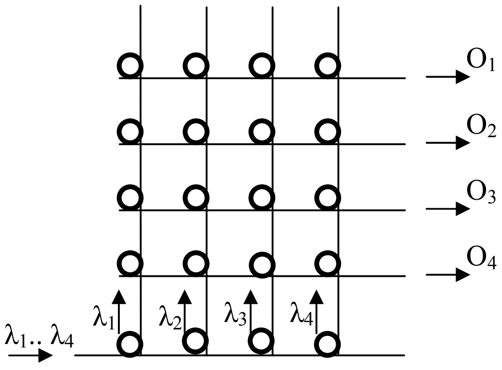


Figure 1: WDM Router based on a Manhattan Layout

In the following, a step-up to this router is presented, namely an Optical Add-Drop Multiplexer (OADM) [7] using four tunable MRs, which has a function equivalent to the input row of the full router.

Design and fabrication

An OADM was designed as shown in figure 2a. It consists of a central waveguide (Iin/Iout) and four Add/Drop waveguides. The waveguides are spaced at 250 µm to allow for a standard fiber-array connection. The size of the OADM, 1.25 x 0.2 mm^2 is mainly determined by this spacing. A specific channel can be added to or dropped from the central waveguides by thermally tuning the MRs placed at each intersection of the central and add/drop waveguides.
A topview and cross-section of a these MRs is shown in figure 2b. The MRs, with a radius of 50 µm and a waveguide cross-section of 2.5 x 0.18 µm^2 are vertically coupled to port waveguides measuring 2.0 x 0.14 µm^2. These dimensions allow good phasematching (both at Neff≈1.5) between the ring and the port waveguides. The vertical gap is fixed at 1 µm while the lateral gap between ring and port waveguides was used as a parameter varied between devices.

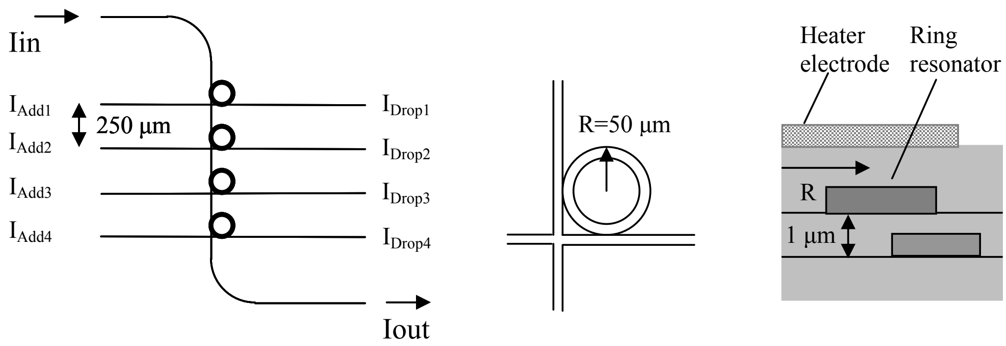


Figure 2a: Layout of the add-drop multiplexer 2b: Topview and coupling region cross-section

The OADM was fabricated using LPCVD Si_3N_4, embedded in PECVD- and thermally grown SiO_2 [2, 8]. The device was annealed after deposition. Chromium heaters were deposited on top of a 4 µm cladding layer using lift-off.
Figure 3 shows a fabricated OADM. The central and add/drop waveguides are clearly discernable as well as the omega shaped heater elements on top of the four micro-ring resonators.

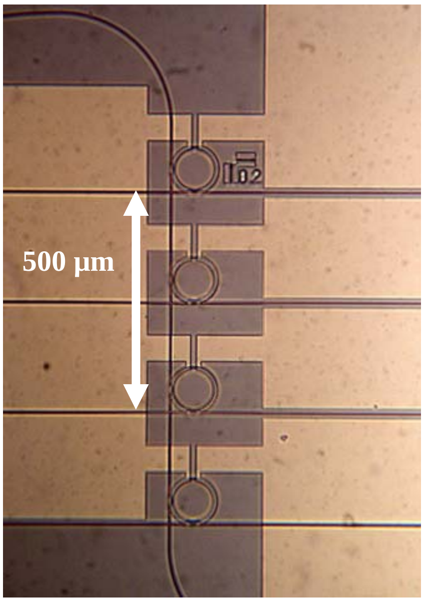


Figure 3: Topview of a four-channel MR OADM fabricated in Si_3N_4

Measurement results and discussion

The OADM was measured using an EDFA broadband source connected to Iin while an Optical Spectrum analyzer with a resolution of 0.05 nm was used to measure Iout and I_{Drop1}-I_{Drop4}. The OADM was configured into two distinct configurations by pre-setting the current through the heater elements on top of the MRs. The first one, the 2-channel configuration has two sets of MRs at equal resonance frequencies while the second, the 4-channel configuration, has these equally spaced at 0.8 nm (100 GHz ITU Grid).

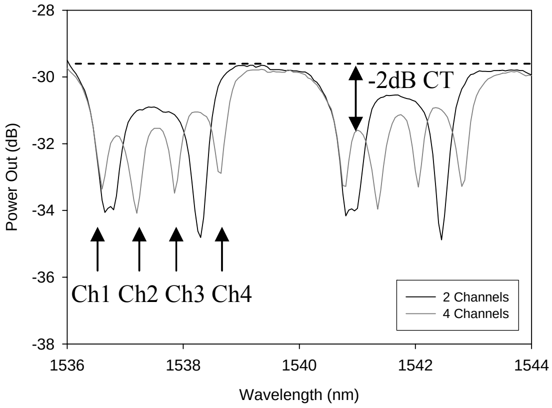
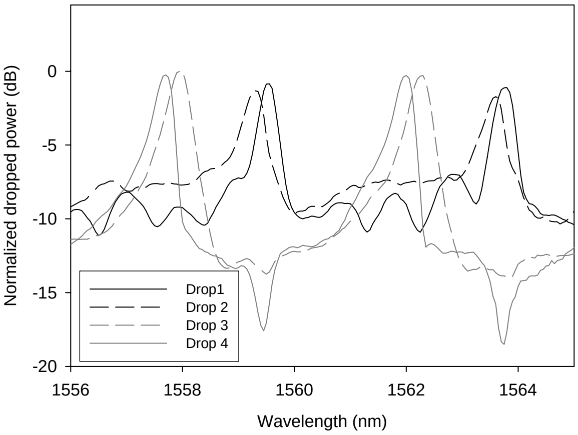
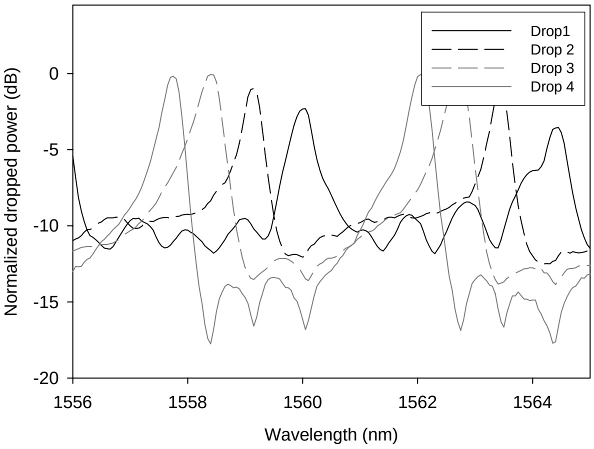


Figure 4: Iout response for a 2-channel and 4-channel OADM configuration



a)



b)

Figure 5a: Response for I_{Drop1}-I_{Drop4} for the 2-channel and b) 4-channel configuration

The configurations could be changed in <1 ms due to the fast thermal tuning response of the MRs [9]. The maximum tuning range for the individual MRs was found to be ≈4 nm at a power dissipation of 0.5W, yielding a thermally induced wavelength shift of 8 pm/mW of dissipated heater power.

Measurements of Iout, shown in figure 4, and I_{Drop1}-I_{Drop4} in figure 5 were performed for both configurations. Figure 4 shows that the minima of the dropped channels are ≈-4dB below the input power level (dashed line) for the 4-channel configuration which indicates that ≈65 % of power is extracted per channel. For two channels the minima decrease to ≈-6 db or 75%. This is less than the expected minimum of -7.5 dB, and can be attributed to a non-perfect alignment of resonance frequencies as can also be concluded from figure 5a. The

4-channel configuration shows a significant channel crosstalk of ≈-2 dB. This, as well as the rather small extraction can be attributed to bad alignment of the ring resonator to its port waveguides. A computer fit to the measurements to obtain the ring parameters reveal asymmetric coupling coefficients of 0.4 ±0.05 and 0.65 ±0.05 at ring losses of 5 dB/cm. The power at the drop ports I_{Drop1}-I_{Drop4} shows a 10 dB extinction although 14 dB is prediced by the fitted parameters. This difference can be partially explained by internal noise in the device due to waveguide crossings as shown in figure 2b. Note that the larger extinction ration for I_{Drop3} and I_{Drop4} in figure 5a is caused by the filtering effect of the first two rings and cannot be attributed to better ring performance. The relatively large dips in I_{Drop4} and, to a smaller extent, also in I_{Drop1}-I_{Drop3}, seen in figure 5b are caused by the filtering effects of preceding MRs.

Conclusions

We showed first measurement results of a thermally tunable OADM consisting of four MRs built in Si_3N_4. It has been shown that the OADM can be configured to drop arbitrarily chosen channels with an extraction efficiency of ≈65%. The extinction ratio of the blocked wavelengths is ≈10 dB. The rather poor extraction and high crosstalk in the device can be attributed to a misalignment in the ring resonators and will be corrected in future devices. Individual rings have already been tested for bandwidth and showed good performance at 10 GBit/s [5] while even higher values are expected. The relatively low FSR of 4.5 nm of the MRs in the OADM will pose problems in network applications. It is however possible to solve this issue by reducing the ring radius or utilizing the Vernier effect by combining multiple MRs of different radii[10].

Acknowledgements

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References

[1] S.Suzuki *et al.,* "Integrated-optic ring resonators with two stacked layers of silica waveguide on Si", *Phot. Tech. Lett.,* vol. 4(11), pp. 1256-1258, 1992.

[2] F.C. Blom *et al.*, "Experimental study of integrated-optics microcavity resonators: Toward an all-optical switching device", *Appl. Phys. Lett.,* vol. 71, pp. 747-749, 1997.

[3] B.Little *et al.*, "Microring resonator channel dropping filters", *J. Lightwave Technol.,* vol. 15, pp. 998-1005, 1997.

[4] E.J.Klein *et al.*, "Wavelength Selective switch using thermally tunable microring resonators", *Proc. LEOS annual meeting, p. MM1, 2003.*

[5] D.H.Geuzebroek, E.J.Klein, H.Kelderman, N.Baker, A.Driessen, "Compact Wavelength-Selective Switch for Gigabit Filtering in Access Networks", *IEEE Phot. Tech. Lett.*, Accepted for publication.

[6] B.Little *et al.,* "Microring resonator arrays for VLSI photonics", *IEEE Phot. Tech. Lett.,* vol. 12, pp. 323-325, 2000.

[7] Sai T. Chu *et al.*, "An Eight Channel Add-Drop Filter Using Vertically Coupled Microring Resonators over a Cross Grid", IEEE Phot. Tech. Lett., Vol. 11, No. 6, pp. 691-693, June 1999

[8] K. Worhoff *et al.,*"Silicon oxinitride - a versatile for integrated optics applications", *J. Electrochemical Society,* vol. 149(8), pp. F85-F91, 2002

[9] R. Meijerink *et al.*, "Thermally tunable, wide FSR switch based on micro-ring resonators", *Proc. Symposium IEEE/LEOS Benelux,* pp. 155-158, 2002

[10] D.H. Geuzebroek *et al.*, "Thermally tunable, wide FSR switch based on micro-ring resonators," *Proc. Symposium IEEE/LEOS Benelux*, pp. 155-158, 2002.