Spectral slicers for WDM access networks have been designed. The ultra-compact device consists of microring resonators with slightly increasing radius to generate a series of WDM channels. The spectral efficiency of the individual channels can be substantially improved by using a cascade of two identical ring resonators as higher order filter without introducing additional channel crosstalk.

Keywords: spectral slicers, WDM system, vertically coupled microring resonators, spectral efficiency, broadband source, crosstalk

Introduction

Conventional Wavelength Division Multiplexing (WDM) systems utilize narrowband coherent laser diodes as light source. These laser diodes are normally fabricated to be tunable over a wide range of wavelengths. With an increasing number of WDM channels, the number of laser diodes is also increasing and consequently the costs. Especially in the access network the use of spectral slicers is an attracting low-cost alternative as they utilize a single broadband source for creating the desired WDM channels. By using spectral slicers, however, the spectral efficiency and the shape of the optical filter response becomes an issue, as the power budget in these low-cost systems without optical amplifiers is critical. In order to realize spectral slicers, several devices such as Arrayed Waveguide Gratings (AWG) and Waveguide Grating Routers (WGR) [1] have been demonstrated. The drawback of these devices, however, is the relatively large space needed. Microring resonators, on the other hand, offer the possibility to realize ultra-compact devices with a chip area well below 1 mm$^2$. Moreover, the spectral efficiency of the individual WDM channels can be improved by cascading several microring resonators as a higher order filter with a nearly box-car shape.

In the following a feasibility study of spectral slicers based on microring resonators is carried out in detail. In addition, a discussion is given of the influence of cascading of microring resonators for a single WDM channel to the spectral efficiency.

Vertically coupled Microring Resonators

In order to realize the spectral slicers vertically coupled microring resonators are proposed, see ref. [2]. The cross section of the single device is given in Fig. 1. The straight waveguides are embedded in Plasma Enhanced Chemical Vapor Deposition (PECVD) SiO$_2$ and function as input and output channels. For an optimal technological realization a relatively thin straight waveguide core should be used to minimize overgrowing effects of the PECVD SiO$_2$ separation layer (g) due to the straight waveguides underneath. By using high refractive index material such as Low Pressure Chemical Vapor Deposition (LPCVD) Si$_3$N$_4$ (n = 1.98), the core thickness of the single mode straight waveguide with a width of 2 µm can be reduced to 140 nm. The ring resonator, also realized in Si$_3$N$_4$, has been designed such that the ring is single mode and has only a small phase mismatch with respect to the in- and output waveguides. During fabrication, Chemical Mechanical Polishing (CMP) is applied twice to remove the surface roughness of the intermediate PECVD SiO$_2$ layers. Fig. 2 shows a typical response of a single MR with 25 µm radius.

Fig. 3 shows the typical propagation loss of a MR as a function of wavelength determined by two ways, first the propagation loss is calculated back for each peak from the spectral responses and
second the propagation loss has been calculated by using quantitative image analysis [3]. The propagation loss increase for longer wavelengths is mainly due to the increasing bending loss of the MR. The ring resonator with the vertically coupled configuration show a relatively low off-resonance on-chip insertion loss, less than 0.1 dB [3].

The scattering and material loss of the in- and output waveguides is given in Fig. 4. The enhanced loss around 1520 nm is mainly due to the N-H overtone vibration, typically for as deposited PECVD SiON [6], [7]. In principle, by annealing the sample at a temperature of 1150 °C the maximum loss can be reduced to about 0.6 dB/cm [7].

**Design of Spectral slicers devices**

The spectral slicers are designed to be a part of a WDM transceivers for the access network as proposed in [8], [9]. Fig. 5 shows schematically its working principle. The broadband infrared source is fed to the input port of the spectral slicer made of a number of microring resonators with slightly different ring radius for selecting the desired part of the source spectrum. The radius of the
individual ring resonators (around 25 µm) is critical as an increase of 12.5 nm is sufficient to select an adjacent channel with 100 GHz channel spacing. In order to have a certain central wavelength based on the ITU grid, tuning can also be applied as demonstrated in [10].

For tuning purposes, a cladding layer such as polymers should be put on top of the microring resonators to allow efficient local heating by electrodes on top of the ring.

In the application of spectral slicers the spectral efficiency, which is the selected part of the power spectrum compared to the power spectrum in the same wavelength range of the source is becoming critical. Cascade of at least two microring resonators in a single WDM channel can substantially improve the spectral efficiency. Fig. 6 shows schematically the layout of the spectral slicers with single ring resonator (S1 with radius 25 µm and S2 with radius 25.0125 µm) and cascade of two identical ring resonators (D1 and D2). Fig. 7 shows the simulation results of drop responses for a single and a cascade of two ring resonators with different ring radius.

![Fig. 5: Working principle of the microring resonators as spectral slicers with a broadband infrared source](image)

![Fig. 6: lay-out of a two-channel spectral slicer based on microring resonators: S1: single ring resonator with radius 25 µm; S2: single ring resonator with radius 25.0125 µm; D1 and D2: set of ring resonators when S1 and S2 are cascaded by two identical ring resonators](image)

![Fig. 7: Drop port responses of a microring resonator based two channel spectral slicer; S1 and S2 curves obtained with single ring resonator; D1 and D2 obtained with the double ring resonators, see also Fig. 6](image)

Table 1 shows the parameters obtained from simulations for a two channel spectral slicer based on single or double ring resonators for each WDM channel. The crosstalk level of the single ring resonator response is –25 dB while for double ring resonator is –27 dB. In order to maintain the crosstalk level at –25 dB, the spectral efficiency of the selected WDM channel is relatively low for the single microring resonator due to the Lorentzian shape of the response. Cascading of at least two microring resonators in a single device results in a box-like shape response [10], [11]. By increasing the coupling factor of the double ring resonators with respect to the single ring resonator,
the response of the double ring resonators can be broadened without deterioration of the crosstalk level. In this way, the spectral efficiency of the WDM channel can be improved by 240%.

<table>
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<tr>
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<th>Radius (µm)</th>
<th>Coupling factor</th>
<th>Propagation loss (dB/cm)</th>
<th>Crosstalk (dB)</th>
<th>Spectral efficiency</th>
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<tr>
<td>Single ring</td>
<td>25 and 25.0125</td>
<td>0.017</td>
<td>2</td>
<td>-25</td>
<td>0.18</td>
</tr>
<tr>
<td>Double ring</td>
<td>25 and 25.0125</td>
<td>0.04</td>
<td>2</td>
<td>-27</td>
<td>0.43</td>
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Table 1: Summary of the parameters of a microring resonator based spectral slicer obtained by simulations

Considering a realistic launch power of 1 mW/ channel an estimated output power of the spectral slicer per channels is –7.4 dBm for single ring and –3.7 dBm for double rings. If the receiver sensitivity is –26 dBm then the power budget is 18.6 dB for a single ring and 22.3 dB for a double ring spectral slicer.

Conclusion

A feasibility study of microring resonators as spectral slicers has been carried out in detail. Cascading ring resonators in a single WDM channel can substantially improve the spectral efficiency. The shift of the resonant wavelengths can be obtained by changing the ring radius of the microring resonators. In order to fit the central wavelengths to the ITU grid, probably thermal tuning should be applied.

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