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ULTRA-COMPACT SPECTRAL SLICER DEVICES BASED ON MICRORING RESONATORS

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In Wavelength Division Multiplexing (WDM), access network spectral slicer devices in connection with a broadband light source are attracting low-cost alternatives for the laser diodes that are required for transmission in the desired wavelength channels. The proposed ultra-compact spectral slicer devices consist of microring resonators with slightly different radius and consequently slightly different resonant wavelength. Single and cascaded multiple microring devices have been fabricated and characterized to demonstrate the desired functionality. Cascaded devices show better performance in term of lower crosstalk, higher rejection ratio and faster roll-off. Moreover, they open the possibility to improve the spectral efficiency of the individual channels without introducing additional channel crosstalk.

Keywords: WDM access network; spectral slicer; crosstalk; rejection ratio; roll-off; cascaded microring resonators.

1. 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 attractive 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[2–5] with a chip area well below $1\,\mathrm{mm}^2$. Moreover, the spectral efficiency (the 3 dB bandwidth/spectral width of a single WDM channel) of the individual WDM channels can be improved by cascading several microring resonators as a higher order filter with a nearly box-car shape spectral response.[6–11] In this paper, spectral slicer devices based on microring resonators will be discussed and the experimental results are demonstrated for the first time.

2. Working Principle of Spectral Slicer Devices

Figure 1 shows the working principle of spectral slicer devices. A certain part of the spectral envelope of a broadband light source, $\mathrm{L}(\lambda)$ is selected by the spectral slicer device with a filter transmission function, $\mathrm{F}(\lambda)$. The shape of the resulting selected wavelength band, $\mathrm{S}(\lambda)$ is important because it influences the channel crosstalk. For a reduced channel crosstalk a fast roll-off of selected wavelength band is required.

Spectral slicer devices based on microring resonators consist of single ring or cascaded multiple microrings. Their working principles are similar to demultiplexers based on microring resonators. For spectral slicer applications, cascaded multiple ring devices have clear advantages because their spectral response has a higher rejection ratio and faster roll-off. This is illustrated in Fig. 2 where a comparison is given between the experimental spectral response of single- and cascaded two-ring devices. In a slicer array, the difference in the ring radius results in a proportional resonant wavelength shift in the spectral response. Therefore, a set of microring(s)

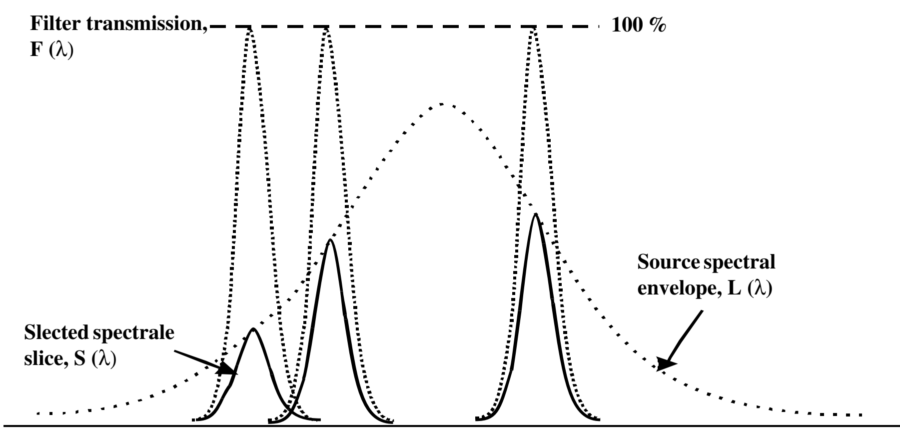

Fig. 1. Working principle of the spectral slicer devices.

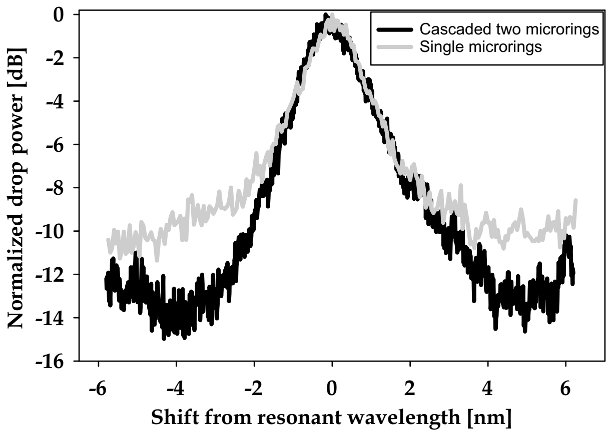

Fig. 2. Spectral responses of microring devices; gray curve: single ring device; black curve: cascaded two-ring device.

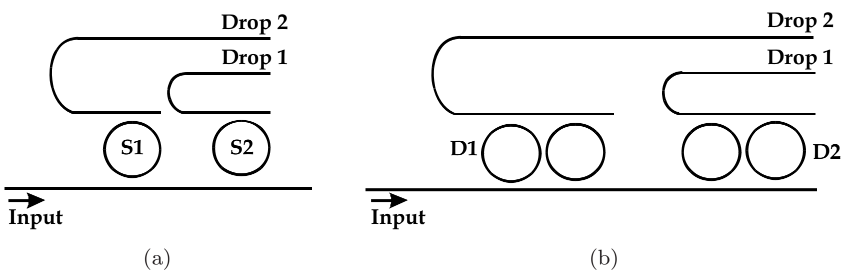

Fig. 3. Schematic layout of the spectral slicer devices: (a) single ring (b) cascaded two-rings.

with different ring radius selects different wavelength and creates a set of channels. Figure 3 shows a schematic layout of two channels spectral slicer devices based on single- and cascaded two-ring. Figure 3(a) shows the device consisting of two single rings (S_1 and S_2) with slightly different ring radius that defines the channel spacing. Figure 3(b) shows the cascaded two-ring (D_1 and D_2) device. The radius of the rings within each set D_1 or D_2 are identical. Between D1 and D2, however, there is a small shift in radius according to the desired resonance wavelength.

3. Design and Realizations

In the design, the vertical coupling configuration of the straight waveguide and microring resonator has been chosen in order to facilitate the technological realization.[12] The radius of the microring has been optimized to be 20 μm resulting in a Free Spectral Range (FSR) of about 10 nm. Figure 4 shows the cross-section of the device realized in SiON technology[13–14] using conventional optical photolithography. The buffer layer is approximately 8 μm thermal oxidized wafers. The straight port waveguides with dimension $2 \times 0.14\,\mu$m and the microring resonators have

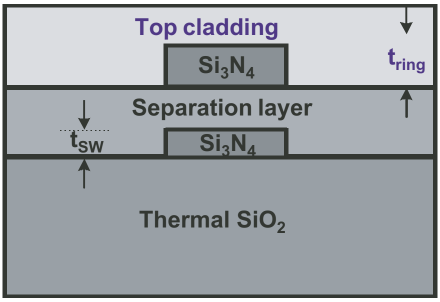

Fig. 4. Schematic layout of cross section of the realized device; t_{ring}: thickness of the ring waveguide; t_{sw}: thickness of the straight waveguide. The separation layer has been made of Tetraetilorthosilicate (TEOS) oxide.

been designed to be single mode and having the same effective refractive index, n_{eff}. Both are made of Si_3N_4[13–14] deposited by low-pressure chemical vapor deposition (LPCVD). Tetraethylorthosilicate (TEOS) oxide ($n = 1.427$) has been used for the separation layer with a thickness of 1 μm to provide the desired coupling of light between the straight waveguide and the microring resonator. The top cladding of this device is air. In the case of cascaded microring devices, the distance between the nearest neighbor rings is about 80 μm to make sure that there is no direct interaction between the rings.[6–9] As a prove of principle, the channel spacing has been designed to be 3 nm. This corresponds to approximately 39 nm increase or decrease of the ring radius.

4. Experimental Results

In order to characterize the devices, end-fire coupling has been used to couple TE polarized light from a tunable laser to the input port of the straight waveguide (see Fig. 3). The output from the drop port (drop 1 and drop 2) has been collected by another objective lens and projected to a detector. The spectral responses of the single- and cascaded two-ring devices as a function of wavelength are presented in Fig. 5 where the black curve is the spectral response obtained from drop 1 and the gray curve is the spectral response obtained from drop 2 (see Fig. 3). By fitting the parameters of the simulation model to the experimental data, the propagation loss inside the microring has been estimated to be 9 dB/cm or 0.1 dB/roundtrip. The field coupling is about 0.65. The FSR obtained by the experiment is 10 nm. The rejection ratio is 10 dB and 16 dB for single- and two-ring devices respectively. The channel spacing obtained from the measurement is about 3.15 nm and 2.4 nm for single- and two-ring devices respectively. The difference in experimental values of the channel spacing compared to the design is mainly due to the technological tolerance of the microring geometry. These results demonstrate that the current fabrication technique can control the ring radius within 8 nm. This is confirmed by a comparison of the resonant wavelength of rings designed with

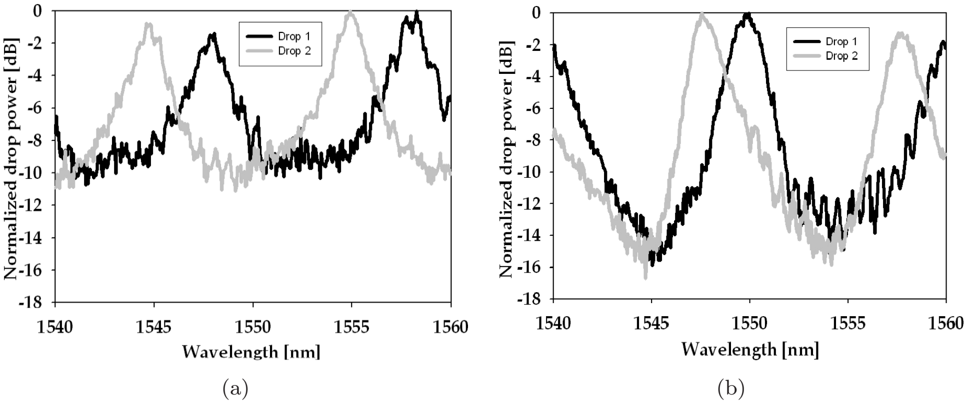

Fig. 5. Spectral response of spectral slicer devices based on microrings with radius of μm: (a) single ring per drop channel (b) two cascaded rings per drop channel.

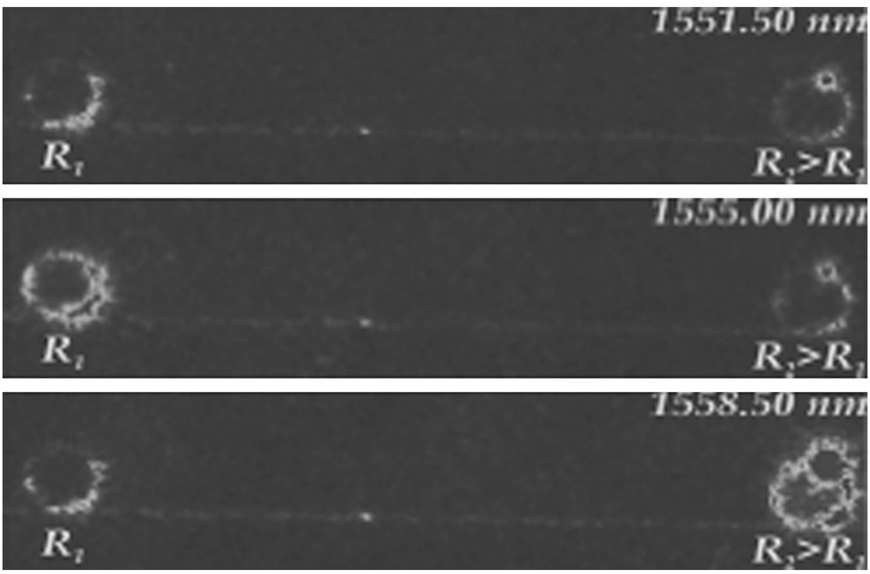

Fig. 6. IR pictures taken with an IR digital camera from the top of the device. Top: off-resonance for both rings at 1551.50 nm; middle: ring with radius R_1 on-resonance and ring with radius R_2 off-resonance at 1555.00 nm; bottom: ring with radius R_2 on-resonance and ring with radius R_1 off-resonance at 1558.50 nm.

identical ring radius that exhibit a variation of the radius of less than 0.5×10^{-3}. The roll-off of the cascaded two-ring devices is 1.28 faster than single-ring devices. The crosstalk of the single-ring device is –9 dB and for the cascaded two-ring device is –11 dB (after correcting for the influence of the shifted the channel spacing). Figure 6 demonstrates the functional behavior of single-ring device already presented in Fig. 5(a) by taking its scattered power with an Infrared (IR) digital camera from the top of the device. The pictures show that at a wavelength of 1551.50 nm, both of the rings, is off-resonance. At 1555.00 nm, only the ring with radius R_1 is on-resonance and at 1558.50 nm, the ring with radius R_2. These pictures confirm qualitatively that the device works as expected.

5. Conclusions

A potential application of microring resonators as spectral slicer devices has been demonstrated for the first time. A better control of the microring radius, however, is required to achieve precise channel spacing as expected in the design. This can be achieved by applying advanced fabrication techniques with improved lithography.

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