Design of the Novel Wavelength Triplexer Using Multiple Polymer Microring Resonators

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Abstract. *We report about new design of wavelength triplexer using multiple polymer optical microring resonators. The triplexer consists of two downstream wavelength channels operating at 1490 ± 10 nm, 1555 ± 10 nm and one upstream wavelength channel operating at 1310 ± 50 nm. The parallel coupled double ring resonator was used for separation of the optical signal band at 1555 nm and filtered out signal bands 1310 nm and 1490 nm. The serially coupled triple optical microring resonator was used for separation of the optical signal band at 1490 nm and filtered out signal bands 1310 nm and 1555 nm. The design was done by using FullWAVE™ software by the finite-difference time-domain method. Simulation showed that optical losses for band at 1555 nm were -3 dB and crosstalk between signal bands 1555 nm and 1490 nm was 24 dB. Calculated optical losses for channel 1490 nm were less than -2.5 dB and signal bands at 1555 nm was filtered out with less than 18 dB loss. The bands at 1310 nm were fully filtered out from both downstream wavelength channels operating at bands 1490 nm and 1555 nm.*

Keywords

Microring resonators, triplexer, polymer optical waveguides.

1. Introduction

There is increasing interest in the optical triplexer structures in the new Passive Optical Network (PON) systems such as Fibre to the Home (FTTH) arising from a great development of ultra-high-speed internet communications for home entertainment or industrial applications. The optical triplexer transmits 1310 ± 50 nm upload data and receives 1490 ± 10 nm download data as well as 1555 ± 5 nm download video signals for cable TV applications. These three wavelengths are used according to the international TDM-PON ITU-T G.983 and G.984 standards.

Most of the existing triplexers use cascade thin film filters (TFF) but it is not easy to integrate TFF with other devices and difficulties with packaging makes TFF unsuitable for mass production and cost reduction [1-4]. Arrayed-waveguide gratings [5-7], planar lens [8], cascaded directional coupler [9] have also been utilized to realize triplexing function. Nowadays there are also the reports on design and properties of the triplexer, which operates on multimode interferometer principle [10, 11]. Another paper reports on using directional couplers based on submicron silicon rib waveguides [12].

In this paper we present a novel triplexer based on multiple polymer optical microring resonators (OMRs). In the frame of it we proposed serially coupled triple OMR to separate signal band at 1555 nm and filtered out bands 1310 nm and 1490 nm. For separation signal band at 1490 nm and filtered out bands 1310 nm and 1555 nm we proposed parallel-coupled double OMR.

Microring resonators are usually made of Si-SiO_2, Ta_2O_5-SiO_2, SiN, SiON and also III/V semiconductors such as GaInAsP on InP and AlGaAs on GaAs [13-17]. Such OMR elements have suitable properties but deposition technologies are complicated and expensive. Therefore we decided in our design to rely on polymer materials as polymers have appropriate properties such as suitable refractive index, low optical losses, reasonable time and temperature stability. Polymer structures can be also fabricated by easy fabrication processes [18-21] and there are also friendly to the environment.

For our OMR we chose Epoxy Novolak Resin (ENR) polymer as core waveguide layer because of its excellent optical properties (optical losses 0.15 dB/cm at 1310 nm, 0.46 dB/cm at 1550 nm) and easy fabrication process [22], [23], [24]. Silicon with silica buffer layer was then used as a substrate because this material provides good compatibility with the silicon-based technology and enables easy integration with other optical and electrical elements.

2. Principle of the Triplexer Structure

A triplexer coupler is designed for the FTTH systems and it is used for demultiplexing of two downstream signal bands (1490/1555 nm) from a single fiber to a receiver and at the same time to couple the upstream signal band

(1310 nm) from a transmitter to the same fiber. Fig. 1a shows a principle of the universal triplexer structure and Fig. 1b shows a concept of our OMR triplexer design.

The structure consists of two multiple microring resonators (see Fig. 1b). In the input of this structure there is a signal band 1550-1560 nm separated by the first micro resonator (I.); afterwards the signal band at 1480-1500 nm is separated by the second micro resonator (II.). Simultaneously, the signal band at 1260-1360 nm goes through the triplexer; however, this band does not affect the bands at 1555 nm and 1490 nm. This arrangement is also designed to provide a minimal crosstalk between the bands.

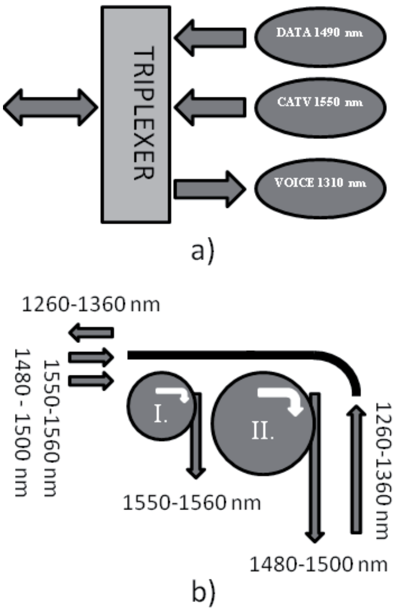

Fig. 1. a) Principle of the triplexer structure, b) the schematic configuration of the OMR triplexer.

3. Design of the Single Mode Optical Ridge Waveguide

Accurate proposition of the microring resonator requires to start with designing single mode (SM) optical waveguides. The design of the SM ridge waveguides was done by using 3D beam propagation method using BeamPROP^{TM} software from RSoft Company [25]; the proposed structure is shown in Fig. 2. ENR polymer was used as core waveguide layer deposited on silica-on-silicon substrate.

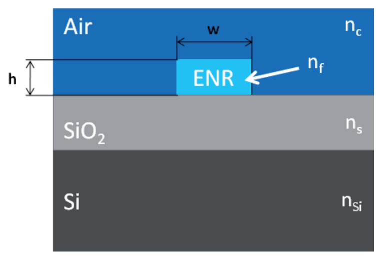

Fig. 2. Schematic view of the ENR optical polymer ridge waveguide.

Protection cover layer was not applied because of possibility of easy optical coupling between bus waveguides and ring resonator.

Prior to the actual proposal the silicon substrate, silica buffer layer and ENR optical waveguide layer were measured by ellipsometry in spectral range from 600 nm to 1600 nm. The obtained data for the most important wavelength are shown in Tab. 1.

λ (nm)	Refractive index (-)		
	Si	SiO_2	ENR
650	3.811	1.465	1.598
1260	3.507	1.457	1.581
1310	3.499	1.456	1.582
1490	3.479	1.456	1.581
1555	3.474	1.456	1.581

Tab. 1. Refractive indices of the applied materials measured by optical ellipsometry.

The dimensions of the SM ridge waveguides calculated for TE mode for wavelength 1310, 1490 and 1555 nm are shown in Tab. 2. From the table it follows that to obtain the SM waveguides for the above mentioned wavelengths the ridges should be 1.42 µm high (*h*) and 0.53 µm wide (*w*). The thickness of the silica buffer layer was set to 3 µm. Previous calculations [26] have shown that this value is sufficient for the out-coupled energy to silicon substrate as the energy of the evanescent wave will be less than 1 %.

λ (nm)	w (µm)	h (µm)
1310	0.53	1.42
1490	0.61	1.62
1555	0.63	1.68

Tab. 2. Calculated waveguide thicknesses for optical polymer waveguides structure shown in Fig. 2 (TE mode).

4. Design of the Optical Microring Resonator Structures

The fundamental building blocks of the OMR structures are one input bus waveguide, ring or disk resonator and output bus waveguide (see Fig. 3a). There are principally two configurations for the coupling between the ring or disk resonator and the bus waveguides, namely, a vertical coupling configuration (see Fig. 3b), where the bus waveguides are either on the top or beneath the ring or disk resonator and the lateral coupling configuration (see Fig. 3c), where the bus waveguides and the ring or disk resonator are in the same plane. Both coupling schemes have advantages and disadvantages and it is up to the device designer to decide which one is for the desired applications more suitable [27]. Here we decided to design a laterally coupled optical microring resonator because it allows deposition in one technology-lithography step.

The most important parameters of the OMR filter are resonant wavelength λ_r, Free Spectral Range (*FSR*), and

Full Width at Half Maximum (*FWHM*). The definition of these parameters can be found in [28]. For OMR, also further parameter are very important, as Finesse *F* and Quality *Q,* but because we designed add/drop optical filter such parameters are not so much important.

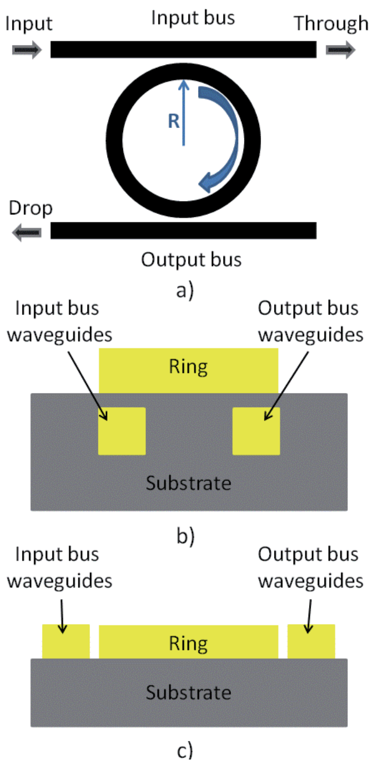

Fig. 3. a) Schematic view of a four-port ring resonator, Cross-section of the b) vertically, c) laterally coupled OM resonator.

The OMR structures were designed by the Finite-Difference Time-Domain method (FDTD) using 2D Full-WAVE™ software [25].

4.1 Micro-Ring Filter 1555 nm

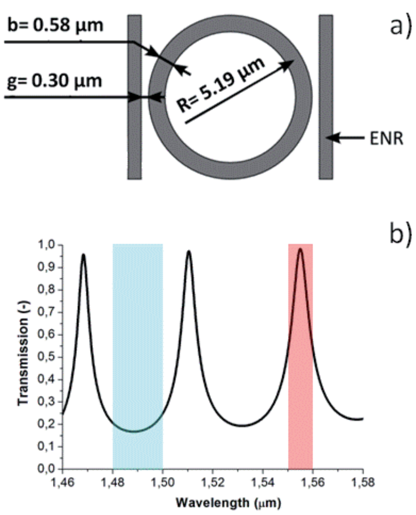

Fig. 4. a) Schematic view of the OMR design, b) transmission characteristic of the OMR design.

The first step was designing OMR optical filters for operation signal band 1555 ± 5 nm and filtered out signal band at 1490 ± 10 nm. The detailed drawing of the designed single OMR structures is shown in Fig.4a and the calculated transmission characteristic for this OMR filter is shown in Fig. 4b. In this case the simulation shows that the signal band at 1490 nm is not adequately filtered out and the resonance curve at 1555 nm signal is not enough wide.

Therefore we studied a possibility to improve the transmission characteristics of this structure by serially coupled double OMR. The simulation showed significantly improved shape of the transmission characteristics. Thus we optimized this structure and proposed serially coupled triple OMR shown in Fig. 5; calculated transmission characteristic is shown in Fig. 6.

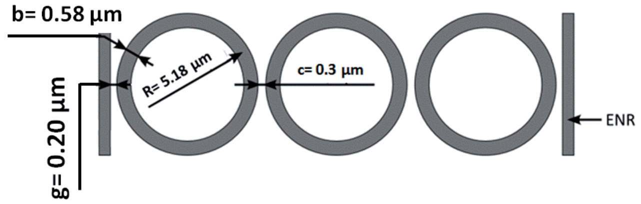

Fig. 5. Schematic view of the designed serially coupled triple OMR structure.

Fig. 6 shows that the value of the FSR is 44 nm and FWHM is 12 nm, which means that this serially coupled triple OMR have suitable properties for operating wavelength band 1555 nm and filtered out the signal band at 1490 nm.

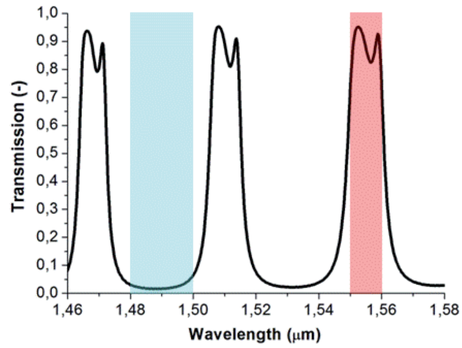

Fig. 6. Transmission characteristic of the serially coupled triple OMR.

4.2 Micro-Ring Filter 1490 nm

Modeling of the OMR showed that it was not possible to use single OMR for optical filter at 1550 nm. Serially coupled triple OMR had suitable properties for this optical filter but the modeling also showed that serially coupled OMR was not appropriate for operating wavelength band at 1490 nm. Therefore, for this purpose, we designed a parallel-coupled double OMR. The drawing of this structure is shown in Fig. 7a and calculated transmission characteristic is given in Fig. 7b.

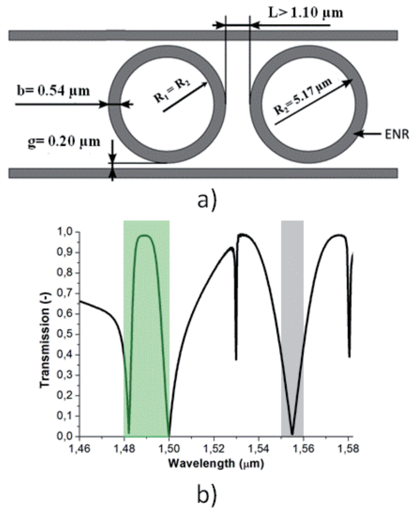

Fig. 7. Parallel-coupled double OMR design, a) schematic view, b) transmission characteristic.

Transmission characteristic showed that properties of such filter were not satisfactory. Therefore we optimized the design of the parallel-coupled double ring resonator and improved the value of the gap (g) between the input waveguide and OMR to be 0.22 µm and the width (b) of the ring resonators to be 0.54 µm. The radius (R_1) of the first resonator was approximately 4.8 µm and radius (R_2) of the second resonator was approximately 5.55 µm. The calculated transmission characteristic for this optimized OMR is given in Fig. 8.

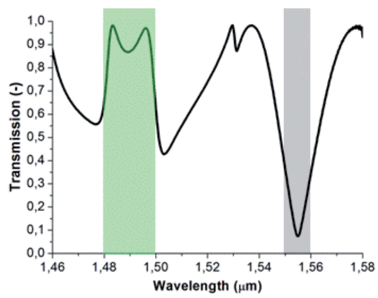

Fig. 8. Transmission characteristic of the optimized parallel coupled double OMR.

The resulting parameters of this proposed parallel coupled double ring resonator are FSR = 44 nm, FWHM = 22 nm and this structure has suitable properties for both operating optical band 1490 ± 10 nm and filter out signal band at 1555 ± 5 nm.

5. Design of the Wavelength Triplexer

The designed optical triplexer consists of serially coupled triple OMR; parallel coupled double OMR and three waveguides with four ports. Schematic configuration of the designed optical triplexer structure is shown in Fig. 9. The OMR structures divided two download signal bands λ_1 = 1480-1500 nm and λ_2 = 1550-1560 nm. The serially coupled triple OMR is used for separation of the wavelength band λ_2 while the parallel coupled double OMR for separation of the wavelength band λ_1. To the input waveguide (Port 1) two signals bands are coupled in. The signal λ_2 is coupled into serially coupled triple OMR and then goes out into the output waveguide (Port 3). The signal λ_1 is not coupled into serially coupled triple OMR and goes farther into the output waveguide but before the output (Port 2) it is coupled into parallel coupled double OMR and goes to output Port 4. The simulation showed that this serially coupled triple OMR had excellent properties and sufficiently filtered out the signal band λ_1 (see Fig. 6). The parallel-coupled double OMR was no ideal for filtering out the signal band λ_2 (see Fig. 8) but inserting it after serially coupled OMR made the most of the signal bend λ_2 separated. This solution guaranteed low crosstalk between the bands. The upload data band λ_3 (1310 ± 50 nm) was coupled into the Port 2 and went through to the Port 1. In Fig. 9 dash line arrows denote transfer of the signal λ_3 to the waveguides 3 and 4 and it is evident that this signal cannot affect the signal bands λ_2 and λ_1 at the output ports 3 and 4, resp. It means that no part of the signal λ_3 was coupled into serially coupled OMR via the Port 3 as well as the parallel OMR did not couple this signal band into the Port 4.

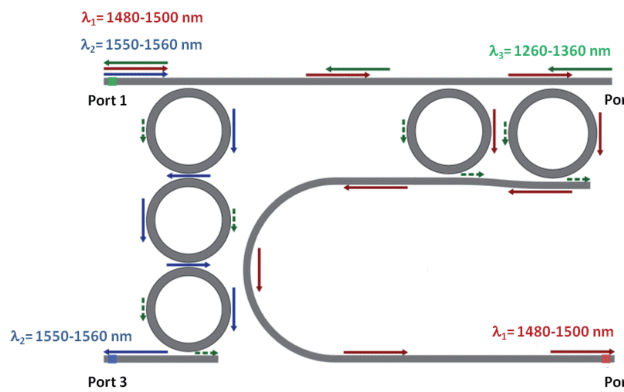

Fig. 9. Schematic configuration of the design optical triplexer.

The calculated transmission characteristic on the output Port 3 is shown in Fig. 10 showing that optical attenuation at band 1555 nm is around -3 dB. The calculated attenuation at the band 1490 nm is -24 dB and for wide band 10 nm this value is -33 dB. The value of the Signal-to-noise Ratio (SNR) is 21 dB.

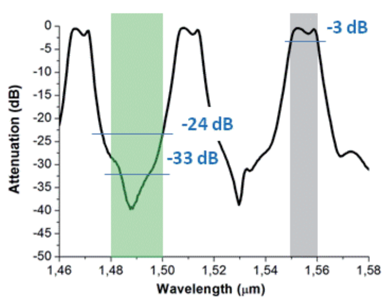

Fig. 10. Transmission characteristic on the Port 3 for wavelength band 1550-1560 nm.

The calculated transmission characteristic on the Port 4 is shown in Fig. 11. Simulation shows that optical attenuation for the signal band 1490 nm are around -2.5 dB and optical attenuation for the signal 1550 nm was determined to -9 dB.

Optical attenuation in the case of the optical band 1555 ± 5 nm was calculated to be -18 dB. The value of the SNR for the major part of the signal band is around 15.5 dB.

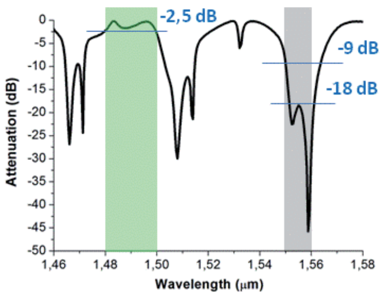

Fig. 11. Transmission characteristic on the Port 4 for wavelength band 1480-1500 nm.

The calculated transmission characteristic for the optical band at 1260-1360 nm on the Port 1 is shown in Fig. 12. Fig. 12 shows that in the spectral range 1260 to 1360 nm there are three bands with low optical losses. When we supposed that maximum of the optical attenuation was at -3 dB for wavelength 1265-1285 nm, 1294 to 1318 nm and 1325-1351 nm then transmitted bandwidth is 70 nm.

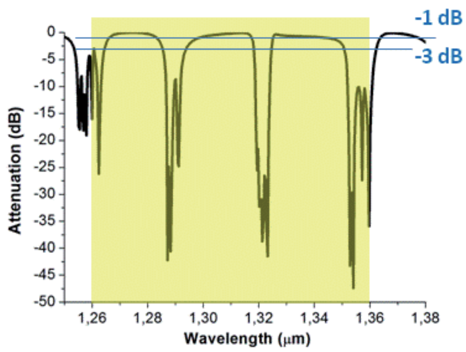

Fig. 12. Transmission characteristic on the Port 1 for wavelength band 1260-1360 nm.

6. Conclusion

We report about design of the polymer optical triplexer that transmits 1310 ± 50 nm upload data and receives 1490 ± 10 nm and 1555 ± 5 nm download data. The serially coupled triple OMR is used for separation of the wavelength band at 1555 nm and parallel-coupled double OMR separates the wavelength band at 1490 nm. The design was done by using 2D FullWAVE^{TM} software. Epoxy Novolak Resin polymer was used as core waveguide layers deposited on silica on silicon substrate. Simulation and modeling showed that this structure had excellent properties. On the output the band at 1555 nm had optical attenuation around -3 dB and crosstalk for the band at 1490 nm was lower than 24 dB while the output for the band at 1490 nm revealed the optical attenuation lower than -2.5 dB and crosstalk for the band at 1555 nm was found lower than 18 dB. The upstream signal band (1310 nm) was not coupled into these two output waveguides.

Acknowledgements

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