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# ACTIVE AND PASSIVE MICRORING RESONATOR FILTER APPLICATIONS IN GaInAsP/InP

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## Abstract

Single and double microring resonator filters are demonstrated with radii of 100 µm and 200 µm. The resonators have the shape of a racetrack. Multimode interference (MMI) couplers and codirectional couplers are used for coupling. The single ring resonator contains two codirectional couplers and includes an integrated gain section, which controls the energy flow in the ring. The passive double ring resonator contains two MMI couplers for I/O coupling and a codirectional coupler in between the rings. A free spectral range of 50 GHz and 100 GHz has been realized.

## I. Introduction

Active and passive ring resonator devices are promising candidates for wavelength filtering, routing, switching, modulation, and multiplexing/demultiplexing applications. Ring resonators do not require facets or gratings for optical feedback and are particularly suited for monolithic integration with other components. The passband shape of ring resonator filters can be custom designed by the use of multiple coupled resonators. The filter characteristic (steep roll-off, flat top and high contrast > 20 dB) depends on the energy flow in the resonators which defines the desired filter shape. Therefore it is important to achieve smooth sidewalls for low waveguide losses, deep etched curvatures for low bending losses and precise waveguide dimensions for power splitting. Steeper roll-off and out-of-band rejection require cascaded microring resonators. The implementation of gain sections within the ring resonator opens the possibility to adjust the energy flow for optimum response. The characteristic response of designed, manufactured and simulated microring resonator filters with codirectional couplers, active sections and multimode interference (MMI) couplers, are presented.

## II. Design and fabrication

We investigated and compared different ring resonator arrangements for a free spectral range (FSR) of 50 GHz and 100 GHz. In a first step we fabricated passive ring resonators with small bending losses and low insertion losses. The device shown in Fig. 1 consists of: InP substrate, GaInAsP ($\lambda_{gap}$=1.06 µm, 0.38 µm), InP etch stop layer (0.020 µm), GaInAsP ($\lambda_{gap}$=1.06 µm, 0.84 µm), InP cap (0.2 µm). The waveguide design assures both, a monomodal propagation of the light in the waveguide and, due to a good confinement, low bending losses. Additionally, the waveguide ridge was deeply etched on the outer side of the waveguide in the curvatures. The waveguide width is 1.8 µm. The dimension of the used 3 dB-MMI couplers are 150 µm x 6 µm. The ring resonators were structured using standard photolithography and a $CH_4/H_2$ reactive ion etching technique with a $SiN_x$ mask, serving also as the mask for the deep etching process. In order to reduce the formation of polymers during dry etching and to minimize the sidewall roughness a small fraction of oxygen was added. The facets of the input and output waveguides have been antireflection coated in order to avoid Fabry-Perot resonances in the straight waveguide section.

## III. Results of the passive double ring resonator

The double ring resonator (DRR) in Fig. 1 consisted of two rings with R = 100 µm which were coupled using two 3dB-MMIs with a length of 150 µm at the input and output port and a codirectional coupler between the two ring resonators, resulting in a FSR of 100 GHz.

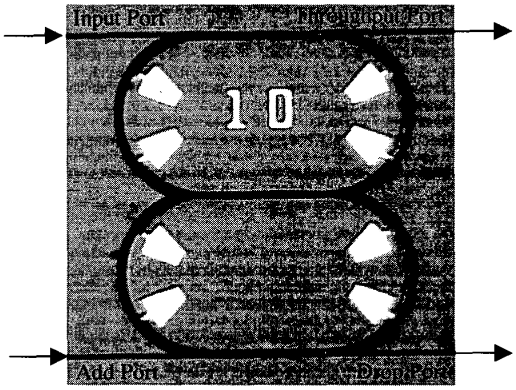

Fig. 1. Photograph of a fabricated DRR.

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The codirectional coupler has a length of 150 µm and a coupler gap of 1 µm. The input region of the codirectional coupler including the deep etching of the waveguide in the curved sections is shown in Fig. 2. The coupling factor was determined to be 0.06. The pads inside the resonators in Fig. 1 are connected to platinum resistors which are located on top of the waveguide in the curved sections. The platinum resistors can be used to adjust the optical length of the resonator to the required wavelength.

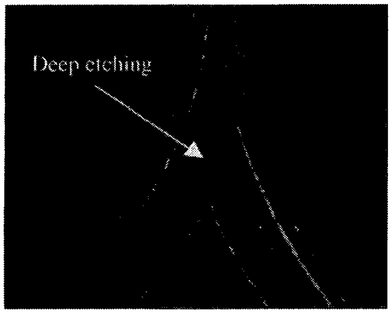

Fig. 2. Deep etching on the outer side of the waveguide in the curvature.

The ring resonator was characterized using a tapered fiber and sweeping the wavelength of an external cavity laser. The ring resonator under investigation here is polarization dependent due to waveguide asymmetry. A polarization dependence of 3 dB was obtained. The measurements reported here have been performed for TE polarization particularly with regard to a future integration with laser components. A characteristic response of the double ring resonator is shown in Fig. 3. The insertion loss was 7 dB (including the coupling losses of approximately 5dB). The contrast of the throughput port and the drop port are about 14 dB.

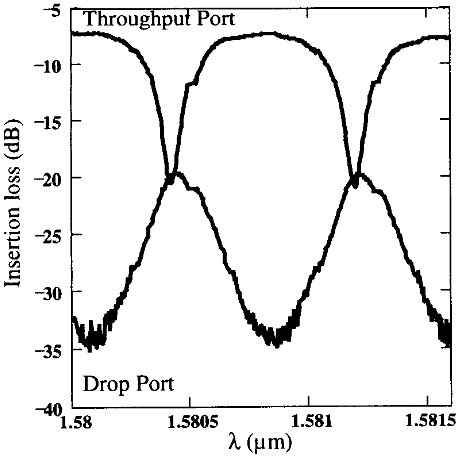

Fig. 3. Filter characteristic of the passive double ring resonator.

The full width at half maximum (FWHM) for both of the ports was measured to be 0.2 nm resulting in a finesse of 4. Cascaded ring resonators as shown in Fig. 1 can be designed for achieving a broader FWHM with lower finesse. The broadening is necessary for practical applications. The other important feature is the incorporation of a tuning function. The platinum resistors enable exact tuning to a specific wavelength. So it is possible to tune to the ITU grid. The diagram in Fig. 4 shows DRR tuning by using the integrated Pt-heaters.

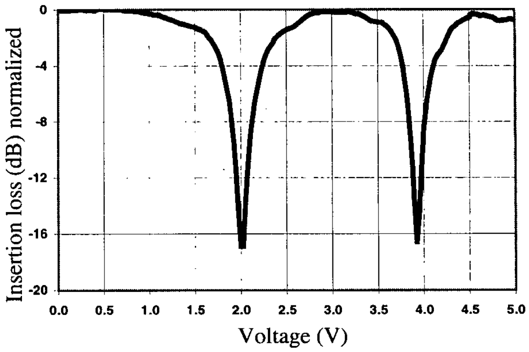

Fig. 4. Tuning of the DRR using integrated Pt –heaters.

The measurement was performed by adjusting the throughput port to maximum transmission at the corresponding wavelength. By detection of the response of the throughput (drop) port the voltage was continuously increased. At a voltage of 2 V and 4 V, the signal is "dropped" with a crosstalk even better than 16 dB. The second minimum at 4 V is due to the fact that the n+1 wavenumber fits into the resonator. DRRs are excellent candidates to be used as interleavers in DWDM systems for the spacial separation of the DWDM channels into two complementary sets at twice the original channel spacing. (e.g.: an incoming spectrum with a channel spacing of 50 GHz is transferred into two sets having a channel spacing of 100 GHz.)

## IV. Simulation

In order to improve the design of single ring resonators a model was developed for parameter extraction. The model for the calculation is shown in Fig. 5.

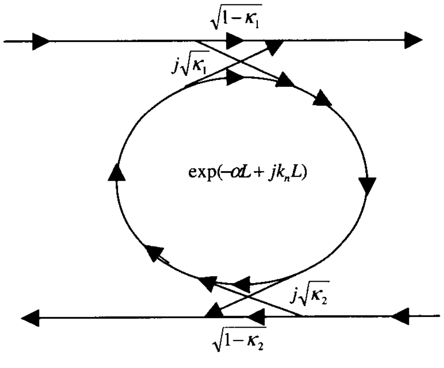

Fig. 5. Simulation model for the SRR.

The intensity relation for the throughput port is given by:

$$\frac{I_{t1}}{I_{i1}}=\frac{1-\kappa_1-2\sqrt{1-\kappa_1}\sqrt{1-\kappa_2}\,e^{-\alpha L}\cos(k_nL)+(1-\kappa_2)e^{-2\alpha L}}{1+(1-\kappa_1)(1-\kappa_2)e^{-2\alpha L}-2\sqrt{1-\kappa_1}\sqrt{1-\kappa_2}\,e^{-\alpha L}\cos(k_nL)} \quad (1)$$

The intensity relation for the drop port is given by:

$$\frac{I_{t2}}{I_{i1}}=\frac{\kappa_1\cdot\kappa_2 e^{-\alpha L}}{1+(1-\kappa_1)(1-\kappa_2)e^{-2\alpha L}-2\sqrt{1-\kappa_1}\sqrt{1-\kappa_2}\,e^{-\alpha L}\cos(k_nL)} \quad (2)$$

with: $I_{i1}$ the inserted intensity, $I_{t1}$ the transmitted intensity, $I_{t2}$ the dropped intensity, $\kappa_{1,2}$ coupling coefficients of the upper and lower coupler, L length of the resonator, $\alpha$ attenuation coefficient, $k_n$ the propagation constant. This first approach simulates the response of the SRR and does not consider the transition losses and the losses resulting from the couplers. The response for a single ring resonator with compensated ring losses and coupling factors of 0.45 for both symmetrical couplers is shown in Fig. 6. The transmission difference between the minima and the off-resonant values for the throughput port is more than 20 dB. Of course, best on/off ratios are achieved for $\alpha = 0$, then the intensity relation (1) = 0.

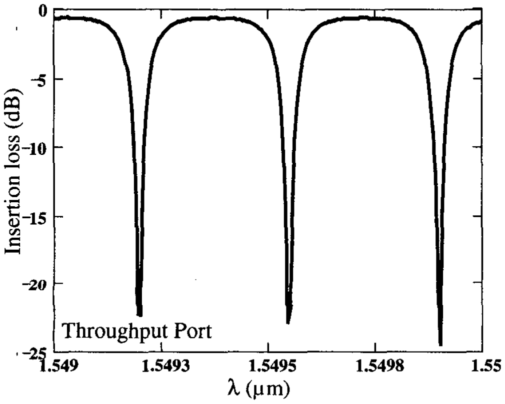

Fig. 6. Simulated SRR with compensated ring losses.

## V. Results of the single ring resonator with active section

The performance of passive ring resonators is limited by internal losses. Therefore an active section has been implemented in a single ring resonator (SRR) (Fig. 7).

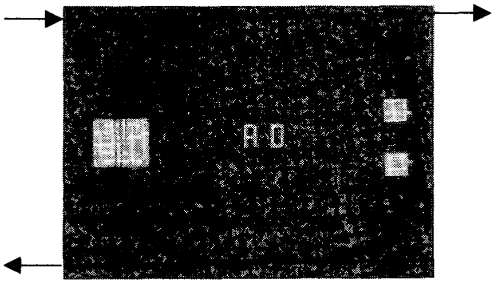

Fig. 7. Photograph of a fabricated SRR with gain section.

A standard ridge waveguide laser structure was used for the gain section, which required an additional epitaxial growth step. The layer sequence of the ridge waveguide structure from top to bottom is: GaInAs (0.2 μm), InP (1.3 μm), 6 quantum wells (Q-1.29), n-GaInAsP (0.2 μm), InP-substrate. The SRR included two codirectional couplers with a length of 250 μm and a coupler gap of 0.8 μm. The ring radius is 200 μm. The coupling factors were determined to be 0.45. This design assures a FSR of approximately 50 GHz. Again a platinum resistor was integrated. The length of the active section was 100 μm. The butt coupling losses at the passive/active waveguide interface have been calculated by the finite difference method (cf. Fig. 8). The calculated vertical and lateral offset between the active and passive waveguide results in a minimum theoretical coupling loss of 1 dB.

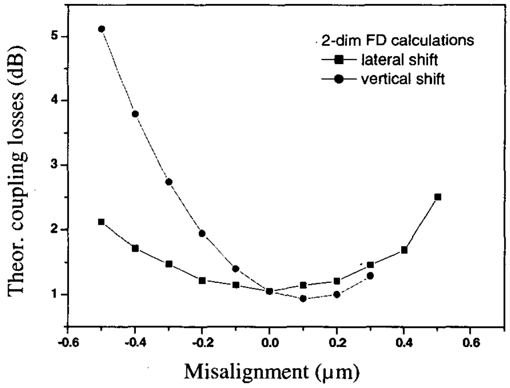

Fig. 8. Calculated coupling losses of the passive/active interface.

A SEM photograph of a fabricated passive/active junction is shown in Fig. 9.

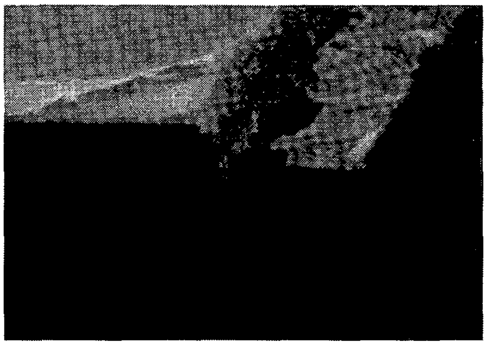

Fig. 9. SEM photograph of the passive/active interface.

The measurement was performed as described for the DRR in TE polarization. The characteristic response of the throughput port is shown in Fig. 10 with the SOA switched on and off. Operating the SOA improves the on/off ratio up to 10 dB and the signal level by about 2 dB. Obviously, the compensation of the internal losses was insufficient and parameter matching has to be improved.

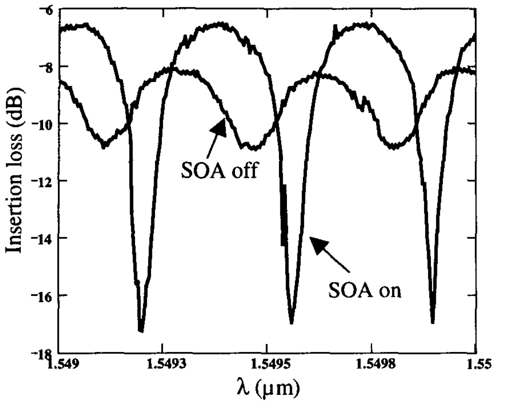

Fig. 10. Result of the SRR with integrated gain section.

In the case of the fabricated SRR with integrated gain section, the coupling losses of the active/passive butt joint are still to high. Therefore the ring losses could not be compensated sufficiently to achieve the expected high on/off ratio predicted by the simulation. The active/passive transition has to be improved.

## VI. Summary

Single and double GaInAsP/InP microring resonators with a free spectral range of 50 GHz and 100 GHz were fabricated and characterized. The single ring resonator with integrated gain section achieved an on/off ratio of 10 dB. The performance is limited by the transition losses at the active/passive interface which have not been compensated sufficiently so far. In purely passive double ring resonators on/off ratios of –14 dB have been realized. In addition, the tuneability of the DRR was demonstrated using platinum resistors. In future, tailored passband characteristics by proper matching of the gain, the coupling factor, the length and using multiple ring resonators, can be realized.

## References

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