Chapter 8

Summary and Recommendations

8.1 Summary

This thesis describes work on microring resonator devices based on Silicon Oxynitride technology carried out in the Dutch BTS and European NAIS project. In the beginning only single ring devices have been considered in order to develop the fabrication technology as well as design and measurement methods and gain a deep understanding of the functional behavior. Later more complex devices consisting of cascaded multiple microring resonators in a parallel configuration with a promising functionality have been realized and demonstrated. In the following a summary and recommendations for future work will be given.

Chapter 1:

This chapter gives a general overview of optical communication and the possible role of microring resonator devices as optical filters for WDM systems. It describes briefly the objective of the BTS and the NAIS project and ends with a brief outline of this thesis.

Chapter 2:

General concepts of microring resonator devices are given in this chapter. The working principle of ring resonator devices and the two basic coupling schemes, lateral and vertical coupling, are described. Thereafter the performance of cascaded multiple rings in serial and parallel configuration are discussed.

Finally two characterization methods, the standard method and quantitative image analysis, are explained in detail.

Chapter 3:

A general route in order to arrive at a realistic design and to realize eventually demonstrator devices is explained in detail. A lot of constraints have a great influence on the design activities, for example the available knowledge, technological facilities and design tools, and also the objectives and time frame of the project. Several activities should be carried out such as intermediate characterizations, functional characterizations followed by system evaluations in order to end up with the final demonstrator devices.

Chapter 4:

The results obtained with microring resonator devices in the lateral coupling configuration are reported in this chapter. The Si_3N_4 based devices were analyzed in the wavelength range of 1510 to 1580 nm and a finesse of up to 182 has been achieved. The most critical issue in this configuration is the gap definition, which is rather difficult to be obtained with conventional optical photolithography.

Chapter 5:

In this chapter, work on single ring resonator devices based on SiON and Si_3N_4 in a vertical coupling configuration are presented. A feasibility study shows that it is difficult to realize single SiON microring resonator devices that can perform as polarization independent wavelength filters. Based on this experience, a polarization diversity scheme is considered and work has been focused on microring resonators optimized for TE polarization. Devices have been realized in Si_3N_4 technology, whereby a finesse of more than 100 could be demonstrated.

Chapter 6:

Increasing the complexity of devices by cascading two or three microring resonators in a parallel configuration a better performance of the filter response could be obtained. A simulation model is developed that allows the design and analysis of the multiple ring devices. Devices have been realized in Si_3N_4 technology and show a promising functionality as bandpass filter. Two-ring devices with equal coupling coefficients exhibit a rather wide passband and narrow stopband, three-ring devices show increased performance.

Chapter 7:

Another potential application of ring resonator devices, spectral slicers are presented. Devices based on microresonators with a radius of 20 μm as well as 15 μm have been designed and realized. A comparison is made between the performance of devices where each stage is made of either a single or a double ring configuration. The latter show much better performance with respect to faster roll-off and lower crosstalk.

Chapter 8:

This chapter presents a summary of the work described in this thesis and gives also conclusions and recommendations for future work.

8.2 Recommendations

As mentioned in the previous chapters, the performance of the filters is mainly determined by the coupling coefficients and propagation loss inside the ring resonator. Therefore simulation tools that can be used to estimate the coupling coefficients should be available. The propagation loss might be decreased by applying appropriate fabrication processes.

In the case of the lateral coupling configuration, coupling coefficients can be estimated by reducing the three-dimensional structure using an effective index method and calculate the field overlap between the mode in the port waveguide and the ring as described in [Klunder 2002 (b)]. Estimation of the coupling coefficients in three-dimensions by a simplified coupled mode theory [Hammer 2003] and semi-experimental estimations obtained by fitting the simulation model to the experimental data are in reasonable agreement (see Sec. 7.4). Fully three-dimensional coupled mode theory, however, is necessary that enable better comparison between those results and allow improved optimization of the design to obtain the desired coupling coefficients.

Developing new fabrication approaches might be useful to decrease the propagation loss inside the ring. With the currently available fabrication process the absorption and scattering loss is in the order of 6 - 8 dB/cm. An annealing process would not reduce the propagation losses significantly because the losses are mainly dominated by the scattering loss. By using a waferstepper with an overlay accuracy of about 100 nm, alignment problems between waveguide and ring mask could probably be solved. Also lower scattering loss could be expected because the roughness on the mask that is transferred directly to the photoresist in conventional optical photolithography by using contact printing will be reduced by using a projection method with size reduction. When the alignment problems have been solved, the incorporation of precise offsets in horizontal direction on the mask become useful and the coupling coefficients could be tailored more efficient to give the desired filter response.

Specific recommendations of some chapters are given in the following:

Chapter 5:

In order to be able to realize polarization independent wavelength filters, polarization diversity scheme in combination with cascading several rings can be used (see Klunder 2002 (a)).

By using this scheme, the devices need to be optimized only for a single polarization. The validity of this approach, however, should be examined by experiments.

Chapter 6:

In order to be able to have the desired filter response, the devices might be tuned e.g. thermo-optically. In the case of parallel cascaded ring devices, tuning the rings could also change the distance between centre to centre of nearest neighbor rings causing in that way an undesired filter response. Additional tuning elements located on the connecting line of the port waveguides could compensate for this effect.

Chapter 7:

Reducing the ring radius seems to cause problems to the quality of the ring layer as by increasing the layer thickness, crack can occur and bending of the wafer. In order to minimize bending of the wafer, growing a layer on both sides of the wafer might help. By applying these treatments, the layer properties such as the thickness, refractive index etc. should be carefully measured as these usually changes.

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