Vertically coupled InP microring resonators fabricated with BCB waferbonding

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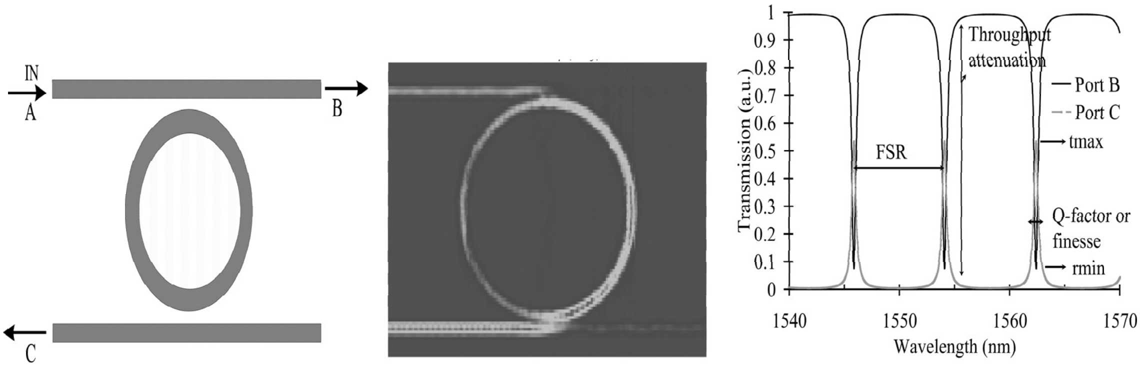
Microring resonators have attracted a lot of attention lately because of their interesting characteristics. They are compact, scalable and versatile. The latter has been proven by numerous applications that have been demonstrated such as wavelength conversion, higher order filters and all-optical logic gates. The different fabrication possibilities will briefly be reviewed. We shall elaborate on the fabrication of vertically coupled InP microring resonators with BCB waferbonding. Microring resonators have been fabricated this way and high Q values are demonstrated together with the influence of the position of the bus waveguides on the performance and low power thermo-optic tuning of the microring.

Introduction

The basic layout of a microring resonator can be seen in Fig. 1(a), it consists of two straight waveguides and a circular one.
The principle of the component is the following: light is injected into one of the straight waveguides. When this light comes into the vicinity of the ring some of it couples into this circular waveguide. The same happens when the circular waveguide comes near the other straight waveguide. In order for constructive interference to occur in the ring the light has to be in phase with itself after travelling the ring. That means that only light with particular wavelengths, is in resonance in the ring. This light can be fully extracted from the input waveguide and transmitted to the output waveguide, the ring resonator therefore acting as a wavelength filter. This principle is illustrated in Fig. 1(b). The transmission characteristic at port B and C can be seen on Fig. 1(c). Some important performance parameters of the filter are indicated on the figure. For more information we refer to among others the review paper by Schwelb [2].

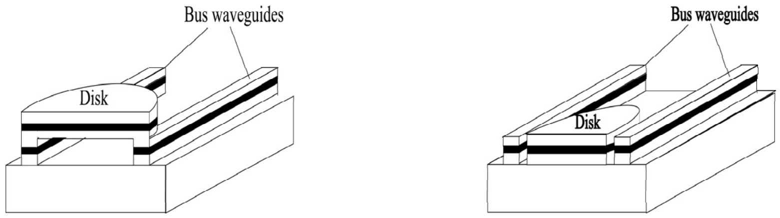
Possibilities for the fabrication of microring resonators

There are two main possibilities for the fabrication of ring resonators: the laterally coupled and the vertically coupled approach. In the laterally coupled approach both the ring and the bus waveguides are in the same plane as can be seen in Fig. 2(a). In the vertically coupled approach the bus waveguides are underneath (or on top) of the ring resonator, Fig. 2(b). Both have their advantages and disadvantages. The main disadvantage for the laterally coupled approach is the fact that for small rings the gap between the ring and the bus waveguide has to be submicron in size to achieve sufficient coupling. This requires e-beam lithography. This problem is circumvented in the vertically coupled approach because the distance between ring and bus waveguide is determined by epitaxial growth. This approach does however require either waferbonding or regrowth.



(a) A basic ring resonator (b) The field of ring resonator in resonance (c) The transmission characteristic

Figure 1: Layout, field and characteristic in resonance of a basic ring resonator



(a) Vertical coupling (b) Lateral coupling

Figure 2: Vertically and laterally coupled microring resonators

Fabrication with BCB waferbonding

We have focused on the vertically coupled approach and more specifically using wafer-bonding with the polymer benzocyclobutene (BCB). The processing sequence is illustrated in Fig. 3 and is as follows. We start out with an epitaxial layerstructure containing two waveguide core layers, Fig. 3a. Then the straight bus waveguides are etched, Fig. 3b. The sample is turned upside down and bonded onto a transfer substrate with BCB, Fig. 3c. The original substrate is then removed and the ring resonator is defined on the backside of the sample, Fig. 3d. The details of the processing are described in [3], [4].

Measurements

Light from a tunable laser source was coupled into the device by a lensed fiber. The output was collected by a lens and imaged onto an IR-camera and a photodetector. Microring resonators with radii from 10 μm up to 30 μm have been fabricated and measured. Q-factors of up to 15 000 have been achieved. Fig. 4 shows measurements of microring resonators.

Thermo-optic tuning

We have applied Cr-contacts on top of the ring. By sending current through these the ring is heated and by thermo-optic effect the filter characteristic of the ring can be tuned, Fig.

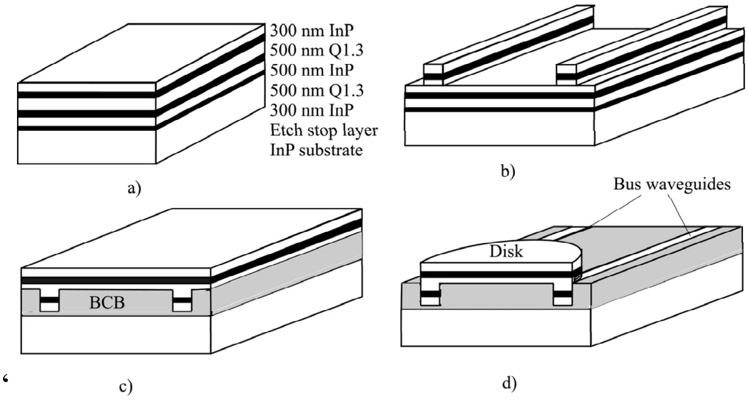
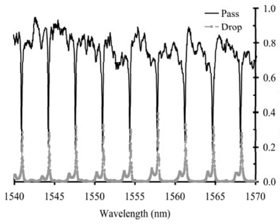
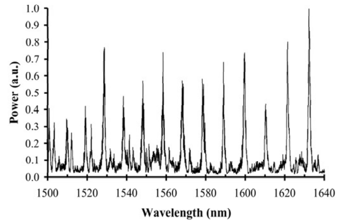


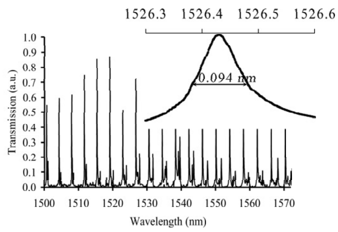
Figure 3: The processing sequence



(a) The drop and pass port of a 30 μm radius microdisk resonator



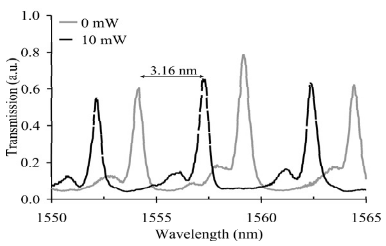
(b) The drop port of 10 μm radius microdisk resonator



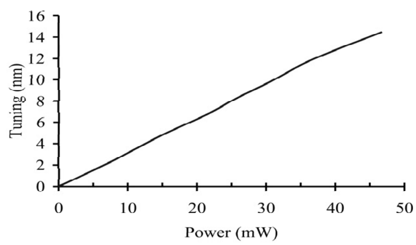
(c) A 25 μ m radius device with 16 000 Q

Figure 4: Measurements for disks with different radii

5(a). Due to the low thermal conductivity of the polymer BCB, this is a very efficient process as can be seen in Fig. 5(b), [1].



(a) The shift of the transmission curve

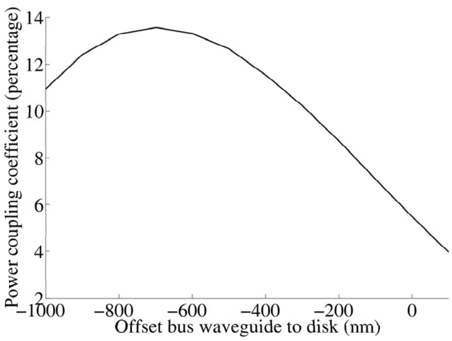


(b) Shift versus input power

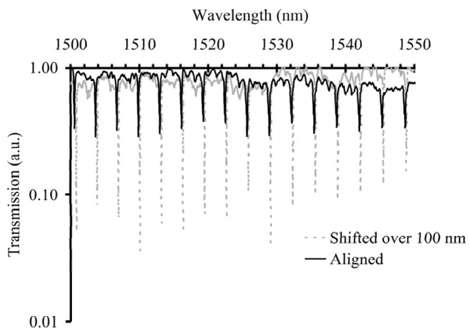
Figure 5: Thermo-optic tuning

Influencing the coupling coefficient

The functionality of the ring can be optimised by adjusting the value of the coupling coefficients. This can be done by altering the composition and layer thicknesses but also by shifting the bus waveguides with respect to the ring resonator. The influence of this shift can be simulated and can be seen in Fig. 6(a). Rigorous calculations of this kind of 3D structure remain very difficult. The simulations are therefore approximate and based on coupled mode theory but altered as described in [5] to describe coupling from a straight waveguide to a bend. As is to be expected, by shifting the bus waveguide inwards the coupling coefficient can be increased significantly. We have demonstrated this effect in Fig. 6(b) where the measurements of a microdisk with 30 μm radius can be seen. By shifting the bus waveguides inwards over 100 nm the in- and output coupling coefficient is increased and the throughput attenuation is significantly improved. A fit of theory to the measurements results in values for the coupling coefficent that increase from about 5 % to around 9 % This fits reasonably with the simulation data.



(a) Simulation of the coupling coefficient versus the shift of the input bus waveguide



(b) Improving the throughput attenuation

Figure 6: Simulation and measurement of a 30 μm radius disk with shifted bus waveguides

Conclusions

We have demonstrated vertically coupled microring resonators fabricated with BCB-waferbonding which function over a wide range of radii and demonstrated high Q devices. These devices can be tuned thermo-optically in a very efficient way. We have demonstrated improvement of the characteristic by shifting the bus waveguides and thus influencing the coupling coefficients.

References

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