Deep glass etched microring resonators based on silica-on-silicon technology

H. Ou, K. Rottwitt and H. Philipp

Microring resonators fabricated on silica-on-silicon technology using deep glass etching are demonstrated. The fabrication procedures are introduced and the transmission spectrum of a resonator is presented.

Introduction: Microring resonators have attracted intense research as fabrication techniques have allowed high-quality waveguides to be produced using high-index-contrast platforms. Since ring resonators support travelling-wave resonant modes, a single ring may be used to completely extract a particular wavelength from a signal bus [1]. Microring resonators are ideal candidates for very-large-scale integrated (VLSI) photonic circuits, since they provide a wide range of optical signal processing functions while being ultra-compact [2].

Microring resonators have been fabricated by using high-index-contrast waveguides Si/SiO_2 [3], Ta_2O_5/SiO_2 [4], GaAs/AlGaAs [5], InGaAsP/InP [6], polymer [7, 8], and Si_3N_4/SiO_2 [9, 10]. The high modal confinement of high-index-contrast waveguides allows small-radii, low-loss bends to be made. Low loss around tight bends makes large free spectral range resonators with high quality factors and finesse possible. Since silica-on-silicon technology has an index contrast of the order of 0.01, low-loss bends with radii smaller than a few millimetres are generally not possible [11]. However, with the development of deep glass etching technology [12], we show that microring resonators obtained by combining silica-on-silicon technology with deep trenches etching are possible.

In this Letter, we present what we believe is the first implementation of a microring resonator in silica-on-silicon technology using deep glass etching. The additional functionality offered by the deep etched resonators could be significant, since it adds a compact non-reflective resonator to a well-developed, commercially viable integrated optics platform.

Fabrication of microring resonators: The fabrication of the silica-on-silicon microring resonators consists of two main steps. The first step is the deposition of three waveguide layers: the buffer, the core and the top-cladding. The processing starts with a four-inch silicon wafer. The buffer layer is a 6 µm-thick layer of pure silicon dioxide, grown by the thermal oxidisation of the silicon substrate. The core is a 3.5 µm-thick Ge-doped glass ($Ge{:}SiO_2$) layer deposited by plasma enhanced chemical vapour deposition (PECVD). The refractive index of the core (n_c) is 1.465 at a wavelength of 1550 nm. Since the refractive index of pure glass (n_b) is 1.445 at 1550 nm, the index contrast ($n_c - n_b$) between the core and buffer is 0.02. The top-cladding layer is boron and phosphorus co-doped glass (BPSG) deposited also by PECVD. The refractive index and thickness of the top-cladding, 1.445 and 6 µm, respectively, are matched to that of the buffer.

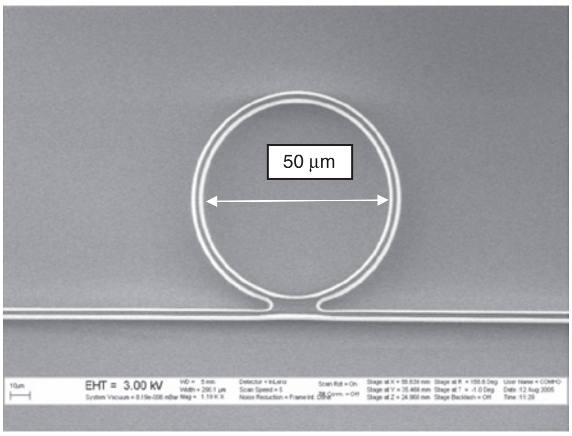

Fig. 1 *Single ring and straight 'bus' waveguide picture taken by SEM*

Ring shown has radius of 25 µm. In this picture, it is clearly shown that the straight waveguide and ring resonator are fused together in the coupling region

The second major fabrication step is deep glass etching. The deep glass etching goes through three layers of the waveguide, and the total etching depth is 15.5 µm. Burned resist was used as the mask material of deep glass etching in order to improve the sidewall roughness, which is a standard waveguide fabrication process used in the cleanroom at Danchip, DTU. As a result, the sidewall of the waveguide is angled (82°) instead of vertical. Two scanning electron microscope (SEM) pictures of the microring resonators after processing are shown in Figs. 1 and 2.

Fig. 1 shows a top-view SEM picture of a single-ring resonator with a radius of 25 µm. The ring and the straight waveguide are designed to be connected at the coupling area. This 'fused' section of the waveguide can greatly increase coupling between guided modes in the straight waveguide and the ring, and also introduce scattering losses in the junction [3].

Fig. 2 shows a tilted cross-sectional SEM picture of a waveguide. As seen from the Figure, in the horizontal direction, the index contrast of the waveguide is increased from 1.465:1.445 to 1.465:1 after trench etching. This contrast is comparable to the other high-index-contrast materials such as Si_3N_4. The relative refractive index difference [13], $\Delta = (n_c^2 - n_b^2)/(2n_c^2)$, for silicon rich silicon nitride (SRSN) with a silica cladding is 0.254, while it is 0.267 for the glass–air interface. The tight confinement of the horizontal optical mode enables low-loss small radii bends in the plane of the wafer. The inset of Fig. 2 shows the fundamental mode field by simulation using the commercial software Olympios. From the inset we can see that the mode confinement in the horizontal direction is much tighter than that in the vertical direction. The simulated birefringence of the straight waveguide with this structure is 0.0016.

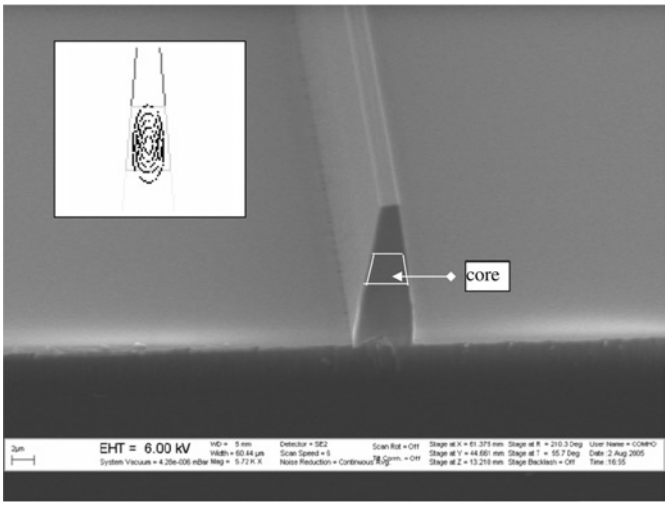

Fig. 2 *Tilted cross-sectional SEM picture of one waveguide after deep etching*

Total etching depth 15.5 µm, including three layers of waveguide: top-cladding, core and buffer layer. Trapezoidal core layer is highlighted. Widths for top and bottom of core layer are 3.4 and 3.9 µm, respectively. Thickness of core layer 3.5 µm.
Inset: Fundamental mode field distribution in core simulated by commercial software Olympios

Results and discussions: The transmission of a straight waveguide coupled to one ring resonator was measured using an optical spectrum analyser (OSA) synchronised with a tunable laser source (TLS). The polarisation was adjusted by a polarisation controller to maximise the depth of the transmission dips corresponding to the resonant mode of the ring.

The transmission spectrum of the one ring resonator with radius of 25 µm is shown in Fig. 3. From the spectrum, the free spectral range (*FSR*) is read to be 10.14 nm. A relationship between the radius of the ring R, the effective group index n_g, and the *FSR* is given by the formula: $FSR = \lambda^2/2\pi R n_g$, where λ is the wavelength. Using the measured value of $FSR = 10.14$ nm, the radius of the ring $R = 25$ µm and a wavelength of $\lambda = 1550$ nm, the effective group index of the resonant mode was found to be $n_g = 1.509$. This value is in good agreement with the structure of the waveguide we used.

Fig. 3 shows a spectrum that has a low finesse periodic response. This may be caused by sidewall roughness [14] and other sources of loss in the resonator (e.g. losses induced by the multimode coupling region).

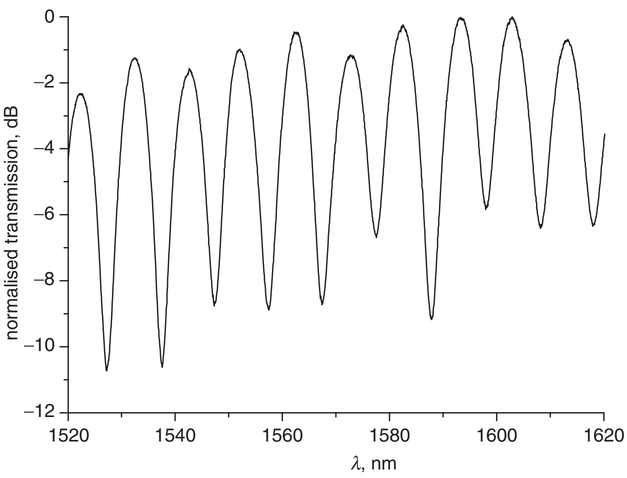

Fig. 3 *Transmission spectrum of one ring resonator with radius of 25 μm*

Conclusions: We have presented, for the first time to the best of our knowledge, microring resonators fabricated based on silica-on-silicon planar lightwave circuit technology and deep glass etching technology. The resonant spectrum is shown and the group index of the waveguide extracted from the free spectral range. This value is consistent with the magnitude expected. This novel deep etched microring resonator adds significant functionality to a mature silica-on-silicon waveguide platform.

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