Fabrication Optimization of Silicon Micro-Ring Filters

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High-index-contrast microring filters have become an attractive technology for chip-scale wavelength-division-multiplexing (WDM), which will enormously reduce the cost and the complexity of optical communication systems. The filtering specifications are stringent, including large free spectral range (FSR), flat-topped passband and high filtering contrast. A group at MIT has demonstrated good filter results for microrings made from SiN [1-3]. However, the fabrication, including frequency matching among rings, was performed on specific e-beam lithography equipment (Raith 150) and may not be universal for all tools. Meanwhile, microrings in Si allow further reduction in device footprint, larger FSR, and larger frequency tuning range. To our knowledge, high-order, multi-stage microring filters in a silicon-on-insulator (SOI) platform have not been reported. Here we present our initial but satisfactory results of such filters.

The devices were fabricated on an SOI wafer with a 250 nm top Si layer and a 3 μm buried oxide. Two types of resists (PMMA and HSQ) and fabrication processes (Fig. 1a and 1b) were applied with the lithography done on a Vistec VB6 e-beam tool operating at 100kV. For HSQ, a dose matrix was always written and inspected before the filters were patterned to account for the aging of HSQ. The HSQ procedure provides a much simpler process and noticeably reduced the sidewall roughness (see Fig. 1c and 1d).

Two types of filters were fabricated with the HSQ process for optical testing. The first was a 6-stage, 2nd order race-track filter. Race tracks can be viewed as stretched ring resonators (Fig. 1e). The parameters are shown in Fig. 1e and the filtering response is shown in Fig. 1g. Note the large free spectral range (> 32nm), over 20 dB attenuation in throughports (dashed) and more than 30 dB contrast in the drop ports (solid). To our knowledge, this is the first reported result on silicon micro race-track filters.

The other type of filter was a three-stage, 3rd order ring filter (see Fig. 1f for parameters and Fig. 1h for filtering response). The throughport attenuations show splits, an indication of resonance frequency mismatch between the center ring and the two outer rings. This observation was originally reported in [3], and was attributed to the extremely small decrease of the width of the center ring with respect to those of the outer ones. Proximity effect in e-beam lithography was identified as the cause of such width reductions [3]. However, proximity effects were significantly reduced at 100kV beam energy and our experiments showed that instead of increasing the dose at the center ring as reported in [3], a decrease of the dose yielded better frequency match. Thus the frequency mismatch in our case is an indication of coupling-induced resonance frequency shift (CIFS) as proposed and analyzed in [4].

References
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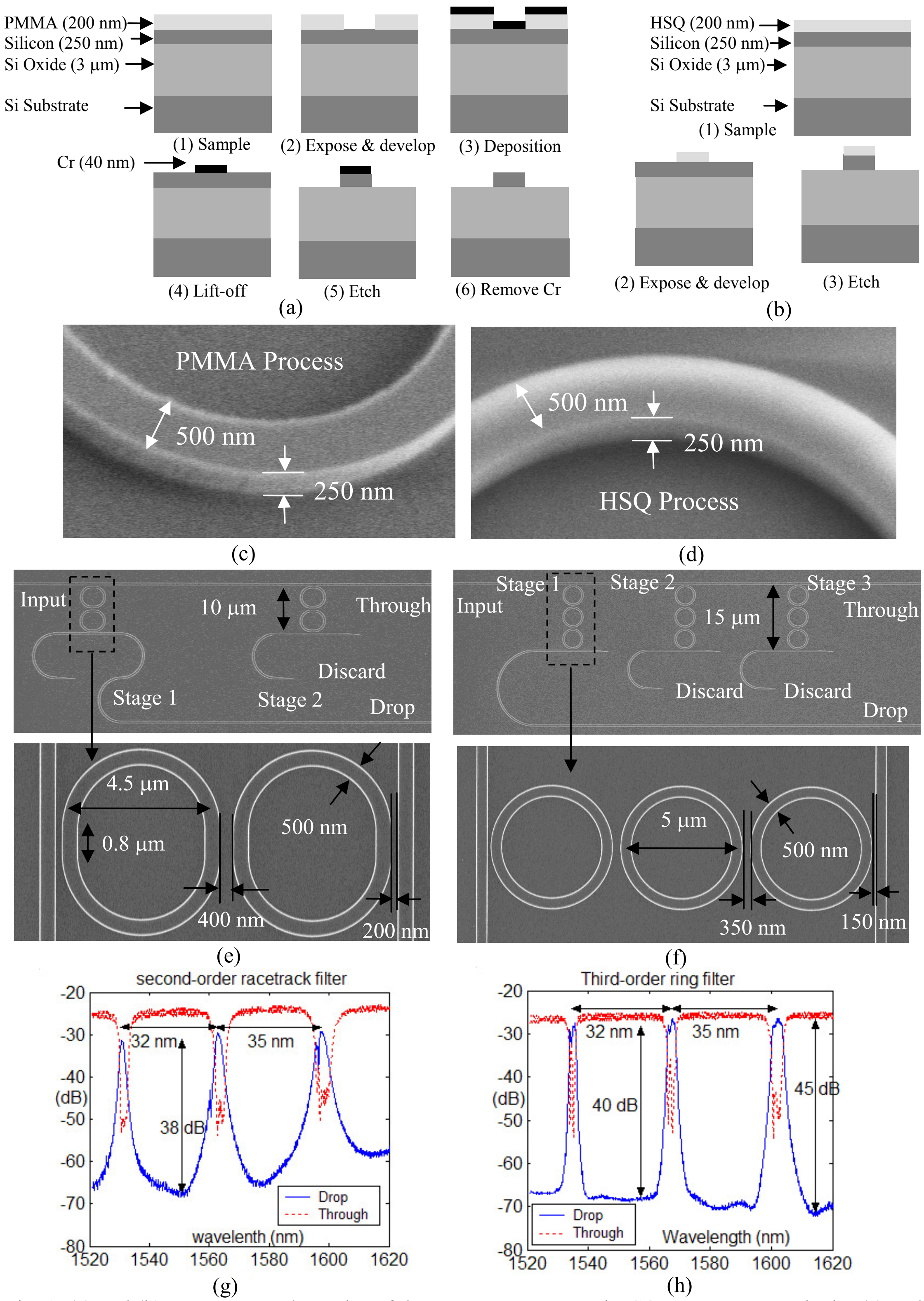

Fig. 1: (a) and (b) are process schematics of the PMMA process and HSQ process, respectively; (c) and (d) are the fabricated waveguides. Clearly the HSQ process yields much smoother waveguides; (e) and (f) show the layout and parameters of multistage 2nd order race-track filters and 3rd order ring filters; (g) and (f): filtering response of the 2nd order race-track filter and 3rd order ring filter. Notice the large FSR, over 20 dB attenuation in throughports (dashed) and more than 30 dB contrast in the drop ports (solid).