Challenges in nanofabrication of strong-confinement photonic devices

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Micro- and nano-photonic devices are critical for all-optical telecommunication networks and are expected to play a significant role in computing as connections within and between microelectronic processors become optical. Of particular importance are photonic devices employing strong confinement of light, such as micron-sized resonators, as they have unique and desirable characteristics. However, their successful realization poses unique fabrication challenges that are not of significant concern for micro- and nano-electronic devices. In this talk, we focus on the two main distinctive challenges in nanofabrication of strong-confinement photonic devices: smoothness and dimensional accuracy.

We distinguish two detriments to the smoothness of photonic structures: the roughness of material boundaries and lithographic inaccuracies affecting pattern fidelity. Photonic devices require smoothly varying structures such as microring resonators and adiabatic mode transformers. When vector-scan electron beam lithography is used (either for mask making or direct writing), these structures are decomposed in rectangles, which are then filled. This can result in writing errors that notably affect the required structure smoothness. For best performance, tailored scanning strategies are needed as illustrated for microrings in Fig. 1.

The dimensional control required for strong confinement photonic structures is significantly tighter than for nano-electronic devices. In high-order filters, the resonators forming the filter need to be frequency aligned to about 1/50000th of their resonance frequency. This corresponds to a relative dimensional control on the average ring-waveguide widths of microring resonators of the order of tens of picometers. We have quantitatively studied the achievable resonance-frequency control at fabrication (Fig. 2) and found that a relative dimensional control of the order of 0.1 nm is achievable on the average ring-waveguide width of nearby microrings. Fig. 3 shows examples of several first-of-kind photonic devices that we have recently demonstrated.

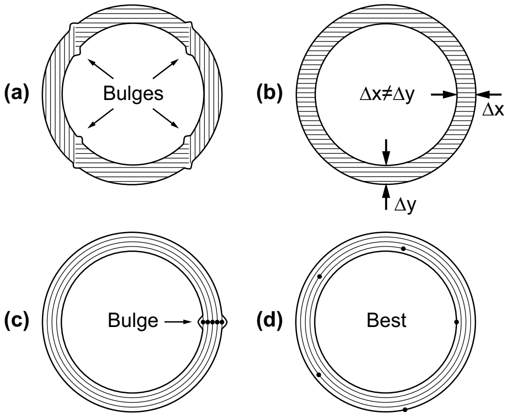

Fig. 1 Electron-beam writing strategies for microring resonators. The dots in (c) and (d) indicate starting and stopping positions of the circular single-pixel lines.

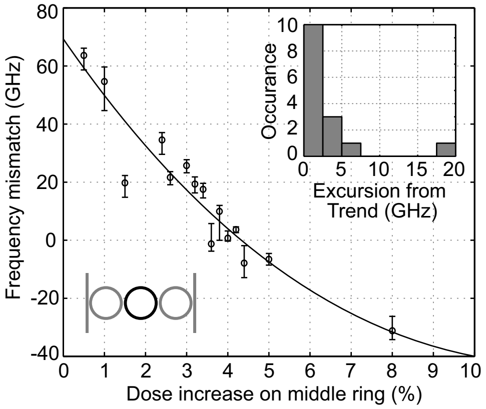

Fig. 2 Resonance frequency mismatch between the middle ring and the outer rings of a third-order microring filter for various middle-ring electron-beam doses. The inset shows the stochastic distribution of frequencies from the trend.

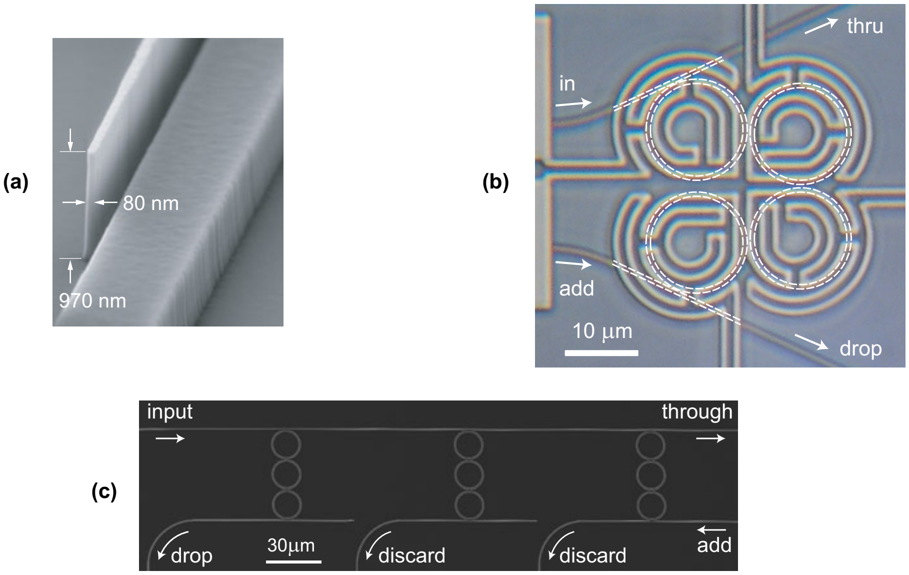

Fig. 3 Micrographs of recently demonstrated photonic devices. (a) Onset of a polarization splitter and rotator made of silicon-rich silicon nitride (SiN). (b) Tunable fourth-order microring add-drop filter showing four Ti heaters and an outline of the four Si microrings hidden below. (c) Multistage microring filter in SiN.