Spectral Trimming of Fano Reflectors on Silicon and Glass Substrates

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Surface-normal ultra-compact narrowband optical filters and broadband reflectors can all be realized via Fano resonances on patterned single layer silicon nanomembranes (SiNM) layers on SOI [1-3]. Recently, we reported Fano filters transferred onto glass or flexible polyethylene terephthalate (PET) substrates [4], employing a low temperature wet-transfer process [5]. Here we report demonstration of broadband reflectors based on Fano resonances, on SOI and on glass substrates, along with the spectral trimming for precise definition of cavity resonances, based on the effective index control of low index oxide layer surrounding patterned SiNM device layer.

The design was done based on finite difference time-domain (FDTD) and rigorous coupled-wave analysis (RCWA) techniques. The patterned SiNM structures on SOI were released with buffered HF (BHF) etching of buried oxide (BOX) layer (Fig. 1(a)), and transferred onto glass substrates (Fig. 1(b)). A micrograph of the transferred SiNM on glass is shown in Fig. 1(b)(ii). The uniform pattern was verified with the diffraction pattern (Fig. 1(b,vi)). Narrow band filter transmission characteristics are shown in Fig. 1(c).The measured broadband reflector reflection results are shown in Fig. 1(d), for two samples with different design parameters, on SOI, and on glass substrate. Notice some degradation of measured maximum reflection after SiNM transferred onto glass substrate, which may be due to the process imperfection. Theoretically the maximum reflection can be ~100% for SiNMs on Si or on glass substrates.

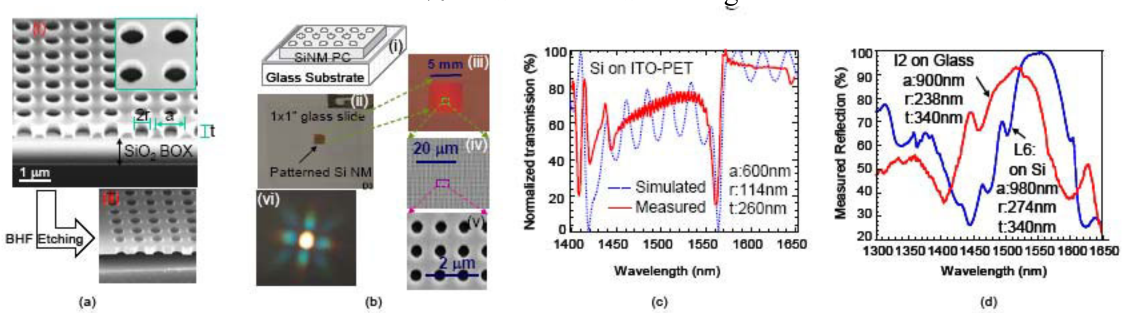

Fig. 1 (a) SEM images of patterned SiNM on SOI before (top) and after (bottom) BHF etching of SiO_2 BOX layer; A zoom-in top view is shown in the top inset. The patterned parameters are defined as SiNM thickness (t); lattice constant (a), and air hole radius (r). (b) (i) Schematic of SiNM transfer onto glass; (ii) a micrograph of a 5x5 mm patterned SiNM transferred onto 1x1" glass slide; (iii-iv) SEM images of pattern top view; (vi) diffraction pattern image; (c) Measured and simulated transmission characteristics of narrow band Fano filters based on patterned SiNM transferred on ITO coated plastic PET substrate; and (d) Measured reflection on Fano broadband reflectors on Si SOI substrate (L6) and transferred on glass substrate (I2), with different design parameters a, r, t.

Spectral trimming is feasible with well controlled partial etching of SiO_2 BOX layer, as shown schematically (top) and experimentally (bottom), in Fig. 2(a) and (b), for different etching times. This leads to different effective indices of bottom oxide layer, which results in precise control of spectral shift (blue-shift). The measured broadband reflection results are shown in Fig. 2(c) and (d), for different BHF etching times. A close to linear dependence on the tuning can be obtained for etching time less than the complete release time (7 min in this case). This indidates Fano resonance shift is only related to the effective index of very thin layers (<200 nm) above and below the patterend SiNM layer, where the field interaction is strong.

Similarly, spectral trimming (red-shift) can also be done with the addition of oxide layer surrounding the patterned SiNMs. This can be accomplished with either PECVD deposition of oxide on top of SiNM, or spin-on-glass (SOG) backfilling of air region above, below, and in the

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air holes of patterned SiNMs, as illustrated in Fig. 3 (a) and (b). The measured reflection results are shown in Fig. 3(c) and (d) for different thicknesses of PECVD oxide. Notice a saturation behavior in resonance shift is observed for oxide layer beyond 150nm. The blue- and red-shifts are also demonstrated on the same SOI sample, as shown in Fig. 4(a), with SiNM surrounded by air (top) and oxide(bottom), (denoted as "ASO" shown in Fig. 2a) has a peak reflection at 1551 nm. The spectral peak shifted to 1500 nm after the BOX layer removal ("ASA" shown in Fig. 2b) and back to 1580 nm after the same sample was back-filled with spin coated SOG solution ("OSO" shown in Fig. 3a). The measured results also agree well with the simulation results, as shown in Fig. 4(b) to (d), based on RCWA simulation technique.

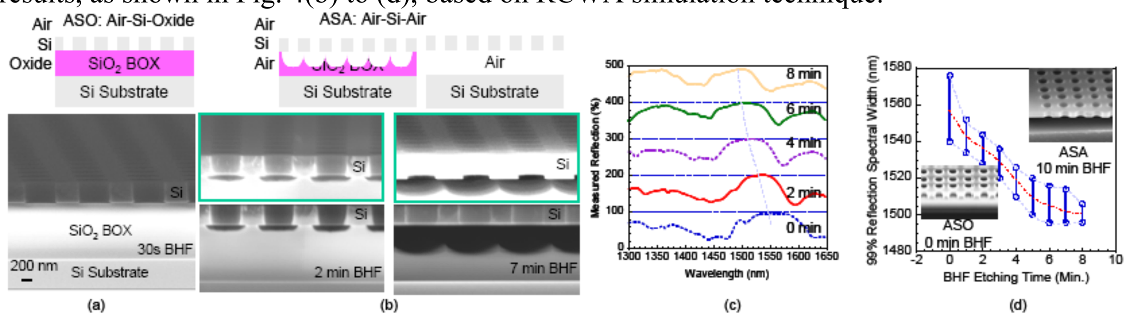

Fig. 2 (a) (top) Schematic of SiNM on SiO_2 (ASO, or air-Si-oxide) without etching, and (bottom) SEM image of Patterned SOI with very short time of BHF etching (30s); (b) (Top) Schematic of SiNM on partially or completed removed SiO_2 layer; and (bottom) SEM images of controlled SiO_2 BHF wet etchings; (c) Measured reflection characteristics (L4) with different BHF etching times (from 0 to 8 min); and (d) 99% reflection spectral widths for different etching times. Structural parameters are t = 365 nm, a = 980 nm, and r = 274 nm.

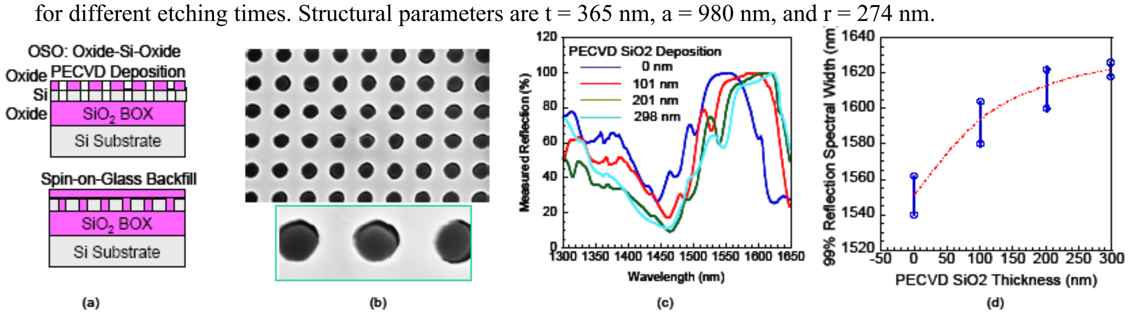

Fig. 3 (a) Spectral trimming (Red-shift) with controlled SiO_2 coating with either PECVD deposition (top) or spin-on-glass (SOG) backfilling; (b) SEM images of Patterned SOI with SOG backfilling, showing the air holes filled with SOg SiO_2; (c) Measured reflection characteristics with different SiO_2 thicknesses deposited on top of the patterned SiNM (from 0 to 298 nm); and (d) 99% reflection spectral widths for different PECVD oxide thicknesses.

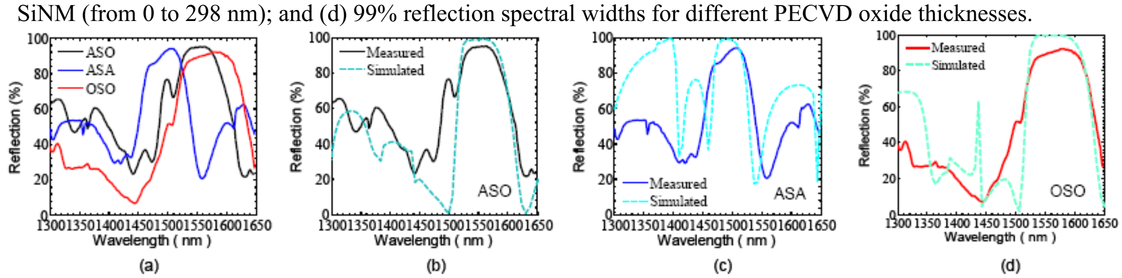

Fig. 4 (a) Measured reflection for the same sample with three configurations: ASO (air-Si-oxide), ASA (air-Si-air) with 4 min BHF of ASO structure; and OSO (oxide-Si-Oxide) with SOG backfill of ASA sample; (b) to (d) Measured reflection results, along with the simulation (fitted) results for ASO, ASA, and OSO configurations.

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