Improving Line Edge Roughness and Photonic Device Performance by Sleeving Exposure Method

D. K. Brown
Institute for Matter and Systems, Georgia Institute of Technology Atlanta, GA
devin.brown@gatech.edu

S.M. Enjaviarsanjan, A. Adibi
School of Electrical and Computer Engineering, Georgia Institute of Technology Atlanta, GA

K. Vyas
GenISys, Inc., Ottawa, Canada

Subwavelength Grating (SWG) resonators are a class of photonic devices which have waveguides consisting of alternating dielectric segments with periodic subwavelength spacing which act like an effective-index medium[1]. SWGs offer unique properties like index engineering and dispersion control and are thus ideal for photonic integrated circuits. However, they also have higher insertion loss than conventional strip or rib waveguides due to scattering losses and fabrication sensitivity. Scattering losses arise from the periodic discontinuities (gaps and interfaces) which create abrupt transitions in refractive index. Even though the periodicity is subwavelength, imperfections and surface roughness lead to backscattering and radiation loss. SWGs are more sensitive to fabrication variations such as line-edge roughness (LER), duty cycle variation, and etch non-uniformity, all of which degrade optical performance.

Photonic devices are often fabricated by electron beam lithography (EBL) due to their high resolution and maskless flexibility allowing direct patterning from a computer aided design (CAD) file. However, EBL can have pattern resolution errors such as abrupt discontinuities due to field stitching[2] or LER caused by beam shot placement inaccuracies[3]. This work investigates primarily how to improve LER using a SWG design (Figure 1) which fits within a 500 µm field. The device was fabricated using HSQ resist on a SOI substrate and etched by ICP (Figure 2). The design was given three treatments of single field pass, four times field multipass with no shift, and a single field pass with double sleeving (Figure 3) using GenISys BEAMER software and exposed on an STS-Elionix ELS-G100 EBL system. The field multipass method can smooth out random errors within the field and the sleeving method helps to smooth out non-ideal shot placement at feature edges especially on angles. The Q factor of the three treatments was measured (Figure 4) and found to be 9,000 for single pass, 28,000 for four times multipass, and 35,000 for double sleeving, which was the best result.

---

[1] C.M. Naraine, et al., Laser Photonics Rev., 17, 2200216 (2023)
[2] A.L. Bogdanov, J. Lapointe, J.H. Schmid, J. Vac. Sci. Technol. B 30, 031606 (2012)
[3] R.J. Bojko et al., J. Vac. Sci. Technol. B 29, 06F309 (2011)

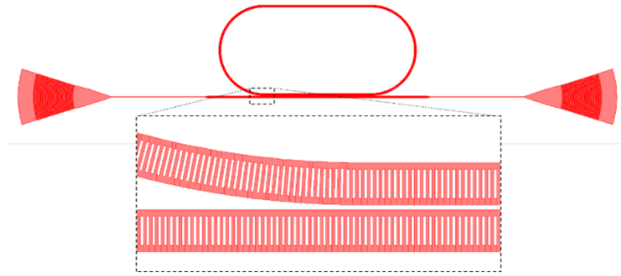

Figure 1: SWG SOI device design. Overall device width is 391 μm from left to right grating couplers. Inset shows fine features of 100 nm line and space of ladder type pattern on upper racetrack and lower straight waveguide. Gap between upper racetrack and lower straight waveguide is varied from 110 nm to 350 nm.

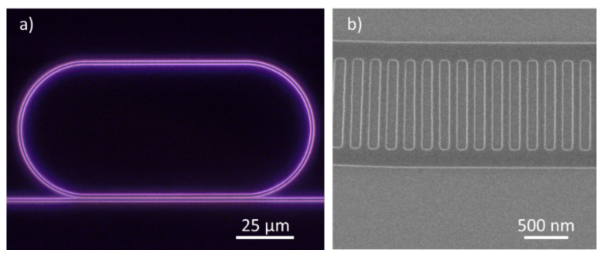

Figure 2: a) Dark field optical image of fabricated SWG after final etch step. b) SEM image of photonic pattern after HSQ develop step showing detail of the ladder type pattern on the waveguides.

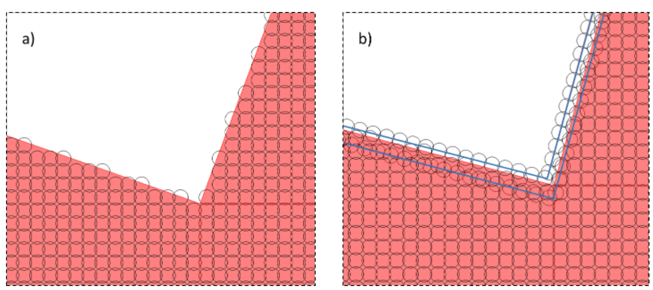

Figure 3: Magnified detail of shot assignment on curved segment of racetrack waveguide. Shot diameter and pitch = 2 nm. a) With no sleeve assignment shots are placed more raggedly on edges with steps. b) With two sleeve line assignments (shown with blue lines) shots create a more smooth edge.

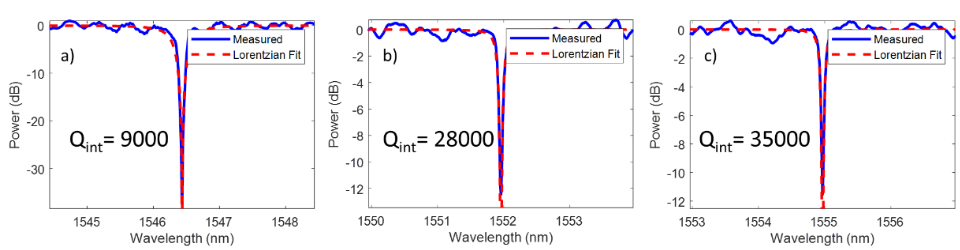

Figure 4: Q factor results for SWG SOI device. a) single pass, no sleeving, Q = 9,000, b) 4 times multipass, Q = 28,000, c) single pass, double sleeve, Q = 35,000.