Optimization of Electron Beam Patterned HSQ Mask Edge Roughness for Low-Loss Silicon Waveguides

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Hydrogen Silsequioxane (HSQ) is a negative-tone electron beam and EUV resist capable of producing features smaller than 10 nm. After development and hardbake, HSQ can be used as a low-optical loss cladding making it an ideal resist for producing telecommunications-band silicon integrated optical waveguides. Since mask roughness is transferred to the waveguide during plasma etching, minimizing mask edge roughness is critical for producing low-loss waveguides.

In this work, HSQ line edge roughness is reduced by simultaneously maximizing electron beam spot overlap and development contrast. Mask roughness is further reduced by employing a 1000° C rapid thermal anneal in O_2. This anneal step also densifies the HSQ mask and increase its plasma etch resistance. In addition, we have explored writing techniques for curved structures to reduce line edge roughness associated with errors in fracturing non-trapezoidal regions. In particular, we increase the segment count by exposing the ring in arc segments with a width of 1° and applying a 0.25° rotational offset for each of four exposure passes. A comparison of 10 µm radius ring resonators with and without this rotational offset is given in Fig. 1. In both curved and straight waveguide sections each of the four exposures is offset by 5 nm in both in-plane directions.

In order to demonstrate the reduced HSQ line edge roughness, 250 nm x 450 nm single-mode Si waveguides are patterned on a SOI substrate using the optimized HSQ process. Waveguides are etched with Cl_2/O_2 plasma and clad with 1 µm of PECVD SiO_2. Figure 2 shows a fabricated waveguide after ICP-RIE. Optical coupling and propagation losses are extracted by fitting a line to the insertion loss as a function of waveguide length. Measured optical propagation losses showing a reduction from ~10 dB/cm with the non-optimized mask to 3 dB/cm with the reduced line edge roughness HSQ mask are given in Fig. 3.

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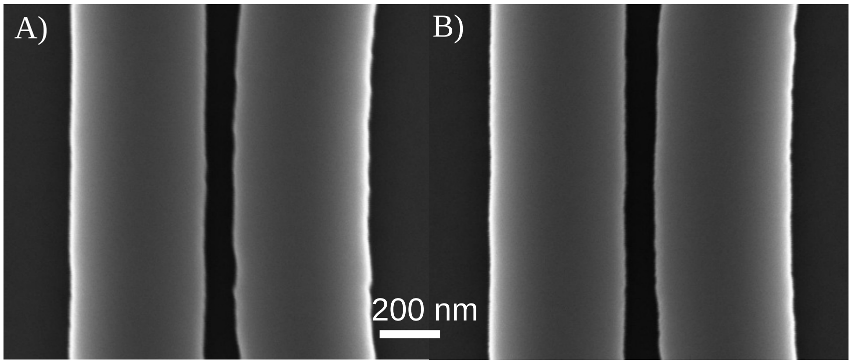

Fig. 1. Top-down scanning electron micrograph showing post-etch Si waveguide with HSQ mask intact. A 450 nm wide straight bus waveguide (left line) is coupled to a 10 µm radius ring resonator (right line). A) without per-pass rotational offset and B) with per-pass rotation offset.

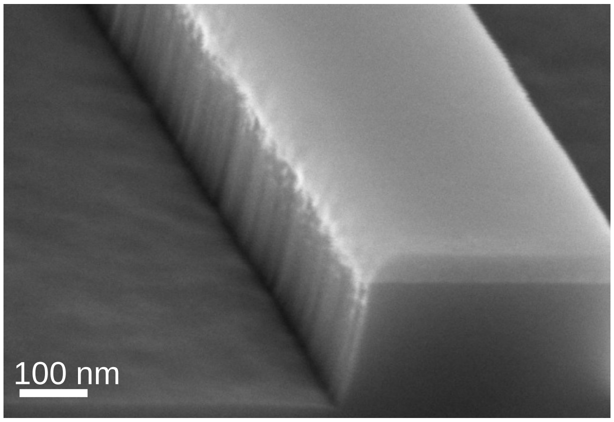

Fig. 2. Angled cross-sectional scanning electron micrograph showing post-etch Si waveguide with HSQ mask intact.

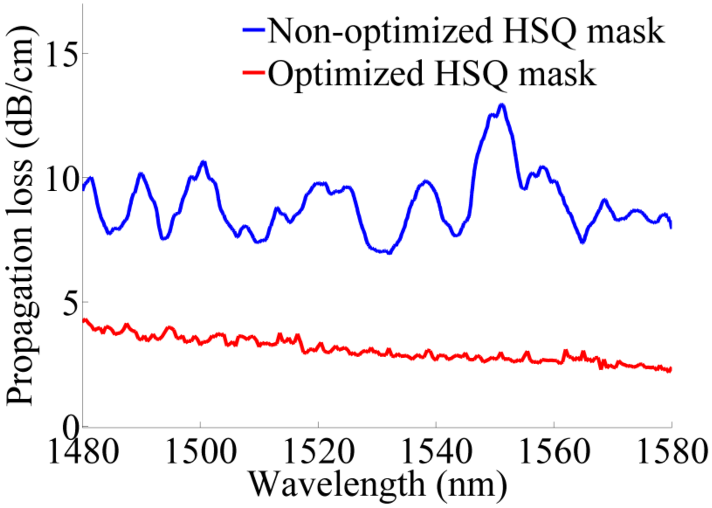

Fig. 3. Measured optical propagation loss for Si waveguides patterned with (red) and without (blue) the optimized HSQ mask.