# E-Beam Lithography Writing Strategies for Low-loss Optical Waveguides

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The rapid growth of silicon photonics is enabling innovations in arenas including nano-optomechanics, biosensing, nonlinear optics, and very-long-wavelength integrated photonics. Amidst the emergence of large-scale integrated silicon photonics fab runs and shared foundry platforms[1], the need for rapid prototyping remains vital. For short-turn feedback, direct-write electron beam lithography remains the preferred patterning strategy. However, photonic devices are highly sensitive to surface and edge roughness, so to discern subtle changes in device performance, patterning must be high-quality. In this work, we report relationships between e-beam writing parameters and waveguide performance. The sensitivity of the measurements, short cycle time for fabrication, and ability to rapidly and automatically collect large volumes of data[2] allow us to clearly distinguish the impact of the writing variables on the waveguide transmission.

We studied the transmission of silicon waveguides of both straight and curved geometries, shown in Figure 1, which are designed for wavelengths near 1550 nm, with a cross-section 400 nm wide by 220 nm thick, from SOI with a 3000 nm thick BOX, and clad with 2000 nm PMMA for testing. We evaluated design properties such as polygon vertex count as well as writing parameters such as writing grid (shot pitch). We also tested writing strategies including overlap or multi-pass writing, which smoothes edges by averaging electronic and environmental noise. A more effective variant of overlap writing in our JEOL JBX-6300FS e-beam is Field Shift writing, in which successive pattern writing passes are offset by one-half of the main field size. Not only do shape edges benefit from multi-pass averaging, but field stitching errors are reduced by averaging one pass written near the field edge with another pass near the field center. Field Stitch writing proves highly effective at reducing loss in waveguides of both straight and curved geometries, as shown in Figure 2. Straight waveguide transmission improved from -4.2 dB/cm to -3.3 dB/cm, while curved waveguides improved from -12.5 dB/cm to -9.3 dB/cm. This performance is consistently obtained (std dev < 1.0 dB/cm) with routinely high yield (>80%), over multiple wafers, which will enable us to build small systems of multiple optical components even in our university prototyping environment.

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[1] Michael Hochberg & Tom Baehr-Jones, Nature Photonics **4**, 492 - 494 (2010).

[2] Ran Ding, Tom Baehr-Jones, Woo-Joong Kim, Xugang Xiong, Richard Bojko, Jean-Marc Fedeli, Maryse Fournier, & Michael Hochberg, Optics Express **18**, 25061-25067 (2010).

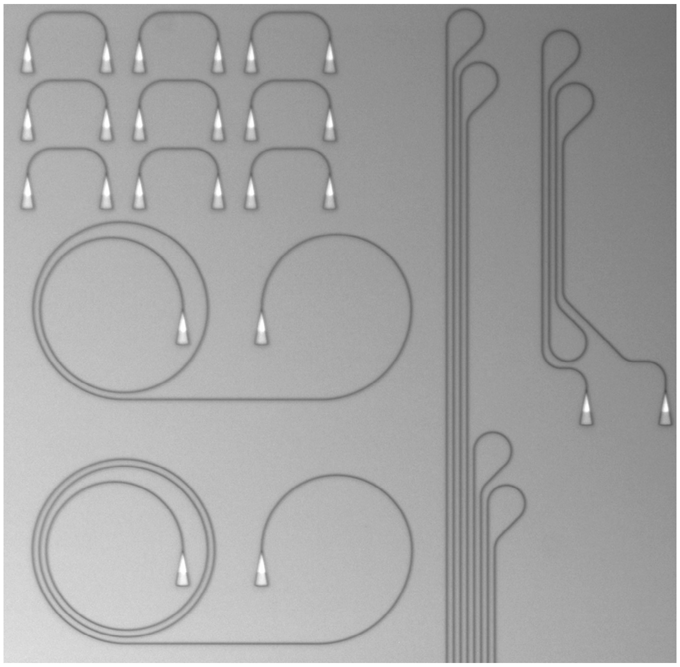

*Figure 1:* Optical micrograph of a test chip, showing both straight and curved waveguides devices. Grating couplers are used for light input and output, allowing rapid automated testing.

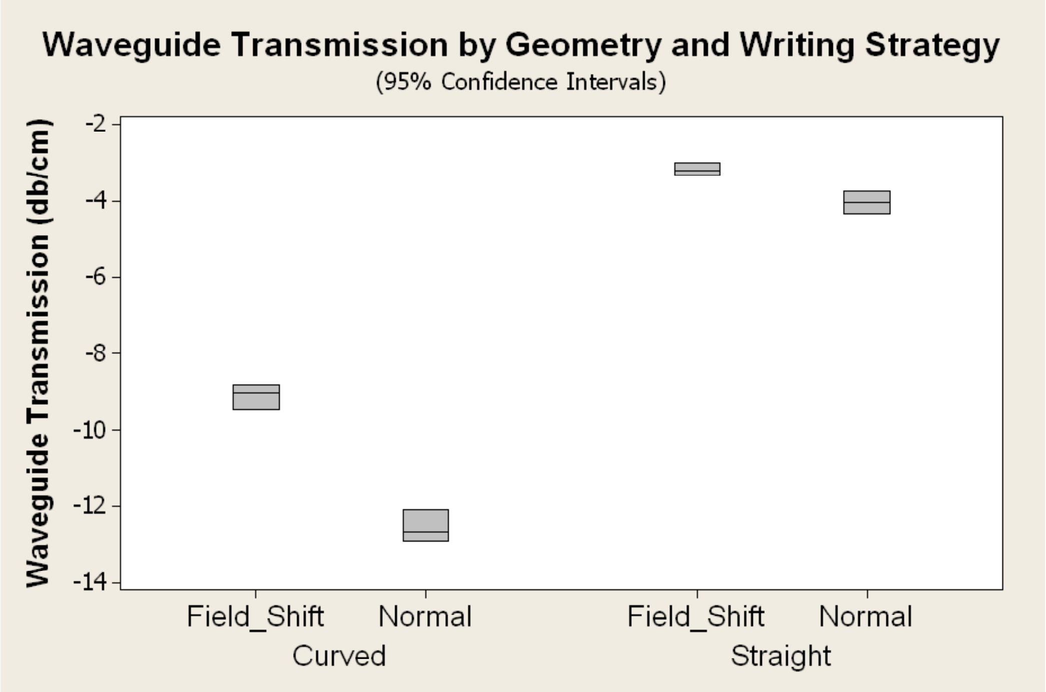

*Figure 2:* Waveguide loss for straight and curved waveguides, for both Field Shift and Normal (single pass) writing. The boxes indicate 95% confidence intervals on transmission loss and represent 60 die from 3 wafers, each die containing 5 straight and 5 curved waveguides.