Improvement of Silicon Waveguide Transmission by Advanced E-Beam Data Fracturing Strategies

N. Shane Patrick, *University of Washington, Seattle WA 98195 patricns@uw.edu*
Richard J. Bojko, *GenISys Inc, San Francisco, CA 94141*
Stefan J.H. Stammberger, *GenISys GmbH, Munich, Germany*
Enxiao Luan, and Lukas Chrostowski, *University of British Columbia, Vancouver, Canada*

In the maturing field of silicon photonics, advances continue in both design and process improvements. Waveguide propagation loss is strongly affected by sidewall roughness, so for fabrication by e-beam lithography, loss is influenced by e-beam writing parameters. Here, we look specifically at fracturing strategies in data preparation for e-beam, and find significant improvement in waveguide loss by utilizing advanced fracturing options.

For our evaluation, we fabricate optical waveguides using a well-characterized, highly-stable baseline fabrication process[1] with HSQ resist exposed by a 100 kV electron beam, a high-contrast TMAH develop, and a Cl_2 ICP etch. Using surface grating couplers[2] for input and output, automated optical measurements are made by scanning input light in the neighborhood of the design wavelength of 1550 nm and measuring optical output. We use a design cell containing grating couplers and both straight and curved waveguides of a range of lengths (Figure 1).

We find significant improvements in grating coupler insertion loss, uniformity, and waveguide loss by implementing new fracturing strategies implemented in the BEAMER pattern data processing software from GenISys, GmbH. First, Beam Step Size Fracturing (BSS, also sometimes referred to as Shot-Pitch Fracturing)[3] is a technique in which, rather than rounding feature sizes to a multiple of the exposure grid (here 6 nm) as in baseline fracturing, shapes are subdivided into several smaller shapes, each with dimensions which are a multiple of the 6 nm writing grid, but with outer edges matching the original design to the full placement grid of 1 nm. Any surplus written area due to shape gridding round-off is buried in the center of the shape, away from the pattern edges. Next, Single Line Edge Smoothing (SLS) is a new technique in which all feature edges are traced using a single-line shape (sometimes referred to a single-pass line) while the bulk of the shape is then exposed with normal beam filling.

While grating couplers using Beam Step Size fracturing show modest improvement of 0.3 dB, the Single Line Edge Smoothing shows a significant loss improvement of 1.2 dB as well as greatly improved uniformity (Figure 2). Both straight and curved waveguide loss also improve by use of Single Line Edge Smoothing, by 0.7 and 1.1 dB/cm respectively (Figure 3). In our paper, we will discuss the likely mechanisms of this improvement as well as present additional device data using these new fracturing methods which represent a significant, incremental improvement in performance of optical waveguides written by e-beam lithography.

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1 R.J. Bojko, J. Li, L. He, *et al*. *J. Vac. Sci. Technol. B,* **29**(6), (2011).
2 Y. Wang, X. Wang, J. Flueckiger, *et al*. *Optics Express*, **22**(17), (2014).
3 M. Lu, D.M. Tennant, C.J. Jacobsen. *J. Vac. Sci. Technol. B,* **24**(6), (2006).

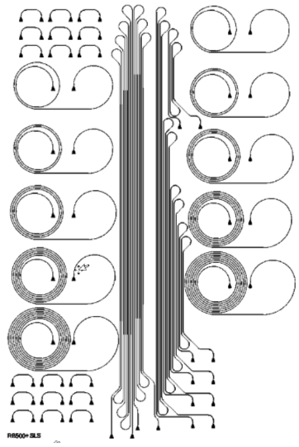

Figure 1. Test cell pattern used for measurement of optical performance. Each 1.7 x 2.8 mm die contains test structures for grating couplers, straight, and curved waveguides.

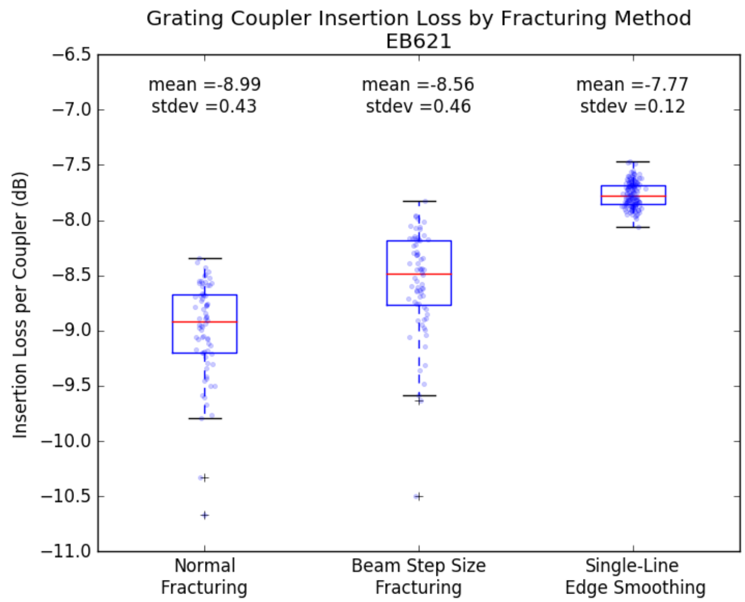

Figure 3. Grating Coupler Insertion Loss for fracturing strategies

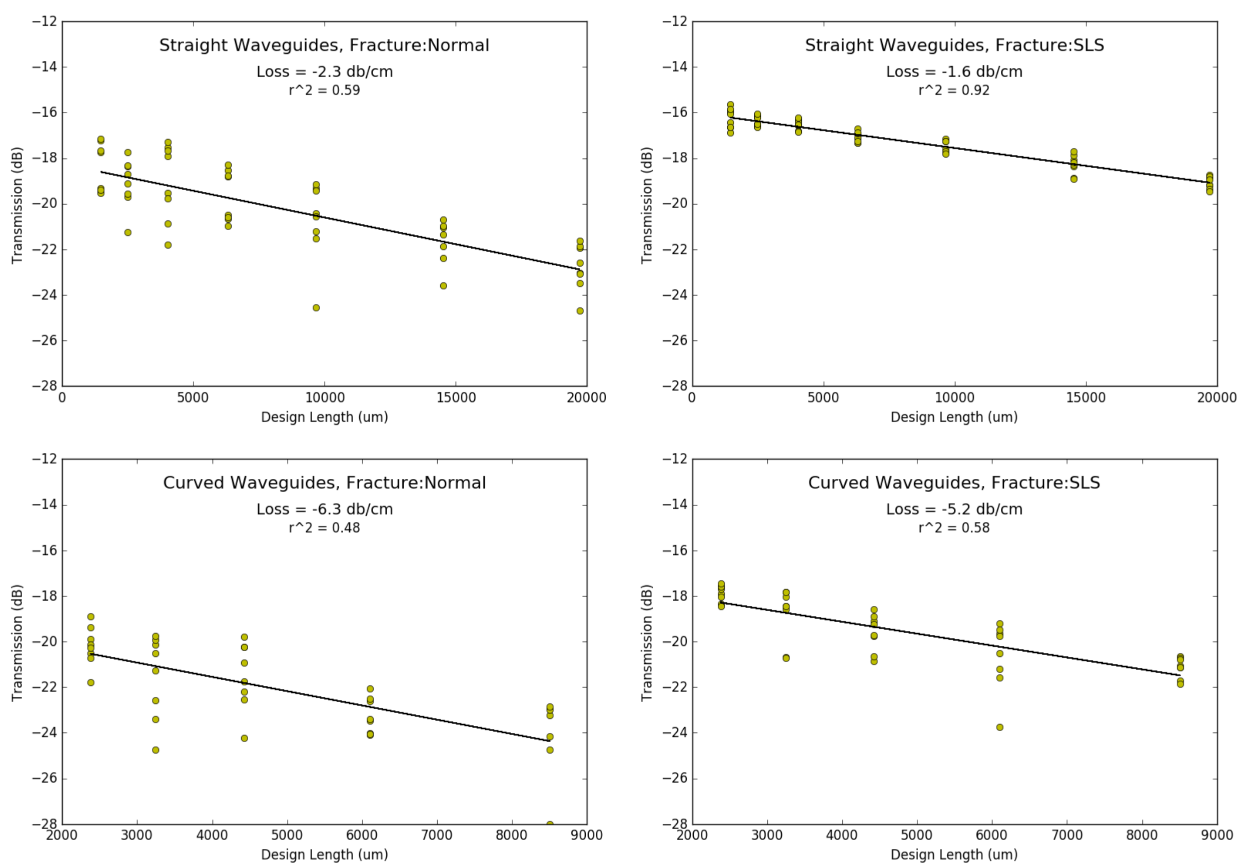

Figure 2. Waveguide loss for straight and curved waveguides for different fracturing strategies.