Ultra-low Loss Stitching for Large-Area Waveguide Based Delay-Line Gyroscopes

Taran Huffman, Michael Davenport, Michael Belt, John E. Bowers and Daniel J. Blumenthal

Department of Electrical and Computer Engineering, University of California, Santa Barbara, CA 93106, U.S.A

Abstract—We report on the design and fabrication of a large-area waveguide delay-line fabricated using four masks stitched together for gyroscope applications. Waveguide loss, including 100 stitches over 3 meters, is measured to be 0.78dB/m with crossing losses of 0.0156dB/crossing yielding predicted ARW of 31.3°/hr/√Hz.

1. Introduction

Modern, high-sensitivity gyroscopes are used in a wide variety of applications including conventional navigation, control of autonomous vehicles, and geographical surveying and mapping. Interferometric optical gyroscopes (IOGs), specifically fiber optical gyroscopes, exhibit higher performance than the most advanced MEMs gyros, but do not compare as well with respect to cost, power dissipation, and size. Advanced photonic chip-scale fabrication techniques have the potential to decrease the fiber optical gyro size, power consumption, weight, and cost. Si₃N₄ ultra-low loss waveguides (ULLWs), with losses below 0.1 dB/m loss [3], are a key component towards integration of chip-scale gyroscopes, as the sensitivity of the delay coil is directly tied to the loss of the waveguide through which the optical signal propagates.

Si₃N₄ ULLWs, just as any other waveguide technology, inherently have a trade-off between optimized waveguide loss (driven by sidewall scattering) and bend radius (determined by the modal confinement within the waveguide core). Thinner waveguide cores lead to reductions in scattering loss and crossing loss, but cause the bend loss to increase [3], driven by reduced modal confinement. This relationship, combined with the fact that a gyroscope’s sensitivity is proportional to its enclosed area (through the scale factor), drives device design considerations toward large area coils. The DUV stepper used in our process has a maximum die size of 21x25mm, limiting the coil radius to 10mm within a single field. To overcome this limitation we have stitched the edges of 4 DUV fields together, doubling the coil radius. Here we present the simulation and design of a stitched waveguide coil as well as the loss measurements from the fabricated delay-line.

2. Design and Simulation

In this paper “die” refers to a single lithographic field from a stepper. To evaluate the design of a single die device with a stitched die device we follow the simulation in [2]. From a simple lithographic test we measure a waveguide stitch to be a 50nm lateral offset in the waveguide. We design our waveguides such that any bend loss is negligible and we can model the crossings as straight – straight crossings. Numerical FDTD was used to simulate the losses of a waveguide crossing and stitch, which yielded expected losses of 0.02dB/crossing and 0.006dB/stitch respectively. The stitching loss is predicted to be much smaller than the crossing loss as it represents a much smaller perturbation to the mode than the crossing. These values were taken, along with a previously demonstrated waveguide loss of 1dB/m, and used in the gyroscope simulation. Consistent with [2] we assume a RIN of -140dBc/Hz and 100mW of on chip power. Two simulations were performed, one with an outer radius of 10mm and one with 20mm, shown in Fig. 1. It should be noted that although we assume each coil has the same waveguide loss, the larger bends of the large area coil would allow for lower loss waveguide designs. This simulation assumes the waveguides are constantly spaced at 50um within the spiral, and includes the reduction of enclosed area as the waveguides spiral inward. Expanding the diameter of a coil beyond a single reticle is necessary for higher sensitivity. A second advantage is a reduced number of crossings, which contribute substantially more loss than the stitches.

3. Fabrication and Measurement

A top-down view of the fabricated coil is shown in Fig. 2. The fabricated coil spirals inward, starting from a 20mm bend radius, for 3 meters making a total of 25 turns. The output waveguide then crosses the spiral outward. There are 50 crossings from the 25 intersections that are met once spiraling in and once exiting out. The 25 turns across the 4 die produce 100 stitches.

The bottom cladding is thermally grown SiO₂ and the Si₃N₄ core was deposited using low-pressure chemical vapor deposition (CVD). The core was defined using a single lithographic step and dry etch. The upper cladding was deposited using plasma enhanced CVD.
To measure the propagation loss of the coil we use the optical backscatter technique detailed in [3]. This measurement includes the crossings, stitches, and any additional impurity scatterers in the waveguide. The optical backscatter trace of our coil is shown in Fig. 3. Fitting a slope to the trace of Fig. 3 yields the wavelength dependent loss of the coil, shown in Fig. 4. The lowest loss of 1.04dB/m occurs at 1595nm. Cut-back crossing test structures were included to separate the crossing loss from this value, yielding a value of 0.0156dB/crossing with R²=0.97. Using this value we find that the waveguide loss, including stitches and additional scatterers, is 0.78dB/m. The minimum stitch length, set by our stepper, is 1mm. Given the anticipated loss of each stitch a similar cut-back structure cannot be used to determine the stitching loss. However, the close agreement between the crossing simulation and measurement suggest the stitching loss should be near the simulated value of 0.006dB/stitch.

4. Conclusion

We demonstrated an integrated waveguide coil with improved scale factor and loss by stitching together multiple lithographic fields. The waveguide loss, combined with 100 stitches over 3 meters, was 0.78dB/m, with a crossing loss of 0.0156dB. This coil, combined with a light source of 100mW and RIN of -140dBc/Hz, has a predicted ARW of 31.3°/hr/√Hz. This value could be improved to a minimum of 16.18°/hr/√Hz if the coil was extended to 122 turns with a length of 13 meters.

We acknowledge support from DARPA.

References: