Frequency Modulated Laser Optical Gyroscope

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Abstract— We fabricated an optical interferometric gyroscope front-end with a tunable laser on the heterogeneous silicon platform. We successfully demonstrated a laser based gyroscope with low noise floor comparable to a commercial ASE based gyroscope.

Keywords—optical gyroscope, FM laser, silicon photonics

I. MOTIVATION

An optical gyroscope is a sensor that detects angular velocity by detection of the Sagnac phase-shift induced by the rotation. Using low loss optic fiber technology, fiber optic gyroscopes (FOGs) have applications in airplanes and other inertial navigation systems [1]. However, because of its large footprint, FOGs are not practical in many growing fields such as robotics and automobiles. An integrated photonic platform [2] which can merge both active and passive devices on a single chip is a promising solution to bring highly sensitive optical gyroscopes into the aforementioned fields.

In [3], the authors analyzed the design of an integrated optical gyroscope on a silicon photonic platform. The device is comprised of two sections. The first section is a heterogeneous Si front-end (Fig 1) comprising of light sources, photodetectors and phase modulators. The second, back-end circuit is an ultra-low loss Si_3N_4 waveguide delay line [4], which can be packaged with the front-end to form a gyroscope.

In this summary, we report measurement results from a fiber gyroscope using an integrated gyroscope front-end. For the first time, we demonstrate a frequency modulated (FM) laser driven fiber gyroscope to have a comparable noise floor with an amplified spontaneous emission (ASE) driven fiber gyroscope. On the basis of optical output power, size, and relative intensity noise (RIN), we show that the FM laser is the preferred choice for an on-chip gyroscope.

II. FRONT-END FABRICATION AND CHARACTERIZATION

The front-end was fabricated on 500 nm SOI with 1 μm buried oxide layer. Waveguides were etched and gain regions were formed by bonding III-V epitaxial material to the top silicon as per the heterogeneous silicon process [5,6]. Metal contacts were added through e-beam deposition for gain and phase modulator sections. SiO_2 was deposited by PECVD, and vias were etched to the contacts. The upper left output is for laser testing, while the two outputs on the right are for coupling to the delay line.

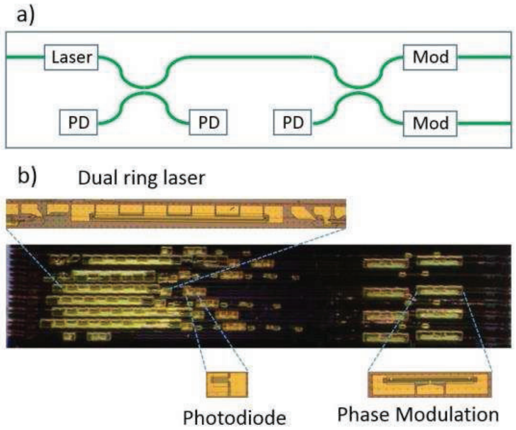

Figure 1. a) Schematic design of the heterogeneous Si front-end. b) Top-down microscope images of a set of six integrated front-ends.

Generally in interferometric gyroscopes, the coherent backscattering noise caused by the interference between the coherent backscattering waves and the primary waves is known to be one of the most significant factors that degrade the sensitivity, as it cannot be distinguished from the Sagnac signal. Therefore, broadband sources with very short coherent length such as an ASE have been used widely so far.

However, an ASE source on the integrated platform faces the problem of high power consumption. As clearly shown in Fig 2a, the L-I slope of the spontaneous emission is one order of magnitude lower than stimulated emission in the laser. Switching to a laser improves the power conversion efficiency and requires a shorter gain region (half in our case); these are of great importance for any integrated device. Moreover, a RIN measurement shown in the inset clearly indicates that the RIN would be lowered by two orders of magnitude.

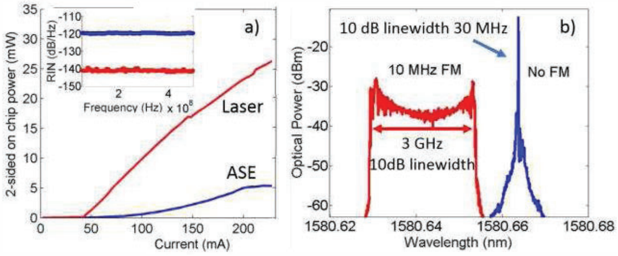

Figure 2. a) Comparison between heterogeneous Si laser and on-chip ASE sources: Output power vs. current. Inset: RIN noise. b) Optical spectra of the heterogeneous Si laser with and without FM.

By modulating the frequency of a laser at high frequency, we effectively diminish the coherence length of the laser. Fig 2b shows the broadening of the linewidth of the Si-heterogeneous ring laser at a modulation frequency of 10 MHz with 3 GHz frequency excursion.

III. FIBER GYROSCOPE WITH FM LASER

Both the on-chip laser and an Agilent 83438A Er-doped ASE source were connected to a fiber gyroscope system for comparison. The test setup is shown in Fig 3. The PM fiber coil is 180 m long with a diameter of 30 cm. The entire setup is placed on a rotation table with high accuracy and large range of rotation.

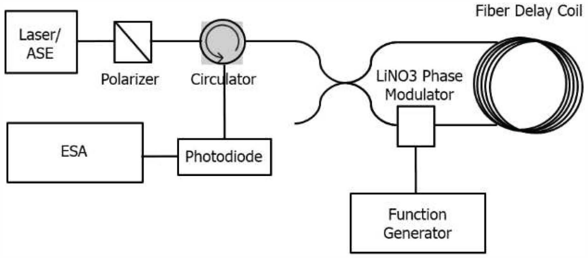

Figure 3. Test setup with fiber gyro system

We measure the Earth rotation rate using an electrical spectrum analyzer for an on-chip laser with and without direct modulation, as well as the ASE. All three comparisons are made with the same photocurrent on the detector. Note though, that the current necessary for the ASE source to achieve the same optical power level is at least ten times higher. As shown in Fig 4a, the noise floor of the gyroscope system using the on-chip laser is reduced by 10 dB through direct modulation. Furthermore, the noise floor is comparable with the commercial ASE source. This experiment illustrates that the collected coherent noise is successfully reduced with FM due to the linewidth broadening and reduced coherence length of the laser.

Fig 4b shows the comparison between scale factor and sensitivity of system as the fiber gyroscope system is rotated at various rates. For high rotation rates (> 0.006 deg/s), the signal increases linearly. However, for sufficiently small rotation rates (< 0.006 deg/s), the signal is insensitive to the rotation, placing a bound on the sensitivity of the gyroscope. As shown in Fig 4b, the lowest sensible rotation of the FM laser is lower than the laser without FM.

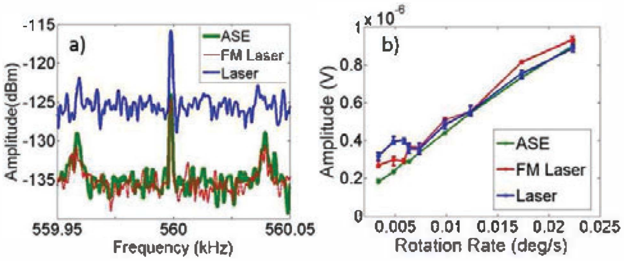

Figure 4. Comparison of sensitivity of FM laser, laser without FM, and ASE source a) Noise floor at earth rotation b) Signal vs. rotation rate

IV. DISCUSSION

Frequency modulation has increased the on-chip laser linewidth from 30 MHz to 3 GHz. This is still smaller than the 6.2 THz linewidth of the ASE, and as a result, the sensitivity of the gyroscope with FM laser is worse due to some residual coherent backscattering noise inside the signal band. However, the overall power consumption of the on chip FM laser is much lower than the commercial ASE source. For the same injection current, the FM laser will outperform the ASE source. Furthermore, for most gyroscopes, the linewidth of the laser is broad enough to avoid the reflections in the system, which primary happen at the connections between the coupler, modulator, and the splices of the fiber coil. With the FM laser, only the backscattering of the fiber close to the center of the loop contributes to the coherent backscattering noise.

In addition, the modulation efficiency of the laser is only 50 MHz/mA, which can be improved. We also noticed strong intensity modulation, which contributes to the RIN. Both these issues can be addressed by better design of the laser.

V. CONCLUSION

With the FM heterogeneous silicon laser, the noise floor of the fiber gyroscope system is reduced by 10 dB, and is comparable with the noise floor when a commercial ASE source is used. The sensitivity is also increased to 0.006 deg/s. For on chip gyroscope, an FM laser is preferred for lower power and smaller size.

For future work, the heterogeneous silicon front-end with 50:50 coupler, high speed modulator, and high speed detector will be fully characterized. We are also interested in replacing the fiber sensing loop with ultra-low loss silicon nitride delay lines [4]. The goal is a fully integrated interferometric waveguide optical gyroscope.

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