Integrated Optical Gyroscope with Inverse Weak Value Amplification

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Oxford PECVD, LPCVD Nitride, DISCO Dicing Saw, XeF_2 Etcher

Abstract:

Weak value amplification has been demonstrated to enhance interferometric signals. We apply inverse weak value amplification to an integrated Sagnac interferometer gyroscope and demonstrate rotation measurement with the weak value gyroscope.

Summary of Research:

Gyroscopes are key elements for systems such as motion sensing and navigation. Optical gyroscopes using Sagnac effect are being widely adopted for their high sensitivity and reliability. Recently, micro optical resonators have been used for integrated optical gyroscopes [1,2], which are compact and robust for field applications. However, Sagnac phase scales with size and quality factor of the ring. Due to the small area and shorter lifetime in the cavity, micro ring resonator gyroscopes are generally less sensitive than optical fiber gyroscopes. Therefore, we apply integrated weak value amplification device to a Sagnac interferometer with ring resonator to increase its signal-to-noise ratio and sensitivity without increasing the size of the ring. This combined weak value gyroscope paves the way for more applications of integrated gyroscopes in fields that require high sensitivity and stability.

Weak value amplification can enhance interferometric signal-to-noise ratio [3], which optical gyroscopes rely on to increase sensitivity. Weak value amplification is a technique that takes a small amount of the dataset in a slightly perturbed system to enhance the signal without increasing the noise floor. For example, in the dark port of a balanced interferometer, ideally there is no light output. However, by introducing a small phase front tilt to the beam, a light beam appears at the dark port and the path-dependent phase shifts can be converted to location shift of the beam. This beam location shift, determined by a location-sensitive detector, yields to a larger signal than a traditional interferometer. In the meantime, it does not add additional noise compared to the traditional interferometers. Therefore, it can also be applied to optical gyroscopes, whose main component is Sagnac interferometer.

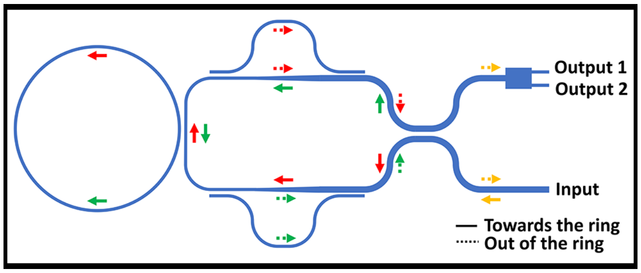

Figure 1: Schematic of integrated gyroscope with inverse weak value amplification (not to scale).

We use our integrated weak value device to detect interferometric signals from a ring resonator to measure rotation as a gyroscope. In a regular Sagnac interferometer, rotation is transferred to a phase difference between the clockwise and counterclockwise propagating light. In our weak value gyroscope, we use integrated weak value device to determine the phase difference between the two paths. The light is sent in through the bright port of the weak value device and gets split into two paths (Figure 1). The two paths couple to the ring resonator in different directions and accumulate Sagnac. Then they become the two inputs of the weak value device. They both go through a phase front tilter and interfere at the multimode directional coupler. The final beam location shift can also be interpreted as a phase front tilt. Therefore, at the dark port of the interferometer, we use a MMI (multimode interferometer) to determine the amount of phase front tilt of the light, which contains the information of rotation-dependent phase shift.

The device is fabricated with silicon nitride platform and CMOS compatible processes. We deposit 300 nm thick silicon nitride on 4 µm of silicon dioxide and pattern the interferometer. Then we etch the silicon nitride layer and deposit another layer of 2 µm silicon dioxide on top with PECVD (plasma enhanced chemical vapor deposition). All waveguides are patterned with DUV photolithography and etched by ICP-RIE (inductively coupled plasma reactive ion etching).

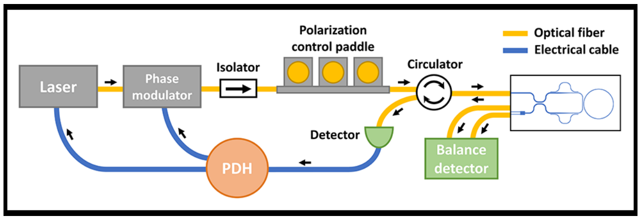

Figure 2: Testing setup of weak value gyroscope with PDH laser stabilization.

To characterize the performance of our weak value gyroscope, we mount the chip onto a motorized rotation stage and measure its angular velocity (Figure 2). We fuse a ribbon fiber with CO_2 laser to couple light around 1550 nm wavelength in and out of the device [4]. The light from the two dark port waveguides is sent to a balanced detector to get the power difference between them. The bright port is sent to a PDH system to lock the laser frequency to the resonance of the ring. The rotation phase in the bright port is in the TE1 mode and it is filtered out with a waveguide taper. We rotate the gyroscope back and forth in 1-sec steps while monitoring the balanced detector reading.

The gyroscope signal increases with rotation speed. The signal is calculated over 20 steps. Each step is averaged over 0.8 sec to avoid acceleration and deceleration. The gyroscope signal follows the rotation pattern of 1-sec rectangle waves as shown in Figure 3. The averaged signal shows linear relationship to the rotation rate up to 8°/sec (Figure 4). The loss of linearity could be due to the laser stabilization running out of tunability for long time operation. It can be improved by optimizing the PDH system settings.

Conclusions and Future Steps:

Integration of weak value amplification device with gyroscope can increase its sensitivity and enjoy the advantage of compactness and low noise. By adding weak value technique into micro ring gyroscopes, the sensitivity could be brought up one magnitude higher, which makes it more practical for field applications. The sensitivity can be improved with better quality factor of the ring resonator.

References:

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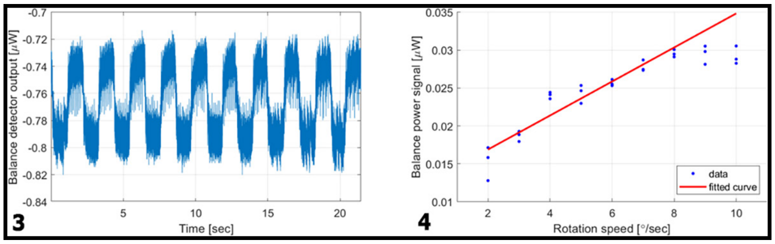

Figure 3, left: Balanced detector output of 5°/sec rotation, 1 sec time step. Figure 4, right: Weak value gyroscope signal vs. rotation speed.