

On-chip Si₃N₄ Gyroscope Enhanced by Ultra-High Weak Value Amplification

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Primary CNF Tools Used: ASML stepper, Suss Gamma Resist Cluster, Oxford 100 Inductively coupled plasma reactive ion etching (ICP-RIE), Oxford 82, Oxford PECVD, Furnace B1, E4, AJA Sputter, SEM Gemini, Veeco Icon AFM, PT VLN Deep Silicon Etch

Abstract:

We demonstrated that the performance of on-chip optical gyroscope can be addressed by applying weak value amplification, which resolves an intrinsic trade-off in the optical gyroscope that the sensitivity increases with the size of the gyro.

Summary of Research:

From everyday navigation using smartphones to controlling the attitude of satellites, modern society increasingly relies on gyroscopes that can precisely track motion in real time while being compact enough to minimize device size. Although optical gyroscopes have demonstrated superior motion detection sensitivity compared to traditional MEMS gyroscopes, they typically face a fundamental tradeoff: increased sensitivity with larger size 1–5. We address this trade-off by employing the weak value amplification (WVA) method, enabling the development of small yet highly sensitive on-chip optical gyroscopes.

We integrate the weak value device, which has demonstrated a signal amplification of 30 dB₆, with a Sagnac interferometer coupled to a ring resonator (Fig 1). The rotating ring resonator generates an optical phase difference between the counter-propagating light due to the Sagnac effect. The weak value device (the left half of the device) can “concentrate” the phase difference information into the dark port (D1, D2) of the Sagnac interferometer, so that the amount of detected light and the resulting shot noise are both reduced, while the detected signal intensity is maintained. Therefore, the weak value amplified interferometer can allow more light participating in the phase sensing up to a point that the detector is saturated, which effectively increases the signal-to-noise ratio. With the phase signal amplified by the 30 dB WVA, a compact optical gyroscope can obtain

a resolution comparable to that of a 35 times bigger gyro without WVA. This enhancement thus resolves the trade-off between the footprint and the resolution intrinsic to any optical gyro based on Sagnac effect. Moreover, different from the regular interferometric gyroscope 3,5,7, the weak value amplified gyroscope naturally has a maximized response to the Sagnac phase without any phase bias used to operate at the interferometer quadrature. Therefore, the weak value enhanced gyro can be operated with a lower cost and in a more compact space by removing the modulation and demodulation electronics, which are required by the regular gyroscopes to produce a quadrature bias.

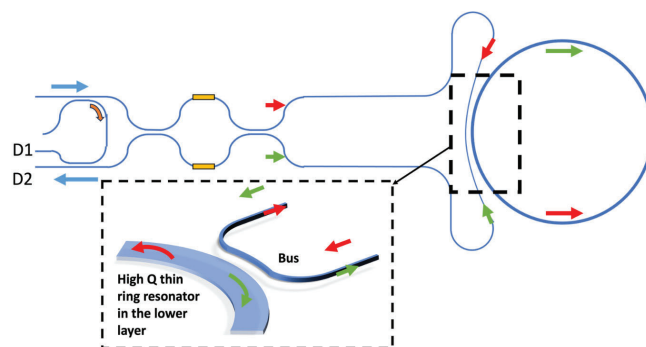


Figure 1: A schematic of the weak value enhanced gyroscope. Inset shows the two-layer structure of the ring-bus coupling.

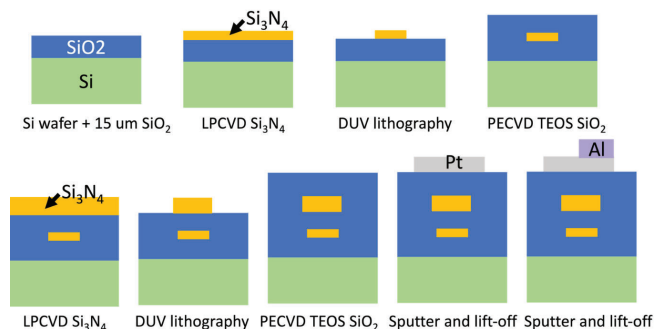


Figure 2: Main fabrication steps.

We fabricate the on-chip optical gyroscope on a CMOS compatible silicon nitride platform. The fabrication process (Fig.2) begins by depositing a ~ 60 nm Si_3N_4 layer using the low-pressure chemical vapor deposition (LPCVD) on top of a 15-um thermal-grown SiO_2 layer as shown in Figure 2. We pattern 5-um ring resonator waveguides with the ASML DUV lithography and etch with OXFORD 100 (inductively coupled plasma reactive ion etcher). The high-aspect-ratio waveguide structure lowers the light propagation loss and thus makes a high-Q ring. The cladding is a 1.5 um SiO_2 layer deposited by OXFORD PECVD with the TEOS recipe. Next, we deposit another 300 nm Si_3N_4 layer using LPCVD to pattern the rest waveguides, including the bus and the interferometer supporting weak value amplification, which requires more confinement and are less sensitive to loss. The cladding is a 3-um TEOS PECVD silicon oxide layer. The PECVD oxide layers are annealed in B1 furnace to outgas the Hydrogen-related impurities. Then, we pattern the microheaters with ASML DUV photolithography. Then, we sputter 10 nm Titanium as an adhesion layer and another 100 nm Pt with AJA sputter. The metal residues remaining on the photoresist are then removed using acetone under sonication to finalize the formation of microheaters on the chip. In order to make pads compatible with wire bonding, we further pattern with the ASML and sputter 1um Al pads at the end of the Pt circuits with 10nm Ti adhesive layer underneath. The liftoff is again done by resist removal in the acetone with sonication. We etch SiO_2 next to the waveguide input tapers with OXFORD 100 to create vertical facets for fiber-to-chip-edge coupling. Si is etched by Bosch process with VLN Si deep etcher to further deepen the facet trench to accommodate fibers.

Conclusions and Future Steps:

We have successfully integrated the weak value amplification with the on-chip optical gyroscope devices. Our future research aims to demonstrate the enhancement in gyroscope performance by weak value amplification.

References:

- [1] Lefevre, H. C. The Fiber-Optic Gyroscope, Second Edition. (Artech House, 2014).
- [2] Dell'Olio, F., Natale, T., Wang, Y.-C. & Hung, Y.-J. Miniaturization of Interferometric Optical Gyroscopes: A Review. *IEEE Sensors Journal* 23, 29948–29968 (2023).
- [3] Feng, C. et al. Interferometric Integrated Optical Gyroscope Based on Silicon Nitride Waveguide Ring. *IEEE Sensors Journal* 24, 23781–23788 (2024).
- [4] Huffman, T., Davenport, M., Belt, M., Bowers, J. E. & Blumenthal, D. J. Ultra-Low Loss Large Area Waveguide Coils for Integrated Optical Gyroscopes. *IEEE Photonics Technology Letters* 29, 185–188 (2017).
- [5] Gundavarapu, S. et al. Interferometric Optical Gyroscope Based on an Integrated Si_3N_4 Low-Loss Waveguide Coil. *Journal of Lightwave Technology* 36, 1185–1191 (2018).
- [6] Mei, Y., Song, M., Jordan, A. N. & Cardenas, J. 30 dB on-chip ultra-high inverse weak value amplification. *Opt. Lett.*, OL 51, 3293–3296 (2026).
- [7] Ma, H., He, Z. & Hotate, K. Reduction of Backscattering Induced Noise by Carrier Suppression in Waveguide-Type Optical Ring Resonator Gyro. *Journal of Lightwave Technology* 29, 85–90 (2011).
- [8] Bauters, J. F. et al. Ultra-low-loss high-aspect-ratio Si_3N_4 waveguides. *Opt. Express*, OE 19, 3163–3174 (2011).