23dB On-Chip Interferometric Signal-to-Noise Enhancement via Weak Value Amplification

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Primary CNF Tools Used: ASML stepper, Oxford 100 Inductively coupled plasma reactive ion etching (ICP-RIE), YES EcoClean Asher, Oxford PECVD, Furnace, JEOL-9500, Woollan RC2 Spectroscopic Ellipsometer, AJA Sputter, Unaxis 770 Deep Silicon Etch, Veeco Icon AFM, PT VLN Deep Silicon Etch, Xactix Xenon Difluoride etcher

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Abstract:

We demonstrate a 23dB On-chip Interferometric Signal-to-Noise Enhancement in the phase response of an on-chip weak value interferometer compared to a standard Mach-Zehnder interferometer paving the way to ultrahigh sensitivity in classical interferometry.

Summary of Research:

Optical interferometry plays a critical role in precision metrology, gravitational wave detection, positioning and navigation, and environmental sensing. However, the sensitivity is fundamentally limited by quantum noises such as shot noise. Classical methods to improve the sensitivity of a measurement usually minimize electronic and technical sources of noise to operate in the shot noise limit. In this limit, the signal to noise ratio (SNR), and thus the sensitivity, can be enhanced by increasing the optical power that reaches the detector up to the point of detector saturation. Quantum strategies to improve the SNR use quantum squeezing to reduce the shot noise level, which, however, is difficult to implement in practice and very susceptible to loss.

Here, we show that weak value amplification (WVA) on a photonic chip is capable of record-breaking sensitivity enhancement by amplifying the signal without increasing the detected optical power. WVA enhances sensitivity by post-selecting photons for detection[1–3]. WVA has previously demonstrated measurements of optical beam displacements of a few femtometers[4] and object velocities as low as 400fm/s[5]. However, these demonstrations were shown on bulky tabletop experiments and can't access large amplifications. Previous on-chip demonstration of WVA showed an enhancement of 7dB[6]. In this work, we have successfully implemented WVA in an integrated photonic device, which offers a compact and stable solution for SNR improvement, achieving a 23dB SNR improvement that is robust against optical loss. The amplification surpasses the record 15dB tabletop quantum squeezing record to the best of our knowledge[7].

We fabricate the device on a CMOS compatible silicon

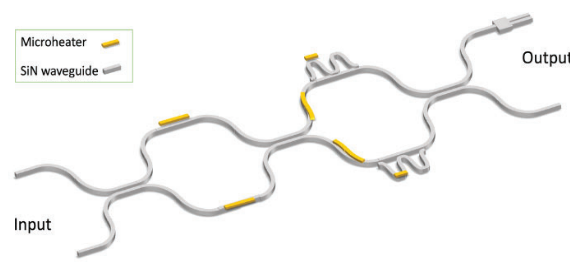

Figure 1: A schematic of A schematic of the integrated ultra-high weak value device.

nitride platform. The device schematic is given in Figure 1. The fabrication process begins by depositing a 300 nm Si_3N_4 layer using LPCVD on top of a 4um thermal-grown SiO_2 layer as shown in Figure 2. We deposit 400nm silicon dioxide by OXFORD PECVD on top of waveguide layer as a hard mask for following etching processes. We pattern the waveguides (single mode: 1.06 um wide, multi-mode: 2 um wide) with JEOL 9500 e-beam lithography and etch with OXFORD 100. The cladding is a 2um SiO_2 layer deposited by OXFORD PECVD with TEOS recipe. Next, we pattern the microheaters with ASML DUV photolithography. Then, we sputter 10 nm Titanium as an adhesion layer and another 100 nm Pt (3 um wide, 100um long) with AJA sputter. The metal residues remaining on the photoresist are then removed using acetone to finalize the formation

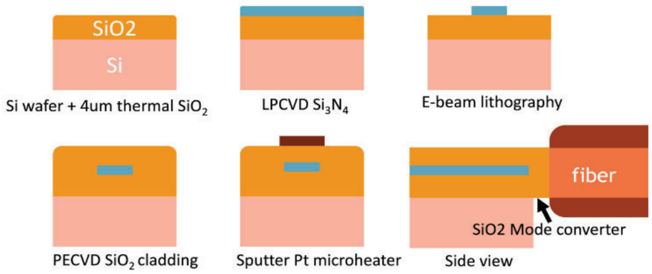

Figure 2: Main fabrication steps.

of microheaters on the chip. To improve fiber-chip coupling efficiency by matching the mode area in fiber (diameter = 10.4um), we pattern mode converters with ASML DUV photolithography at the end of inversed waveguide tapers (short sections of SiO2 measuring 10um in length and tapering from 20um to 11.5um in width suspended in the air).[8,9]We etch 6 um SiO2 with OXFORD 100 and then etch Si by 160um with Bosch process with VLN deep Silicon etcher. Finally, we undercut the silicon under the mode converter consist of silicon dioxide with Xactix Xenon Difluoride (XeF2) etcher.

Conclusions and Future Steps:

We have successfully tested 23dB SNR improvement by weak value amplification in fabricated integrated photonic devices. Our future research aims to apply this technique to capture phase signals from external information carriers, such as making a highly sensitive gyroscope.

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