Precise Phase Measurement with Weak Value Amplification on Integrated Photonic Chip

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Primary CNF Tools Used: Low pressure chemical vapor deposition (LPCVD), plasma-enhanced chemical vapor deposition (PECVD), JEOL 9500, ASML stepper, Oxford 100 ICP-RIE, AJA sputterer

Abstract:

We show, for the first time, phase measurement with weak value amplification on an integrated photonic chip. We demonstrate 9 dB improvement of signal over an on-chip Mach-Zehnder interferometer with equal amount of detected optical power.

Summary of Research:

Weak value amplification has shown the ability to make sensitive measurements with a small portion of the light signal, including beam deflection measurement of 400 frad with 63 µW out of 3.5 mW light power [1], frequency sensitivity of 129 kHz/√Hz with 85 µW out of 2 mW [2] and temperature sensor with 4-fold enhancement [3]. By introducing a perturbation and post-selection of the light, weak value amplification can amplify the signal to overcome technical noises, resulting in a higher signal-to-noise ratio (SNR) with less power. However, tabletop setups are space consuming and vulnerable to environmental changes. By taking this technique to the integrated photonics regime, we can largely improve its robustness and compactness, making it a good candidate for precision metrology.

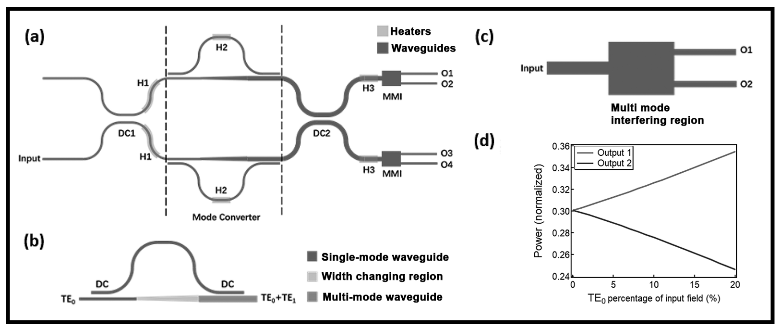

Figure 1: (a) Layout of device with heaters (not to scale). DC: direction-al coupler; H: heater; MMI: multi-mode interferometer; O: output. (b) Layout of a multimode interferometer. (c) Layout of a multi-mode interferometer. (d) Output power of MMI vs ratio of TE_0 and TE_1 mode.

We used an integrated Mach-Zander interferometer (MZI) followed by a multi-mode interference wave-guide (MMI) (Figure 1(a)) to achieve weak value measurement. To introduce the misalignment, in other words, a spatial phase tilt in a waveguide, we designed the structure in Figure 1(b) to couple a small part of the light in TE_0 to TE_1. This is based on the fact that the Hermite-Gaussian expansion of a free space tilted beam is mainly a combination of fundamental and first order modes [4]. Since eigenmodes of a waveguide are similar to Hermite-Gaussian modes, we applied the theory on waveguide eigenmodes TE_0 and TE_1.

We design a multimode coupler to couple light from fundamental mode to higher order mode. As shown in Figure 1(b), the lower waveguide is a single mode waveguide, which transits to a multimode waveguide through an adiabatic taper. The upper waveguide couples a slight portion of light from TE_0 in lower waveguide. Then it couples back in to the lower waveguide, but to TE_1 mode, since the TE_1 mode supported by the lower waveguide is designed to be phase matched with TE_0 in the upper waveguide.

Another necessary component is needed to measure the "location shift" at the dark port, which translates to measuring the ratio of TE_0 and TE_1 modes. We used an MMI (multi-mode interferometer, Figure 1(c)) as simulation (Figure 1(d)) shows that its output power is dependent on the ratio of the input TE_0 and TE_1 modes.

We then fabricated the device with CMOS-compatible processes. The fabrication started with a 4-inch silicon wafer with 4 µm of thermally grown silicon dioxide. We deposited a layer of 289 nm silicon nitride with low pressure chemical vapor deposition (LPCVD). Then we used e-beam lithography to pattern the waveguides and etched the silicon nitride with inductively coupled plasma reactive ion etching (ICP-RIE). As cladding on the waveguides, we deposited 2.6 µm of silicon dioxide with plasma enhanced chemical vapor deposition (PECVD). Finally, we sputtered 100 nm of platinum with lift-off method for heaters.

We compare our weak value device with a standard on-chip MZI with same footprint working in quadrature. We launch 1 mW of laser power at 1570 nm with a tapered optical fiber. The phase signal is introduced by applying a modulated 1V, 10 kHz voltage to the heater 1. The outputs are imaged onto a balanced detector and we measure the signal on an RF spectrum analyzer.

We demonstrate 9 ± 1.9 dB signal improvement over the regular MZI in the weak value device with equal amount of detected optical power. When detected powers are 14 µW, weak value device has a signal of 66.17 dBm, while the regular MZI shows 75.33 dBm. For the regular MZI to also show a signal of 66.17 dBm, it requires a higher detected power of 40.5 µW.

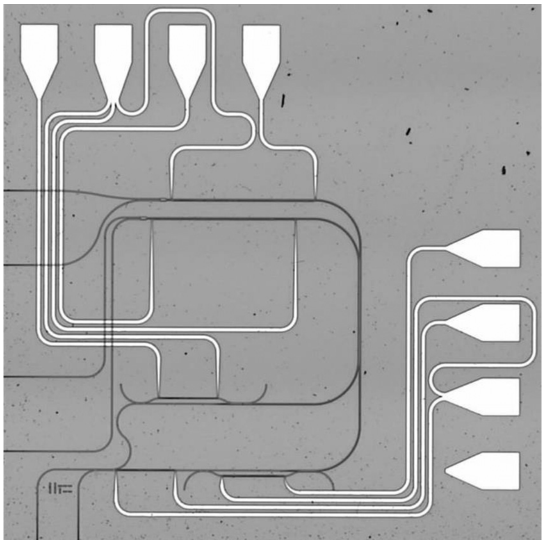

Figure 2: Microscope capture of the device. The device is wrapped around to reduce footprint.

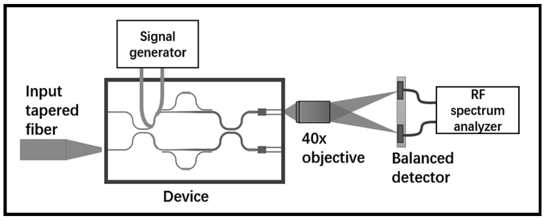

Figure 3: Illustration of testing setup.

Conclusions and Future Steps:

In conclusion, we have shown that on-chip weak value device is a good candidate for phase related metrology, including temperature drift and frequency shift. As it provides higher signal with same amount of optical power, it can monitor the optical signal in a system without consuming a large portion of the light. On the other hand, in a detector saturation limited system, weak value device is able to further increase the signal.

References:

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