Integrated Chip-scale Wavemeter with 300 MHz Free Spectral Range

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Abstract: We designed, fabricated and characterized an integrated chip-scale wavemeter based on an unbalanced Mach-Zehnder interferometer with 300 MHz free spectral range using low-loss Si3N4 platform. We also integrated an optical hybrid to provide phase information.
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1. Introduction and motivation

Wavemeters based on fixed-delay interferometers are commonly used to estimate wavelength sweep rates and linearize continuously tunable laser sweeps [1–3]. Various types of interferometers can be used for this application, and commonly Mach-Zehnder or Michelson interferometers are employed. Such interferometers are typically realized in fiber. The benefit of using a fiber lies in extremely low propagation loss allowing for practically arbitrary path length imbalance and consequently arbitrary free spectral range of the interferometer. However, polarization stability of fiber based interferometers can be a problem. One way to compensate for polarization fluctuations is the use of polarization-maintaining fiber and components, but this comes at the expense of significantly higher cost. Another approach, suitable for Michelson based architecture, lies in the use of the universal time-reversal operator in the form of a Faraday rotating mirror [4]. An ideal Faraday rotator followed by a mirror cancels any effect of the medium birefringence and guarantees that the beam always returns with opposite polarization with the respect to input state. Nevertheless fiber based interferometers still suffer from sensitivity to vibrations, temperature vibrations and are relatively bulky in size.

Chip-scale integration can improve the stability and provide reduced cost, size and weight. We design a chip-scale Mach-Zehnder based interferometer realized in low-loss Si_3N_4 waveguide platform. The use of Si_3N_4 waveguide platform brings a few key benefits: low propagation loss and high polarization extinction ratio. Losses as low as 0.045 dB/m have been demonstrated around 1580 nm using 40 nm thin Si_3N_4 films [5]. Here we opt to use thicker 90 nm Si_3N_4 film as it allows for tighter bends and reducing the wavemeter footprint. The area of the 62.1 cm long delay line is only 3.5 mm x 6.5 mm and the total chip size comprising two wavemeter designs is approximately 8 mm x 13 mm (see Figure 1). Due to the high-aspect ratio, Si_3N_4 waveguides provide very high polarization extinction, up to 75 dB [6] making the Mach-Zehnder type interferometer extremely stable in terms of polarization.

We designed two types of wavemeters that we call A and B (see Figure 1). Type A is an unbalanced Mach-Zehnder interferometer (UMZI) that can be used to count fringes and monitor the sweep, but cannot be used to detect the phase as its two outputs are phase inverted (180º phase shift). Detection of phase allows for more precise wavelength tracking as well as detection of the direction of the wavelength sweep, so sweep reversals can thus be accounted for and tolerated. In fiber, this is commonly achieved by using 3x3 fiber couplers that produce 120º phase shifts between the arms [7]. A 3x3 multimode interference (MMI) coupler could provide the same functionality [8],

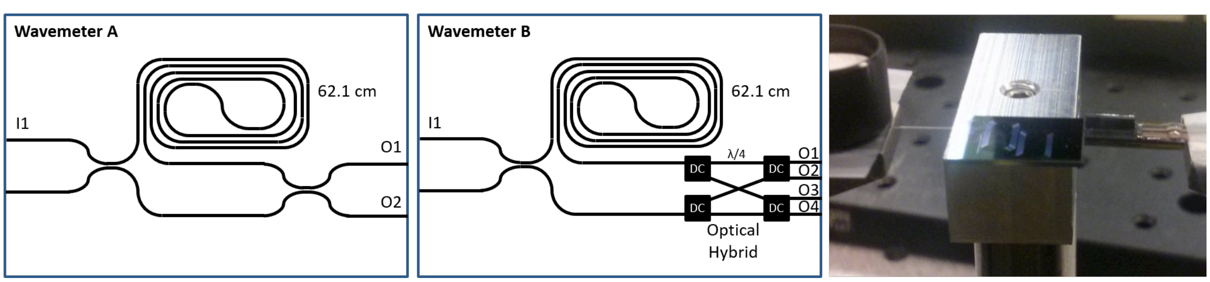

Fig. 1. (Left) Design of wavemeter A. An unbalanced Mach-Zehnder interferometer with 62.1 cm of length unbalance. (Center) Design of wavemeter B. Introduction of optical hybrid allows for phase measurement. (Right) A chip comprising both types of wavemeters. For input we use cleaved fiber, we collect the outputs using a V-groove fiber array (also with cleaved fibers).

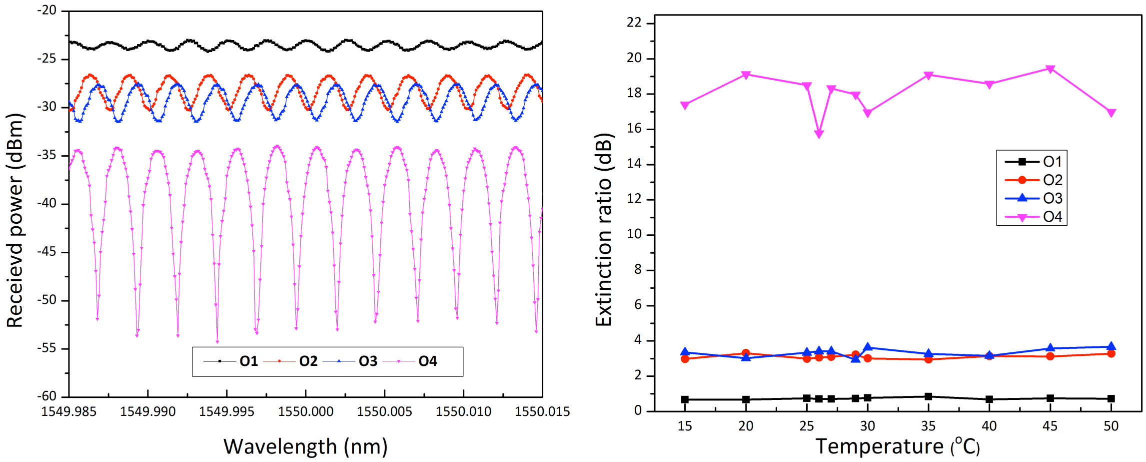

Fig. 2. (Left) Measured response of Type B wavemeter design showing phase shift between different output ports. (Right) Extinction ratio as a function of chip temperature. The wavemeter is mostly unaffected by the change of temperature by 35 ºC.

but here we adopt a bit different approach. We introduce an optical hybrid in Type B design to provide I and Q demodulation of the phase. Optical hybrids are commonly used in coherent receivers for the same functionality.

2. Measurements and conclusion

The wavemeters were fabricated in-house at the University of California, Santa Barbara. We use inverse tapers to improve fiber coupling efficiency. Coupling loss to cleaved fiber is measured to be <3 dB per interface. The couplers in the UMZI were designed to compensate for higher propagation loss in the longer arm, but as propagation loss was higher than anticipated, some fringes have reduced extinction ratios. We measured the propagation loss utilizing optical frequency domain reflectometry to be around 0.24 dB/cm. The output power of the laser source during measurements shown in Figure 2 was set to 0 dBm and the system loss was measured to be around 4 dB in total. Thus the total insertion loss of the wavemeter is estimated to be < 18 dB (including coupling and waveguide loss). Nevertheless, the wavemeter offers up to 20 dB extinction ratio and both the extinction ratio and the phase shift between the arms are largely insensitive to temperature changes. Thus, wavelength estimation is independent of temperature. Some measured results are shown in Figure 2. Additional data presented at the conference will show laser wavelength measurements and long term stability tests.

To conclude, we have, to the best of our knowledge, fabricated and characterized a chip-scale wavemeter with record low free-spectral range of 300 MHz. The key benefits of integration are reduced dimensions and improved stability.

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