CMOS-Compatible Temperature Insensitive Silicon Ring Resonators

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Abstract:

We propose a new class of resonant silicon optical devices which are passively temperature compensated based on tailoring optical mode confinement in waveguides. We demonstrate their operation over a wide temperature range of 80 degrees.

Summary of Research:

High temperature sensitivity is one of the fundamental limitations of silicon photonic devices due to the large thermo-optic coefficient of silicon (~ 1.86 × 10^-4 K^-1). Most of the solutions proposed to date to overcome this problem involve delocalizing the mode and overlaying a polymer coating with a negative thermo-optic coefficient [1,2], but polymers are currently not compatible with any complementary metal oxide semiconductor (CMOS) process. Another approach is to use local heating of silicon itself to dynamically compensate for any temperature fluctuations [3,4]. However, an active compensation scheme is both cumbersome (requiring thermo electric coolers and controllers) and power hungry.

Here we demonstrate the control of the thermal drift of photonic structures by tailoring the degree of optical confinement in silicon waveguides. The basic photonic structure we propose consists of a ring resonator overlapped to a balanced Mach-Zehnder interferometer (MZI) [5]. The schematic of the device is shown in Figure 1(a). The additional degree of freedom in the choice of waveguide widths [6], apart from just the lengths, enables one to set the thermal dependence of the MZI to counteract the thermal drift of the ring. In fact, in using this approach, we can design temperature-insensitive MZIs, Figure 2(a), or MZIs having large negative temperature sensitivity, Figure 2(b). The waveguide widths and lengths are chosen in the two arms of the MZI to give a balanced transmission (Δ(n·L)_MZI = 0), Figure 1(b), while having a strong negative temperature sensitivity overall:

\[
\left( \frac{\partial}{\partial T} \Delta(n \cdot L)_{MZI} < 0 \right)
\]

The ring has a large enough waveguide width to enable highly confined single mode operation, and consequently strong positive temperature sensitivity:

\[
\left( \frac{\partial}{\partial T} \right)
\]

The relative temperature sensitivities of the ring and the MZI, compared in Figure 1(c), are designed to be equal and opposite to cancel each other out.

The fabricated device, Figure 3(a), shows temperature stability over a large temperature range of over 80 K. Transmission spectra of this device at the bar port were measured at different temperatures. The transmission around 1565.5 nm for several different temperatures is shown in Figure 3(b). For reference, the theoretical lineshapes at these temperatures are shown. The measured data agree very closely with the theoretical lineshapes. In this particular case, the oscillation in the wavelength at the transmission minima was less than 1 nm. We measured less than 3 dB worst case degradation in the transmission minima of 1565.63 nm. Continuous operation over 80° was demonstrated by passing...
a 1 Gbps, $2^7$-1 pseudo-random data at a bar port resonance of 1542.375 nm. Figure 3(c) shows the eye patterns at different temperatures overlaid together, which clearly shows that the eye never closes at any temperature. In fact the quality factor of these eye patterns ($Q_{\text{eye}} = |\mu_1 - \mu_0|/(\sigma_1 + \sigma_0)$) never goes below 10 indicating an error free operation (BER < $10^{-12}$). The eye opening decreases and increases with temperature as expected due to the oscillatory temperature dependence of the device.

References: