Fully Reconfigurable Silicon Photonic Interleaver

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Abstract: We demonstrate a fully reconfigurable 125 GHz flat passband silicon photonic interleaver with a box-like spectral response and 20 dB extinction ratio.

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Optical interconnect networks utilizing wavelength-division multiplexing (WDM) technology present a solution to the electrical interconnect bottleneck by offering a larger bandwidth and lower power consumption in high-performance microelectronic chips [1-3]. To realize this goal, high speed silicon-based modulators and germanium photodetectors have been demonstrated [4,5]. However, their integration with a WDM system has been limited by the optical bandwidth of the multiplexers/de-multiplexers. As such, a broad and flat passband interleaver with high extinction ratio and rapid rolloff on the band edges is essential to combine or separate a comb of WDM signals [6]. Several on-chip interleaver designs have been demonstrated and have shown to be sensitive to fabrication variations in waveguide width and coupling gap, which results in performance degradation of the filter [7,8]. Here we demonstrate a silicon photonic interleaver with full reconfiguration capability which can compensate these fabrication imperfections.

Our interleaver design is comprised of an asymmetric Mach-Zehnder interferometer (MZI) coupled with 3 identical microring resonators as shown in Fig. 1(a). To achieve a box-like transmission spectrum with a flat passband and high extinction ratio, it is critical that the power coupling coefficient (k_0) of the splitter and the directional coupler is kept at 3 dB and the path difference (dL) between the asymmetric MZI arms is equal to half the length of the ring (L_{ring}). In addition, the coupling coefficients (k_1, k_2, and k_3) between the MZI arm and the ring resonators are 0.94, 0.36 and 0.75 respectively. The transfer function of the device can be expressed as:

$$H_{bar}(z) = \frac{1}{2}\left[\left(\frac{p_1+z^{-2}}{1+p_1z^{-2}}\right)\left(\frac{p_2+z^{-2}}{1+p_2z^{-2}}\right) - \left(\frac{p_3+z^{-2}}{1+p_3z^{-2}}\right)z^{-1}\right] \qquad (1)$$

$$H_{cross}(z) = \frac{-j}{2}\left[\left(\frac{p_1+z^{-2}}{1+p_1z^{-2}}\right)\left(\frac{p_2+z^{-2}}{1+p_2z^{-2}}\right) + \left(\frac{p_3+z^{-2}}{1+p_3z^{-2}}\right)z^{-1}\right], \qquad (2)$$

where $p_m = \sqrt{1-k_m}$, $z^{-1} = e^{-j\frac{2\pi}{\lambda}n_g dL}$, and n_g is the group index of the device and λ is the free space wavelength.

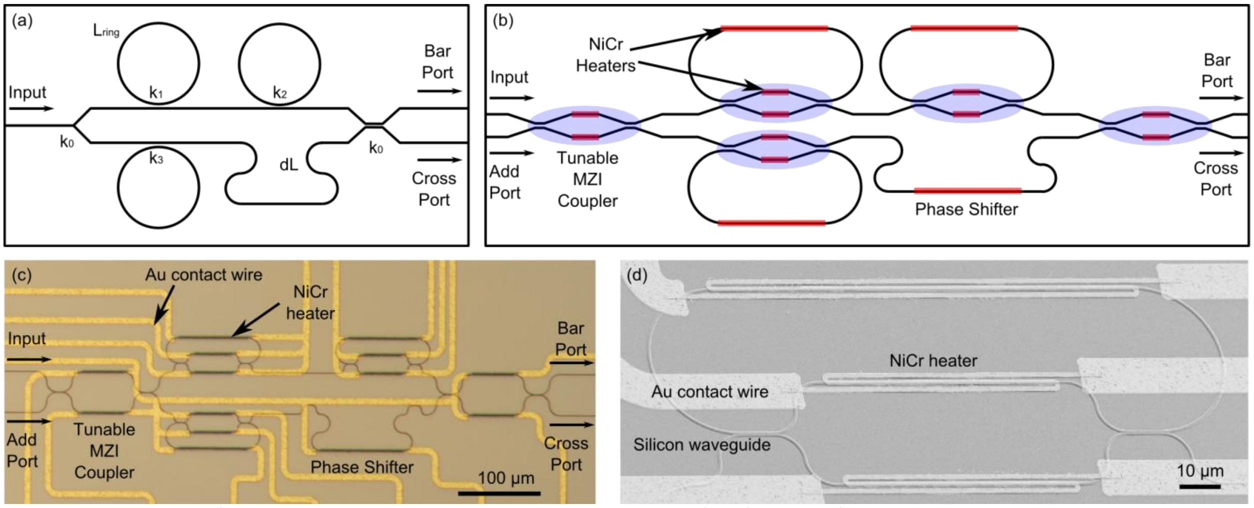

Fig. 1. (a) Schematic of the silicon photonic interleaver design. (b) Schematic of the fully reconfigurable silicon photonic interleaver. (c) Top view microscopic image of the device. (d) SEM image of the MZI coupled ring resonator.

Due to the challenge in achieving the exact designed coupling at each region during fabrication, we propose an equivalent design with full reconfiguration capability which employs a thermo-optically tunable MZI coupler (indicated by the blue regions in Fig. 1(b)) at each coupling region [9,10]. This allows the coupling coefficient of each region to be controlled independently without any crosstalk. For a lossless tunable MZI coupler, the effective coupling is $k_{\mathrm{eff}} = 4\cdot\mathrm{kappa}\cdot(1-\mathrm{kappa})\cdot\cos^2(\Delta\varphi/2)$ where kappa is the power coupling coefficient at each directional coupler of the MZI and $\Delta\varphi$ is the phase difference between the 2 arms. Hence, by tuning the phase of one arm, k_{eff} can be reconfigured within a full range from 0 to ~1 when kappa is ~0.5.

We fabricate the interleaver on a 250 nm silicon-on-insulator wafer with 3 µm of buried oxide using standard fabrication processes. First the 450 nm x 250 nm channel waveguides are patterned using e-beam lithography and chlorine-based etching. After resist stripping, the etched structures are clad with 1 µm thick silicon oxide layer using plasma enhanced chemical vapor deposition to confine the optical mode. Finally, 260 nm of nichrome (NiCr) microheaters are evaporated on the cladding and 300 nm of gold (Au) contact pads are defined using a lift-off process. The fabricated device is shown in Figs. 1(c,d).

We demonstrate a 3 dB passband width of 125 GHz for our device. We couple a tunable light source into the input through a polarization controller. The light output at the bar port and cross port are collimated through a lens and collected at the detector to measure the insertion loss of TE polarized light (set by the polarization controller). Figure 2(a) shows the transmission spectra of the device before thermal tuning. One can observe that the spectrum of each port does not complement the other, and the extinction ratios of the bar and cross ports are 7 dB and 9 dB respectively. With the fully reconfigurable interleaver, we can easily reconfigure the coupling and the phase at the critical regions. Figure 2(b) shows the spectra of the optimized device after thermal tuning. It is shown that the spectra of the bar and cross ports within the wavelength range of 1535 – 1580 nm are clean and complementary. The zoom-in spectra in Fig. 2(c) illustrates that our interleaver has a 125 GHz flat passband and box-like spectral response. The extinction ratios of the bar and cross ports are measured to be 18 dB and 20 dB respectively.

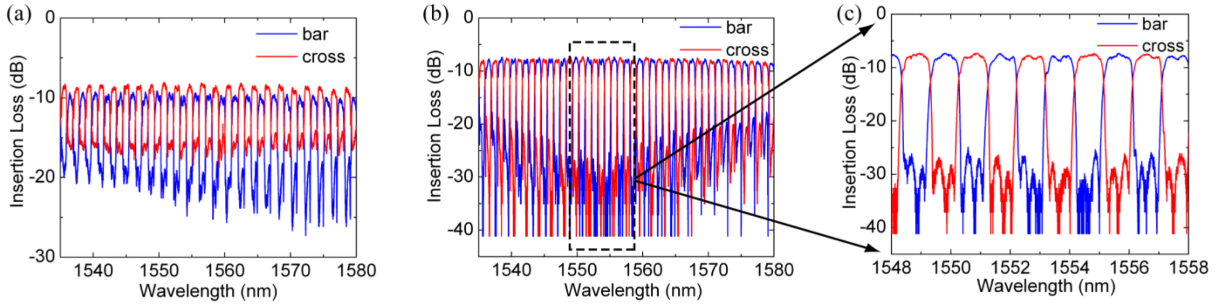

Fig. 2. Transmission spectra of the triple ring MZI interleaver (a) before thermal tuning, (b) after thermal tuning, (c) zoom-in spectra of Fig. 2(b)

To conclude, we have demonstrated a 125 GHz flat passband silicon photonic interleaver with a box-like spectral response and 20 dB extinction ratio. Our interleaver can be implemented in the WDM system and integrated with the high-speed on-chip modulators and photodetectors. The WDM signals can be multiplexed/de-multiplexed by this interleaver without significant distortion or loss. In addition, our interleaver has full reconfiguration capability to compensate for any fabrication variations. This fully reconfigurable design can also be implemented in other on-chip devices where coupling is critical and reconfigurability is desired.

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