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A WDM Silicon Photonic Transmitter based on Carrier-Injection Microring Modulators

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Abstract: We present a 5 x 10 Gbps WDM silicon photonic transmitter based on carrier-injection type microring modulators. Resonant wavelengths can be adjusted by both thermal heaters and bias tuning.

OCIS codes: (200.4650) Optical interconnects; (250.5300) Photonic integrated circuits

Silicon photonics technology provides a scalable alternative to meet the future bandwidth demands of high-performance computing systems with low power consumption [1]. Microring resonators with slightly different radii can be easily cascaded to a single waveguide to form wavelength division multiplexing (WDM). Fig. 1 (a) shows a schematic of a CMOS photonic link. Carrier-injection-based microring modulators can be driven by small voltage swings to achieve large modulation because of the large current flow above threshold. Due to its inherent slow diffusion time, however, pre-emphasized driving signals are required for high-speed operation [2]. To tune the resonance of the rings to the input laser wavelength and compensate for any thermal drifts, a tuning scheme is also required.

In this work, we demonstrate a 50 Gbps silicon photonic WDM transmitter based on carrier-injection microring modulators. Both thermal tuning and bias tuning methods are available to adjust the resonant wavelength of the microring. A DAC-controlled CMOS circuitry in a 2Vpp driver shows automated wavelength locking. This represents an important step towards a fully integrated WDM CMOS photonics link. Our efforts on using flip-chip bonding technique will enable chip scale integration between CMOS and photonic chips in a single step. We expect a much compact package with improved high frequency performance.

Fig. 1(b) shows the fabricated 5-channel photonic transceiver with the flip-chip bonding pad array in the center and the wirebond pads for packaging to PCB in the peripheral. Basic element of each channel consists of a microring resonator with an integrated Ge waveguide photodiode at its drop port and an integrated heater, as shown in Fig. 1 (c). Two layers of metal implemented by a standard damascene process facilitate the complex metal routing. The total footprint of the photonic transceiver is currently limited by the bonding pads and the matching CMOS circuits at 65 nm technology nodes. The microring resonators with slightly increasing radii around 5 µm generate a series of WDM channel, and support more than 20 channels with 80 GHz spacing at 1.3 µm wavelengths. Optical transmission spectrum of a microring resonator in Fig. 1 (d) exhibits a quality factor of 12,000 with an on/off extinction ratio of 18 dB.

In the previous proof-of-concept single channel demonstration [3, 4], the high-speed performance of the transmitter was limited by unexpected high contact resistance of the photonic device and long bonding wires. There was also no drop port incorporated with the microring. Here we tailor the photonic device to meet the needs for WDM transceivers. By driving the microring modulators with external pre-emphasized electrical signals at 10 Gbps (Fig. 2 (a)), we demonstrate that the optical output signals at all five channels have a clear eye opening with healthy margin (Fig. 2 (b-f)). We also demonstrate a 12.5 Gbps operation in Fig. 2 (g). A 2Vpp CMOS driver wirebonded to the microring shows 9 Gbps operation with energy efficiency of 473 fJ/bit.

A local heater is implemented by doping silicon at the same step as the p-i-n junction formation to provide wide range red shift. A sheet resistance of around 800Ω/□ is achieved in a 50 nm silicon slab layer. Fig. 3 (a) shows the resonance shifts in relation to various heater biases with a tuning efficiency of 23µW/GHz, or 44mW/FSR. Fig. 3 (b) describes the bias tuning results for more energy efficient fine tuning to blue-shift the resonant wavelength. We intentionally detune the input laser wavelength to -0.3nm of the microring resonance to exemplify the mismatch due to fabrication variations. A control loop for bias-based tuning circuits [3] increases the anode voltage of the p-i-n diode to blue-shift the resonant wavelength due to accumulated free carriers in the ring waveguide with an efficiency of 6.8 µW/GHz. Optical power is monitored at the through port of the microring. It monotonically decreases during the tuning process and remains at a low power level after the microring resonance locked to the laser wavelength.

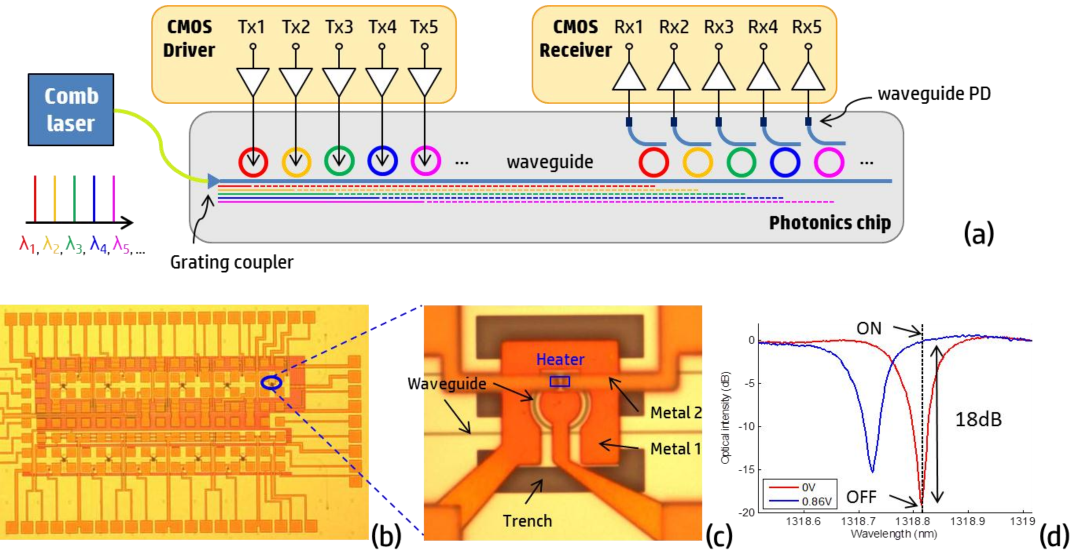

Fig. 1. (a) Schematics of a WDM CMOS photonic link. (b) A fabricated 5-channel silicon photonic transceiver. (c) Microscope image of a microring modulator. (d) Optical transmission of the microring modulator at 0V and 0.86V.

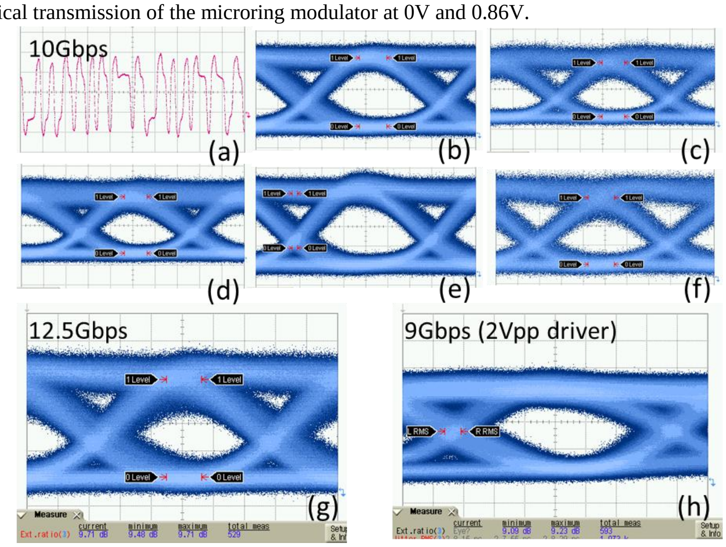

Fig. 2. Eye diagrams of (a) 10 Gbps pre-emphasis input signal, (b-f) 10 Gbps optical signal at five different channels, (g) 12.5 Gbps optical signal, and (h) 9 Gbps optical signal with a 2 Vpp CMOS driver.

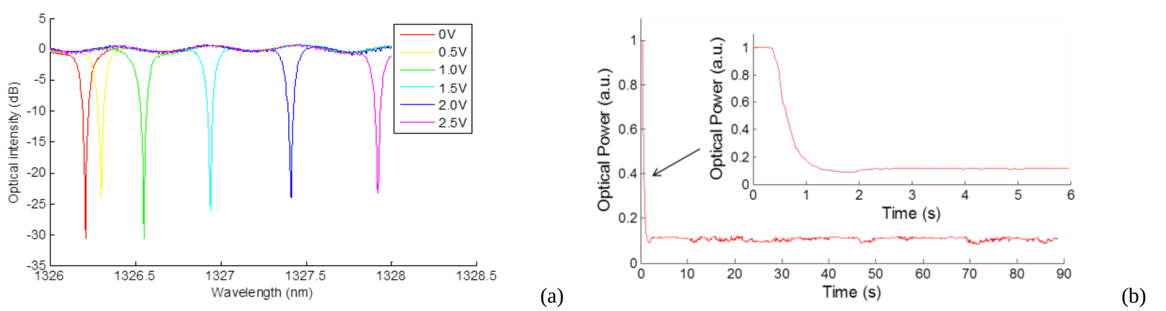

Fig. 3. (a) Microring transmission spectra at various heater biases. (b) Wavelength stabilization by CMOS circuitry. The optical power is monitored at the through port waveguide.

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