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DPSK Modulation Using a Microring Modulator

Kishore Padmaraju[1], Noam Ophir[1], Sasikanth Manipatruni[2], Carl B. Poitras[2], Michal Lipson[2], Keren Bergman[1]

1: Department of Electrical Engineering, Columbia University, 500 West 120th Street, New York, New York 10027, USA
2: School of Electrical and Computer Engineering, Cornell University, 428 Phillips Hall, Ithaca, New York 14853, USA
kpadmara@ee.columbia.edu

Abstract: We present the first experimental demonstration of DPSK modulation using a microring modulator. A 250-Mb/s electro-optic silicon microring modulator is shown with a measured 2-dB power penalty in comparison to a commercial $LiNbO_3$ phase modulator.

OCIS codes: (060.5060) Phase modulation; (200.4650) Optical Interconnects; (130.4110) Modulators

As multi-core processors (MCPs) continue to scale in size and complexity, the emerging interconnect-bandwidth bottleneck will have to be resolved by technology that transcends traditional electronic interconnects. The lower power dissipation and improved scalability of photonic links over electronic links at high data rates is motivating the development of photonic networks-on-chip (NoCs) for MCPs. Through a combination of individual nanophotonic components, such as waveguides, switches, detectors, and modulators, a photonic NoC enables inter-core communication at data rates currently unfeasible with electronic NoCs. In the realm of nanophotonic modulators, microring modulators are an ideal candidate for photonic NoCs because of their small size and low power consumption.

Electro-optic microring modulators have demonstrated on-off-keyed (OOK) modulation in a variety of material platforms [1-3]. Phase modulation is an attractive alternative to OOK modulation as it offers superior receiver sensitivity (with balanced detection), lower susceptibility to nonlinear effects, and potentially improved spectral efficiency [4]. In this work, we report the first experimental implementation of differential-phase-shift-keyed (DPSK) modulation using a microring modulator.

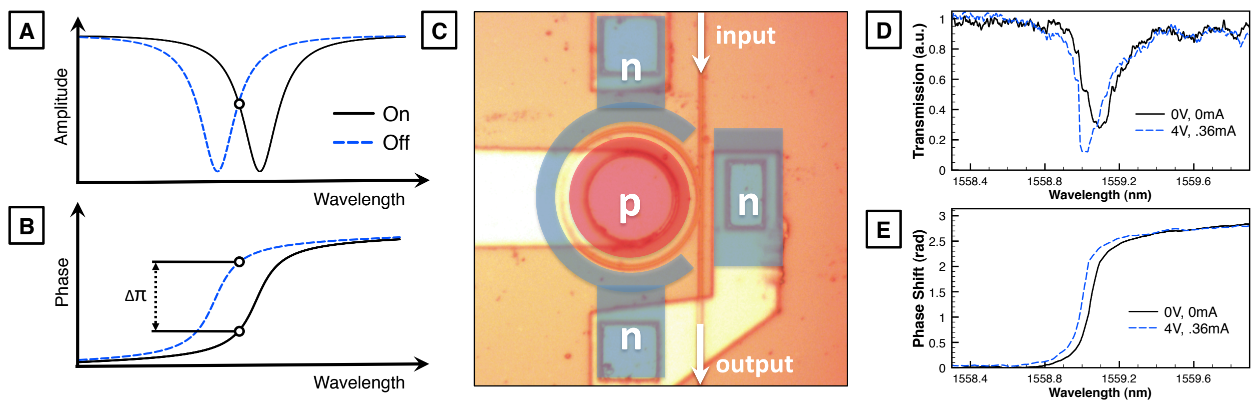

Figure 1: (a,b) DPSK modulation is produced by positioning the laser wavelength at (**o**), at which it experiences a constant amplitude between resonance transitions and a π phase shift. **(c)** Microscope image of microring with metal contacts and indicated doping. **(d)**Transmission spectrum and **(e)** phase response of the device.

Current iterations of microring modulators induce optical modulation through a change in the optical length of the microring. The subsequent change in the resonance condition is used to produce the amplitude modulation found in OOK (Fig. 1a). In an electro-optic silicon microring the modulation mechanism is a p-i-n junction formed by appropriately doping the inner and outer regions of the microring (Fig. 1c). Application of an electrical signal allows the injection of carriers into the ring, affecting the refractive index through free-plasma dispersion, and reducing the optical length of the microring. In addition to the blue shift of the resonance, there is also a significant blue shift in the phase response of the microring (Fig. 1b). For over-coupled microrings, the shift in the phase response can be used to produce the π phase shift needed for differential-phase-shift-keyed (DPSK) modulation [5].

The device used in this work, fabricated at the Cornell Nanofabrication Facility, was designed for quasi-TE operation using a waveguide height of 250 nm and width of 450 nm. A surrounding Si slab of 50 nm was used for the doping. A coupling gap of 200 nm over-coupled the 18-μm-radius microring with the waveguide. The Q-factor of the microring is ~13000. Application of a DC current to the device confirmed the blue shift of both the transmission spectrum (Fig. 1d) and phase response (Fig. 1e) of the microring modulator. The phase response was measured using a modulation phase-shift method [6].

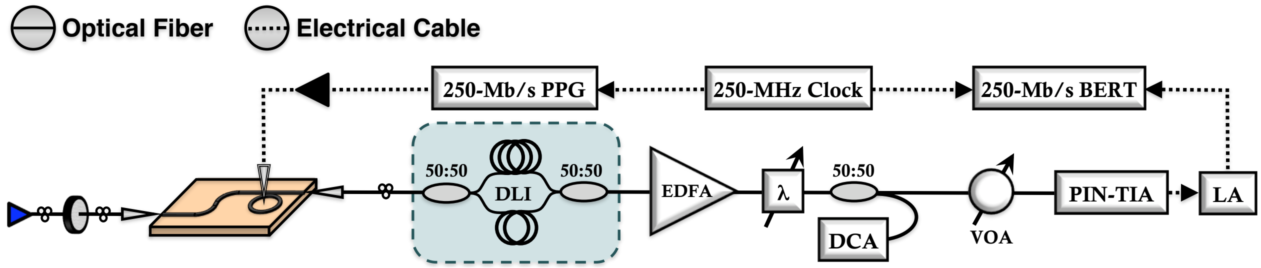

Figure 2: Experimental setup.

In our experimental setup (Fig. 2), a pulsed-pattern generator (PPG) was used to generate a 250-Mb/s non-return to zero (NRZ) 2^7-1 pseudo-random bit sequence (PRBS) RF signal. The 0.65-V_{pp} signal was biased at 3.60 V to drive the microring modulator. A CW tunable laser at a wavelength of 1559 nm was set to a TE polarization before being launched onto the chip at a power of 11.5 dBm. The microring phase-modulated signal egressing from the chip was fed into a thermally stabilized delay line interferometer (DLI) for DPSK demodulation. The demodulated signal was amplified with an erbium-doped fiber amplifier (EDFA), passed through a filter (λ) and a variable optical attenuator (VOA), before being received on a PIN-TIA photodetector followed by a limiting amplifier (LA). A BER tester (BERT) was used for BER measurements and a digital communications analyzer (DCA) was used to record eye diagrams. For the back-to-back comparison, we bypassed the chip and used a commercial $LiNbO_3$ phase modulator (rated for up to 10-Gb/s operation) to modulate the CW tunable laser.

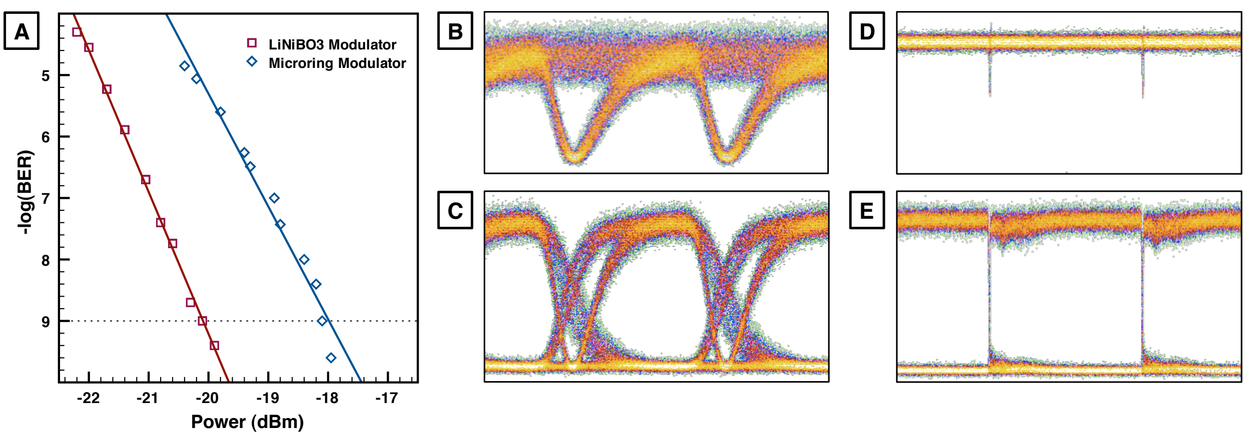

Figure 3: **(a)** Measured BER curves for microring modulated DPSK and for $LiNbO_3$ modulated DPSK. The microring modulated signal **(b)** before and **(c)** after the DLI. The $LiNbO_3$ modulated signal **(d)** before and **(e)** after the DLI.

The BER curves in Fig. 3a show a 2-dB power penalty (measured at a BER of 10^{-9}) for the microring modulator in comparison to the commercial $LiNbO_3$ phase modulator. The eye diagrams in Figs. 3b and 3d show the microring-modulated and $LiNbO_3$-modulated signals before the DLI, respectively. The amplitude chirp in Fig. 3b is a result of the resonance shift of the microring during bit transitions. The eye opening of the demodulated microring-modulated signal (Fig. 3c) is comparable in quality to that of the $LiNbO_3$ modulator (Fig. 3e). However, the relatively long carrier lifetimes of the device used in this experiment result in longer bit transitions for the microring.

We have shown the first experimental demonstration of microring-based DPSK modulation using a silicon electro-optic microring modulator, validated with BER measurements at 250 Mb/s to show an acceptable power penalty in comparison to a commercial modulator. Faster modulation rates are deemed possible using devices with shorter carrier lifetimes and using the pre-emphasis methods that have been shown for OOK [7], positioning the microring modulator as a potential high-speed low-power phase modulator for future photonic on-chip interconnects.

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