60 Gb/s PAM-4 Operation with a Silicon Microring Modulator

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Abstract—We report high-speed pulse-amplitude modulation (PAM) with silicon microring modulators. We demonstrate PAM-4 signals up to 30 GBaud.

Index Terms—Optical modulator, Silicon-on-insulator, Integrated optics, Electro-optic modulation, Optical resonators, Ring resonators, Optical interconnects

I. INTRODUCTION

SILICON microring modulators represent a promising technology to meet the bandwidth requirements in next generation computing systems [1] and short-reach optical interconnects [2]. A 60 Gb/s OOK microring modulator has been demonstrated [3]. More recently, a 320 Gb/s, 8-λ, WDM transmitter based on microring was reported [4]. As the data rate increases, the need for reducing the power consumption and cost becomes exponential [5]. The use of advanced modulation formats has the benefit of higher spectral efficiency and lower bandwidth requirements for the driver, effectively decreasing the complexity and cost. Microring modulators for high modulation formats have been demonstrated for coherent and non-coherent applications, e.g. 56 Gb/s QPSK modulator [6] and 24 Gb/s PAM modulator [7].

In this paper, we present a CMOS compatible silicon microring modulator working in C-band for high-speed pulse-amplitude modulation up to 30 GBaud. In a further consideration, the modulator includes a dopant heater as a demonstration that advanced modulation formats are possible while being robust to wavelength and thermal fluctuations [8].

II. DESIGN AND FABRICATION

We designed and optimized the modulator with the aid of the dynamical model presented in [9]. The modulator uses carrier depletion mode in the p-n junction. The light is coupled into, from a polarization maintaining fiber, and out of the chip via TE surface grating couplers. A 60 nm thick slab is used to implement the p-n junction. The ring radius is 8 μm, the coupling gap 230 nm and the centered p-n junction 1.5 μm wide. The p-n junction spans 75% of the ring circumference while the heater spans roughly 20% of the circumference. Dimensions of the p-n junction are labeled in Fig. 1 which also shows a photograph of the device.

The modulator was fabricated through the multi-project wafer (MPW) service at IMEC, Belgium. The process flow uses UV lithography procedures for mask definition.
III. MEASUREMENTS

Transmission spectrum is firstly acquired at varied bias, as depicted in Fig. 2. The extinction ratio is greater than 30 dB when no voltage is applied and the quality factor is roughly $Q \sim 97500$. The extinction ratio decreases as the applied voltage decreases. This behavior indicates that the modulator is over-coupled.

Fig. 3 describes how we create the multi-level RF signal as well as our experimental setup. The skew between the channels is adjusted for each baud rate. We transmit the RF signal to the silicon chip using a 40 GHz microprobe. A 250 μm spaced fiber array is used to achieve optical I/O via TE surface grating couplers. The light is amplified with an erbium-doped fiber amplifier (EDFA) and filtered with a tunable optical filter. The signal is detected with a 80 GHz digital sampling oscilloscope.

The modulator is then driven by a PAM-4 signal with $V_{pp} = 3.5\, V$ for baud rates of 16.5, 25 and 30 GBaud. We use a 3-bit DAC to generate the 4-level signal, one channel is left unused. As depicted in Fig. 4, we observe a clear eye opening up to 30 GBaud for an extinction ratio greater than 2 dB between adjacent levels. The RF signal is biased at $-5.5\, V$ as we found this point to be the optimal trade-off between noise and extinction ratio.

In Fig. 4, we notice slight skews in both time and power. The former is due to a delay mismatch between the channels before the DAC while the later is due to a non-optimal generation of the PAM-4 signal. Both of these phenomenon are present in the electrical signal before the modulator.

IV. CONCLUSION

A silicon microring modulator has been used to generate an optical PAM-4 signal, the fastest to our knowledge, at 30 GBaud (60 Gb/s) with clear eye opening and more than 2 dB of extinction ratio between adjacent levels. We expect improvement in performance using a better driving signal and DSP as no pre-compensation nor post signal processing was used.

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REFERENCES