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Optical Interconnects 2014
3rd IEEE Photonics Society Optical Interconnects Conference
4 - 7 May 2014
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Optical Interconnects Conference 2014 Program-at-a-Glance

Sunday, 4 May 2014	Monday, 5 May 2014	Tuesday, 6 May 2014	Wednesday, 7 May 2014
All Sessions are in Commodore A			
Welcome & Introduction to Working Group Statement: Commodore A 4:00pm-4:15pm	**Opening Remarks** 8:30am-8:45am	**TuA: Optical Interconnects II** 8:30am-9:45am	**WA: Enabling Computer Subsystems** 8:30am-9:45am
Introduction to Massive Online Learning: Commodore A 4:15pm-4:45pm	**MA: Optical Interconnects I** 8:45am-10:00am	**EXHIBITS/COFFEE BREAK:** COMMODORE B 9:45am-10:15am	
Introduction to Large Scale Data Centers: Commodore A 4:45pm-5:15pm	**EXHIBITS/COFFEE BREAK:** COMMODORE B 10:00am–10:30am	**TuB: LASERS for Optical Interconnects** 10:15am-12:00pm	**WB: Electronics for Photonics** 10:15am-12:00pm
	MB: Silicon Photonics: Ring Resonator Tuning and Control 10:30am-12:00pm	**LUNCH BREAK (ON OWN)** 12:00pm-1:30pm	
Working Group Session 1: Aurora, Britannia, Cambria, and Lenore 5:15pm-6:30pm	**LUNCH BREAK (ON OWN)** 12:00pm–1:30pm	**TuC: VCSEL Based Optical Interconnects** 1:30pm-3:30pm	**WC: Engineering for Low Cost and Energy** 1:30pm-3:30pm
	MC: Silicon Photonics for Interconnects: Modulators 1:30pm-3:30pm	**EXHIBITS/COFFEE BREAK:** COMMODORE B 3:30pm-4:00pm	
REFRESHMENT BREAK: Aurora, Britannia, Cambria, and Lenore 6:30pm-6:45pm	**EXHIBITS/COFFEE BREAK:** COMMODORE B 3:30pm-4:00pm	**TuD: Photonics for Extreme-Scale Systems** 4:00pm-5:30pm	**WD: Advances in Enabling Technologies** 4:00pm-5:15pm
Working Group Session 2: Aurora, Britannia, Cambria, and Lenore 6:45pm-8:00pm	**MD: Hybrid Integrated Optical Systems** 4:00pm-5:15pm	**TuP: Poster Session** Bay Terrace 5:30pm-7:00pm	**Registration Hours:** Commodore Foyer A Sunday, 4 May: 2:00pm-6:00pm Monday, 5 May: 7:30am-5:00pm Tuesday, 6 May: 8:00am-5:00pm Wednesday, 7 May: 8:00am-4:00pm
	Welcome Reception: Commodore B 5:15pm-7:00pm		
	Working Group Problem Findings: Commodore A 7:00pm-8:00pm		

We propose an optical switching network architecture called OpenScale. The idea of "small world" topology is employed to construct a flexible and highly scalable network. Simulations verified that proposed architecture can achieve eminent scalability.

TuP7

Small-Signal Frequency Responses for Si Micro-Ring Modulators, Y. Ban, J. Lee, *Yonsei University, Seoul, Korea*, B. Yu, *Yonsei University, Seoul, Korea*, S. Cho, *Samsung Advanced Institute of Technology, Yongin, Korea* and W. Choi, *Yonsei University, Seoul, Korea*

We present a new small-signal model for the modulation frequency response of a Si micro-ring modulator. The model is based on the coupled-mode theory and has the well-known second-order system characteristics. The accuracy of the model is confirmed with measured Si MRM small-signal frequency response.

TuP8

Heterogeneously Integrated Long Wavelength VCSEL-Based Transceivers for Chip to Chip Optical Interconnections, R. Rivers, D. Geddis and K. Komirisetty, *Norfolk State University, Norfolk, USA*

The research presented includes the design and fabrication of a long wavelength VCSEL-based optical transceiver. The VCSEL is integrated on an Indium Tin Oxide (ITO) metal-semiconductor-metal (MSM) photodiode. This device was designed for chip to chip optical interconnects.

TuP9

Optimization of Highly Efficient Mode Converter for Coupling Light into Large-Slot Photonic Crystal Waveguide, X. Zhang, *University of Texas at Austin, Austin, TX, USA*, H. Subbaraman, A. Hosseini, *Omega Optics, Inc., Austin, TX, USA* and R. Chen, *University of Texas at Austin, Austin, TX, USA*

We demonstrate a highly efficient mode converter for coupling light into a silicon slotted photonic crystal waveguide with slot width as large as 320nm. The loss of the mode converter is measured to be 0.08dB.

TuP10

Silica-Microfiber-Based Opto-Electrical Printed Circuit Boards for Board-Level Optical Interconnects, P. Wang and Q. Hao, *Huawei Technologies Co., Ltd., Shenzhen, China*

We propose an opto-electrical printed circuit board for board-level optical interconnects based on low-loss silica microfibers.

Small-Signal Frequency Responses for Si Micro-Ring Modulators

Yoojin Ban[1], Jeong-Min Lee[1], Byung-Min Yu[1], Seong-Ho Cho[2], and Woo-Young Choi[1]
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[2]*High Performance Device Group, Samsung Advanced Institute of Technology, Yongin, Gyeonggi-do, Korea*

Abstract: We present a new small-signal model for the modulation frequency response of a Si micro-ring modulator. The model is based on the coupled-mode theory and has the well-known second-order system characteristics. The accuracy of the model is confirmed with measured Si MRM small-signal frequency response.

Si photonics is attracting a great amount of research interest as it is the best platform for realizing high-bandwidth, low-power, and small footprint optical interconnect systems [1, 2]. One of the key components for optical interconnect systems based on Si photonics is a Si electro-optic modulator that can provide large bandwidth and high modulation efficiency with small size and power consumption [3]. A Si micro-ring modulator (Si MRM) is a very attractive device in this regard and there have been several reports of very high-speed operation [4, 5]. An accurate modeling of Si MRM characteristics is crucial for successful realization of the Si MRM. In particular, an accurate but easy-to-use model for Si MRM modulation bandwidth is of great interest for Si MRM performance optimization as well as Si MRM driver circuit design. Although there have been several reports of numerical analyses of Si MRMs [6, 7], such approaches can be time-consuming and do not provide physical insights. Previously, we reported an analytic small-signal frequency model for the Si MRM based on the round-trip analysis [8]. In this paper, we present a new small-signal model based on the coupled-mode theory (CMT) [9]. Our new model is much more convenient to use as it has the well-known second-order system characteristics. In addition, we confirm the accuracy of our model with measured results.

Fig. 1 shows dimensions of the Si MRM used for our investigation. The input light in a bus waveguide is partially coupled into the ring and, after experiencing round-trip phase shifts, coupled out to the bus waveguide. The round-trip phase shift is electrically tunable with an embedded reverse biased PN junction for high-speed modulation. The figure also includes a photograph of the Si MRM used for the present study. It is fabricated through the OpSIS-IME multi-project-wafer foundry service on 220-nm thick Si on 2-μm thick buried oxide layer. Fig. 2 shows the measured transmission characteristics of the device biased at -1 V.

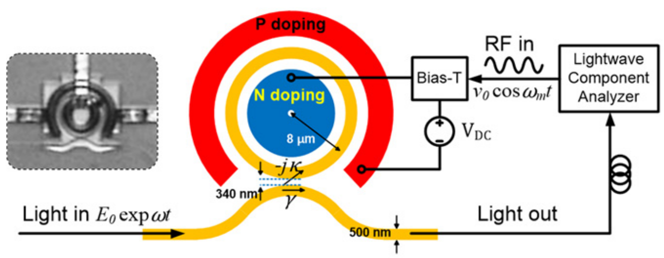

Fig. 1. Structure of a Si MRM (Photograph of the Si MRM)

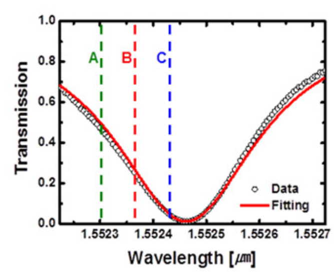

Fig. 2. Transmission at -1 V bias voltage

From the CMT, Si MRM dynamics can be modeled as [9]

$$\frac{da(t)}{dt} = \left(j\omega_0 - 1/\tau\right)a(t) - j\mu E^i(t) \text{ and } E^t(t) = E^i(t) - j\mu a(t). \tag{1}$$

In the above equation, $a(t)$ represents the total energy stored in the ring with resonance angular frequency ω_0. ω_0 is given as $2\pi mc/(\eta_0 L)$ with the mode number m, the speed of light c, the group index of the ring η_0, and the ring circumference L. $E^i(t)$ and $E^t(t)$ represent input and output light field, respectively, where $E^i = E_0 \exp(\omega t)$. τ is the decay time constant satisfying $1/\tau = (1-\alpha^2+\kappa^2)c/(2\eta_0 L)$, where α represents the round-trip loss and κ is the coupling coefficient for the ring-bus coupler. μ is the mutual coupling coefficient satisfying $\mu^2 = \kappa^2 c/(\eta_0 L)$. η_0 ~4, α ~0.956 and κ ~0.262 can be determined for our MRM from the measured transmission characteristic shown in Fig. 2.

When the MRM is modulated by the applied small voltage signal, $v_0\cos(\omega_m t)$, around the bias voltage, the group index can be expressed as $\eta(t) = \eta_0 + (\partial \eta / \partial v)\, v_0\cos(\omega_m t)$. Then, Eq. (1) is modified as

$$\frac{da(t)}{dt} = \left(j\omega_0 - 1/\tau\right)\eta_0\left[1/\eta_0 - v_0/\eta_0^{\,2}(\partial\eta/\partial v)\cos(\omega_m t)\right]a(t) - j\mu E^i(t), \text{ and } E^t(t) = E^i(t) - j\mu a(t). \quad (2)$$

Since the mutual coupling is not very much affected by the instantaneous group index change, we assume μ does not change with time [10].

After applying the usual small-signal approximation to Eq. (2), we can derive h(t), defined as $E^{\,i}(t)/E^{\,t}(t)$, as

$$h(t) = H_0 + H(\omega_m)\exp(j\omega_m t) + H\left(-\omega_m\right)\exp(-j\omega_m t),$$

$$\text{where } H_0 = \frac{j\omega - j\omega_0 + 1/\tau - \mu^2}{j\omega - j\omega_0 + 1/\tau} \text{ and } H(\omega_m) = \mu^2\frac{v_0}{2j\omega_m\eta_0}\frac{\partial\eta}{\partial v}\left[\frac{j\omega_0 - 1/\tau}{j\omega - j\omega_0 + 1/\tau} - \frac{j\omega_0 - 1/\tau}{j\omega_m + j\omega - j\omega_0 + 1/\tau}\right]. \quad (3)$$

After taking the Laplace transform of Eq. (3), we obtain $\Delta(s)$, MRM small-signal response in the s-domain for modulation frequency ω_m relative to DC response, as

$$\Delta(s) = \left|\frac{H(\omega_m)H_0^{\,*} + H^*(-\omega_m)H_0}{H_0 H_0^{\,*}}\right| = G\frac{s+z}{s^2 + (2/\tau)s + D^2 + 1/\tau^2} = G\frac{s+z}{(s+1/\tau+jD)(s+1/\tau-jD)}, \quad (4)$$

where z is roughly equal to μ^2, and detuning D that indicates how far the input light frequency is away from the resonance frequency is given as $D = |\,\omega - \omega_0\,|$. As can be seen from Eq. (4), $\Delta(s)$ has one zero and two complex poles.

Fig. 3 (a) shows measured frequency responses with the input light detuned at 4, 12, and 20 GHz from the resonance using the lightwave component analyzer. The difference in DC gain is due to the difference in the slope of the transmission curve for each detuning as can be seen in Fig. 2. To remove the frequency dependence of our measurement setup and the grating coupler, we normalized 20- and 12-GHz detuning responses with 4-GHz detuning response. Fig. 3 (b) and (c) show the resulting normalized responses as well as the calculated results obtained from Eq. (4). Measurement and calculation results are in very good agreement, confirming the accuracy of our small-signal model. .

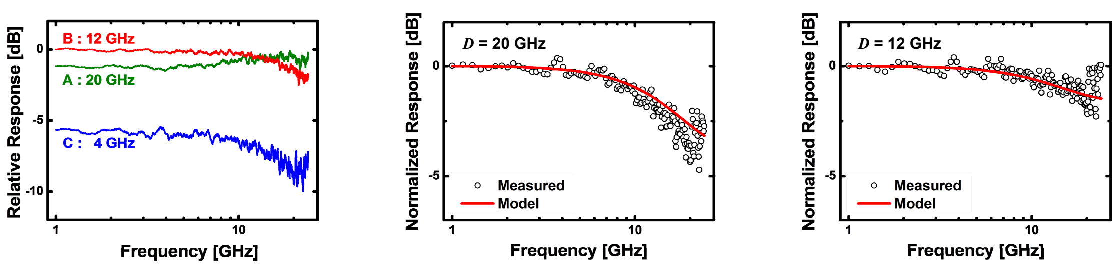

Fig. 3. (a) Frequency response at different detuning level, normalized frequency response of (b) 20 GHz detuning and (c) 12 GHz detuning

In summary, we derived and confirmed a new small-signal model of a Si MRM based on the coupled mode theory. With our small-signal model, the complicated modulation dynamics of Si MRM can be easily analyzed as the resulting model has the well-known second order system characteristics. It should be very useful for designing and analyzing Si MRMs as well as Si MRM driving circuits.

References

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