IEEE
SiPhotonics

IEEE Silicon Photonics Conference
15 -18 April 2024 ▪ Hilton Tokyo Bay, Japan
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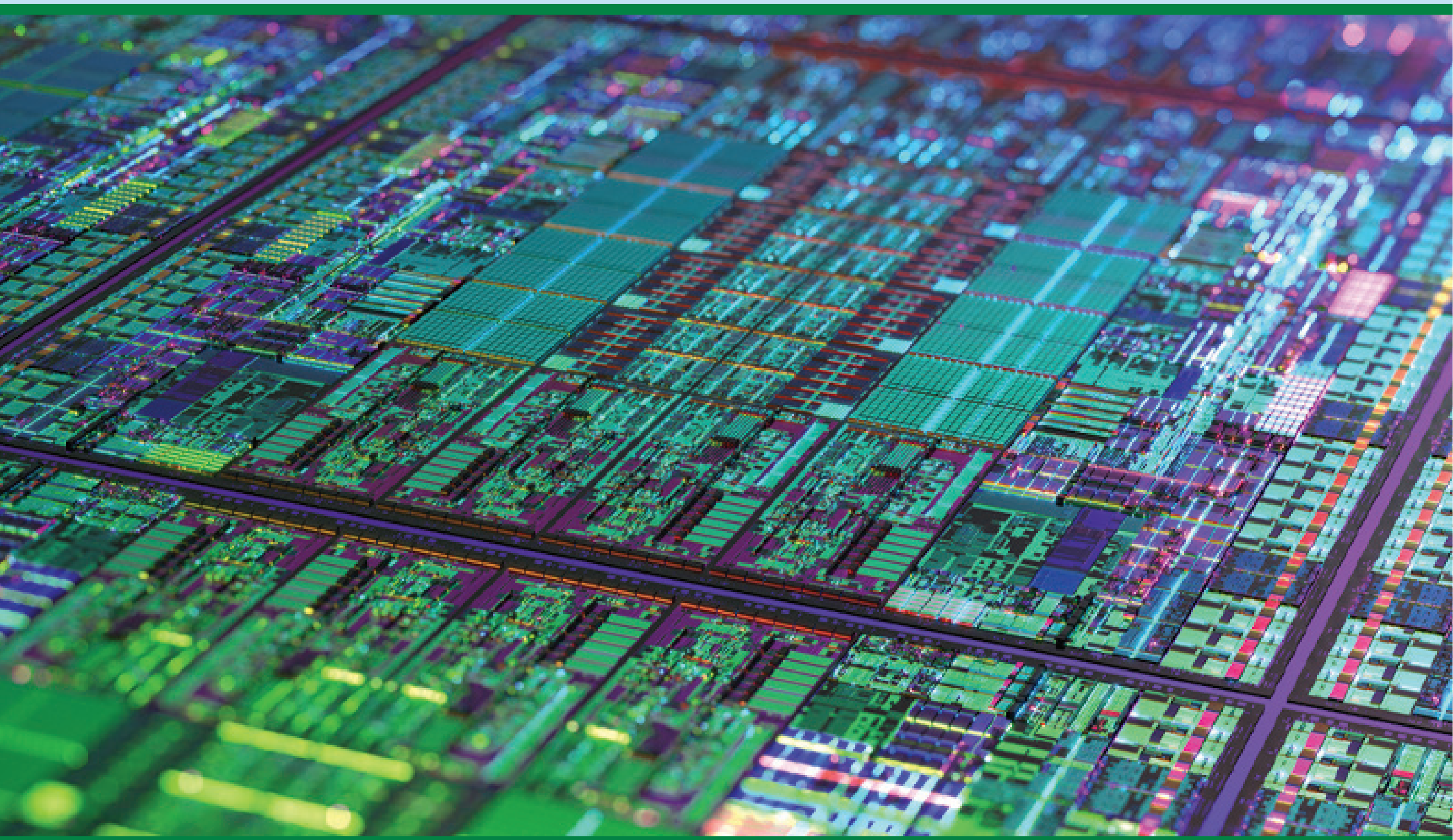

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NTT Device Technologies Laboratories,
Japan

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Science and Technology, Japan

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2024 IEEE Silicon Photonics Conference
Program-at-a-Glance

General Sessions will be held in Ambio I | Breaks & Exhibits will be held in Ambio II | Lunch & Posters will be held in G&S 2nd Floor

	Sunday, 14 April	Monday, 15 April	Tuesday, 16 April	Wednesday, 17 April	Thursday, 18 April	
8:30am		*8:30-10:00am* MA Conference Welcome & Plenary Session	*8:30-10:00am* TuA ENA: Photonic Computing & Quantum Applications	*8:30-10:00am* WA EPICS: Photonic Devices & Systems	*8:30-10:00am* ThA PD: Micro-ring Resonators	8:30am
8:45am						8:45am
9:00am						9:00am
9:15am						9:15am
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10:00am		*10:00-10:30am | BREAK & EXHIBITS*				10:00am
10:15am						10:15am
10:30am		*10:30-12:30pm* MB APD: Transmitters & Receivers	*10:30-12:00pm* TuB APD: Modulators & Phase Shifters	*10:30-12:30pm* WB ENA: Novel Metrology Technology	*10:30-12:30pm* ThB APD: Heterogeneous Lasers & Packaging	10:30am
10:45am						10:45am
11:00am						11:00am
11:15am						11:15am
11:30am	*11:30am - 5:00pm* Synopsys Workshop: Foundry PDK-Driven Silicon Photonic IC Design for Aerospace & Defense, Datacom, and High-Performance Computing *11:30am Lunch Service* *12:00pm Workshop Begins* *1:15pm-1:30pm Break* *3:30pm - 3:45pm Break*					11:30am
11:45am						11:45am
12:00pm			12:00-12:30pm PD - Post-Deadline			12:00pm
12:15pm						12:15pm
12:30pm		*12:30-2:00pm* *LUNCH & POSTER SESSION I*	*12:30-2:00pm* *LUNCH & POSTER SESSION II*	*12:30-2:00pm* *LUNCH & POSTER SESSION III*	*12:30-2:00pm* *LUNCH & POSTER SESSION IV*	12:30pm
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2:00pm		*2:00-4:00pm* MC EPICS: Photonic & Electronic Integration	*2:00-4:00pm* TuC Industry Special Session: Eco-System for Silicon Photonics Industrization	*2:00-4:00pm* WC PD: Grating Couplers & Antennas	*2:00-3:45pm* ThC PD: Advances in Passive Devices	2:00pm
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3:45pm					*3:45-4:15pm* *BREAK & EXHIBITS*	3:45pm
4:00pm		*4:00-4:30pm | BREAK & EXHIBITS*				4:00pm
4:15pm					*4:15-6:00pm* ThD NMP: Functional Materials & Structures	4:15pm
4:30pm		*4:30-6:30pm* AMF Workshop: Future of Optical Technologies	*4:30-5:30pm* TuD PD: MZI Devices & Circuits	*4:30-6:00pm* WD NMP: Light Emission & Detection Materials		4:30pm
4:45pm						4:45pm
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6:30pm		*6:30-8:00pm* AMF Recpetion *Lounge O*				6:30pm
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Continued from **Wednesday, 17 April**

9:45am **WA4 - Complex Electro-Optic Frequency-Response Characterization of a Si Ring Modulator**

» Youngkwan Jo (Korea, Republic of)[1], Yongjin Ji (Korea, Republic of)[1], Hyun-Kyu Kim (Korea, Republic of)[1], Stefan Lischke (Germany)[2], Christian Mai (Germany)[2], Lars Zimmermann (Germany)[3], Woo-Young Choi (Korea, Republic of)[1] (1. Yonsei University, 2. IHP-Leibniz Institut für innovative Mikroelektronik, Frankfurt (Oder), 3. IHP-Leibniz Institut für innovative Mikroelektronik, Frankfurt (Oder) and Technische Universität Berlin)

10am **Break & Exhibits**

Ambio Foyer & Ambio II

10:30am **WB - ENA: Novel Metrology Technology**

Ambio I

Chaired by: Shota Kita (Japan)

10:30am **WB1 (Invited) - III-V-on-Silicon-Nitride Mode-Locked Lasers**

» Bart Kuyken (Belgium)[1] (1. Ghent university - IMEC)

11am **WB2 - Rapid wavelength measurements with a silicon photonic wavemeter**

» Brian Stern (United States)[1], Bob Farah (United States)[1], Kwangwoong Kim (United States)[1], Robert Borkowski (United States)[1], Kovendhan Vijayan (United States)[1], Farshid Ashtiani (United States)[1], David Bitauld (France)[2] (1. Nokia Bell Labs, 2. III-V Lab)

11:15am **WB3 - Multimode-Fiber Imaging Using a Wavelength-Scanned Integrated Optical Phased Array**

» Gaolei HU (Hong Kong)[1], Yue Qin (Hong Kong)[1], Hon Ki Tsang (Hong Kong)[1] (1. The Chinese University of Hong Kong)

11:30am **WB4 - K-clock interferometer-integrated Si photonics SLG FMCW LiDAR**

» Shumpei Yamazaki (Japan)[1], Takemasa Tamanuki (Japan)[1], Mikiya Kamata (Japan)[1], Toshihiko Baba (Japan)[1] (1. Yokohama National University)

11:45am **WB5 - High-performance integrated spectrometer with broad operation temperature range**

» Ang Li (China)[1], Feixia Bao (China)[1], Shilong Pan (China)[1] (1. Nanjing University of Aeronautics and Astronautics)

12pm **WB6 - Optical frequency comb-based photonic sampling for microwave characterization of wafer-level silicon photonic transceiver chips**

» Junfeng Zhu (China)[1], Xinhai Zou (China)[1], Ying Xu (China)[1], Chao Jing (China)[1], Yali Zhang (China)[1], Zhiyao Zhang (China)[1], Shangjian Zhang (China)[1], Yong Liu (China)[1] (1. Research Center for Microwave Photonics, University of Electronic Science and Technology of China)

12:15pm **WB7 - Optical Beam Steering of 16x64 Optical Phased Arrays with Small-range Tunable Lasers**

» Chien-Yu Chung (Taiwan)[1], Hansen Kurniawan Njoto (Taiwan)[1], Wei-Xun Chen (Taiwan)[1], Wei-Chung Peng (Taiwan)[1], Tsung-Han Lee (Taiwan)[1], Ying-Hsueh Chen (Taiwan)[1], Yin-Cheng Hong (Taiwan)[1], San-Liang Lee (Taiwan)[1] (1. National Taiwan University of Science and Technology)

12:30pm **WP - Lunch & Poster Session III**

G&S

WP1 - First Demonstration of a Fully Integrated Hybrid External Cavity Laser in Edge-Coupling Configuration via µTransfer-Printing

» Fatih Atar (Ireland)[1], Yeasir Arafat (Ireland)[1], Gautham Paikkath (Ireland)[2], Artem Vorobev (Ireland)[2], Brian Corbett (Ireland)[1], Liam O'Faolain (Ireland)[2], Simone Iadanza (Switzerland)[3] (1. Tyndall National Institute, University College Cork, 2. Munster Technological University, 3. Paul Scherrer Institut)

WP2 - On the dynamic and static extinction ratio of germanium electro-absorption modulators

» Daniel Steckler (Germany)[1], Stefan Lischke (Germany)[1], Anna Peczek (Germany)[1], Lars Zimmermann (Germany)[1] (1. IHP-Leibniz Institut für innovative Mikroelektronik, Frankfurt (Oder))

Complex Electro-Optic Frequency-Response Characterization of a Si Ring Modulator

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***Abstract*—Electro-optical (E/O) frequency-response of a Si ring modulator (RM) is characterized both in the magnitude and the phase domain for RM-based coherent transmitter performance optimization. The RM's complex E/O responses are measured with heterodyne coherent reception, and the measured results are confirmed with the simulated.**

Keywords—Si ring modulators, phase modulation, electro-optic response, heterodyne measurements

I. INTRODUCTION

Si photonics has shown significant advancement over the past decade, enabling mass-producible large-scale photonics integrated circuits (PICs) for such applications as high-performance optical interconnects, sensors, neuromorphic computing, and quantum photonics [1]. In particular, Si photonic interconnect solutions based on the intensity-modulation direct detection (IM/DD) technique have made great contribution in enhancing data-center interconnect performances in terms of bandwidth, power consumption, size, and cost. However, with the continuously increasing demand for services based on hyper-scale data centers, there still exists strong desire for further performance improvement [2,3]. With this, there are emerging research interests in the coherent modulation technique for the short-reach applications [4]. The coherent technique can provide much higher transmission capacity but has been used mainly for long-distance applications. In order to bring the coherent technique to the short-reach applications, there are many technical challenges that need to be overcome, and one of them is realization of compact yet high-performance I/Q modulators in the Si photonics platform.

Si ring modulators (RMs) offer the great advantage of the small device footprint and their excellent IM/DD modulation performance has been well demonstrated [5]. In addition, coherent modulators based on the Si RM have been recently reported [6-8], which clearly demonstrate the feasibility of using Si RMs as high-performance coherent transmitters. With this development, there is a strong need for clear understanding of the Si RM phase modulation characteristics, but not many previous research results are available on this topic. In this paper, the E/O frequency responses of the Si RM are characterized both in the magnitude and the phase domain with the heterodyne coherent reception technique. The measurement results are confirmed with the simulated results obtained with the Si RM model based on the coupled-mode theory. This model provides a powerful tool for analyzing and optimizing Si RMs for coherent applications.

II. DEVICE DESCRIPTION

Fig. 1(a) presents a chip photograph of a Si RM fabricated with the IHP Si photonics technology. The RM has 16-µm radius, 220-nm coupling gap, and a rib waveguide structure with 220-nm thickness, 500-nm width and 100-nm slab thickness. The nominal peak carrier concentrations of PN diode in the ring waveguide are 7 x 10^{17} cm^{-3} for P dopant and 3 x 10^{18} cm^{-3} for N dopant. The RM is designed to have the over-coupling condition [9], which provides 2π phase shift around the resonance, λ_{res}. With this, π-phase modulation at the operation wavelength, λ_{in}, can be achieved while maintaining the same optical intensity as graphically shown in Fig. 1(b). The fabricated RM has 10.0-dB insertion loss, V_π of 5.7 $V_{peak\text{-}to\text{-}peak}$ at λ_{in}.

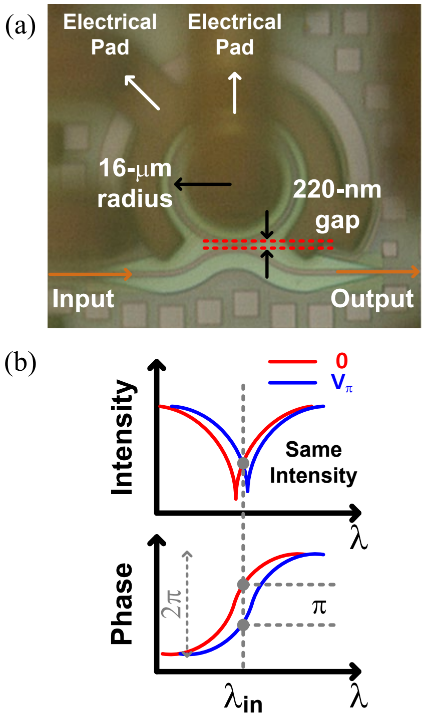

Fig. 1. (a) Chip photograph of a fabricated Si RM, (b) phase modulation operation point of over-coupled RM.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. NRF-2020R1A2C2015089). Also, we thank IC Design Education Center (IDEC) for EDA tool support.

III. COMPLEX E/O RESPONSE CHARACTERIZATION

Fig. 2(a) shows the measurement setup for complex E/O response characterization of the π-phase-modulated Si RM. The electrical signal is supplied from the RF signal source and amplified by an RF amplifier so that the desired V_π is delivered to the RM through a bias-T. The laser source feeds an optical input to the RM, and the modulated signal is amplified by an erbium-doped fiber amplifier (EDFA) and received through a commercial coherent receiver (CoRx). Another laser source supplies a local oscillator (LO) signal to the CoRx for heterodyne reception. The resulting CoRx output signals are acquired with a real-time oscilloscope (RTO) for an off-line digital signal processing (DSP). The DSP performs carrier frequency offset compensation and digital bandpass filtering. By taking fast-Fourier transformation, the complex E/O response of RM can be obtained. The response of the CoRx and the response of the RF amplifier are de-embedded.

In addition, the complex E/O frequency response of the RM is simulated using the coupled-mode theory (CMT) model [10]. The time-domain responses of the RMs can be calculated with the model parameters obtained from the measured optical transmission spectra and electrical reflection coefficients. Then, by taking Fourier transformation of the time-domain responses, the complex E/O frequency response can be determined.

Fig. 2(b) shows the measured and the simulated magnitude and phase frequency responses. Although measurement data contain a certain amount of errors most likely due to incomplete de-embedding of the components used in the measurement, the overall measurement results agree well with the simulation results. In Fig. 2(b), the 3-dB drop in the magnitude response is observed at 18.5 GHz, and at this frequency, the phase response increases about $+0.25\pi$ compared from the low-frequency value. This coincidence of 3-dB magnitude drop and 0.25π phase increase at the same frequency suggests that Si RM phase modulation can be modeled with a simple one-pole system. This can be confirmed with the RM small-signal model given in [11], which has two-poles and one-zero. In the case of the over-coupled Si RM with λ_{in} close to λ_{res}, one-pole and one-zero cancel each other out so that its characteristics are dominated by one pole.

IV. CONCLUSION

The complex E/O frequency responses of the Si RM are characterized. The measured responses are confirmed with the simulation results. Our characterization technique provides a power tool with which the RM can be best optimized for desired coherent transmitter performance.

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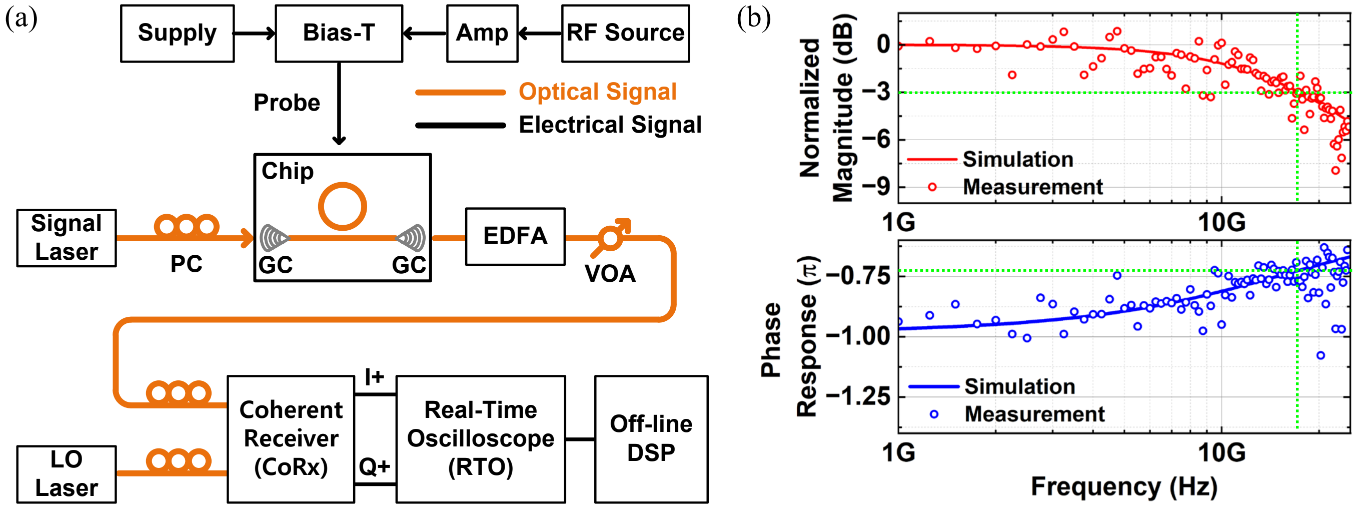

Fig. 2. (a) Measurement setup for characterization of complex E/O responses of the RM and (b) measured and simulated normalized meagnitude and phase responses of the RM. (PC: polarization controller, GC: grating coupler, EDFA: erbium-doped fiber amplifier, VOA: variable optical attenuator, DSP: digital-signal processing)