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OPTO DAILY CONFERENCE SCHEDULE

SATURDAY	SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY
		OPTO PLENARY SESSION 8:00 TO 10:10 AM		**OPTO POSTER SESSION** 6:00 TO 8:00 PM	

Optoelectronic Materials and Devices

Program Chair: **James G. Grote**, Air Force Research Lab. (USA)

- 9742 **Physics and Simulation of Optoelectronic Devices XXIV** (Witzigmann, Osiński, Arakawa), p. 238
- 9743 **Physics, Simulation, and Photonic Engineering of Photovoltaic Devices V** (Freundlich, Lombez, Sugiyama), p. 244
- 9744 **Optical Components and Materials XIII** (Jiang, Digonnet), p. 245
- 9745 **Organic Photonic Materials and Devices XVIII** (Tabor, Kajzar, Kaino, Koike), p. 248
- 9746 **Ultrafast Phenomena and Nanophotonics XX** (Betz, Elezzabi), p. 251
- 9747 **Terahertz, RF, Millimeter, and Submillimeter-Wave Technology and Applications IX** (Sadwick, Yang), p. 255
- 9748 **Gallium Nitride Materials and Devices XI** (Chyi, Fujioka, Morkoç), p. 259
- 9749 **Oxide-based Materials and Devices VII** (Teherani, Look, Rogers), p. 263

Photonic Integration

Program Chair: **Yakov Sidorin,** Quarles & Brady LLP (USA)

- 9750 **Integrated Optics: Devices, Materials, and Technologies XX** (Broquin, Nunzi Conti), p. 267
- 9747 **Terahertz, RF, Millimeter, and Submillimeter-Wave Technology and Applications IX** (Sadwick, Yang), p. 255
- 9751 **Smart Photonic and Optoelectronic Integrated Circuits XVIII** (He, Lee, Eldada), p. 270
- 9752 **Silicon Photonics XI** (Reed, Knights), p. 272
- 9753 **Optical Interconnects XVI** (Schröder, Chen), p. 275
- 9754 **Photonic Instrumentation Engineering III** (Soskind, Olson), p. 278

Nanotechnologies in Photonics

Program Chair: **Ali Adibi,** Georgia Institute of Technology (USA)

- 9755 **Quantum Sensing and Nano Electronics and Photonics XIII** (Razeghi), p. 280
- 9756 **Photonic and Phononic Properties of Engineered Nanostructures VI** (Adibi, Lin, Scherer), p. 286
- 9758 **Quantum Dots and Nanostructures: Growth, Characterization, and Modeling XIII** (Huffaker, Eisele, Dick), p. 292
- 9757 **High Contrast Metastructures V** (Chang-Hasnain, Fattal, Koyama, Zhou), p. 290
- 9759 **Advanced Fabrication Technologies for Micro/Nano Optics and Photonics IX** (von Freymann, Schoenfeld, Rumpf), p. 294

CONFERENCE 9751

Tuesday–Thursday 16–18 February 2016 • Proceedings of SPIE Vol. 9751

Smart Photonic and Optoelectronic Integrated Circuits XVIII

Conference Chairs: **Sailing He,** KTH Royal Institute of Technology (Sweden); **El-Hang Lee,** Inha Univ. (Korea, Republic of); **Louay A. Eldada,** Quanergy Systems, Inc. (USA);

Program Committee: **Ray T. Chen,** The Univ. of Texas at Austin (USA); **Shanhui Fan,** Stanford Univ. (USA); **Chennupati Jagadish,** The Australian National Univ. (Australia); **Jürgen Jahns,** FernUniv. Hagen (Germany); **Stefan A. Maier,** Imperial College London (United Kingdom); **Joachim Piprek,** NUSOD Institute LLC (USA); **David V. Plant,** McGill Univ. (Canada); **Andrew W. Poon,** Hong Kong Univ. of Science and Technology (Hong Kong, China); **Ali Serpengüzel,** Koç Univ. (Turkey); **Qian Wang,** A*STAR - Data Storage Institute (Singapore); **Michael R. Watts,** Massachusetts Institute of Technology (USA); **Dan-Xia Xu,** National Research Council Canada (Canada); **Lin Yang,** Institute of Semiconductors (China)

TUESDAY 16 FEBRUARY

WELCOME AND OPENING REMARKS. . . . . 1:30 PM TO 1:40 PM

Sailing He, KTH Royal Institute of Technology (Sweden)

SESSION 1. . . . . TUE 1:40 PM TO 3:10 PM

Advances in Silicon Photonics

Session Chairs: **Lin Yang,** Institute of Semiconductors (China); **Sailing He,** KTH Royal Institute of Technology (Sweden)

Silicon photonics: some remaining challenges *(Invited Paper)*, Graham T. Reed, Optoelectronics Research Ctr. (United Kingdom) . . . . [9751-1]

Schematic-driven silicon photonics design *(Invited Paper)*, Lukas Chrostowski, The Univ. of British Columbia (Canada) . . . . [9751-2]

From materials to devices to systems: the development of silicon photonics for advanced communications *(Invited Paper)*, Andrew P. Knights, McMaster Univ. (Canada) . . . . [9751-3]

SESSION 2 . . . . TUE 3:40 PM TO 5:40 PM

Plasmonic Nano-Lasers, Antennas, and Structures

Session Chair: **Sailing He,** KTH Royal Institute of Technology (Sweden)

Nanolasers and related issues for integrated photonics applications *(Invited Paper)*, Cun-Zheng Ning, Arizona State Univ. (USA) . . . . [9751-4]

Nano-antennas from the visible to the mid-infrared: material considerations and applications *(Invited Paper)*, Stefan A. Maier, Imperial College London (United Kingdom). . . . . [9751-5]

Efficient optical coupling into ultra-compact plasmonic slot waveguide using dipole nanoantennas *(Invited Paper)*, Qian Gao, Fanghui Ren, Alan X. Wang, Oregon State Univ. (USA) . . . . [9751-6]

Ultrafast generation and relaxation of non-equilibrium carriers in plasmonic nanostructures *(Invited Paper)*, Prineha Narang, California Institute of Technology (USA) and Northrop Grumman Corp. (USA) . . . . [9751-7]

WEDNESDAY 17 FEBRUARY

SESSION 3 . . . . WED 8:10 AM TO 10:20 AM

Smart Structures for Photonic Integration

Session Chair: **Andrew W. Poon,** Hong Kong Univ. of Science and Technology (Hong Kong, China)

Polarization diversity circuit for a silicon optical switch using silica waveguides integrated with photonic crystal thin film waveplates, Koki Sugiyama, Keio Univ. (Japan); Takafumi Chiba, Takayuki Kawashima, Shojiro Kawakami, Photonic Lattice Inc. (Japan); Hiroshi Takahashi, Sophia Univ. (Japan); Hiroyuki Tsuda, Keio Univ. (Japan) . . . . [9751-8]

Resolving the controversy in the physical origin of enhanced optical gain/absorption in micro/nano waveguiding dielectric or plasmonic structures in photonic integrated circuits via the concept of geometrical energy velocity *(Invited Paper)*, Seng-Tiong Ho, Xi Chen, Northwestern Univ. (USA); Yingyan Huang, OptoNet, Inc. (USA) . . . . [9751-9]

Development of broadband antireflection of high-index substrate using SiN_x/SiO_2, Kim Peng Lim, Keh Ting D. Ng, Qian Wang, A*STAR - Data Storage Institute (Singapore) . . . . [9751-10]

Silicon-nanodisk-based metasurface for subwavelength phase and polarization control, Ye Feng Yu, Ramón Paniagua-Domínguez, Alexander Y. Zhu, Yuan Hsing Fu, Boris Luk'yanchuk, Arseniy I. Kuznetsov, A*STAR - Data Storage Institute (Singapore). . . . . [9751-11]

Photonic-crystal-based visible-light optical filter, Swati Rawal, Brahm Raj Singh, Jaypee Institute of Information Technology (India) . . [9751-12]

Bandgap engineering of InGaAsP/InP laser structure by photo-absorption-induced point defects, Mohammad Kaleem, COMSATS Institute of Information Technology (Pakistan); Sajid Nazir, London South Bank Univ. (United Kingdom). . . . . [9751-45]

SESSION 4 . . . . WED 10:50 AM TO 12:00 PM

Advanced Hybrid PICs

Session Chair: **Andrew W. Poon,** Hong Kong Univ. of Science and Technology (Hong Kong, China)

Integration of two-dimensional semiconductors with photonic structures *(Invited Paper)*, Vinod Menon, The City College of New York (USA). . . . [9751-13]

Ultra-thin oxide interlayer wafer bonding for heterogeneous III-V/Si photonics integration, Qian Wang, A*STAR - Data Storage Institute (Singapore) . . . . [9751-14]

All-optical SR flip-flop based on SOA-MZI switches monolithically integrated on a generic InP platform, Stelios Pitris, Christos Vagionas, Ctr. for Research and Technology Hellas (Greece) and Aristotle Univ. of Thessaloniki (Greece); George T. Kanellos, Ctr. for Research and Technology Hellas (Greece); Rifat Kisacik, Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration (Germany); Tolga Tekin, Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration (Germany) and Technische Univ. Berlin (Germany); Ronald Broeke, Bright Photonics B.V. (Netherlands); Nikos Pleros, Ctr. for Research and Technology Hellas (Greece) and Aristotle Univ. of Thessaloniki (Greece). . . . . [9751-15]

Lunch/Exhibition Break . . . . Wed 12:00 pm to 1:30 pm

SESSION 5 . . . . WED 1:30 PM TO 3:20 PM

Smart Light Sources I

Session Chair: **Qian Wang,** A*STAR - Data Storage Institute (Singapore)

Broadband SLED-based light source and spectrometer, Yonathan Dattner, Luxmux Technology Corp. (Canada); Orly Yadid-Pecht, Univ. of Calgary (Canada) and Luxmux Technology Corp. (Canada) . . . . [9751-16]

Lasing characteristics of integrated lasers with whispering-gallery mode microresonator *(Invited Paper)*, Yong-Zhen Huang, Xiu-Wen Ma, Yue-De Yang, Jin-Long Xiao, Yun Du, Institute of Semiconductors (China) . . . . [9751-17]

Integration of mode-locked diode lasers *(Invited Paper)*, Ann C. Coleman, The Univ. of Texas at Dallas (USA). . . . . [9751-18]

Ultra-high-Q silicon nitride microresonators for on-chip frequency comb generation *(Invited Paper)*, Minghao Qi, Yi Xuan, Yang Liu, Xiaoxiao Xue, Andrew J. Metcalf, Pei-Hsun Wang, Jian Wang, Ben Niu, Kyunghun Han, Min Teng, Daniel E. Leaird, Andrew M. Weiner, Purdue Univ. (USA) . . . [9751-19]

SESSION 6 . . . . WED 3:50 PM TO 5:40 PM

Smart Light Sources II

Session Chair: **Qian Wang,** A*STAR - Data Storage Institute (Singapore)

Generic heterogeneously integrated III-V lasers on silica with metal-coated high-reflectance etched mirror *(Invited Paper)*, Qian Wang, A*STAR - Data Storage Institute (Singapore). . . . . [9751-20]

Patterned semiconductor inverted quantum-dot photonic devices *(Invited Paper)*, James J. Coleman, The Univ. of Texas at Dallas (USA). [9751-21]

Tunable on-chip light sources using III-N nanowire arrays and two-dimensional atomic crystals *(Invited Paper)*, Zetian Mi, Songrui Zhao, Yong-Ho Ra, Xianhe Liu, Binh Le, Renjie Wang, McGill Univ. (Canada). [9751-22]

High-efficiency and compact semiconductor lasers with monolithically integrated switches for generation of high-power nanosecond pulses in time-of-flight (TOF) systems, Sergey O. Slipchenko, Aleksandr A. Podoskin, Olga S. Soboleva, Maxim S. Zakharov, Kirill V. Bakhvalov, Dmitrii N. Romanovich, Nikita A. Pikhtin, Il`ya S. Tarasov, Ioffe Physical-Technical Institute (Russian Federation); Timur A. Bagaev, Maxim A. Ladugin, Alexsandr A. Marmalyuk, Vladimir A. Simakov, JSC "Research Institute" POLYUS "them. M.F. Stelmaha" (Russian Federation). . . . . [9751-23]

POSTERS-WEDNESDAY. . . . . WED 6:00 PM TO 8:00 PM

Conference attendees are invited to attend the OPTO poster session on Wednesday evening. Come view the posters, enjoy light refreshments, ask questions, and network with colleagues in your field. Authors of poster papers will be present to answer questions concerning their papers. Attendees are required to wear their conference registration badges to the poster sessions.

Poster authors, view poster presentation guidelines and set-up instructions at http://spie.org/PWPosterGuidelines.

Compact transverse-magnetic mode-pass polarizer based on one-dimensional photonic crystal waveguide, Dong Wook Kim, Moon Hyeok Lee, Yudeuk Kim, Inha Univ. (Korea, Republic of); Kyong-Hon Kim, Inha Univ (Korea, Republic of) . . . . [9751-43]

A compact picosecond-pulsed laser source using a fully integrated CMOS driver circuit, Yuting He, Yuhua Li, Orly Yadid-Pecht, Univ. of Calgary (Canada) . . . . [9751-44]

THURSDAY 18 FEBRUARY

SESSION 7 . . . . THU 8:10 AM TO 10:10 AM

Signal Processing and Optical Interconnects

Session Chair: **Ray T. Chen,** The Univ. of Texas at Austin (USA)

Actively stabilized silicon microring resonator switch arrays for optical interconnects *(Invited Paper)*, Li Yu, Andrew Poon, Hong Kong Univ. of Science and Technology (Hong Kong, China) . . . . [9751-24]

On-chip optical matrix processor for parallel computing *(Invited Paper)*, Lin Yang, Jianfeng Ding, Lei Zhang, Ruiqiang Ji, Institute of Semiconductors (China) . . . . [9751-25]

Ultrafast optical signal processing on silicon-based platforms *(Invited Paper)*, Dawn Tan, Singapore Univ. of Technology & Design (Singapore) . . . . [9751-26]

Recent advances in strained silicon photonics *(Invited Paper)*, Pedro Damas, Xavier Le Roux, Mathias Berciano, Delphine Marris-Morini, Eric Cassan, Laurent Vivien, Institut d'Électronique Fondamentale (France). . . . . [9751-27]

SESSION 8 . . . . THU 10:40 AM TO 12:00 PM

Optoelectronic Integrated Circuits

Session Chair: **Lin Yang,** Institute of Semiconductors (China)

Design and optimization of photolithography friendly photonic components, James Pond, Xu Wang, Jonas Flückiger, Adam Reid, Jens Niegemann, Lumerical Solutions, Inc. (Canada). . . . . [9751-28]

Verilog-A passive and active components modeling for silicon photonic circuits process design kit (PDK) assembly, Bayram Karakus, Fabien Gays, André Myko, Thomas Anfray, Christophe Kopp, CEA-LETI (France) . . . [9751-29]

An integrated Mach-Zehnder modulator bias controller based on eye-amplitude monitoring, Min-Hyeong Kim, Hyun-Yong Jung, Yonsei Univ. (Korea, Republic of); Lars Zimmermann, IHP GmbH (Germany); Woo-Young Choi, Yonsei Univ. (Korea, Republic of) . . . . [9751-30]

Tunable arrayed waveguide grating driven by surface acoustic waves, Antonio Crespo-Poveda, Univ. de València (Spain); Alberto Hernández-Mínguez, Paul-Drude-Institut für Festkörperelektronik (Germany); Bernardo Gargallo, Univ. Politècnica de València (Spain); Klaus Biermann, Abbes Tahraoui, Paulo V. Santos, Paul-Drude-Institut für Festkörperelektronik (Germany); Pascual Muñoz, Univ. Politècnica de València (Spain); Andrés Cantarero, Maurício M. de Lima Jr., Univ. de València (Spain). . . . . [9751-31]

Lunch/Exhibition Break . . . . Thu 12:00 pm to 1:30 pm

SESSION 9 . . . . .THU 1:30 PM TO 3:20 PM

Optical Sensing and Imaging I

Session Chairs: **Qian Wang,** A*STAR - Data Storage Institute (Singapore); Sailing He, KTH Royal Institute of Technology (Sweden)

Gas sensors using single layer patterned interference optical filters, Thomas D. Rahmlow Jr., Robert L. Johnson, Kieran Gallagher, Omega Optical, Inc. (USA). . . . . [9751-32]

Integrated microsystems for optical sensing and imaging applications *(Invited Paper)*, Stefan Sinzinger, Roman Kleindienst, Technische Univ. Ilmenau (Germany) . . . . [9751-33]

Vertical split-ring resonators apply on sensing and metasurface, Wei-Lun Hsu, Pin Chieh Wu, Jia Wern Chen, Ting-Yu Chen, National Taiwan Univ. (Taiwan); Bo Han Cheng, Academia Sinica (Taiwan); Wei Ting Chen, National Taiwan Univ. (Taiwan); Greg Sun, Univ. of Massachusetts Boston (USA); Din Ping Tsai, Research Ctr. for Applied Sciences - Academia Sinica (Taiwan) . . . . [9751-34]

Low-cost fabrication of optical waveguides, interconnects, and sensing structures on all-polymer-based thin foils, Maher Rezem, Christian Kelb, Axel Günther, Maik Rahlves, Eduard Reithmeier, Bernhard Roth, Leibniz Univ. Hannover (Germany) . . . . [9751-35]

Frequency range selection method of trans-impedance amplifier for high-sensitivity lock-in amplifier used in the optical sensors, Chang-In Park, Su-Jin Jeon, Tae-Ryong Kim, Myung-Gi Ji, Byung-Hee Son, Mi Jung, Young-Wan Choi, Chung-Ang Univ. (Korea, Republic of). . . . . [9751-36]

SESSION 10 . . . . THU 3:50 PM TO 5:50 PM

Optical Sensing and Imaging II

Session Chair: **Sailing He,** KTH Royal Institute of Technology (Sweden)

Real-time 3D imaging using 4D light-field, Guangqi Hou, Institute of Automation (China); Chi Zhang, Institute of Automation (China) and Univ. of Chinese Academy of Sciences (China); Zhenan Sun, Institute of Automation (China) . . . . [9751-37]

Super-resolution PMD cameras for applied metrology, Henrik Lietz, Jörg Eberhardt, Hochschule Ravensburg-Weingarten (Germany) . . . . . [9751-38]

Realization of error compensation algorithm in resistive read-out network for gamma-ray imaging detection system, Su-Jin Jeon, Young-Wan Choi, Chang-In Park, Byung-Hee Son, Mi Jung, Teak-Jin Jang, Chun-Sik Lee, Chung-Ang Univ. (Korea, Republic of) . . . . [9751-39]

Modeling and calibration of pulse-modulation based ToF imaging systems, Andreas Süss, Fraunhofer-Institut für Mikroelektronische Schaltungen und Systeme (Germany) and IMEC (Belgium); Gabor Varga, Fraunhofer-Institut für Mikroelektronische Schaltungen und Systeme (Germany) and RWTH Aachen Univ. (Germany); Michael Marx, Peter Fürst, Stefan Gläsener, Fraunhofer-Institut für Mikroelektronische Schaltungen und Systeme (Germany); Wolfram Tiedke, TriDiCam GmbH (Germany); Melanie Jung, Andreas Spickermann, Bedrich J. Hosticka, Fraunhofer-Institut für Mikroelektronische Schaltungen und Systeme (Germany) . . . . [9751-40]

Benchmarking time-of-flight based depth measurement techniques, Andreas Süss, Véronique Rochus, Maarten Rosmeulen, Xavier Rottenberg, IMEC (Belgium) . . . . [9751-41]

A hybrid 3D LIDAR imager based on pixel-by-pixel scanning and DS-OCDMA, Gunzung Kim, Jeongsook Eom, Yongwan Park, Yeungnam Univ. (Korea, Republic of). . . . . [9751-42]

OPTO

An integrated Mach-Zehnder modulator bias controller based on eye-amplitude monitoring

Min-Hyeong Kim*[a], Hyun-Yong Jung[a], Lars Zimmermann[b], and Woo-Young Choi[a]
[a]Department of Electrical and Electronic Engineering, Yonsei University, Seoul 120-749, South Korea; [b]IHP, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany

ABSTRACT

A novel integrated Mach-Zehnder modulator (MZM) bias controller based on eye-amplitude monitoring is demonstrated in IHP's 0.25-µm BiCMOS technology. The bias controller monitors the MZM output light, automatically moves the MZM bias voltage to the optimal value that produces the largest eye amplitude, and maintains it there even if the MZM transfer characteristics change due to thermal drift. The controller is based on the feedback loop consisting of Si photodetector, trans-impedance amplifier, rectifier, square amplifier, track-and-hold circuit, comparator, polarity changer, and charge-pump, all of which are monolithically integrated. The area of the controller is 0.083-mm^2 and it consumes 92.5-mW. Our bias controller shows successful operation for a commercially-available 850-nm $LiNbO_3$ MZM modulated with 3-Gbps PRBS data by maintaining a very clean eye for at least 30 minutes. Without the controller, the eye for the same MZM modulation becomes completely closed due to thermal drift. The data rate is limited by the Si PD integrated in the controller not by the controller architecture. Since our controller is based on the Si BiCMOS technology which can also provide integrated Si photonics devices on the same Si, it has a great potential for realizing a Si MZM with an integrated bias controller, which should fully demonstrate the advantage of electronic-photonic integrated circuit technology.

Keywords: Optical communication, Mach-Zehnder modulator, bias controller, feedback circuit

1. INTRODUCTION

The Mach-Zehnder modulator (MZM) is widely used for high-speed optical communications due to its wide modulation bandwidth, high extinction ratio, and low chirping. Presently, most MZMs are based on $LiNbO_3$ but Si MZMs realized with Si processing technology on Si wafers have been recently reported [1]-[2], demonstrating an exciting possibility for monolithic integration of MZMs and electronic circuits on a Si platform.

It is well known that MZMs experience the thermal drift during its operation [3]. As an example, Fig. 1 shows measured MZM transfer curves for a commercially available $LiNbO_3$ MZM (AZ-2K1-20-PFU-SFU-850-UL from EOSPACE). After a few minutes of initial operation, its transfer curve shifts significantly and, due to this, the accumulated eye diagram is greatly degraded as can be seen in Fig. 2. For stable and reliable operation, a bias controller that searches the optimal MZM bias voltage and maintains it is an absolute requirement. With the advent of Si MZMs, there is a need for the integrated MZM bias controller monolithically implemented on the same Si platform. As a first step for realizing such a Si MZM integrated with the bias controller, we design a bias controller in IHP's 0.25-µm BiCMOS, which is fully compatible with IHP's electronic-photonic integrated circuit technology, and successfully demonstrates its operation using an external 850-nm MZM.

*teramhkim@gmail.com

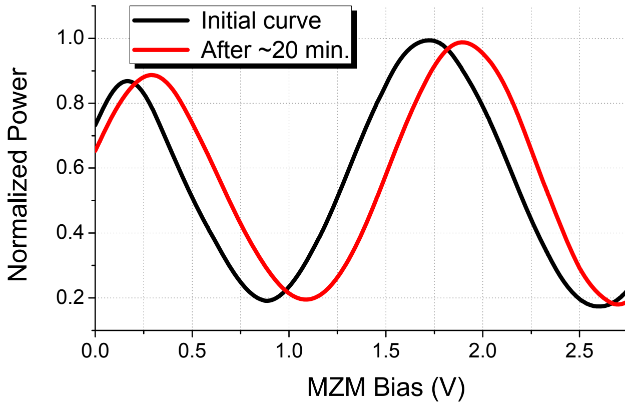

Figure 1. Normalized optical power transfer curve of $LiNbO_3$ MZM

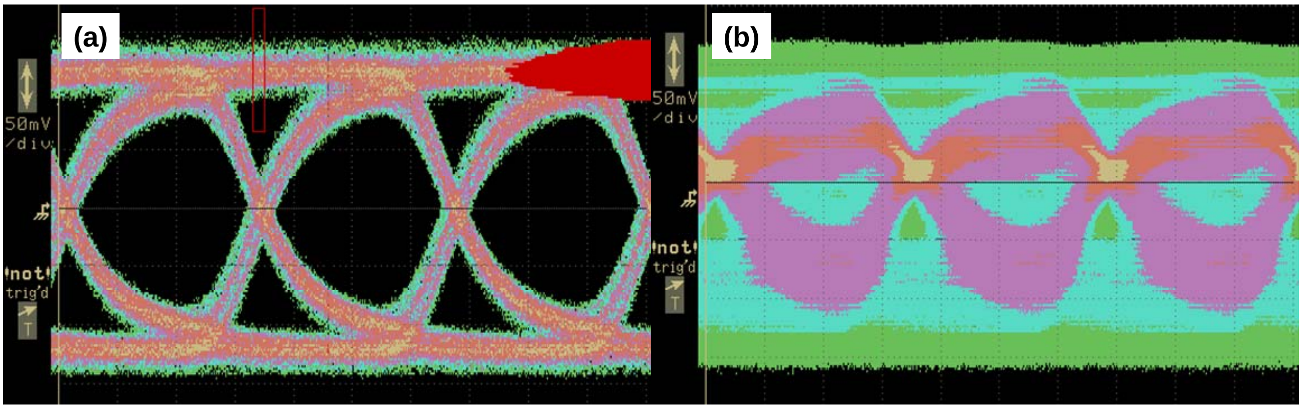

Figure 2. Accumulated eye diagrams of 3-Gb/s PRBS data modulated with $LiNbO_3$ MZM
(a) for initial 20 seconds, (b) for 30 minutes

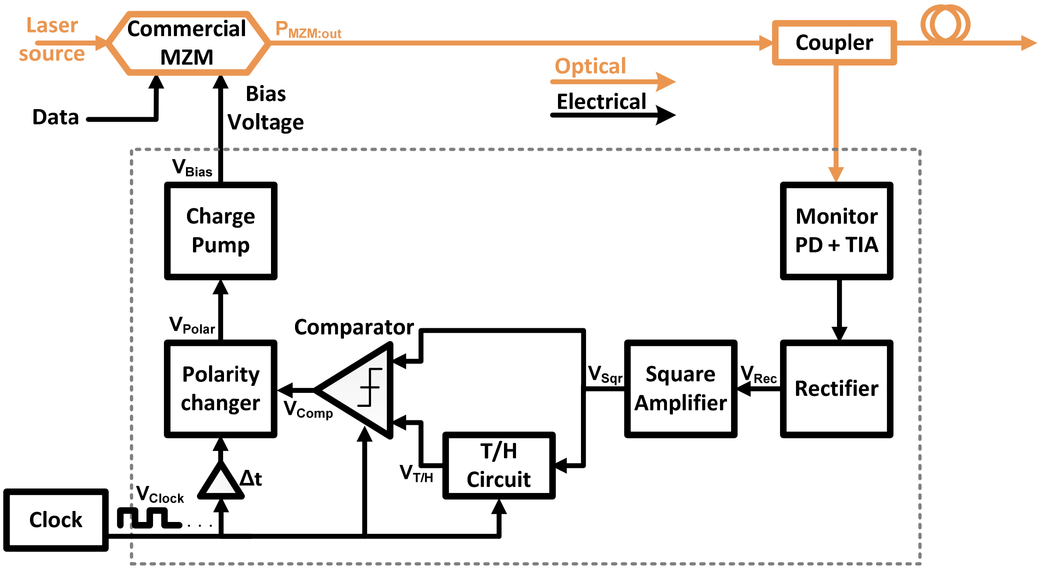

Figure 3. Block diagram of MZM bias controller based on eye-amplitude monitoring

2. BIAS-CONTROL ALGORITHM

The dotted box in Fig. 3 shows the block diagram of out MZM bias controller. It consists of monitor photodetector (PD), trans-impedance amplifier (TIA), rectifier, track-and-hold (T/H) circuit, comparator, polarity changer, and charge-pump (CP), all of which are monolithically integrated. As shown in Fig. 4(a), the best modulation efficiency is achieved when the MZM is biased at the quadrature point ($V_{Quad+/-}$). A portion of MZM output light is coupled into the monitor PD and converted into voltage signals with the TIA. The rectifier produces signals (V_{Rec}) representing the amplitude of modulated signals at a given MZM bias. In order to provide the amplitude's large sensitivity near the optimum bias point, a square amplifier is used after the rectifier. Fig. 4(b) shows the rectifier output and the square amplifier output with improved sensitivity near the optimum bias.

In order to decide which direction the bias should be moved for the optimal value, the amplitude information is temporarily stored in the T/H circuit. Then, a comparator compares the stored previous value ($V_{T/H}$) with the new value (V_{Sqr}). When the new value is higher than the stored one, the CP maintains its polarity but when it is not, the polarity is reversed by the polarity changer. In this way, the optimal bias can be automatically approached. All these operations are done with the clock signal (V_{Clock}) provided externally, which is independent of the MZM data rate. In our bias controller, the bias voltage dithers around the optimal value once it has been found. The amount of this dithering depends on the clock frequency and the CP slew rate, and can be determined as required by the application. For the present study, 50-kHz square-wave clock is used.

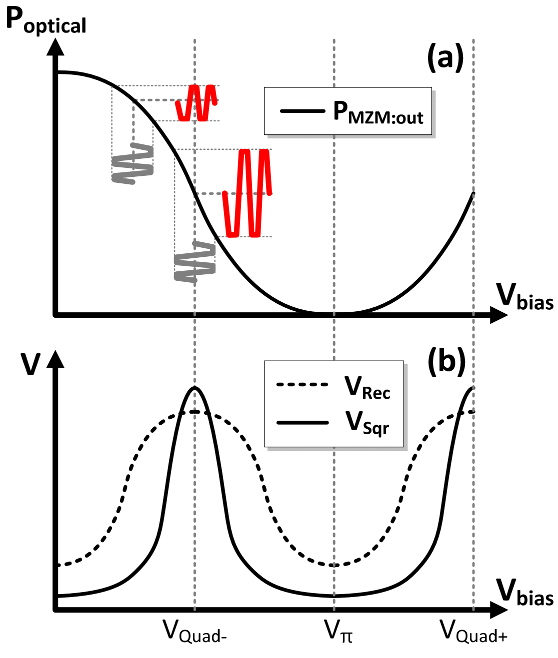

Figure 4. (a) MZM transfer curve (b) rectifier output (V_{REC}) and square amplifier output (V_{SQR})

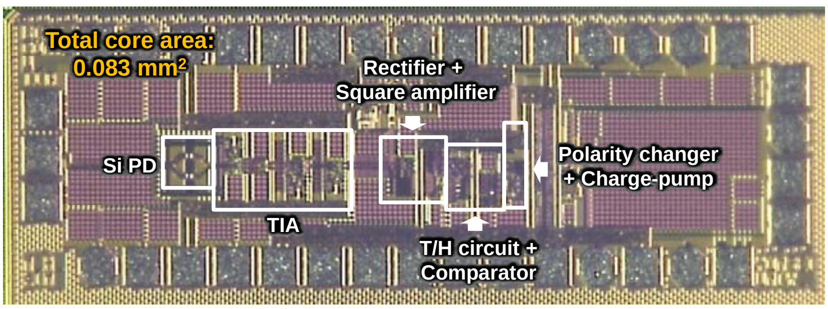

Figure 5. Chip photograph of MZM bias controller

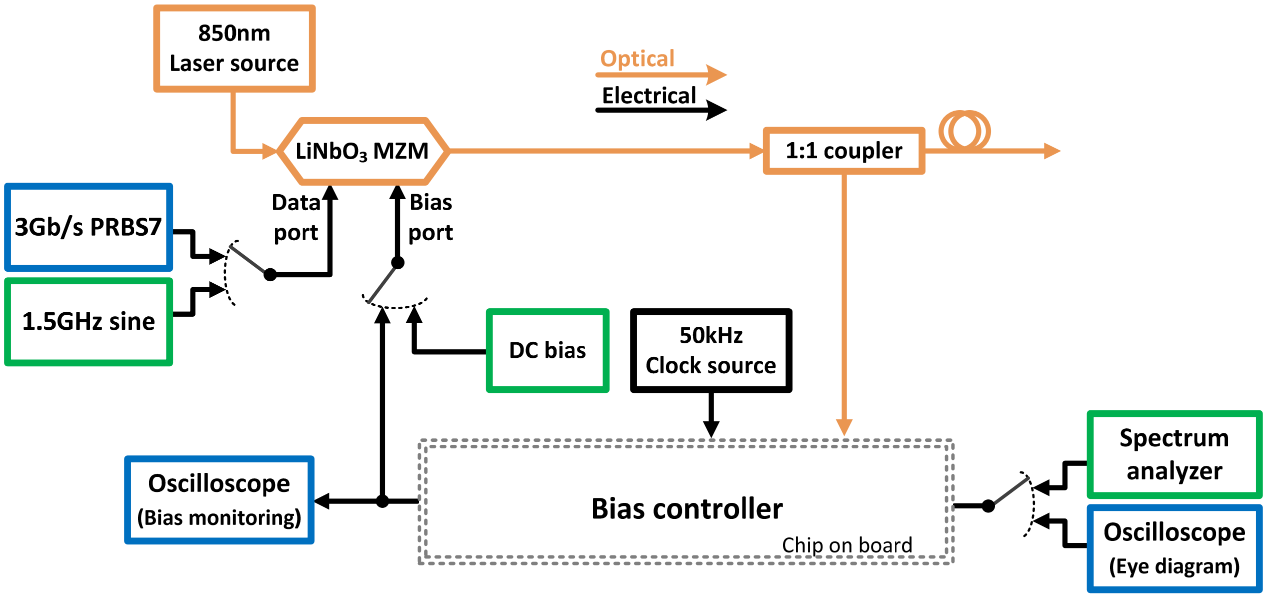

Figure 6. Measurement setup for data modulation (w/ blue equipment) and harmonics test (w/ green equipment)

3. MEASUREMENTS

Fig. 5 shows the chip photograph. It is fabricated by IHP's 0.25-µm BiCMOS technology and its area is approximately 0.083-mm^2. For testing purpose, a Si PD is integrated in the circuit that can detect 850-nm light but with a very low responsivity of 0.0125-A/W. Due to this, large optical power of 13-dBm is needed into the PD for reliable operation of the controller. However, this problem should go away when the controller is integrated with Si MZM and Ge PD in EPIC technology [4]. The supply voltage is 2.5-V and the controller consumes 92.5-mW, most of which is due to TIA and the rectifier.

Fig. 6 shows the measurement setup. In order to verify that the controller successfully searches the optimum bias, harmonic components of the MZM output light is measured when it is sinusoidally modulated at 1.5-GHz. At the optimum bias, the MZM should produce the largest first-order harmonic component and the smallest 2nd-order harmonic component. Fig. 7 shows the ratio of the measured first-order to the 2nd-order during 30 min MZM operation with and without the bias controller. Without the bias controller, the ratio changes greatly as its transfer characteristics change due to thermal drift. However, with the bias controller on, the ratio remains at a fixed value indicating that the bias is maintained near the optimum value throughout the MZM operation. The reason that the ratio is less than the maximum value is due to the slight dithering operation of our controller.

Fig. 8 shows the measured transient response of the bias voltage after the controller is turned on. As can be seen in the figure, the bias voltage approaches the optimum bias voltage and remains there while slightly dithering around the optimum value. The tracking speed is about 1-mV/µsec and the dithering amplitude is about 40-mV$_{p2p}$, both of which can be changed by circuit design.

Accumulated eye diagrams are measured when the MZM is modulated with 3-Gb/s 2^7-1 PRBS data. The data rate is limited by the speed of the Si PD integrated in our test chip not by our controller architecture. Fig. 9(b) shows the eye diagram measured for 30 minutes with the bias controller on. Compared to the eye diagram measured for initial 20 seconds, there is no observable degradation of the eye quality. Compared to the eye diagram measured without the controller shown in Fig. 2(b), the improvement in eye quality is significant, clearly confirming the successful operation of our controller.

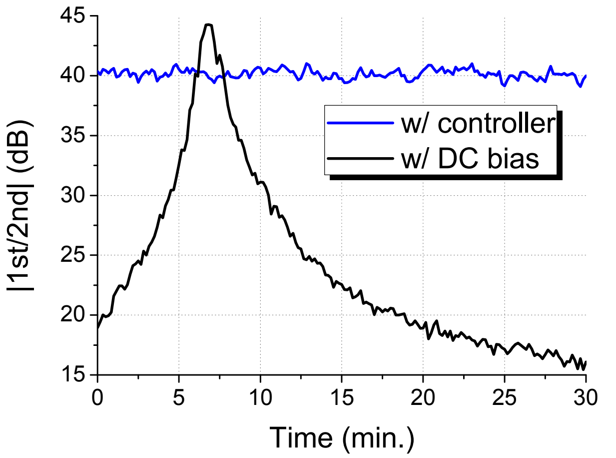

Figure 7. Ratio of first and 2nd-harmonic components for 1.5-GHz modulation of MZM with and without bias controller

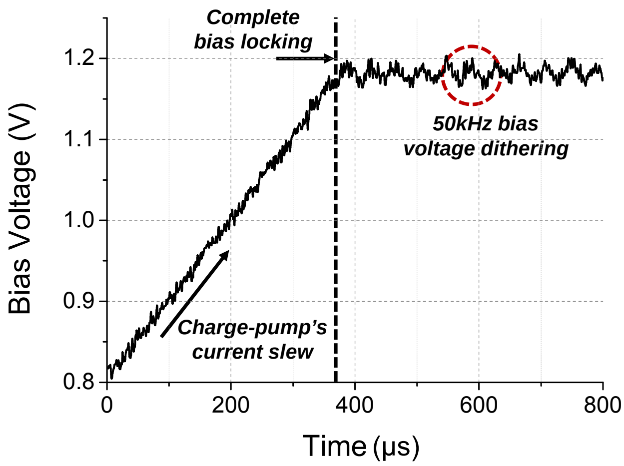

Figure 8. MZM bias voltage transient

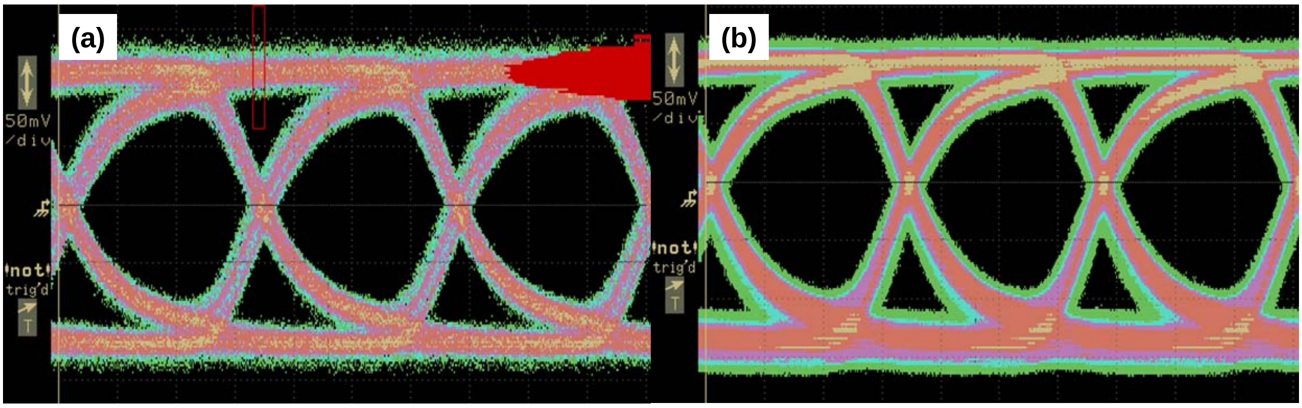

Figure 9. Accumulated eye diagram of 3-Gb/s data modulated with $LiNbO_3$ MZM with bias controller (a) for initial 20 seconds (b) for 30 minutes

4. CONCLUSION

A new type of an integrated MZM bias controller is demonstrated. Our bias controller monitors the eye amplitude of the MZM output light and automatically searches the optimum MZM bias voltage and maintains it there. A prototype chip realized in IHP's 0.25-µm BiCMOS with an integrated Si PD can provide the successful bias control for 3Gbps modulation of a commercial 850-nm MZM. Since our controller is based on the Si processing technology fully compatible with EPIC realization, it has a great potential of providing Si MZM with an integrated bias controller.

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