

PCSI

Room Keahou I - Session PCSI-MoM2

High-k Dielectrics and Ferroelectrics

Moderator: Peter Maurer, University of Chicago

11:10am **PCSI-MoM2-33 Non-Volatile Optical Phase Shifters on Si Photonics Platform**, *Mitsuru Takenaka, Yuto Miyatake, Rui Tang, Kazuma Taki, Naoki Sekine, Kouhei Watanabe, Tomohiro Akazawa, Hiroya Sakumoto, Dhruv Ishan Bhardwaj, Masahiro Fujita, Hanzhi Tang*, The University of Tokyo, Japan; *Kotaro Makino, Junji Tominaga, Noriyuki Miyata, Makoto Okano*, National Institute of Advanced Industrial Science and Technology (AIST), Japan; *Kasidit Toprasertpong, Shinichi Takagi*, The University of Tokyo, Japan

INVITED

A programmable Si photonic integrated circuit (PIC) [1] is emerging for various applications, including communication [2], computing [3, 4], and sensing [5]. To adjust its functionality, the optical phases of signals need to be controlled through multiple optical phase shifters integrated into the PIC. However, thermo-optic (TO) phase shifters, which are commonly used in silicon PICs, have high power consumption [6]. Moreover, their volatility leads to complex electrical wiring, especially when the number of phase shifters is large. As an alternative to TO phase shifters, we have investigated non-volatile optical phase shifters based on a III-V/Si MOS capacitor [7, 8], phase change materials [9], and ferroelectric HfZrO₂ [10]. In this paper, we present our recent results of these non-volatile optical phase shifters.

Acknowledgement: This work was partly supported by JST-Mirai Program (JPMJM20A1), JST, CREST (JPMJCR2004), JSPS KAKENHI (JP23H00172), and “Advanced Research Infrastructure for Materials and Nanotechnology in Japan” of MEXT Grant Number JPMXP1224UT1028, and partly based on results from project (JPNP16007) commissioned by NEDO.[1]W. Bogaerts et al., *Nature* 586(7828), 207–216 (2020).[2]K. Tanizawa et al., *Opt. Express* 23(13), 17599 (2015). [3]Y. Shen et al., *Nat. Photonics* 11(7), 441–446 (2017). [4]X. Qiang et al., *Nat. Photonics* 12(9), 534–539 (2018). [5]X. Zhang et al., *Nature* 603(7900), 253–258 (2022).[6]M. Takenaka et al., *J. Lightwave Technol.* 37(5), 1474–1483 (2019).[7]J.-H. Han et al., *Nat. Photonics* 11(8), 486–490 (2017).[8]R. Tang et al., *Laser Photon. Rev.* 17(11), (2023).[9]Y. Miyatake et al., *IEEE Trans. Electron Devices* 70(4), 2106–2112 (2023). [10]K. Taki et al., *Nat. Commun.* 15(1), 3549 (2024)

11:50am **PCSI-MoM2-41 In-Situ Analytical Study on Atomic Layer Deposition of Metal Silicate Thin Films Using Hexachlorodisilane and Water**, *Gaeun Kim, Eunsang Lee, Yo-Sep Min*, Konkuk University, Republic of Korea

Atomic layer deposition (ALD) is a critical process in the fabrication of modern electronic devices due to its ability to precisely grow thin films through the chemical adsorption of precursors.[1] Various metal oxide films can be deposited at low temperatures using metal precursors such as alkoxides or halides, along with water as the oxygen precursor. However, when using hexachlorodisilane (HCDS) and H₂O for SiO₂ ALD, challenges arise at low temperatures or with limited precursor exposure, often necessitating higher deposition temperatures or the use of Lewis base catalysts like pyridine or ammonia.[2] Through in-situ analyses using Fourier transform infrared spectroscopy (FTIR) and quartz crystal microbalance (QCM), we propose that metal hydroxyl groups (M-OH, where M represents Al, Ti, or Zn) located near silanol (Si-OH) groups facilitate the chemisorption of HCDS and H₂O at low temperatures, eliminating the need for catalysts. To elucidate the role of these metal hydroxyl groups, we conducted in-situ analyses of the ALD processes for metal silicate using trimethylaluminum, TiCl₄, or diethylzinc with FTIR and QCM. The hydrogen bonding between M-OH (or M-O-Si) and silanol groups may enhance the nucleophilicity of the oxygen of silanol, thereby promoting SiO₂ ALD. Although the M-OH groups promote the growth of silica, they gradually become covered by silica layers as ALD cycles repeat, reducing their effectiveness as promoters. Since the basicity of M-OH affects the strength of hydrogen bonding with silanol, we investigated the basicity of these M-OH groups using acetylacetone (Hacac) as a probe molecule. Among the M-OH groups studied, Zn-OH exhibited the highest basicity, followed by Al-OH and Ti-OH. We also discuss the correlation between the basicity and the effectiveness of the M-OH promoter.

11:55am **PCSI-MoM2-42 Enhanced Dielectric Properties of HfO₂ Thin Films Produced via Novel Catalytic Atomic Layer Deposition Process**, *Sara Harris, Matthew Weimer, Arrelaine Dameron, Dane Lindblad, Aaron Wang*, Forge Nano

Optimized high- κ dielectric materials are widely utilized as gate oxides and dielectric barriers in compound semiconductor devices such as GaN HEMT
Monday Morning, January 20, 2025

and MEMS [1]. Monolithic high- κ dielectric materials have inherent performance tradeoffs demonstrated by hafnium oxide (HfO₂) which has a high dielectric constant but a low breakdown voltage and high leakage current limiting overall efficacy as a dielectric barrier[2]. Composite materials such as HfAlO_x can improve dielectric performance by combining the high dielectric constant of HfO₂ with the wider band gap and higher breakdown voltage of aluminum oxide (Al₂O₃) unlocking capabilities for next generation dielectric materials [2]. Atomic layer deposition (ALD) exploits precise control over self-limiting surface chemistry allowing for discreet nanolayers that can be tailored to optimize bulk film dielectric performance with a level of control that is not possible via other deposition techniques (CVD and PVD). This work demonstrates HfO₂ thin films deposited via ALD with enhanced dielectric properties achieved through the addition of a novel catalytic conversion step known as a CRISP Process. HfO₂ deposited via the CRISP process has 29% higher GPC, 7% higher density, more ideal stoichiometry, 44% less carbon impurity and larger crystal grains when compared to films growth with O₃ alone. In pursuit of high performing dielectric materials several compositions of ALD deposited nanolaminates were studied through the incorporation of small amounts of Al₂O₃ into bulk HfO₂. Discreet nanolayer formation is demonstrated via cross sectional scanning electron microscopy (SEM) shown in Figure 1. With varying amounts of Al₂O₃, dielectric constant, κ , can be increased from 16.2 to 19.2, the dielectric strength (breakdown voltage) can be increased from 6.9 to 7.8 MV/cm, and the leakage current density can be reduced from 3.3×10^{-9} to 8.1×10^{-12} J at 60V/m. Work is ongoing to tune layer composition for the best overall performance. In the future, full characterization in GaN HEMT devices is planned for both the HfO₂ – O₃ and HfO₂ – CRISP processes.

[1] S. Kol, et al., *Acta Physica Polonica A* 136, 6, (2019), pp. 873-881

[2] A.M. Mumlyakov et. al., *Journal of Alloys and Compounds* V858 (2021), 157713

12:00pm **PCSI-MoM2-43 Improving Hot Electron-Induced Punchthrough (Heip) via Dual Sti Sidewall Process in Dram**, *Jaehyeon Jeon*, Sungkyunkwan University, Korea; *Byoungdeog Choi*, Sungkyunkwan University (SKKU), Republic of Korea

As device scaling continues, higher electric fields develop in MOSFETs, leading to the generation of hot carriers in the channel and increased off-current due to hot-electron-induced punchthrough (HEIP) in pMOSFETs. In low-power DRAM, minimizing pMOSFET off-current is crucial to reducing standby power consumption, making HEIP immunity improvement essential for meeting standby current requirements. The primary factor behind HEIP degradation is electron trapping in the top region of the STI liner nitride. To enhance HEIP immunity, solutions such as increasing the gate length using a large tabbed-gate design or thickening the STI sidewall oxide to reduce electron trapping in the STI liner nitride have been proposed. However, while a large tabbed-gate design can improve HEIP immunity, it also increases chip size, making it impractical for low-power applications. A thicker STI sidewall oxide is a more viable solution, offering improved HEIP immunity without degrading DRAM performance. Nonetheless, in 10nm-scale DRAM products, increasing the core STI sidewall oxide thickness transforms the long-axis cell STI structure from an oxide-nitride configuration to a fully oxide-filled structure. This shift causes abnormal recess formation during cell gate fin patterning, resulting in VTS variability degradation. This paper presents and validates a process method that increases the core sidewall oxide thickness to improve HEIP immunity while maintaining the oxide-nitride structure in the cell STI region, which is critical for optimizing fin pattern formation.

Author Index

Bold page numbers indicate presenter

— A —

Akazawa, Tomohiro: PCSI-MoM2-33, 1

— B —

Bhardwaj, Dhruv Ishan: PCSI-MoM2-33, 1

— C —

Choi, Byoungdeog: PCSI-MoM2-43, 1

— D —

Dameron, Arrelaine: PCSI-MoM2-42, 1

— F —

Fujita, Masahiro: PCSI-MoM2-33, 1

— H —

Harris, Sara: PCSI-MoM2-42, 1

— J —

Jeon, Jaehyeon: PCSI-MoM2-43, 1

— K —

Kim, Gaeun: PCSI-MoM2-41, 1

— L —

Lee, Eunsang: PCSI-MoM2-41, 1

Lindblad, Dane: PCSI-MoM2-42, 1

— M —

Makino, Kotaro: PCSI-MoM2-33, 1

Min, Yo-Sep: PCSI-MoM2-41, 1

Miyata, Noriyuki: PCSI-MoM2-33, 1

Miyatake, Yuto: PCSI-MoM2-33, 1

— O —

Okano, Makoto: PCSI-MoM2-33, 1

— S —

Sakumoto, Hiroya: PCSI-MoM2-33, 1

Sekine, Naoki: PCSI-MoM2-33, 1

— T —

Takagi, Shinichi: PCSI-MoM2-33, 1

Takenaka, Mitsuru: PCSI-MoM2-33, 1

Taki, Kazuma: PCSI-MoM2-33, 1

Tang, Hanzhi: PCSI-MoM2-33, 1

Tang, Rui: PCSI-MoM2-33, 1

Tominaga, Junji: PCSI-MoM2-33, 1

Toprasertpong, Kasidit: PCSI-MoM2-33, 1

— W —

Wang, Aaron: PCSI-MoM2-42, 1

Watanabe, Kouhei: PCSI-MoM2-33, 1

Weimer, Matthew: PCSI-MoM2-42, 1