National Taiwan University - University of Tsukuba Joint Workshop

（物理工学域・TREMS 共催）

15;00-18:00, 22 November 2024

University of Tsukuba, Tsukuba City, Japan

Program

1. 15:00-15:15: Welcome, A. Uedono + Take a photo (15 min)
2. 15:15-15:50: Y.-P. CHIU, Cross-sectional STM for investigating interface property in heterostructures and future electronics (35 min)
3. 15:50-16:15: O.TAKEUCHI, Pump-probe SPMs for investigating ultrafast nanoscale phenomena (25 min)
4. 16:15-16:25: Brake (10 min)
5. 16:25-17:00: K.-Y. LEE/ P.-C. LIAO: The correlation of the third quadrant characteristics and the Schottky area ratios in a 4H-SiC SBD-embedded MOSFET (35 min)
6. 17:00-17:25: K. MATSUKI: Impact of electron irradiation on SiC power MOSFET performance (25 min)
7. 17:25-18:00: C. H. WU: High-Speed VCSELs for Optical Interconnect (35 min)

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EDUCATION

Dep. of Physics, National Taiwan Normal University, Taiwan 2005 Ph.D., Physics

PROFESSIONAL EXPERIENCES

Distinguished Professor, Dept. of Physics, National Taiwan University, Taiwan (present)
Adjunct Researcher, Institute of Atomic and Molecular Sciences, Academia Sinica, Taiwan (present)
Adjunct Researcher, Institute of Physics, Academia Sinica, Taiwan (present)
Visiting Scholar, Juelich Research Center, Germany

RESEARCH AREAS

STM/Cross-sectional STM measurements (Gate-tunable STM/XSTM for Semiconductor devices; Light-modulated STM/XSTM for Optoelectronic Materials); Interface Science; Low-dimensional Materials Electronic Structure; Complex Oxides

RECENT PUBLICATIONS

1. Hao-Yu Chen, Hung-Chang Hsu, Chuan-Chun Huang, Ming-Yang Li, Lain-Jong Li*, and Ya-Ping Chiu*. Directly Visualizing Photoinduced Renormalized Momentum-Forbidden Electronic Quantum States in an Atomically Thin Semiconductor. *ACS Nano* 16, 9660 (2022).
2. Jing-Kai Huang*, Yi Wan, Junjie Shi, Ji Zhang Zeheng, Wang Wenxuan, Wang Ni, Yang Yang, Liu Chun-Ho, Lin Xinwei Guan, Long Hu, Zi-Liang Yang, Bo-Chao Huang, Ya-Ping Chiu, Jack Yang, Vincent Tung, Danyang Wang, Kourosh Kalantar-Zadeh, Tom Wu, Xiaotao Zu, Liang Qiao, Lain-Jong Li* & Sean Li*. High-κ perovskite membranes as insulators for two-dimensional transistors. *Nature,* 605, 262 (2022).
3. [Invited] Bo-Chao Huang, Chun-Chih Hsu, Ying-Hao Chu, and Ya-Ping Chiu*. Atomically resolved interlayer electronic states in complex oxides by using cross-sectional scanning tunneling microscopy. *Progress in Surface Science*, 97, 100662 (2022).
4. Chun-Chih Hsu, Bo-Chao Huang, Michael Schnedler, Ming-Yu Lai, Yuh-Lin Wang, Rafal E. Dunin Borkowski, Chia-Seng Chang, Ting Kuo Lee, Philipp Ebert*, and Ya-Ping Chiu*. Atomically-resolved interlayer charge ordering and its interplay with superconductivity in $YBa_2Cu_3O_{6.81}$. *Nature Communications,* 12, 3893 (2021).
5. Hung-Chang Hsu, Bo-Chao Huang, Shu-Cheng Chin, Cheng-Rong Hsing, DucLong Nguyen, Michael Schnedler, Raman SankarRafal E. Dunin-Borkowski, Ching-Ming Wei, Chun-Wei Chen, Philipp Ebert*, and Ya-Ping Chiu*. Photodriven Dipole Reordering: Key to Carrier Separation in Metalorganic Halide Perovskites. *ACS Nano,* 13, 4, 4402 (2019).
6. Bo-Chao Huang, Pu Yu*, Y. H. Chu, Chia-Seng Chang, Ramamoorthy Ramesh, Rafal E. Dunin-Borkowski, Philipp Ebert, and Ya-Ping Chiu*. Atomically Resolved Electronic States and Correlated Magnetic Order at Termination Engineered Complex Oxide Heterointerfaces. *ACS Nano,* 12, 1089 (2018).

SPEECH

Cross-sectional STM for investigating interface property in heterostructures and future electronics

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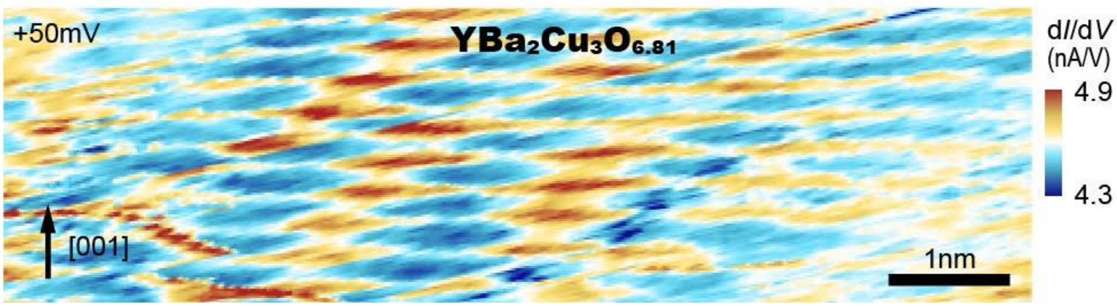
ABSTRACT:

Interface science has recently received significant attention due to the development of state-of-the-art materials and devices that provide powerful ways to create and manipulate charge, spin, orbital, and lattice degrees of freedom at interfaces. Motivated by the fact that nanoscale interface science is critical for device applications, this talk will focus on sharing the measurement capabilities of mapping the interfacial properties of heterostructured structures using cross-sectional scanning tunneling microscopy (XSTM) and elucidating the mechanisms inherent in these materials and devices.1-6

In my lab, the establishment of the XSTM technique has provided a measurement tool for probing the electronic structure and band alignment of interfaces in cutting-edge heterostructured materials. Recently, this technique has been improved by integrating an illumination light source, which enables the observation of spatially resolved mapping images of photogenerated carriers at perovskite grains.

The platform now combines gate-, source- and drain- tunable biasing and will be used to explore the electronic structure of cutting-edge device interfaces. This will be a potential demonstration of characterization capabilities and provide critical insights into the exploration and innovation of future electronic devices.



[Representative work] Due to the XSTM/STS approach, the methodology significantly advances the understanding of the microscopic spatial interplay of superconductive and charge-ordered phases and their interlayer coupling along the *c* direction in $YBa_2Cu_3O_{6.81}$, something, which remained elusive since the discovery of superconductivity in $YBa_2Cu_3O_{6.81}$ **35** years ago.[1]

Ref. [1]: Chun-Chih Hsu, Bo-Chao Huang, Michael Schnedler, Ming-Yu Lai, Yuh-Lin Wang, Rafal E. Dunin-Borkowski, Chia-Seng Chang, Ting-Kuo Lee, Philipp Ebert, Ya-Ping Chiu, *Nature Communications* volume 12, Article number: 3893 (2021).

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EDUCATION

Graduation from School of Engineering, The University of Tokyo, Japan 2000 Ph.D., Engineering

RESEARCH AREAS

Development of unique measurement techniques in the field of scanning probe microscopy combined with pump-probe technique.

RECENT PUBLICATIONS

1. H. Mogi, Y. Arashida, R. Kikuchi, R. Mizuno, J. Wkabayasi, N. Wada, Y. Miyata, A. Taninaka, S. Yoshida, O. Takeuchi, and H. Shigekawa, “Ultrafast nanoscale exciton dynamics via laser-combined scanning tunneling microscopy in atomically thin materials”, npj 2D Materials and Applications 6,72 (2022); doi:10.1038/s41699-022-00345-1.
2. Y. Arashida, H. Mogi, M. Ishikawa, I. Igarashi, A. Hatanaka, N. Umeda, J. Peng, S. Yoshida, O. Takeuchi, and H. Shigekawa, “Subcycle mid-infrared electric-field-driven scanning tunneling microscopy with a time resolution higher than 30 fs”, ACS Photonics 9, 9, 3156-3164 (2022); doi:10.1021/acsphotonics.2c00995.
3. S. Yoshida, Y. Arashida, H. Hirori, T. Tachizaki, A. Taninaka, H. Ueno, O. Takeuchi, and H. Shigekawa, “Terahertz scanning tunneling microscopy for visualizing ultrafast electron motion in nanoscale potential variations”, ACS Photonics 8, 315-323 (2021), DOI:10.1021/acsphotonics.0c01572.

SPEECH

Pump-probe SPMs for investigating ultrafast nanoscale phenomena

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ABSTRACT

In the IT devices around us, such as PCs, smartphones and smart cars, numerous semiconductor nanoelements are working at clock rates already higher than 1 GHz. So, to investigate and improve such semiconductor nanoelements, our group has been working on developing ultrafast microscopes by combining scanning tunnelling microscopy (STM) with pump-probe technique.

In this presentation, I first review the basic concepts of the pump-probe STM (Fig. 1) and present its three different implementations we have developed in our group. Figure 2 is a demonstrative experimental result measured with one of the three microscopes. It revealed the carrier dynamics in a C_{60} thin film with ~4 monolayer thickness grown on Au(111) substrate with ~1 nm spatial resolution and ~1 ps temporal resolution. I will clarify the abilities and limitation of our microscopes and also briefly mention about time resolved STM/AFM with a little different concept.

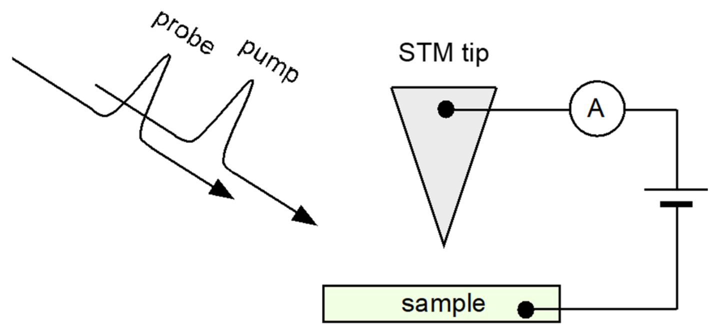

Fig. 1: Concept schematic of pump-probe STM. Conventional STM measures the tunnel current flowing through the small gap between a metallic tip and a biased conductive sample. In pump-probe STM, two pulses, pump pulse and probe pulse are applied to this tunnel gap and the response of the tunnel current to the probe pulse is precisely measured by lockin technique.

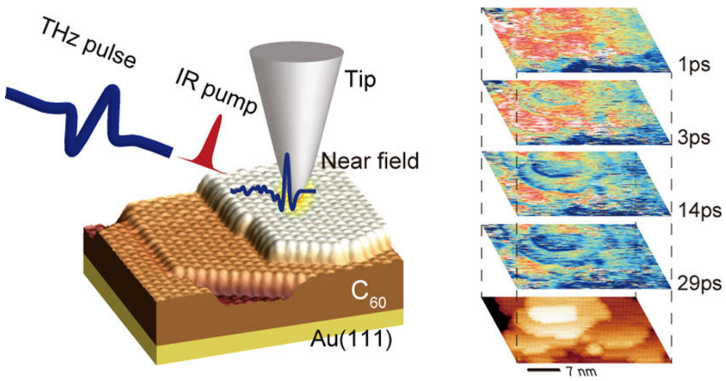

Fig. 2: Picosecond (ps = 10^{-12} sec) time-resolved scanning tunneling microscopy measurement of the carrier dynamics in a C_{60} thin film with ~4 monolayer thickness grown on Au(111) substrate. It is clearly visualized that the carriers doped in the LUMO band from the Au substrate is localized at the surface steps with one molecular heights in their ~10 ps lifetime. [2]

References: [1] S. Yoshida et al., The European Physical Journal Special Topics 222, 1161-1175 (2013); DOI: 10.1140/epjst/e2013-01912-2 [2] S. Yoshida et al., ACS Photonics 8, 315-323 (2021); DOI:10.1021/acsphotonics. 0c01572 [3] Y. Arashida, ACS Photonics 9, 9, 3156-3164 (2022); DOI:10.1021/acsphotonics.2c00995

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EDUCATION

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PROFESSIONAL EXPERIENCES

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Committee/board member (ICSCRM, ISPSD, IFEEC)

RESEARCH AREAS

SiC power semiconductor devices, fabrication processes, characterization and application

RECENT PUBLICATIONS

1. Pei-Chun Liao, Kung-Yen Lee, Wan-Ting Hsieh, Chih-Jung Chang, Chun-Ju Chen, Ruei-Ci Wu, Yan-Yu Wen, "The relationship of voltage variations in the third quadrant and the Schottky area ratios in a 4H-SiC SBD-embedded MOSFET," Materials Science in Semiconductor Processing, 186, 109026, (2025)
2. Ruei-Ci Wu, Kung-Yen Lee, Yan-Yu Wen, and Pei-Chun Liao, "The correlation of the drain-source capacitance variation and the P-pillar structures in a 4H-SiC quasi super junction MOSFET," Materials Science in Semiconductor Processing, 178, 108413, (2024)
3. Shih-Hsuan Chen, Chih-Lun Liu, Chien-Neng Huang, Hsiang-Min Hsieh, Ping-Kai Chang, Ruei-Ci Wu, Kung-Yen Lee and Chih-Fang Huang, "Modulation of Ciss of a 4H-SiC Planar MOSFET with a Shorter Sidewall and a Thicker Gate." IEEE Electron Device Letters, Volume 44, No.11, p1825-1828. (2023)
4. Catherine Langpoklakpam, An-Chen Liu, Kuo-Hsiung Chu, Lung-Hsing Hsu, Wen-Chung Lee, ShihChen Chen, Chia-Wei Sun, Min-Hsiung Shih, Kung-Yen Lee, Hao-Chung Kuo, "Review of Silicon Carbide Processing for Power MOSFET," Crystal, 2022, 12 (2), 245 Feb. 11, (SCI, IF: 2.589) (2022)
5. Po-Yu Chen, Kung-Yen Lee*, Po-Chun Huang, Jia-Han Li, Forng-Chen Chiu, Jing-Fa Tsai, and ShuTing Hsu, "The performance analysis of the low-speed direct-drive generators for harvesting current energy," IET Renewable Power Generation, 2022, 1–12, Sept. 12, 2022

SPEECH

The correlation of the third quadrant characteristics and the Schottky area ratios in a 4H-SiC SBD-embedded MOSFET

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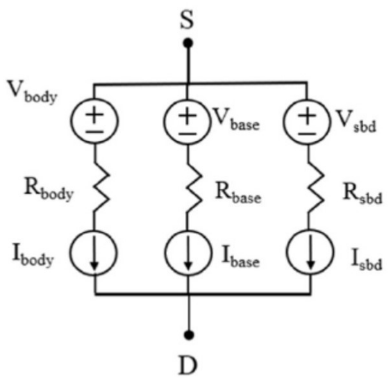

Fig. 1. The equivalent circuits for an SBD-embedded MOSFET.

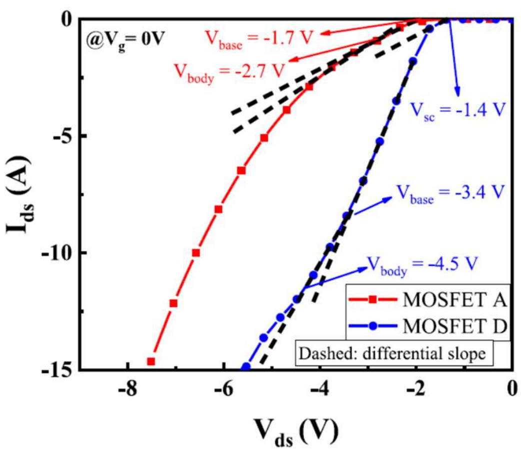

Fig. 2. The measured third quadrant Ids−Vds curves of the MOSFETs A and D.

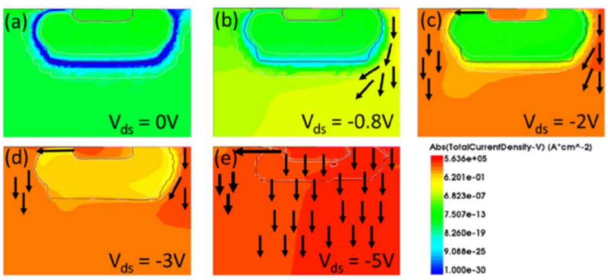

Fig. 3. The simulated electron current densities of MOSFET D at Vgs = 0 V and Vds = 0, -0.8 -2, -3, -5 V.

ABSTRACT

Based on the measured and the TCAD simulation results, this paper provides a detailed description of the third quadrant characteristics of the Schottky barrier diode (SBD) embedded MOSFETs with different Schottky area ratios of 2.6 %, 5.3 %, and 14.7 %. As the Schottky area ratio increases, the shift of the third quadrant turn-on voltages of the MOSFETs influenced by the gate voltage decreases. The shift rates in the conventional MOSFET and SBD-embedded MOSFETs are from 57.2 % to 0 % when Vgs changes from 0 V to □ 4 V. The shift rate becomes 0 % when the Schottky area ratio is larger than 5.3 %. Simultaneously, the TCAD simulation results and the measured results indicate that the SBD-embedded MOSFETs can effectively suppress the conduction of the low barrier diode and the body diode.

Furthermore, the SPICE models were built to explain the physics mechanisms. The fitting error between the measured and fitting results is as low as 1.3 % among the models with the different Schottky area ratios.

Kotaro MATSUKI was born in Houfu-city, Yamaguchi, Japan in July 2000. He received a B.E degree from University of Tsukuba in 2023. He is pursuing a Master's degree in the power electronics laboratory, University of Tsukuba.
His current research interest is a study of SiC power semiconductor devices.
Kotaro Matsuki is a member of the Japan Society of Applied Physics.

Impact of electron irradiation on SiC power MOSFET performance

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A pin diode built into an SiC power MOSFET can be used as an FWD in inverter circuits. However, the reverse recovery characteristics of body-pin diodes are inferior to those of SBDs. High-energy electron irradiation is one method to control the carrier lifetime in the drift layer by introducing point defects, which improves the reverse recovery characteristics of the body-pin diode. However, this may affect the MOS channel characteristics. In this study, we analyze electron-irradiated SiC power MOSFETs, focusing on their effects on the drift layer resistance (R_{drift}) and MOS channel characteristics such as the threshold voltage (V_{th}), subthreshold swing (SS), and transconductance (g_{m}).

Commercially available 1.2 kV-class SiC trench MOSFETs were irradiated with electrons at 4.6 MeV in 20 kGy increments up to 400 kGy at room temperature. 600 V-class Si power MOSFETs were also used for comparison. No thermal treatment was performed after the irradiation.

Figure 1 shows the dose dependence of the reverse recovery charge (Q_{rr}) of the body diode. Electron irradiation at 40 kGy reduced Q_{rr} by approximately half. In other words, electron irradiation effectively improves reverse recovery characteristics. However, it should be noted that the on-resistance (R_{on}) of the MOSFET increased, as shown in Fig. 2. The degraded R_{on} can be attributed to the increase in resistance in both the drift layer and the MOS channel (R_{ch}) owing to defect generation.

To investigate the effect of irradiation on the MOS channel in detail, we analyzed the transfer characteristics to evaluate V_{th}, SS, and g_{m}. Figure 3 compares the subthreshold characteristics of the SiC and Si MOSFETs. The changes in the subthreshold characteristics are significantly different between the SiC and Si MOSFETs. Evidently, a large shift in V_{th} by –6 V and degradation in SS were observed for the Si MOSFETs, while a smaller shift in V_{th} by –1 V and no degradation in SS were observed for the SiC MOSFETs, as indicated in Fig. 4.

The changes in g_{m} also show different trends for the SiC and Si MOSFETs, as shown in Fig. 5. Considering the voltage drop in the drift layer, the drain current (I_{d}), R_{ch}, and g_{m} of a power MOSFET can be expressed using Eqs. (1)–(3) [1]. Here, resistances other than R_{drift} and R_{ch} are assumed to be negligible. As shown in Eq. (3), g_{m} of a power MOSFET depends not only on the channel mobility but also on R_{drift}. Therefore, to remove the influence of the change in R_{drift}, the corrected transconductance (g_{m}') was introduced, as shown in Eq. (4). From Eq. (2), R_{drift} can be derived from the extrapolated intercept of the R_{on} - $(V_{\mathrm{gs}} - V_{\mathrm{th}})^{-1}$ plot [1], and the obtained R_{drift} at different doses are shown in Fig. 6. It was found that R_{drift} increases with the dose owing to the reduced carrier density caused by the introduction of point defects in the drift layer [2]. From Eq. (4), g_{m}' can be calculated at each point of the I_{d} - V_{gs} curves shown in Fig. 3. The variation of the peak ratio of g_{m} and g_{m}' is shown in Fig. 7. Both g_{m} and g_{m}' in the Si MOSFETs decreased with irradiation. On the other hand, irradiation reduced g_{m} but hardly changed g_{m}' in the SiC MOSFETs. This implies that g_{m} of the SiC MOSFETs decreased owing to the increase in R_{drift}, not R_{ch}. Considering the trends of SS and g_{m}', it can be concluded that the density of interface defects in the Si MOSFETs increased under electron irradiation. By contrast, in the SiC MOSFETs, electron irradiation was found to have minimal impact on the MOS channel properties, except for a small shift in V_{th}. Therefore, the MOS interface of SiC MOSFETs is more resistant to electron irradiation than that of Si MOSFETs.

$$I_{\mathrm{d}}=\frac{W}{L}\mu_{\mathrm{FE}}C_{\mathrm{ox}}\left(V_{\mathrm{gs}}-V_{\mathrm{th}}\right)\left(V_{\mathrm{ds}}-I_{\mathrm{d}}R_{\mathrm{drift}}\right) \qquad (1)$$

$$R_{\mathrm{ch}}=\left[W\mu_{\mathrm{FE}}C_{\mathrm{ox}}\left(V_{\mathrm{gs}}-V_{\mathrm{th}}\right)/L\right]^{-1}=R_{\mathrm{on}}-R_{\mathrm{drift}} \qquad (2)$$

$$g_{\mathrm{m}}=\left.\frac{\partial I_{\mathrm{d}}}{\partial V_{\mathrm{gs}}}\right|_{V_{\mathrm{ds}}}=\frac{W}{L}\mu_{\mathrm{FE}}C_{\mathrm{ox}}V_{\mathrm{ds}}\left(\frac{R_{\mathrm{ch}}}{R_{\mathrm{on}}}\right)^{2} \qquad (3)$$

$$\mu_{\mathrm{FE}}=\frac{L}{WC_{\mathrm{ox}}V_{\mathrm{ds}}}g_{\mathrm{m}}\left(\frac{R_{\mathrm{on}}}{R_{\mathrm{on}}-R_{\mathrm{drift}}}\right)^{2}=\frac{L}{WC_{\mathrm{ox}}V_{\mathrm{ds}}}g_{\mathrm{m}}' \qquad (4)$$

[1] S. L. Rumyantsev, et al., Semicond. Sci. Technol., **24**, 075011 (2009).
[2] J. Vobecky, et. al., IEEE Trans. Electron Devices, **62**, 1964 (2015).

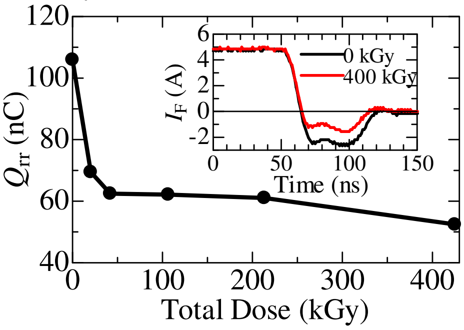

Fig. 1. Change of Q_{rr} in irradiated SiC MOSFETs measured at 175 °C.

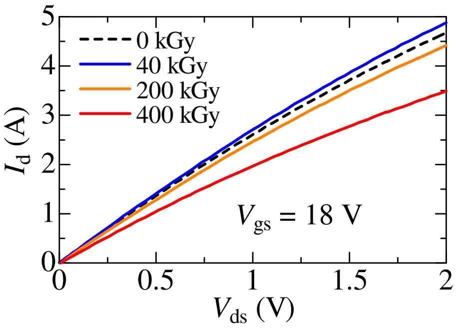

Fig. 2. Output characteristics shift in SiC MOSFETs under electron irradiation.

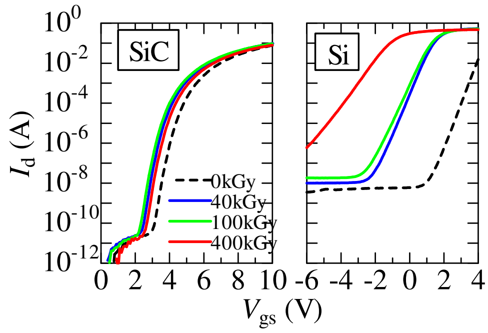

Fig. 3. Subthreshold characteristics shift in SiC and Si MOSFETs under electron irradiation.

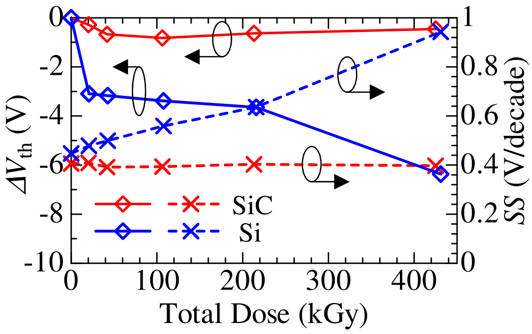

Fig. 4. Shift in V_{th} and degradation in SS of irradiated SiC and Si MOSFETs.

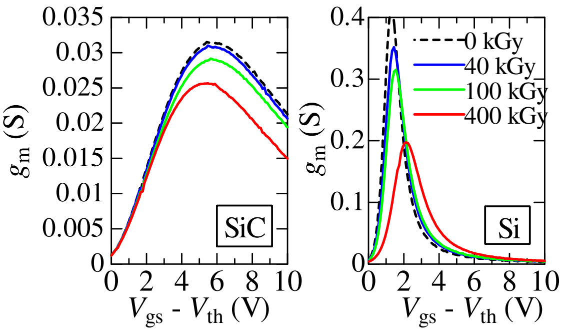

Fig. 5. Change of g_m in irradiated SiC and Si MOSFETs.

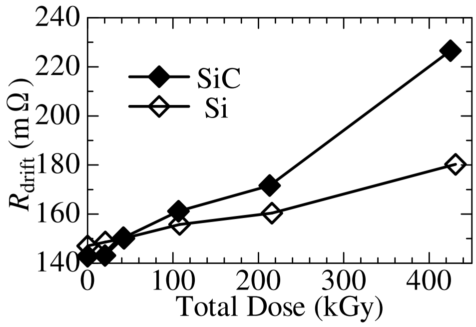

Fig. 6. Increase in R_{drift} for SiC and Si MOSFETs with different doses.

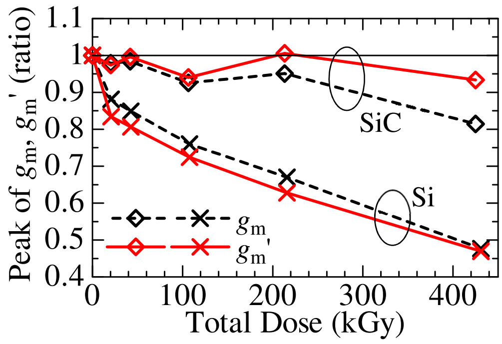

Fig. 7. Changes in g_m and g_m' for SiC and Si MOSFETs with different doses.

Prof. Chao-Hsin Wu (吳肇欣)

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EDUCATION

University of Illinois at Urbana-Champaign, USA, 2010 Ph.D. in ECE

PROFESSIONAL EXPERIENCES

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Associate Director of the Nano-Electro-Mechanical-Systems (NEMS) Research Center

Chief Executive Officer, NTU-TSMC Research Center

RESEARCH AREAS

Compound semiconductor optoelectronic and microelectronic devices

RECENT PUBLICATIONS

1. Y. -C. Yang, Z. Wan, C. -C. Chiu, I. -C. Liu, G. Xia and C. -H. Wu, "80 Gbps PAM-4 Data Transmission with 940 nm VCSELs Grown on a 330 µm Ge Substrate," in IEEE Electron Device Letters, doi: 10.1109/LED.2024.3462949.
2. Hao-Tien Cheng, Ya-Ting Liang, Yun-Ting Huang, Shu-Jui Hsu, Wei-Hao Lin, Milton Feng, and Chao-Hsin Wu, "Electro-optical logics by three-terminal quantum-well-light-emitting transistors integration," Photonics Research vol. 12, issue 8, pp. A51-A62 (2024)
3. Chi-En Chen, Shih-Min Huang, Tzu-Jui Wang, Ming-Chieh Hsu, Kuan-Chieh Huang, Jau-Yang Wu and Chao-Hsin Wu, "High temperature tolerant Ge-on-Si single photon avalanche diode at the communication wavelength" IEEE Electron Device Letters, 2024, doi: 10.1109/LED.2024.3416186
4. Te-Hua Liu, Sung-Pu Yang, Yun-Cheng Yang, and Chao-Hsin Wu, “High-Power and Low RIN Performance of a 1.55 µm DFB Laser for 10 Gb/s Satellite Optical Links.” IEEE Electron Device Letters, vol. 45, no. 3, pp.428 - 431, 2024. doi:10.1109/LED.2023.3347755.
5. Mukul Kumar, Shu-Yun Ho, Shu-Jui Hsu, Pin-Chia Li, Shu-Wei Chang, Chao-Hsin Wu, “Current Gain Enhancement at High-Temperature Operation of Triple-Quantum-Well Heterojunction Bipolar Light-Emitting Transistor for Smart Thermal Sensor Application,”IEEE Transactions on Electron Devices, vol. 71, no.1, pp.896-903, 2023, doi: 10.1109/TED.2023.3339084.

SPEECH

High-Speed VCSELs for Optical Interconnect

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ABSTRACT

The relentless demand for faster data rates and higher bandwidth in telecommunications, data centers, and emerging generative AI applications underscores the critical need for advanced optical communication technologies. Vertical-Cavity Surface-Emitting Lasers (VCSELs) stand at the forefront of this technological evolution, offering unparalleled advantages in terms of efficiency, scalability, and integration capabilities. This presentation delves into the cutting-edge realm of high-speed VCSELs, with a special emphasis on oxide-confined VCSELs, which are pivotal for achieving high-speed data communication.

We commence with a foundational overview of VCSEL technology, highlighting its operational principles and the significant advantages offered by oxide confinement, including enhanced modulation speeds and reduced power consumption. The discourse then transitions to the myriad applications of high-speed VCSELs, ranging from data center transceivers and Active Optical Cables (AOC) to co-packaged optics for chiplet integration, and their critical role in supporting the bandwidth-intensive requirements of Generative AI technologies.

Central to our exploration is the recent progress in oxide-confined VCSEL technology, encapsulating the latest design innovations, technical breakthroughs, and the notable contributions of leading industry players and academic institutions. Through selected case studies, we underscore the real-world impact and the transformative potential of these advancements in optical interconnects. The presentation addresses the existing challenges facing VCSEL technology and posits future directions for research and development. By navigating the current limitations, we spotlight the roadmap for VCSELs in ushering in a new era of optical communications.