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Creation of Semiconductor Plasmonic Functional Devices and Their Application to the Next Generation Beyond 5G Terahertz Wireless Communications

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As we are required to change to a new normal society over the COVID-19 pandemic, the use cases of smartphones are diversifying to an extent far beyond our imagination, and people's demand for wireless communication technology that enables "higher speed, higher capacity, and massive connections" continues unabated. In this regard, research and development of the next generation Beyond 5G (B5G), i.e., 6G and 7G are being actively conducted in order to cope with the increasing traffic volume in mobile communications. However, there is the technological difficulties, called "THz gap," over the entire THz electromagnetic spectral range due to the fundamental physical limits on both existing electronic and photonic technology. In such a situation, graphene has attracted considerable attention due to its massless and gapless energy spectrum. This lecture reviews recent advances in the research for the creation of semiconductor plasmonic functional devices and their application to the next generation beyond 5G terahertz (THz) wireless communications.

2D electronic and plasmonic THz devices based on graphene-based 2D materials, particularly highlighting the THz sources and detectors. Carrier-injection pumping of graphene can enable negative-dynamic conductivity in the THz range, which may lead to new types of THz lasers. The dual-gate graphene channel transistor (DG-GFET) structure serves carrier population inversion in the lateral p-i-n junctions under complementary dual-gate biased and forward drain biased conditions, promoting spontaneous incoherent THz light emission. A laser cavity structure implemented in the active gain area can transcend the incoherent light emission to the single-mode lasing. We designed and fabricated the distributed feedback (DFB) DG-GFET. A teeth-brash-shaped DG structure is introduced as the DFB cavity having the fundamental mode at 4.96 THz. Broadband rather intense (~80 μW) amplified spontaneous emission from 1 to 8 THz and weak (~0.1 μW) single-mode lasing at 5.2 THz were observed at 100K in different samples. When the substrate-thickness dependent THz photon field distribution could not meet the maximal available gain-overlapping condition, the DFB cavity cannot work properly, resulting in broadband LED-like incoherent emission. To increase the operating temperature and lasing radiation intensity, further enhancement of the THz gain and the cavity Q factor are mandatory. Plasmonic metasurface structures promoting the super-radiance and/or instabilities are promising for giant THz gain enhancement.

In terms of THz detection, nonlinear nature of graphene plasmons enables drastic enhancement of detection responsivity that can well outperform any existing room-temperature fast detectors. Recently we experimentally demonstrated 100-Gbit/s-class fast and sensitive THz detection in an ADGG-GFET utilizing current-driven plasmonic and photothermoelectric rectification mechanisms.

In the final part, we introduce the double-graphene-layered van der Waals heterostructures to mediate the photon/plasmon assisted resonant tunneling working for highly efficient THz sources and detectors. Future trends towards the smarter society based on the 6G and 7G THz wireless communications are also discussed.

When:	**13:00 – 14:00 JST, October 31st, 2022.**
Where:	**Zoom Online**
Link:	**To be emailed shortly for pre-registered attendees**
Language:	**Japanese (presentation) / English (slides)**
Fee:	**Free of charge**
Pre-Registration:	**Mandatory. To preregister, <Click here!> or ☞**
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Taiichi Otsuji is a professor at the Research Institute of Electrical Communication (RIEC), Tohoku University, Sendai, Japan. He received the B.S. and M.S. degrees in electronic engineering from Kyushu Institute of Technology, Fukuoka, Japan, in 1982 and 1984, respectively, and the Dr. Eng. degree in electronic engineering from Tokyo Institute of Technology, Tokyo, Japan in 1994. From 1984 to 1999 he worked for NTT Laboratories, Kanagawa, Japan. In 1999 he joined Kyushu Institute of Technology as an associate professor, being a professor in 2002. He joined RIEC, Tohoku University, in 2005. His current research interests include terahertz electronic, photonic and plasmonic materials/devices and their applications. He has authored and co-authored 280 peer-reviewed journal papers and more than 600 conference proceedings including 200 invited presentations, and holds 11 Japanese and 7 US patents. He is the recipient of the Outstanding Paper Award of the 1997 IEEE GaAs IC Symposium in 1998, Prizes for Science and Technology in Research Category, the Commendation for Sci-ence and Technology by the MEXT, Japan, in 2019, and the 59th Achievement Award of the IEICE (Institute of Electronics, Information, and Communication Engineers), Japan, in 2022. He has served as an IEEE Electron Device Society Distinguished Lecturer since 2013. He is a Fellow of the IEEE, OPTICA (former OSA), and JSAP (Japan Society of Applied Physics), a Senior Member of the IEICE, and a member of the MRS (Materials Research Society) and SPIE (International Society for Optical Engineering).