Bandwidth Measurement of Terahertz Detector Using High Electron Mobility Transistor by Heterodyne Mixing

Y. Ueda[1], T. Nukariya[2], S. Suzuki[1], and M. Asada[2]

[1] Graduate School of Science and Engineering, Tokyo Institute of Technology

[2] Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology

***Abstract*—We measured the bandwidth of a terahertz detector using an InAlAs/InGaAs high-electron–mobility-transistor by heterodyne mixing with UTC-PD and a frequency multiplier as a radio frequency (RF) and local oscillator (LO), respectively. The intensity of the intermediate signal was measured by changing the frequency of UTC-PD, and a very high bandwidth of up to 26 GHz was obtained.**

I. INTRODUCTION

Terahertz (THz) wireless communication has been extensively studied in the recent past[1-3]. Ultrahigh capacity data transmission can be achieved with a simple modulation scheme using a wide bandwidth. Detectors with high current sensitivity are required for high data rate. A THz detector using field-effect transistors (FETs), with very high potential and sensitivity, has already been developed[4-7]. Wireless data transmission (at approximately 10 Gbits/s) has also been demonstrated[8]. The FET detector bandwidth is an important parameter to estimate the potential for high data rate. However, it has not been reported yet. In this study, we measured the THz detector bandwidth using an InP-based high-electron-mobility transistor (HEMT) by heterodyne mixing technique, and we obtained a wide bandwidth of 26 GHz.

II. EXPERIMENTAL RESULTS

Fig. 1 shows the schematic device structure of our HEMT THz detector. An InP-based InAlAs/InGaAs composite-channel HEMT with two-finger T-shaped gates is integrated at the center of bow-tie antenna. The gate length and gate width are 100 nm and 10 μm, respectively. The obtained subthreshold swing (S.S.) and maximum transconductance ($g_{m.max}$) of fabricated device were 85 mV/dec and 0.9 S/mm. The gate voltage is set at the threshold voltage in the detection scheme. The induced voltage is generated in the antenna by irradiation of the THz wave, and the detection current flows to the drain by rectification with the nonlinearity in I_d-V_{gs} characteristics of HEMT. The MIM capacitor C_{MIM} is connected between the drain and the source. In this experiment, HEMT detectors with various C_{MIM} of 0, 18, and 36 fF were fabricated.

In the current sensitivity measurement, 280 GHz signal was generated by the frequency multiplier and focused on the HEMT detector using Tsurupica™ lens. The detection current was measured with lock-in technique, which was used for reduction in surrounding noise. The measured current sensitivity S_i as a function of the received power is shown in Fig. 2. The maximum S_i of ~4.7 A/W was obtained in small received power region. S_i drops with received power, because the nonlinearity of I_d-V_{gs} characteristics degrades with voltage. The estimated sensitivity from I_d-V_{gs} characteristics of fabricated device are also shown in Fig. 2. The theoretical curve is well fitted with the experiments. The sensitivity is independent on C_{MIM}.

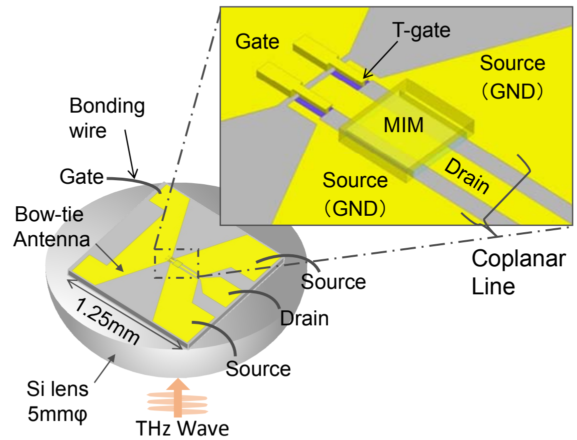

Fig. 1 Schematic device structure of the HEMT THz detector. Two-finger T-shape gates are integrated at the center of bow-tie antenna. The detection current flows to drain by rectification with the nonlinearity in I_d-V_{gs} characteristics of HEMT

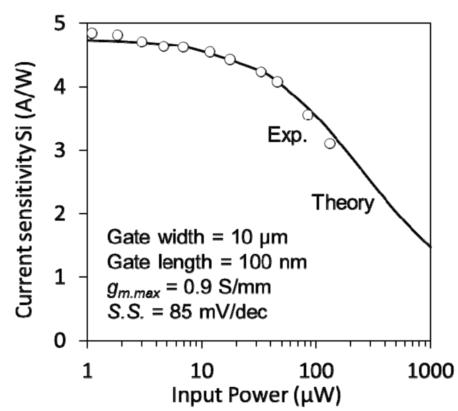

Fig. 2 Current sensitivity as a function of irradiated power. Blue circles are the experiment values. Solid line is the estimated sensitivity from I_d-V_{gs} characteristics of fabricated device.

The measurement setup for the HEMT detector bandwidth is shown in Fig. 3. Heterodyne mixing was carried out using UTC-PD and frequency multiplier as a radio frequency (RF) and local oscillator (LO), respectively. The intermediate signal generated by mixing utilized the nonlinearity in I_d-V_{gs} characteristics of HEMT is amplified using a low noise amplifier (LNA), and observed by spectrum analyzer. The dependence of conversion gain of the HEMT mixer on LO signal intensity was measured and shown in Fig. 4. The output power of UTC-PD and IF signal were fixed at 0.1 μW and 10

GHz in this measurement. The conversion gain was increased with LO signal intensity and saturated at around 40 μW. A good conversion efficiency of –2dB of the RF signal was obtained at LO signal intensity of 40 μW. The experiments were well fitted with the theory.

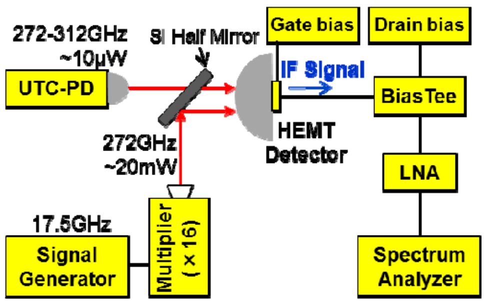

Fig. 3 Measurement setup for HEMT detector bandwidth by heterodyne mixing, using UTC-PD and multiplier.

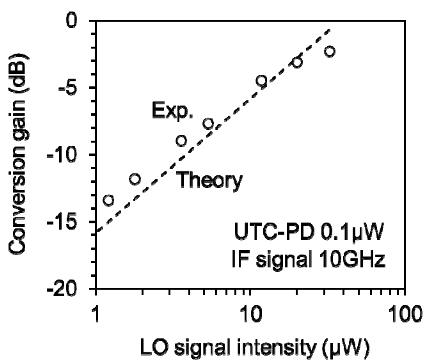

Fig. 4 Dependence of conversion gain of the HEMT mixer on LO signal intensity.

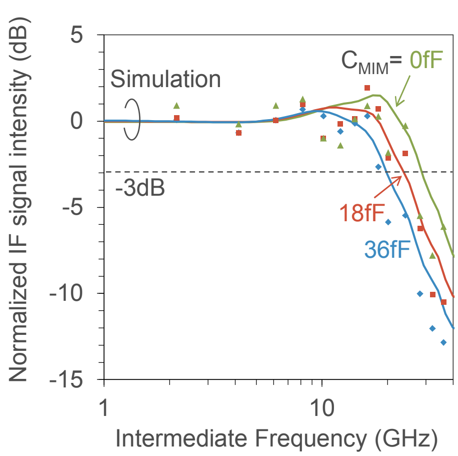

Fig. 5 Intensity of intermediate signal as a function of frequency. Simulation results fit well with the experiments.

The intensity of the intermediate HEMT detector signal was measured with various C_{MIM}, by changing the UTC-PD frequency from 272 GHz to 312 GHz (Fig. 5). The LO frequency was fixed at 272 GHz. A very wide 26 GHz bandwidth was obtained in the HEMT detector with a 0 fF C_{MIM}. Curves from electromagnetic simulation nicely fit with the experimental points. Further, the bandwidth is limited by coplanar line characteristics and inductance of bonding wire in the device package. By optimizing the structure, a bandwidth wider than 100 GHz can be obtained.

III. Conclusion

We measured the bandwidth of a terahertz detector using an InAlAs/InGaAs high-electron–mobility-transistor by heterodyne mixing with UTC-PD and a frequency multiplier as a radio frequency (RF) and local oscillator (LO), respectively. The intensity of the intermediate signal was measured by changing the frequency of UTC-PD, and a very high bandwidth of up to 26 GHz was obtained. THz wireless communication with high data rate is expected using the HEMT detector.

Acknowledgements

The authors thank Emeritus Professors Y. Suematsu and K. Furuya of the Tokyo Institute of Technology for their continuous encouragement. We also thank Professors S. Arai and Y. Miyamoto and Associate Professors M. Watanabe and N. Nishiyama of the Tokyo Institute of Technology for fruitful discussions and encouragement. This work was supported by Scientific Grants-in-Aid from the Ministry of Education, Culture, Sports, Science and Technology, Japan; the Industry–Academia Collaborative R&D Program from the Japan Science and Technology Agency, Japan; and the Strategic Information and Communications R&D Promotion Programme (SCOPE) from the Ministry of Internal Affairs and Communications.

References

[1]. T. Nagatsuma, S. Horiguchi, Y. Minamikata, Y. Yoshimizu, S. Hisatake, S. Kuwano, N. Yoshimoto, J. Terada, and H. Takahashi, "Terahertz wireless communications based on photonics technologies," Opt. Express, vol. 21, no. 20, pp. 23736-23747, Sep. 2013.

[2]. S. Koenig, D. Lopez-Diaz, J. Antes, F. Boes, R. Henneberger, A. Leuther, A. Tessmann, R. Schmogrow, D. Hillerkuss, R. Palmer, T. Zwick, C. Koos, W. Freude, O. Ambacher, J. Leuthold, and I. Kallfass, "Wireless sub-THz communication system with high data rate," *Nat. Photonics*, vol. 7, pp. 977–981, Oct., 2013.

[3]. G. Ducournau, P. Szriftgiser, A. Beck, D. Bacquet, F. Pavanello, E. Peytavit, M. Zaknoune, T. Akalin, and J. Lampin, "Ultrawide-bandwidth single-channel 0.4-THz wireless link combining broadband quasi-optic photomixer and coherent detection," *IEEE Trans. Terahertz Sci. Tech.*, vol. 4, no. 3, pp. 328–337, Mar., 2014.

[4]. W. Knap, V. Kachorovskii, Y. Deng, S. Rumyantsev, J.-Q. Lü, R. Gaska, M. S. Shur, G. Simin, X. Hu, M. Asif Khan, C. A. Saylor and L. C. Brunel, "Nonresonant detection of terahertz radiation in field effect transistors," *J. Appl. Phys.*, vol. 91, no. 11, pp. 9346-9353, Jun. 2002.

[5]. E. Öjefors, A. Lisauskas, D. Glaab, H. G. Roskos, and U. R. Pfeiffer, "Terahertz Imaging Detectors in CMOS Technology," *J. Infrared, Millimeter, and Terahertz Waves*, vol. 30, pp. 1269-1280, Aug. 2009.

[6]. T. Watanabe, S. B. Tombet, Y. Tanimoto, Y. Wang, H. Minamide, H. Ito, D. Fateev, V. Popov, D. Coquillat, W. Knap, Y. Meziani, and T. Otsuji, "Ultrahigh sensitive plasmonic terahertz detector based on an asymmetric dual-grating gate HEMT structure," *Solid-State Electronics,* vol. 78, pp. 109-114, Jun. 2012.

[7]. Y. Miyajima, T. Nukariya, and S. Suzuki, "Terahertz Detector Using 70-nm T-Gate InAlAs/InGaAs HEMT Integrated with Bow-tie Antenna," *Int. Conf. IRMMW-THz*, Arizona, USA, W5-P27.3, 2015.

[8]. L. Tohmé, S. Blin, G. Ducournau, P. Nouvel, D. Coquillat, S. Hisatake, T. Nagatsuma, A. Pénarier, L. Varani, W. Knap and J.-F. Lampin, "Terahertz wireless communication using GaAs transistors as detectors," *Electron. Lett.*, vol. 50, no. 4, pp. 323-325, Feb. 2014.