A High Power Performance 60 GHz Push-Push Oscillator MMIC in Metamorphic HEMT Technology

J.-W. Lee, S.-W. Kim, G.-S. Seol, and K.-S. Seo

1School of Electronics and Information, Kyung Hee University, 446-701, Korea
2School of Electrical Engineering, Seoul National University, 151-742, Korea

Tel: +82-31-201-3730, Fax: +82-31-204-3740, E-mail:jwlee@khu.ac.kr

Abstract — This paper reports a high power 60 GHz push-push oscillator fabricated using 0.12 µm GaAs metamorphic high electron-mobility transistors (MHEMTs). The devices with a 0.12 µm gate-length exhibited good DC and RF characteristics such as a maximum drain current of 700 mA/mm, a peak $g_m$ of 660 mS/mm, an $f_T$ of 170 GHz, and an $f_{MAX}$ of more than 300 GHz. By combining two sub-oscillators having 6 × 50 µm peripheries MHEMT, the push-push oscillator achieved 5.8 dBm of output power at 59.9 GHz with good fundamental suppression. This is the first monolithic push-push oscillator in 60 GHz band fabricated using MHEMT technology, and demonstrates a potential of MHEMT for cost effective millimeter wave commercial applications.

Index Terms — Push-push oscillator, metamorphic, high electron-mobility transistor (HEMT), millimeter-wave circuit.

I. INTRODUCTION

Heterostructures of InAlAs/InGaAs metamorphic high-electron mobility transistors (MHEMT) have attracted widespread attention for their high power and high frequency capability with low cost compared to lattice matched HEMTs on InP substrates. By using the optimized indium content in the channel, the advantages of high breakdown characteristics of GaAs PHEMT and the excellent millimeter-wave performance of InP HEMT can be combined. A good breakdown capability of MHEMT is achievable for frequencies above 60 GHz by using indium content in the range of 30-40%. Recently, MHEMTs on GaAs substrates have been reported with high power-added efficiency and high power at 60 GHz [1].

For signal sources for millimeter-wave short range communication and next generation lightwave systems, various approaches have been reported. Push-push approach has similar technical advantages as the doubler one, while it can be realized in a more compact form. Because the two sub-oscillators in the push-push approach operate at one-half of the output frequency ($f_{out}$), achievable resonator quality factor is higher and effect of parasitic is lower than the fundamental oscillator approach. Also, the push-push oscillator has such advantages as doubled output power from two sub-oscillators and reduced load pulling effect due to virtual ground formation at the output.

Previously reported push-push oscillators were demonstrated using InP HBT, GaAs PHEMT, and SiGe HBT [2-4], and push-push oscillator implemented using MHEMT operating in V-band and above was not fully investigated. In this paper, we have investigated the potential of push-push oscillator implemented using MHEMT technology for high power applications.

II. EPILAYER AND FABRICATION

High performance metamorphic In$_{0.4}$AlAs/In$_{0.35}$GaAs HEMTs having 0.1 µm gate length have been successfully developed using 4-inch in-house double recess MMIC process, where the measured $f_T$ of more than 200 GHz have been reported[5].

Fig. 1. Schematic of metamorphic HEMT epitaxial layer.
Figure 1 shows the epitaxial layer of the metamorphic HEMT used in the push-push oscillator. The epitaxial layer was optimized for W-band power applications by adopting 35% indium content in the channel. Double recess using a dual cap layer is adopted to achieve high breakdown voltage of about 7 V. The 0.12 µm T-gate was defined by electron beam lithography using tri-layer resist process. Exposure to Ar plasma treatment was employed to improve Schottky characteristics of the device which lead to better RF performance.

III. OSCILLATOR DESIGN

The large-signal model for the transistors was constructed based on EHEMT model using in-house modeling tools, and Agilent Advanced Design System (ADS) was used for the design [6]. Passive MMIC components such as coplanar waveguide (CPW) lines, metal-insulator-metal (MIM) capacitors, and thin-film-resistor (TFR) were modeled based on the measured S-parameters up to 50 GHz. The circuit schematic of the designed push-push oscillator is shown in Fig. 2.

As the sub-oscillators operate at the fundamental frequency, $f_0 = 1/2f_{out}$, a large periphery of $6 \times 50 \mu m$ was chosen to achieve high power. Using the small-signal model of the MHEMT, a sub-oscillator was designed to oscillate at $f_0$ with proper design of matching networks. The outputs of two sub-oscillators were combined and the input/output matching networks were designed so that two sub-oscillators operate out of phase with each other. Thus, the fundamental and odd harmonics cancel out, and the even harmonics are added in phase. The second harmonic is used at the output. For efficient power combining at the output, two sub-oscillators were combined at the drain [3]. The oscillation in even mode is suppressed by the same matching networks. The correct phase difference between the two sub-oscillators was examined, and the simulation predicted a second harmonic oscillation at 60 GHz. The output matching network was further optimized to achieve the maximum output power.

IV. MEASUREMENT AND RESULTS

Figure 4 shows the V-band microwave test setup used to measure the oscillator performance. For on-wafer measurement of both output power and oscillation frequency, the output of push-push oscillator was connected to a RF probe, and then to a WR-15 V-band waveguide. The output spectrum and phase noise performance was measured using Agilent E4448A spectrum analyzer. The oscillation frequency was determined by down-converting the signal by Agilent 11970V harmonic mixer via a 10 dB WR-15 coupler. The output power at 60 GHz was measured using HP V8486A power sensor (50~75 GHz) and HP 438A power meter.
Figure 5 shows the measured output spectrum of the push-push oscillator at $V_{DS} = 1.9$ V, $V_{GS} = -0.47$ V. The oscillator output power and frequency tuning characteristics depending on $V_{GS}$ is shown in Fig. 6. The loss of probe tip, waveguide components, and coupler in the V-band measurement setup is about 3.5 dB, and is accounted for correcting the measured output power. Over $V_{GS} = -0.43$ to $-0.48$ V, the output power ranged from 6.8 dBm to 5.8 dBm with the oscillation frequency changed from 58.7 to 59.9 GHz. This corresponds to a tuning range of 2.0 %.

Figure 7 shows the phase noise characteristics of the push-push oscillator measured at $V_{DS} = 1.9$ V, $V_{GS} = -0.48$ V, which resulted in phase noise of $-72.68$ dBC/Hz at 1-MHz offset frequency. The phase noise was measured using the built-in function of the Agilent E4448 spectrum analyzer without output buffer amplifier.

To examine the correct push-push oscillation and fundamental suppression, the fundamental oscillation frequency at $f_0$ was measured using conventional 2.4 mm coaxial cable measurement setup. The fundamental power suppression of more than 35 dBC shown in Fig. 8 indicates the high symmetry of the fabricated oscillator and proper push-push operation.

V. CONCLUSION

This paper reports on a high power 60 GHz push-push oscillator using 0.12 $\mu$m MHEMT fabricated on GaAs substrates. Realized in a compact form, the
oscillator exhibited high power level and good fundamental suppression, demonstrating the potential of MHEMT technology for low cost millimeter-wave commercial applications.

ACKNOWLEDGEMENT

This work was supported by the National Program for Tera-level Nano-devices of the Ministry of Science and Technology as one of the 21-Century Frontier Programs.

The authors would like to thank Prof. Y. Kwon, W.-Y. Choi, and K.-W. Kim for providing V-band measurement.

REFERENCES

[1] M. Zaknoune, M. Ardouin, Y. Corider, S. Bollaert, B. Bonte, and D. Theron, “60-GHz high power performance In_{0.35}Al_{0.65}-In_{0.35}Ga_{0.65}/As metamorphic HEMTs on GaAs,” *IEEE Electron Device Lett.* vol. 24, no. 12, pp. 724-726, Dec., 2003.


