Extended Abstracts of the 2012 International Conference on Solid State Devices and Materials, Kyoto, 2012, pp196-197

Fabrication of AlGaN/GaN HEMTs with Slant Field Plates by Using Deep-UV Lithography

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1. Introduction

AlGaN/GaN-based high electron mobility transistors (HEMTs) are expected to be widely used for high power and high frequency applications owing to their outstanding properties, such as high electron mobility and high breakdown electric field. The use of field plates (FP) in GaN HEMTs enhances breakdown voltage and boosts power performance due to the mitigation of crowded electric field at the gate edge [1-3]. However, the induction of additional gate capacitance due to field plate degrades high frequency performance [4]. A solution to the trade-off between breakdown voltage and frequency response is the slant field plate structure. In 2006, Y. Dora et al. demonstrated that the slant field plate possess superior performance in electric field suppression compared with the conventional field plate [5].

In order to improved GaN HEMTs RF performances, the T-shaped slant gate is introduced. The deep-UV lithography process with PMMA/P(MMA-MAA)/PMMA tri-layer resists is used to form the T-shaped resist cavity. While the sensitivity of P(MMA-MAA) is just a little higher than that of PMMA at deep-UV wavelength, it is difficult to achieve a well T-shaped resist cavity by deep-UV lithography. An angle exposure technique was introduced to improve this process realized on GaN-on-Si HEMTs in this work. With the assistance of angle exposure technique, the T-shaped gate is carefully designed as an integrated slant field plate to further improve the power performance.

2. Experimental

The AlGaN/GaN HEMT structure used in this work is grown on silicon substrate by MOCVD. The epitaxial structure consisted of a 30 nm-thick AlN nucleation layer, a 1 μm-thick GaN buffer layer, and a 20 nm-thick AlGaN interlayer. Fabrication of the GaN HEMTs started with ohmic-contact formation. Ti/Al/Ni/Au metal stacks were evaporated as ohmic metals and subsequently annealed in N_2 ambient at 850℃ for 30 seconds. Mesa etching was performed by ICP-RIE system with Cl_2/Ar gas for device isolation.

A tri-layer resist system (PMMA/ copolymer P(MMA-MAA)/PMMA) was used to fabricate sub-micron slant T-shaped gates by using deep-UV lithography. Fig. 1 shows the proposed tri-layer process for enlarging the top to bottom ratio of the T-shaped gate. A Ti metal layer of 20nm was deposited on top of the tri-layer resists followed by patterned and DHF wet etch. the patterned Ti metal layer played the role of mask for the following tilted deep-UV lithography process. The wafer was tilted to perform an angle exposure. As shown in Fig. 1 (b) (c), two of angle exposures were applied from the opposite sides. For each exposure, only half of exposure-dose was applied. The Ti metal layer was follow-up removed by DHF before development. Then, Ni/Au metal stack was evaporated and lifted off as gate contact for those two kinds of devices. PECVD silicon nitride was deposited as a passivation layer. DC (Agilent E5270), pulse IV (Accent DIVA 225) and S-parameters (HP85112A vector network analyzer), and continuous wave load pull measurements were taken in this work.

3. Results and discussion

Fig. 2 shows the cross-section profile of the T-shaped gate fabricated by angle exposure. It has a small footprint of 0.6 μm, a large upper layer of 2.5 μm and a slant sidewall of 30°. This T-shaped gate is integrated slant field plate and suitable for high-voltage RF operation.

A load-pull system was used to measure the power performance of the field plated GaN HEMTs at 8 GHz. In order to obtain the maximum output power in this device, various drain-source voltages were then applied. Attributed to the slant field plate, the device could be biased to 60 V for load-pull measurement. Fig. 3 shows the output power density was saturated at V_{DS} = 50 V and the self-heating effect started to dominate the output power density at V_{DS} = 60 V. At V_{DS} = 50 V, an output power density of 5.0 W/mm, a linear gain of 10.4 dB and a PAE of 16.7 % were achieved. Fig. 4 shows the smallsignal performance of this device was also measured, a current gain cut-off frequency of 24 GHz and a maximum oscillation frequency of 49 GHz were achieved.

4. Conclusion

In this chapter, the improved deep-UV lithography processes for T-shaped gate fabrication is discussed. By using an angle exposure technique, a well-defined T-shaped gate with slant sidewalls has been successfully fabricated on AlGaN/GaN/Si HEMT. Through surface passivation, the slant field plate formed as the gaps beneath T-shaped gates filled with PECVD silicon nitride. The slant field-plated AlGaN/GaN HEMT exhibited a f_T of 24 GHz and a f_{max} of 49 GHz, and could be biased at 50 V for RF power measurement. An output power of 5.0 W/mm was achieved at 8 GHz. This result demonstrated the power capability of AlGaN/GaN HEMTs on silicon substrate in x-band.

References

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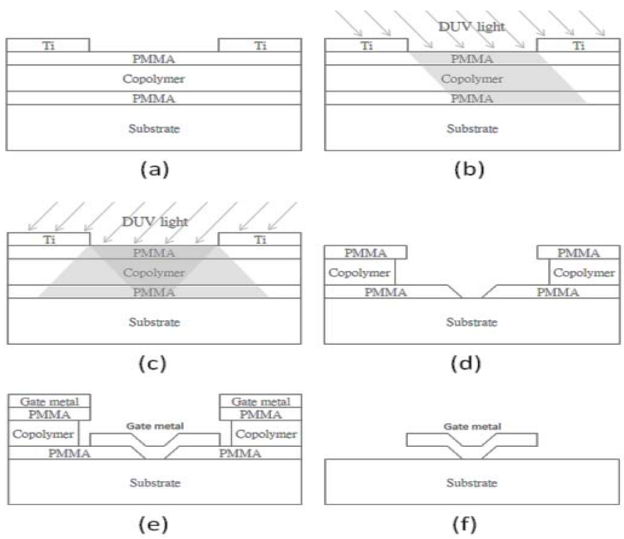

Fig. 1 Fabrication process of the AlGaN/GaN HEMT with slant field-plate structure using deep-UV lithography with angle exposure.

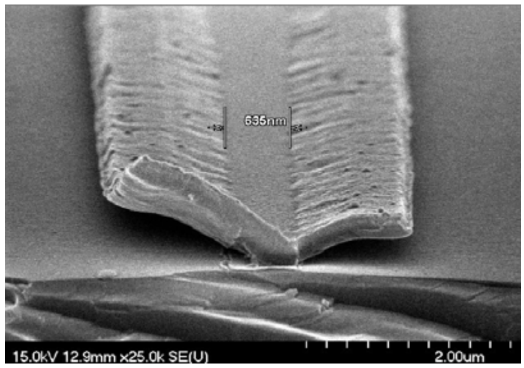

Fig. 2 Cross-section profile of T-shaped gate with slant sidewall.

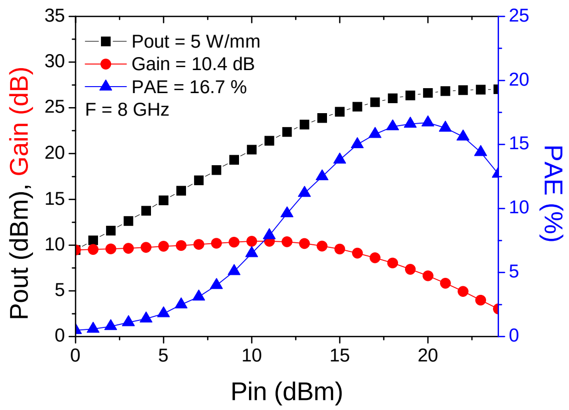

Fig. 3 Power measurement of the AlGaN/GaN HEMT with slant gate at 8 GHz. V_{GS} = -1.5 V, V_{DS} = 50 V.

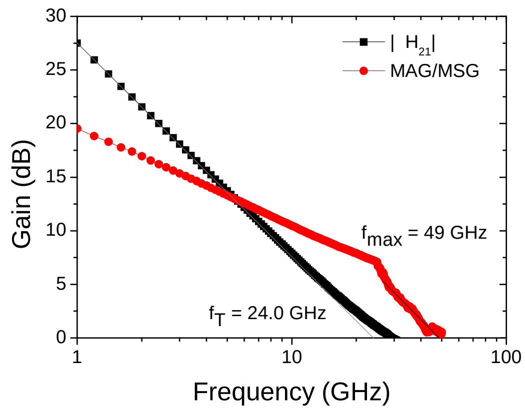

Fig. 4 RF performance at V_{DS} = 10 V and V_{GS} = -1.7 V for AlGaN/GaN HEMT. Extrapolation with -20 dB/dec yields f_T = 24 GHz and f_{max} = 49 GHz.