14W X-Band AlGaN/GaN HEMT Power MMICs

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Abstract: The development of an AlGaN/GaN HEMT power MMIC on SI-SiC designed in microstrip technology is presented. A recessed-gate and a field-plate are used in the device processing to improve the performance of the AlGaN/GaN HEMTs. *S*-parameter measurements show that the frequency performance of the AlGaN/GaN HEMTs depends significantly on the operating voltage. Higher operating voltage is a key to higher power gain for the AlGaN/GaN HEMTs. The developed 2-stage power MMIC delivers an output power of more than 10W with over 12dB power gain across the band of 9～11GHz at a drain bias of 30V. Peak output power inside the band reaches 14.7W with a power gain of 13.7dB and a PAE of 23%. The MMIC chip size is only 2.0mm×1.1mm. This work shows superiority over previously reported X-band AlGaN/GaN HEMT power MMICs in output power per millimeter gate width and output power per unit chip size.

Key words: X-band; AlGaN/GaN; HEMTs; power MMIC
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1 Introduction

AlGaN/GaN high electron mobility transistors (HEMTs) are promising for next generation high power and high frequency applications due to the excellent transport properties of AlGaN/GaN heterostructure grown on SI-SiC substrate. Key features are that AlGaN/GaN HEMTs can deliver high output power density, operate at high voltages, and show high output impedance, which is important for higher output power level, higher power-added efficiency, and wide-band matching, respectively. Power monolithic microwave integrated circuits (MMIC) are an important kind of solid-state microwave power device due to their smaller size, higher uniformity, higher power gain, and higher reliability. AlGaN/GaN HEMT MMICs have received rapidly growing interest in the research community[1～4]. Usually microstrip technology[1,3,4] and coplanar wave guide (CPW) technology[2] are used to design power MMICs. Compared with CPW technology, AlGaN/GaN HEMT MMICs designed in microstrip technology, which is widely used in the design of GaAs power MMICs, have much smaller chip size and simpler RF grounding schemes. In this paper, a microstrip two-stage high-power AlGaN/GaN HEMT MMIC is presented that operates between 9.0 and 11.0GHz with more than a 12dB power gain, and has a 14.7W peak pulsed output power inside the band and a chip size of only 2.2mm^2.

2 Frequency performances of AlGaN/GaN HEMTs

The MMIC process has been reported previously[6,7]. The AlGaN/GaN epitaxial layers are grown on SI-SiC substrate. A recessed-gate and a field-plate are used in AlGaN/GaN HEMTs processing to improve device performance. Via-hole grounding is realized using inductively-coupled plasma (ICP) reactive ion etching. The gate length is 0.35μm and the field-plate is chosen to be 0.5μm to balance the power and frequency performances. The pinch-off voltage of the AlGaN/GaN HEMTs is about −2.0V. The *S*-parameter measurement is used to evaluate the frequency performance of the developed AlGaN/GaN HEMTs with a gate-width of 0.2mm. Figures 1 and 2 show the

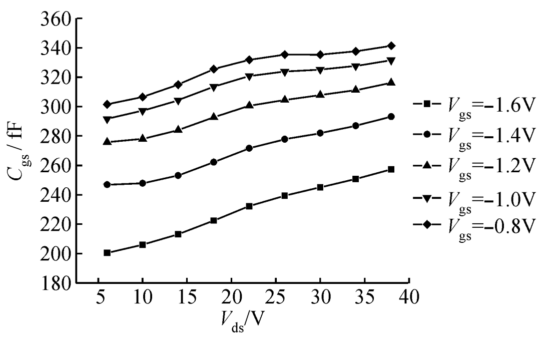

Fig.1 Variation of C_{gs} with drain voltage at different gate biases

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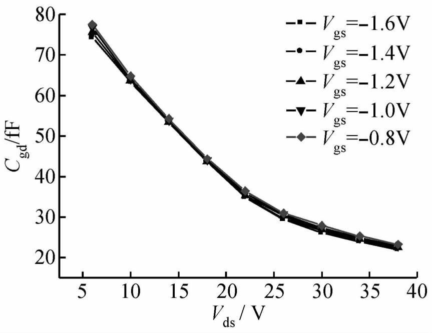

Fig. 2 Variation of C_{gd} with drain voltage at different gate biases

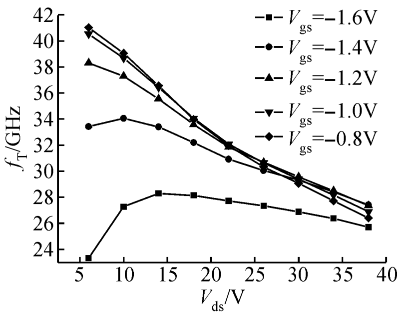

Fig. 3 Variation of f_T with drain voltage at different gate biases

variation of C_{gs} and C_{gd} with drain voltage at different gate biases, respectively. As drain voltage increases, C_{gd} decreases rapidly but C_{gs} increases gradually. The deep extension of the high-field region toward the drain electrode leads to the deep decrease of C_{gd}[8].

The variations of current gain cut-off frequency f_T and maximum oscillation frequency f_{MAX} with drain voltage at different gate biases are given in Figs. 3 and 4, respectively. As drain voltage increases around the normal gate bias of about $-1.2V$, f_T decreases while f_{MAX} increases rapidly.

The analysis of the variation of frequency performance with drain voltage suggests that higher operating voltage is a key to higher power gain for AlGaN/GaN HEMTs.

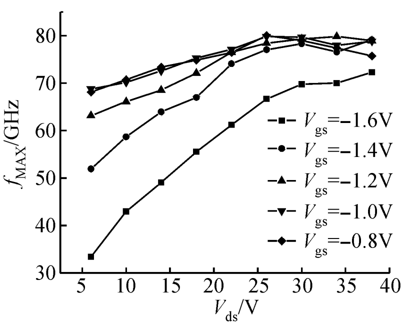

Fig. 4 Variation of f_{MAX} with drain voltage at different gate biases

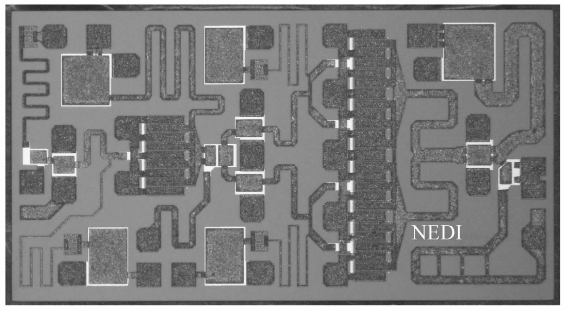

Fig. 5 Photograph of the developed AlGaN/GaN HEMT power MMIC

3 Circuit design of the AlGaN/GaN HEMT power MMIC

The AlGaN/GaN HEMT power MMIC is designed in microstrip technology as a two-stage amplifier based on 4 transistors with $6\times100\mu m$ gate width as the output stage and one transistor with $8\times125\mu m$ gate width as the driving stage. Figure 5 shows the photograph of the developed AlGaN/GaN HEMT power MMIC. The chip size is only $2.0mm\times1.1mm$. The thickness of the chip is 0.8mm. The MMIC design is based on S-parameter measurements and load-pull measurements of the unit cell AlGaN/GaN HEMTs. The output matching circuit is optimized for maximum output power in the frequency range from 8.5 to 11.5GHz. In the gate bias networks, resistors are used to improve decoupling. Resistors in the MMIC are realized using an active layer of the epitaxial structure.

4 Results and discussion

The developed MMIC chip is attached to a copper carrier for RF performance measurements. The CW measured S-parameters of the X-band MMIC at a drain bias of 15V is illustrated in Fig. 6. Power performances of the MMIC are measured in pulsed-mode. The pulse width and the duty cycle are $100\mu s$

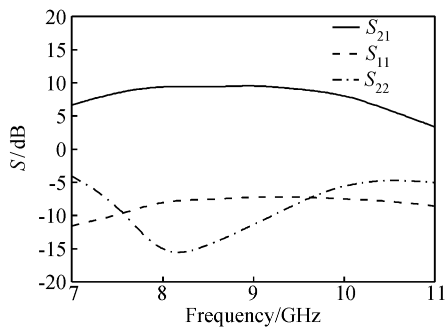

Fig. 6 CW measured S-parameters of the X-band MMIC at a drain bias of 15V

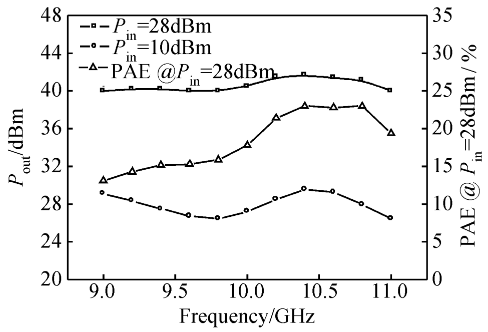

Fig.7 Pulsed output power as a function of frequency at different input power levels and a drain bias of 30V $P_{out}>40$dBm across the band of 9～11GHz

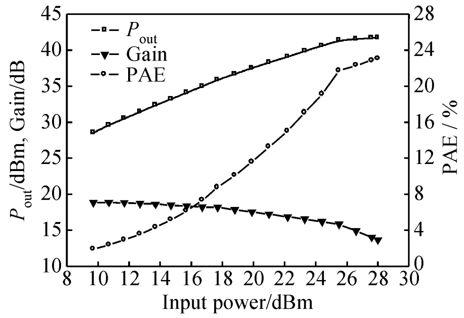

Fig.8 Pulsed output power performances of the X-band MMIC as a function of input power level at 10.4GHz and a drain voltage of 30V $P_{max}=41.7$dBm (14.7W)

and 10%, respectively. Figure 7 presents the pulsed output power as a function of frequency with different input power levels under 30V operating voltage. The X-band MMIC delivers greater than 10W output power across the band of 9～11GHz when the input power level is 28dBm. The MMIC demonstrates a small signal gain of more than 17.2dB at an input power level of 10dBm inside 9～11GHz. Compared with the result from Fig.6, the developed MMIC reveals higher small signal gain in pulsed-mode operation. Pulsed output power performance of the X-band MMIC as a function of input power levels a 10.4GHz is illustrated in Fig.8. The developed MMIC exhibits a maximum output power of 14.7W and a power gain of 13.7dB at an input power level of 28dBm and a drain voltage of 30V.

The output power leads to a power density of 6.1W/mm at the MMIC level and a power density of 7.6W/mm at the transistor level, which is close to the results of discrete AlGaN/GaN HEMTs[6]. In this case, the small signal gain is about 18.5dB, the associated power-added efficiency (PAE) is 23%, and the MMIC is at about 5dB gain compression. Considering the 2.2mm^2 chip size, the output power per unit chip size reaches 6.68 W/mm^2. A comparison of performances of X-band AlGaN/GaN HEMT MMICs is given in Table 1. This work shows superiority in output power per millimeter gate width and output power per unit chip size.

5 Conclusion

An AlGaN/GaN HEMT power MMIC designed in microstrip technology on SI-SiC substrate is presented. The chip size is only 2.0mm×1.1mm. *S*-parameter measurements show that frequency performances of the AlGaN/GaN HEMTs depend significantly on operating voltage. Higher operating voltage is a key to higher power gain for the AlGaN/GaN HEMTs. The developed two-stage MMIC operates across the band of 9～11GHz and delivers a peak pulsed output power of 14.7W with a power gain of 13.7dB and a PAE of 23% at 10.4GHz and 30V operating voltage. Compared with previously reported results of X-band AlGaN/GaN HEMT power MMICs, this work shows superiority in output power per millimeter gate width and output power per unit chip size.

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Table 1 Comparison of performances of X-band AlGaN/GaN HEMT MMICs

Reference	P_{out} /W	Gp /dB	PAE /%	Frequency /GHz	Drain bias/V	Chip size /(mm×mm)	P_{out} density /(W/mm)	P_{out} density /(W/mm^2)	Measurement condition
[4]	25.4	14.8	21	10	30	3×4.5	2.23	1.88	50μs,10%
[1]	20	18	30	9.5	35	3×4	5.0	1.67	100μs,10%
[3]	20	12	25	10	40	4.5×3	4.16	1.48	100μs,10%
[5]	19	11.75	43	10	23.5		4.75		Pulse-mode
This work	14.7	13.7	23	10.4	30	2×1.1	6.12	6.68	100μs,10%

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14W X 波段 AlGaN/GaN HEMT 功率 MMIC

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摘要： 报道了研制的 SiC 衬底 AlGaN/GaN HEMT 微带结构微波功率 MMIC，芯片工艺采用凹槽栅场板结构提高 AlGaN/GaN HEMTs 的微波功率特性. *S* 参数测试结果表明 AlGaN/GaN HEMTs 的频率特性随器件的工作电压变化显著. 研制的该 2 级功率 MMIC 在 9～11GHz 带内 30V 工作，输出功率大于 10W，功率增益大于 12dB，带内峰值输出功率达到 14.7W，功率增益为 13.7dB，功率附加效率为 23%，该芯片尺寸仅为 2.0mm×1.1mm. 与已发表的 X 波段 AlGaN/GaN HEMT 功率 MMIC 研制结果相比，本项工作在单位毫米栅宽输出功率和芯片单位面积输出功率方面具有优势.

关键词： X 波段；AlGaN/GaN；高电子迁移率晶体管；功率 MMIC

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