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An 8GHz Internally Matched AlGaN/GaN HEMT Power Amplifier with RC Stability Network

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Abstract: 8GHz 20W internally matched AlGaN/GaN HEMTs have been developed. The input and output matching networks are realised with microstrip lines on a 0.381mm thick alumina substrate. To improve the stability factor K of the device, a lossy RC network is used at the input of the device. The developed internally matched power amplifier module exhibits 43dBm (20W) power output with a 7.3dB linear gain, 38.1% PAE, and combined power efficiency of 70.6% at 8GHz.

Key words: AlGaN/GaN HEMTs; internally match; power combining; power amplifier
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1 Introduction

With the rapid development of the wireless communication, the demand for a solid-state power amplifier has been continually increasing over the last decade. One major trend is the demand for more power at higher frequencies. The GaN-based family of semiconductors has quickly gained attention because of its excellent power ability. For example, the package size of an amplifier can be reduced due to high power density and the size and weight of the cooling unit can be also reduced, which is a great advantage especially for satellite communication systems, due to stability at high temperature. However, device input and output imedances decrease and the device width increases in proportion to the total gate width, creating a serious problem of uniform and low-loss matching. To solve such matching limitations and exhibit the basic device capabilities, the introduction of an internally matched form is natural[1~3]. Efforts have been made toward developing internal matching networks for high-power GaN HEMTs. Okamoto *et al*. reported a C-band internally matched GaN power amplifier with 60W output power. Cree Inc. reported a C-band 550W GaN power amplifier working under pulse conditions[4~6].

In this paper, we have developed an X-band internally matched power amplifier with a GaN-based recessed-gate HEMT. To avoid the source impedance and load impedance entering the unstable region in the Smith chart, at frequencies less than 4GHz and stable factor $K<1$ we employed an RC lossy network at the input of the device to make the transistor unconditionally stable. We also used isolation resistors to suppress odd-order oscillations. The developed internally matched power amplifier using four GaN HEMTs with 0.25μm gate length and 2mm gate width demonstrated an output power (continuous wave) of 20W at 8GHz with 38.1% power added efficiency (PAE), a 7.3dB linear gain, and combined power efficiency of 70.6%.

2 Device characteristics and circuit design

The AlGaN/GaN heterojunction FET developed in this work is schematically shown in Fig. 1. An undoped AlGaN/GaN heterojunction FET was grown on a SiC substrate. The 50mm epitaxial SiC wafer grown by MOCVD was provided by the Institute of Semicon-

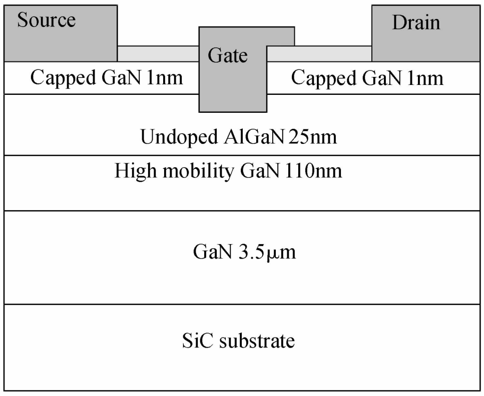

Fig. 1　Schematic of fabricated AlGaN/GaN FP-FET with recessed-gate structure

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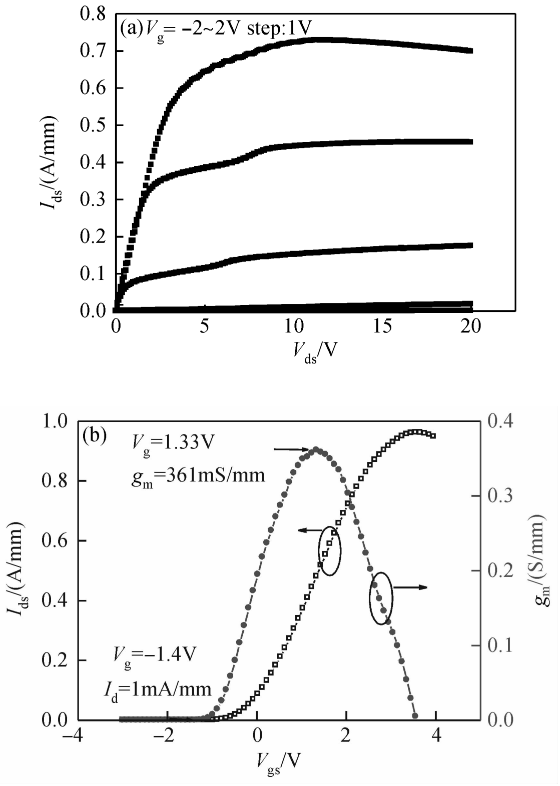

Fig.2 (a) I-V characteristics; (b) DC transfer characteristics of the GaN FET

ductors of the Chinese Academy of Sciences and the GaN HEMTs were fabricated using a field-modulating plate (FP) and a recessed gate structure process[7]. The gate length was chosen to be 0.25μm.

The DC characteristics of the device were measured first. The device has characteristics of I_{max} = 0.75mA/mm, $V_{pinchoff}$ = − 3V, and g_m = 361mS/mm. The current gain and power gain cutoff frequencies were about 28 and 38GHz, respectively. Figure 2 shows the DC performance of the devices.

The circuit topology of the amplifier is schematically shown in Fig. 3. The circuit design was based on small-signal S-parameters and load-pull measurement. To make the amplifier exhibit the maximum power ability, we used a focus load-pull measurement system to obtain the optimum power load impedance. The output matching circuit was designed to match the optimum power load impedance. A tree structure microstrip line was used to combine the power. An input matching network consisting of bond wires, an RC stability network, and tree structure microstrip lines were designed for minimum return loss. We used bond wire inductance as an integral part of the matching network to absorb input series capacitance C_{gs} of the FET, which is necessary to make each wire length equal and avoid any transverse resonances. A two section microstrip transformer on an alumina substrate was used for widening bandwidth with a low impedance transformation ratio. The input and output circuits of the FET are matched to 50Ω, transformed to 100Ω, and combined to give 50Ω.

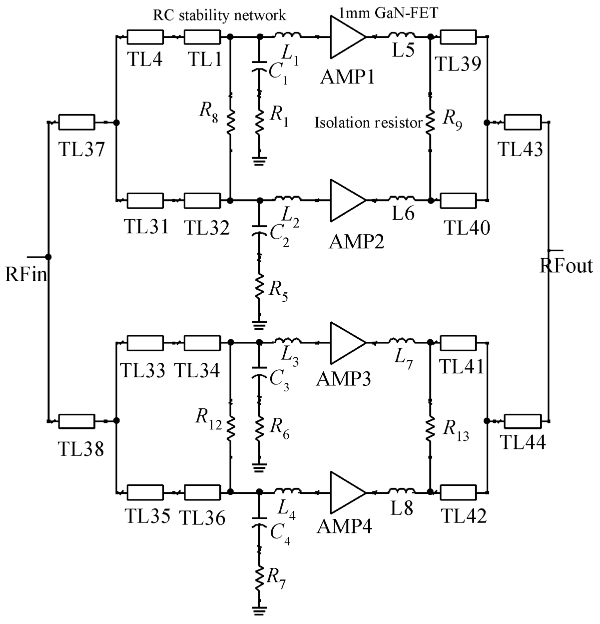

Fig.3 Circuit topology of the amplifier

Because the device we used has a gate width of 2mm and the output power is comparatively high, the stability of the amplifier should be ensured first. So we take two measures to eliminate potential oscillation. First, a lossy RC network was employed to elevate the circuit's K-factor at lower frequencies. This can help to suppress the potential low frequency oscillation. Figure 4 shows the K-factor of the circuits with and without an RC lossy network and indicates that circuits with an RC lossy network are unconditionally stable over the whole frequency band. Also, the RC network can provide the gain compensation, thus achieving gain flatness. Figure 5 shows that the RC network was designed to eliminate gain peaks at low bands and has little effect at high bands. Since the lossy network would harm the gain of the amplifier, the value of the resistor must be carefully optimized to minimum the insertion loss. Figure 5 shows that the insertion loss is about 1dB because of the use of

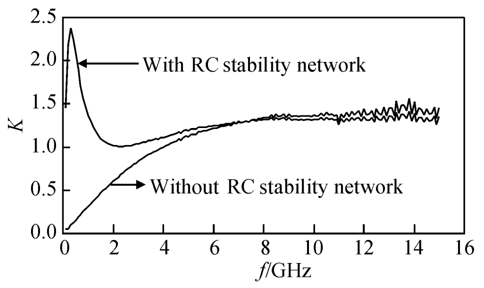

Fig.4 Comparison of K-factor between the circuits with and without an RC stability network

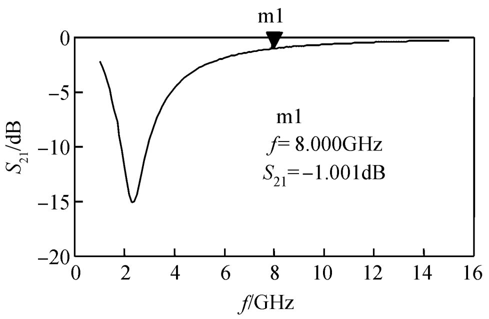

Fig. 5　Frequency response (S_{21}) of the RC stability network

the RC network; a 1dB insertion loss is acceptable to improve the circuit's stable ability. Second, we employed isolation resistors placed on the matching circuits to suppress the odd oscillation that comes from imbalances between devices.

3　Performances

The circuits and chips are housed in a hermetic copper package. Figure 6 shows a photograph of the X-band internally matched amplifier. The package size excluding flange and leads is 12mm × 14mm. The power amplifier is mounted on a specially designed test fixture for gain, return loss, and large-signal power evaluation.

Figure 7 shows the measured and designed small signal parameters for the power amplifier at a drain bias of 30V. A small signal gain of 7dB is measured at a frequency of 8.0GHz. The measured and designed S parameters agree well.

The power characteristics measured under CW operating conditions at 8.0GHz are shown in Fig. 8. By biasing the amplifier at V_{ds} = 30V and I_{ds} = 1340mA, the GaN-FET power amplifier demonstrates an output power at 1dB gain compression (P_{1dB}) of 20W (2.5W/mm) and 38.1% power added efficiency at 8GHz.

We also measured a single 20 × 100μm device. By biasing at V_{ds} = 30V and I_{ds} = 310mA, the transistor is capable of delivering a maximum RF power of 38.5dBm at 8GHz. Thus, we can obtain a combined power efficiency of about 70.6%.

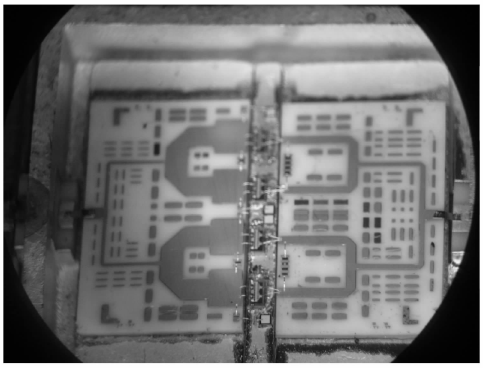

Fig. 6　Photograph of the X-band internally matched amplifier

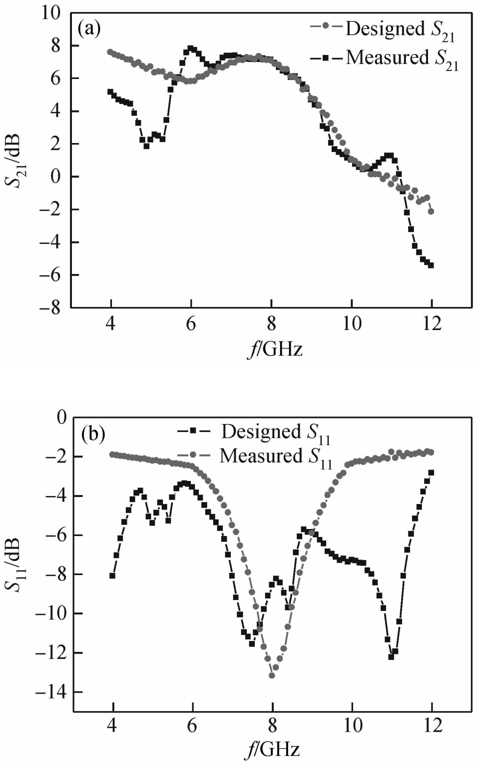

Fig. 7　Small signal performance difference between the design and the measure

4　Conclusion

An internally matched GaN-FET power amplifier operating at 8GHz was developed. Due to the diversity of devices, the potential instability of the designed amplifier may be serious. So a matching network with a lossy RC network was designed to ensure the reliability of the circuits. The power amplifier consists of four parallel 20 × 100μm AlGaN/GaN HEMTs, RC stability networks, and a Wilkinson combiner/divider. The CW P_{1dB} at 8GHz was 43dBm (20W)

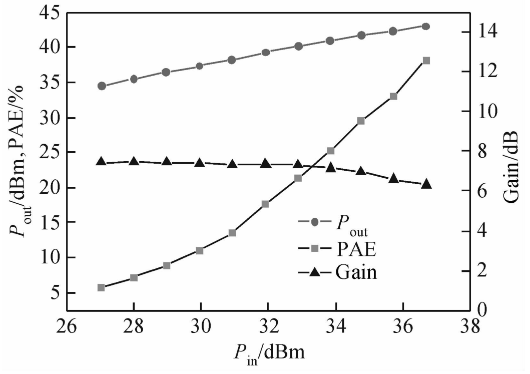

Fig. 8　CW power performance of the amplifier at 8GHz　Bias point: V_{ds} = 30V and I_{ds} = 1340mA

with a maximum PAE of 38.1%, a linear gain of 7.3dB, and a combined power efficiency of 70.6%. The measured and designed S parameters agree well and the power performance of the amplifier also achieves our design goal.

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8GHz带有RC稳定网络的AlGaN/GaN HEMTs内匹配功率合成放大器的设计

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摘要： 设计了工作在8GHz的基于AlGaN/GaN HEMTs的内匹配功率合成放大器.输入和输出匹配电路制作在0.381mm厚的氧化铝陶瓷基片上,为了提高整个电路的稳定因子K,在电路输入端增加了片上RC有损网络.在8GHz测出连续波1dB压缩点时的输出功率为$P_{1dB}=43$dBm(20W),线性增益7.3dB,最大PAE为38.1%,合成效率达到70.6%.

关键词： AlGaN/GaN HEMTs；内匹配；功率合成；微波功率放大器

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