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JOURNAL OF SEMICONDUCTORS

Low Noise Distributed Amplifiers Using a Novel Composite-Channel GaN HEMTs*

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Abstract: Low noise distributed amplifiers (DAs) using the novel low noise composite-channel $Al_{0.3}Ga_{0.7}N/Al_{0.05}Ga_{0.95}N/GaN$ HEMTs (CC-HEMTs) with 1μm-gate-length are designed and fabricated. Simulated and measured results of the DAs are characterized. The measured results show that the low noise DAs have input and output VSWR (voltage standing wave ratio) of less than 2.0, associated gain of more than 7.0dB and gain ripple of less than 1dB in the frequency range from 2 to 10GHz. Noise figure of the DAs is less than 5dB in the frequency range from 2 to 6GHz, and less than 6.5dB in the frequency range from 2 to 10GHz. The measured results agree well with the simulated ones.

Key words: low noise; distributed amplifiers; composite-channel; GaN HEMTs
EEACC: 2520D; 2570A
CLC number: TN4 **Document code**: A **Article ID**: 0253-4177(2008)12-2297-04

1 Introduction

Distributed amplifiers (DAs) offer broadband operation because of the synthetic lumped-element approximate transmission line realized by the active device capacitances and intervening inductances. GaAs and Si-based DAs have been reported in many literatures. However, the low breakdown voltage limits their power density. For decades, GaN-based HEMTs with high breakdown field and high saturation velocity are emerging as the promising candidates for RF/microwave power amplifiers[1~3]. Owing to the great progress made in material growth and fabrication techniques, several groups have reported excellent microwave noise performance of AlGaN/GaN HEMTs[4~6]. GaN-based DAs have been researched by authors in Refs. [7, 8]. Novel structure GaN CC-HEMT shows excellent low noise performance demonstrated in our previous papers[3,4~10]. This paper focuses on low noise DAs using low noise CC-HEMT. Measurement results show noise figure of less than 5dB at frequency from 2 to 6GHz, input and output VSWR of less than 2.0, associated gain of more than 7.0dB and gain ripple of less than 1dB at frequency from 2 to 10GHz.

2 Fabrication and characteristics of device

The sample used in this paper was grown by metal-organic chemical vapor deposition (MOCVD) on (0001) sapphire substrates in an Aixtron AIX 2000 HT system. The details of material growth and device fabrication are described in Ref. [10]. The epitaxial layer structure contains a 2.5μm undoped GaN buffer layer and a 6nm undoped $Al_{0.05}Ga_{0.95}N$ layer. The barrier layer consists of a 3nm undoped spacer, a 21nm doped ($2\times10^{18}cm^{-3}$) carrier supply layer, and a 2nm undoped cap layer. Different from the conventional AlGaN/GaN HEMT, a thin layer (6 nm) of AlGaN with 5% Al composition incorporates between the $Al_{0.3}Ga_{0.7}N$ barrier and the GaN buffer layer.

Fabrication steps of the integrated circuit include mesa isolation, source/drain ohmic contact and gate contact formations, silicon nitride deposition and etching, and air-bridge and electroplating. The fabrication of passive components is incorporated, including low-loss transmission lines and metal-insulator-metal capacitors. In order to reduce loss of transmission lines and improve quality factor of capacitors, polyimide dielectric is inserted between metal and GaN buffer layer. Figure 1 shows the photograph of the DA chip.

The key of the CC-HEMT lies in the channel design. Because of the reduced transverse E-field at the $Al_{0.3}Ga_{0.7}N/Al_{0.05}Ga_{0.95}N$ interface, the scattering at the heterointerface is reduced and low noise CC-HEMT is obtained. Detail description is shown in our previous paper[10]. Figure 2 shows the DC transfer characteristics of CC-HEMT. The maximum drain

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* Project supported by the National Natural Science Foundation of China (No. 60776052)

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Received 16 June 2008, revised manuscript received 14 July 2008

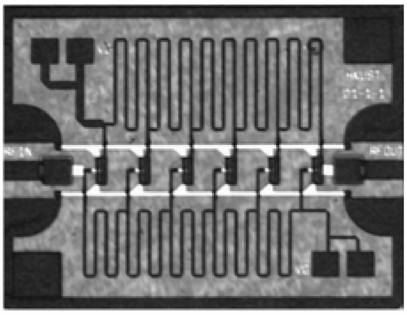

Fig. 1 Photograph of the distributed amplifier with GaN CC-HEMTs

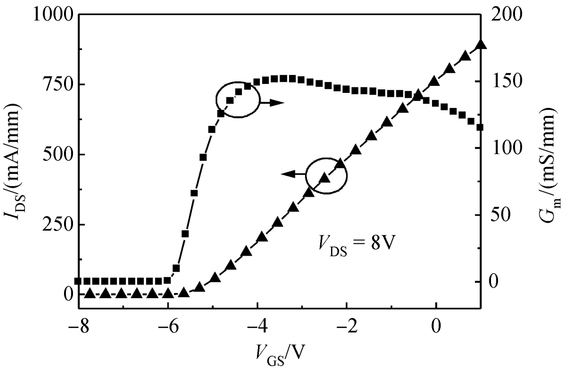

Fig. 2 DC transfer characteristics of CC-HEMT

current density is around 750mA/mm, and DC extrinsic transconductance (G_m) is about 150mS/mm at DC bias $V_{DS} = 8V$. A current gain cut-off frequency f_T and a maximum oscillation frequency f_{max} are 12 and 30GHz respectively at DC bias $V_{DS} = 8V$ and $V_{GS} = -4V$. The CC-HEMT shows excellent low noise performance, as shown in Fig. 3. Minimum noise figure is less than 3.2dB at frequency below 10GHz and maximum gain is 10dB at a frequency of 2GHz.

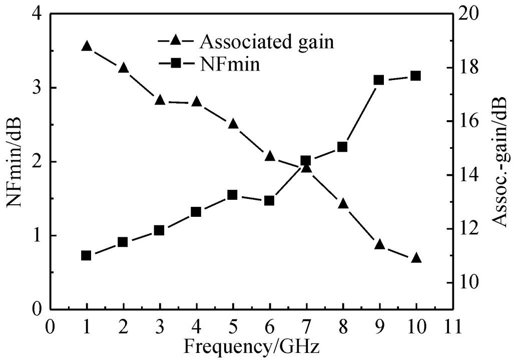

Fig. 3 Minimum-noise figure (NFmin) and associated gain (Ga) of CC-HEMT with 1μm-gate-length at $V_{DS} = 6V$ and $I_{DS} = 12\% I_{dss}$

3 Circuit design

Distributed amplification is a way of adding device transconductances without adding device parasitic capacitances. In this amplification technique, the input and output capacitances of the HEMTs are linked through inductors to form artificial transmission lines. The two artificial lines, i. e., the gate-line and the drain-line, are designed to match the load and source impedances in such a way. By optimizing the gate-line impedance, the frequency band of the amplifier can be maximized. The distributed amplifier (DA) is designed using Agilent advanced design system (ADS) software. The active devices of the DA come from six GaN CC-HEMTs with the same size, whose symbols are T1, T2, T3, T4, T5 and T6, as shown in Fig. 4. The GaN CC-HEMTs have the gate length of 1μm, the gate width of 100μm, and the gap between gate and source of 1μm and the gap between

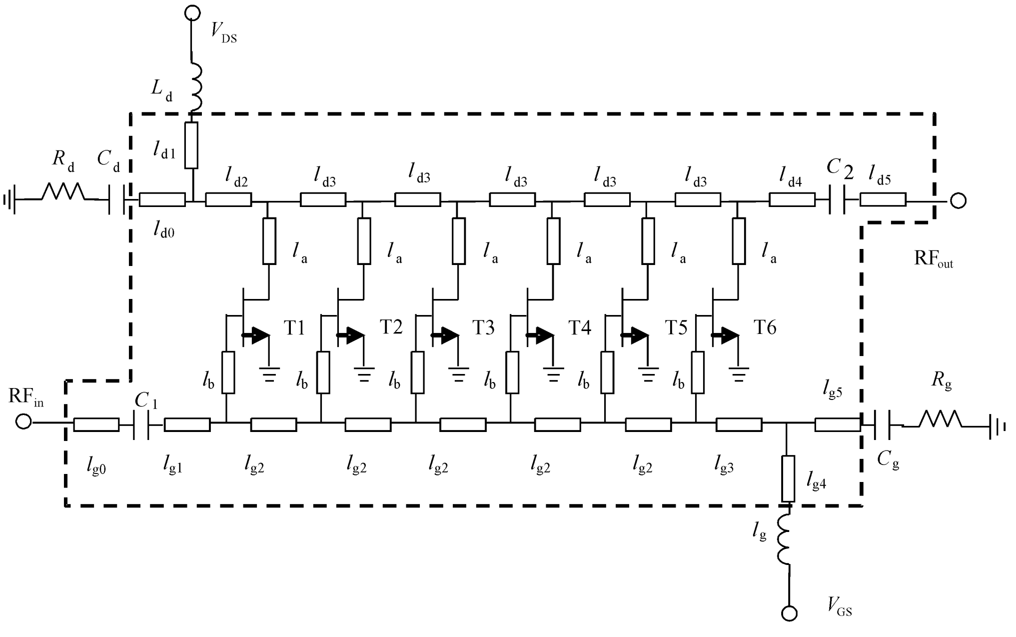

Fig. 4 Schematic of the distributed amplifier with GaN CC-HEMTs

Table 1　Design parameters values of the distributed amplifier

Parameter		l_{g0} /μm	l_{g1} /μm	l_{g2} /μm	l_{g3} /μm	l_{g4} /μm	l_{g5} /μm	l_a /μm	C_1 /pF	C_2 /pF	C_g /pF	C_d /pF
Value	Width	75	40	10	10	10	10	10	3	3	20	20
	Length	150	40	1150	200	50	100	100				
Parameter		l_{d0} /μm	l_{d1} /μm	l_{d2} /μm	l_{d3} /μm	l_{d4} /μm	l_{d5} /μm	l_b /μm	R_g /Ω	R_d /Ω	L_g /nH	L_d /nH
Value	Width	30	30	30	10	40	75	10	90	50	30	30
	Length	170	70	190	1550	40	150	180				

gate and drain of 1μm. The values of the small signal S-parameters and noise parameters of the active device (GaN CC-HEMT) in this design are from measured results. The passive components include gate-lines, drain-lines, capacitors, inductors and resistors. The components within dot line frame are on chip, others are off chip in Fig. 4. Transmission lines (l_{g1}, l_{g2}, l_{g3}, l_{g4}, l_{g5}, l_{d0}, l_{d1}, l_{d2}, l_{d3}, l_{d4}) are used to replace the inductors of the DA. The characteristic impedance of a transmission line is given as,

$$Z_C(\omega) = Z_0\sqrt{1-\left(\frac{\omega}{\omega_c}\right)^2}$$

where $Z_0 = \sqrt{\frac{L}{C}}$, $\omega_c = \frac{2}{\sqrt{LC}}$.

The characteristic impedances of above transmission lines are frequency dependent and drop to 0 at cut-off. But, large bandwidths are still obtainable. For a given HEMT, its input and output capacitances are known. Then, the problem is to find an optimum (Z_0, ω_c) pair that maximizes the bandwidth of the transmission lines. Note that, this optimum (Z_0, ω_c) pair depends on the reference impedance level (e. g., 50Ω), and the bandwidth definition. The gate-line design is done first. Then, the drain-line must be designed to match the load, and the phase shifts of the gate and drain lines must be equalized. The gate and drain-lines must be terminated with resistive loads R_g and R_d in order to have the unwanted signals dissipating on these resistive loads. The resistive losses are the causes of the attenuation in transmission lines. Hence, in gain determination the losses of the transmission lines can not be neglected. No matter how small the attenuation per section is, the total attenuation of a distributed amplifier increases geometrically with increasing number of sections. On the other hand, the gain of a distributed amplifier increases arithmetically. Minimum noise figure of the DA is designed according to trade-off among noise figure, VSWR and gain. In schematic of Fig. 4, l_{g0} and l_{d5} are coplanar waveguide lines with impedance of 50Ω as measurement pads. C_1 and C_2 are MIM (metal-insulator-metal) decouple capacitors of input and output terminals. External components of the chip are SMD (surface mounted device) resistors R_g and R_d as terminal loads that absorbs reverse electromagnetic wave, SMD inductors L_g and L_d as AC choke, SMD capacitors C_g and C_d as AC access for R_g and R_d. RF_{in} and RF_{out} are signal input port and output port. DC voltage of gate bias and drain bias are V_{GS} of −4V and V_{DS} of 6V. Design parameters values of all components are given in Table 1.

4　Circuit performance

Fabricated DA chips are adhered on PCB by silver paste. The passive components (inductors, capacitors and resistors) off chip are soldered on PCB too. DC pads of the chip are connected to PCB by gold wire bonding. DA circuits are measured on wafer and Cascade Microprobe station is used. Input and output pads of chip are directly connected by RF microprobes, and DC bias are connected to supply power by PCB. Agilent PNA E8363B is used to measure the small signal S-parameters and Agilent 8975A noise figure analyzer is used to measure noise figure. Figure 5 shows VSWR1 (for input port) and VSWR2 (for output port) of the DAs. They are less than 2.0 at frequency from 2 to 10GHz. Measured results are close to simulated results. Measured associated gain of 7.0dB is less than simulated results of 8.0dB and their gain ripple is less than 1dB at frequency from 2 to 10GHz, as shown in Fig. 6. Noise figures are less than 5 and measured values are little more than simulated results at frequency from 2 to 6GHz as shown in Fig. 7.

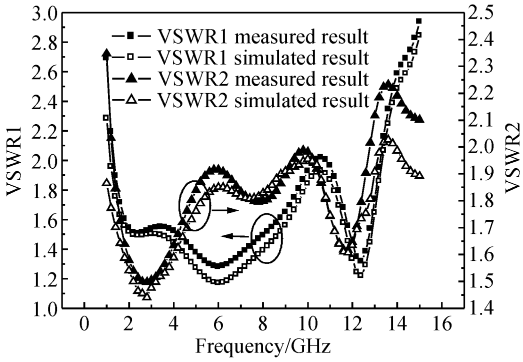

Fig. 5　Measured and simulated input and output VSWR at V_{DS} = 6V, V_{GS} = −4V

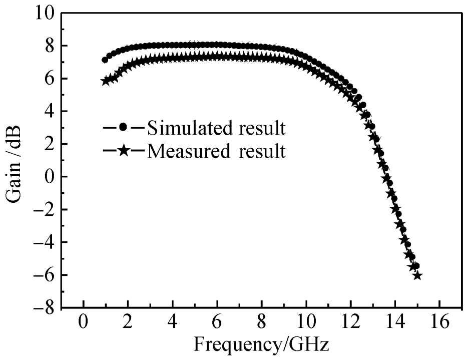

Fig.6 Measured and simulated associated gain at $V_{DS}=6V$, $V_{GS}=-4V$

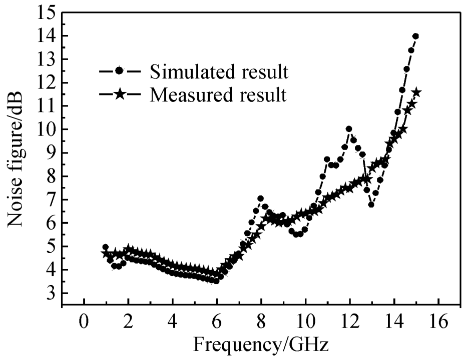

Fig.7 Measured and simulated noise figure at $V_{DS}=6V$, $V_{GS}=-4V$

5 Conclusions

A broadband low noise distributed amplifier has been implemented using GaN-based CC-HEMTs. The DA with 1 × 100μm GaN CC-HEMTs shows broadband and low noise figure. These results show the promising potential of the GaN-based CC-HEMTs for the next-generation wireless communication system.

Acknowledgement The authors would like to acknowledge Prof. Kai Mei Lau who works in Department of Electronic and Computer Engineering, Hong Kong University of Science and Technology for providing GaN CC-HEMT materials.

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一种采用新型复合沟道 GaN HEMTs 低噪声分布式放大器*

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摘要： 设计研制了一种新型的低噪声分布式放大器，采用了栅长为1μm的低噪声复合沟道 $Al_{0.3}Ga_{0.7}N/Al_{0.05}Ga_{0.95}N/GaN$ HEMT（CC-HEMT）．给出了低噪声分布式放大器的仿真和测试结果．测试结果显示低噪声分布式放大器在2～10GHz频率范围内，输入和输出端口驻波比均小于2.0，相关增益大于7.0dB，带内增益波纹小于1dB．在2～6GHz频率范围内，噪声系数小于5dB；在2～10GHz频率范围内，噪声系数小于6.5dB；测试结果与仿真结果较吻合．

关键词： 低噪声；分布式放大器；复合沟道；GaN HEMTs
EEACC： 2520D；2570A
中图分类号： TN4 **文献标识码：** A **文章编号：** 0253-4177(2008)12-2297-04

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* 国家自然科学基金资助项目（批准号：60776052）

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2008-06-16 收到，2008-07-14 定稿