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Cascode Connected AlGaN/GaN Microwave HEMTs on Sapphire Substrates*

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Abstract: Fabrication and characteristics of cascade connected AlGaN/GaN HEMTs grown on sapphire substrates are reported. The circuit employs a common source device, which has a gate length of 0.8μm cascode connected to a 1μm common gate device. The second gate bias will not only remarkably affect saturated current and transconductance, but also realize power gain control. Cascode device exhibits a slight lower of f_T, a less feedback, a largely greater of maximum available gain and a higher impedance compare to that of common source device.

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1 Introduction

RF system, now in development, requires amplifiers operating over a decade GHz bandwidth while providing tens to hundreds of watts with high power added efficiency. AlGaN/GaN high electron-mobility transistor (HEMT) technology has established itself as a strong contender for such applications because of its large electron velocity (3×10^7cm/s), wide bandgap (3.4eV), high breakdown voltage (50V for GHz), and sheet carrier concentration. The state-of-the-art AlGaN/GaN HEMT has increased power densities to 6~9W/mm both grown on sapphire and SiC substrates[1~3]. Most reported devices are single-gate common source (CS) HFET demonstrating excellent microwave performance with lower noise and higher cutoff frequency. Cascode device, compared with traditional CS device, has advantage of high output impedances, high power gain, much reduced feedback parasitic, and will find its wide applications in microwave circuits such as broadband power amplifier[4], phase shifter[5], and pre-distorters[6]. Thus GaN based cascode device has potential applications for extreme high power, high temperature, broadband block and system. Previously, GaN-based cascode HEMTs and flip-chip bonded broadband amplifier have been reported[7,8]. In this paper, a cascode HEMT with gate length 0.8μm, total gate width 320μm is designed and fabricated, its DC and microwave performance are analyzed and compared with singal-gate common source device. Its good characteristics will be very useful and helpful in design of our high power broadband amplifier.

2 Cascode connected HEMT design and fabrication

The design of 4 fingers cascode connected

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HEMT with unit finger width 80μm is schematically shown in Fig. 1 of which the CS stage employs a short gate(L_g= 0.8μm) common source device optimized for frequency performance, the CG stage compactly cascode connected to CS stage with a longer gate length(L_g= 1.0μm) optimized for high breakdown voltage. The source-drain spacing of CS and CG devices are 4 and 4.2μm, respectively. MIM capacitors between the gate of CG device and ground is employed to provide good AC grounding. Unlike some conventional cascode FETs, the CS and CG devices are separated by a 4μm wide strip of ohmic contact metallization. This metallization could provide a low-resistance cascode connection of the devices meanwhile allow the devices to operate as two cascade-connected transistors with no interaction between the depletion region of the devices.

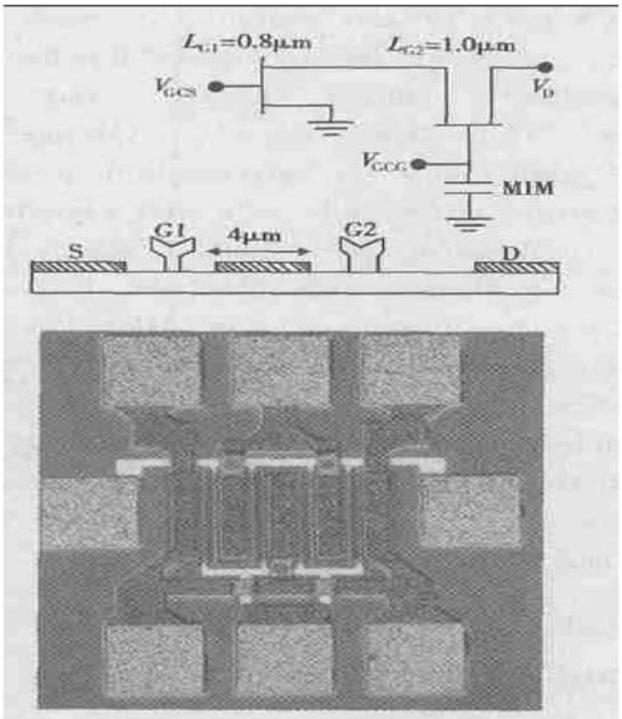

Fig. 1 Schematic diagram, device cross section, and die photo of fabricated 320μm cascode connected HEMT

The epitaxial material was grown by metal organic chemical vapor deposition (MOCVD) on sapphire substrate. The structure consisted of 3.5μm GaN buffer layer, 110nm high transconductance GaN layer, 23nm undoped AlGaN layer. The sheet electron concentration and electron Hall mobility at room temperature were $1.3\times10^{13}/cm^2$ and $1120cm^2/(V\cdot s)$, respectively.

Devices fabrication started with mesa etching for good device isolation, Ti/Al/Ti/Au ohmic contacts were then evaporated and annealed at 730℃ for 50s. Metal gate and top plate of MIM grounding capacitor were formed by Pt/Ti /Au triple-layer, after that the wafer was passivated with 200nm Si_3N_4. A new type airbridges fabricated by electric plating was used to interconnection of source and drain area in order to diminish parasitic capacitor. The interconnection metal was finally thickened to 2.5μm to minimize parasitic transmission resistance and inductor.

3 DC characteristics

I-V characteristics of the 0.8μm×320μm cascode AlGaN/GaN HEMT are shown in Fig. 2. The gate voltage of CG stage V_{g2} was biased at + 2.0V and - 0.5V, while the gate voltage of CS stage V_{g1} ranged from - 5 to 1V, the maximum V_{ds} voltage

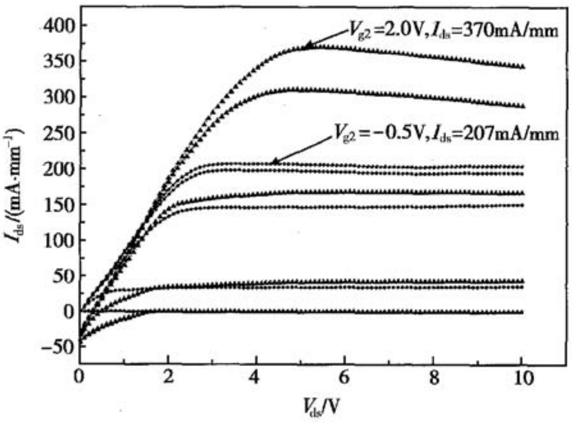

Fig. 2 *I-V* characteristics of cascode HEMT with variable V_{g2}

was 10V. When the second gate was biased at 2.0V, about 370mA/mm saturated current density was obtained. The relative low saturated current may result in connecting metal resistance between CS and CG devices which were largely increased after rapid annealing, so can not provides low resistance connection. With the second gate went down to a lower voltage(− 0.5V), drain current was remarkably suppressed to 207mA/mm.

In Fig. 3, the dependence of the transconductance g_m on V_{g1} and V_{g2} of CG device with drain biased at 10V is illustrated and also compared with a single-gate AlGaN/GaN device, every envelop of g_m curve corresponds to g_m versus V_{g1} under a fixed V_{g2} voltage. g_m of cascode connected device increases as the bias of the second gate becomes more positive, and achieves its peak value 138.33mS/mm at V_{g2}= 2.0V, while traditional single-gate device can achieves a g_m value 149.5mS/mm. The relative lower g_m value of cascode connected device can be explained and approximated as[9]

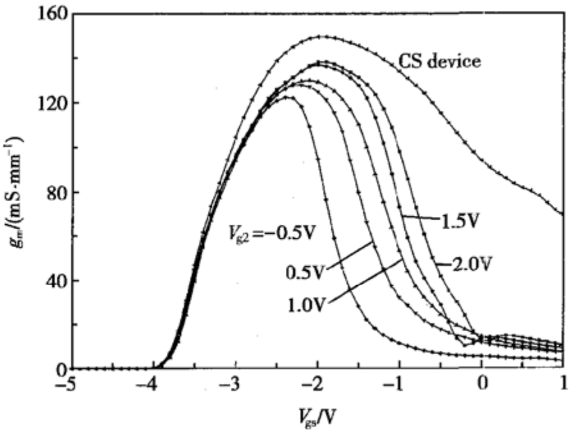

Fig. 3 Dependence of DC transconductance on V_{g1} and V_{g2} with V_{ds}= 10V

$$g_{m\text{-cascode}} = g_{m1}\left(1 - \frac{1}{1 + g_{m2}R_{ds2} + R_{ds1}/R_{ds2}}\right) \quad (1)$$

where g_{m1}, g_{m2}, R_{ds1}, R_{ds2} are the transconductance and output resistance of CS and CG devices.

4 Microwave performance

Frequency performance within 15GHz was measured with HP 8510C network analyzer and Agilent ICCAP with device biased at V_{ds}= 10V, V_{g2} = 2.0V, V_{g1} = − 2.0V where attained peak transconductance, both CS and CG devices were kept in saturation region. A single-gate AlGaN/GaN HEMT was fabricated on the same wafer and measured for comparison.

Two port S-parameter of cascode and CS device has been plotted in Fig. 4. The cascode device achieves largely reduced signal feedback——S_{12} is about 10dB lower than that of CS device, such result can be explained theoretically as insertion of CG stage provides well shielding effect between input and output port by diminishing of Miller effect[10]. Slightly decrease of S_{22} on cascode device hints that cascode device can maintain high output impedance, even though the cascade device has wider gate width than CS device. But the most attractive merit is that more than 10dB extra forward gain (S_{21}) can be obtained from cascode configuration device in a wide frequency range.

Forward current gain H_{21} of the two kinds of device was plotted in Fig. 5. A decrease was seen in f_T from 13.4GHz to 9GHz for the cascode configuration compared to the common source device. This decrease in f_T can be understood by noting the additional pole in the simplified expression for the current gain of the cascode configuration given by[11]

$$H_{21,\text{cascode}}(f) \approx \frac{1}{\left(1 - \frac{f}{jf_{T,CG}}\right) \times \frac{1}{jf_{T,CS}}} \quad (2)$$

where $f_{T,CG}$ and $f_{T,CS}$ refer to the cutoff frequencies of the common gate and common source device, respectively.

Cascode connected device has the advantage of higher power gain. Its maximum stable gain MSG of the cascode configuration is higher than that of the single-gate FET and can be analytically stated as:

$$\text{MSG}^{\text{cascode}} = \text{MSG}^{\text{CS}} \times \text{MSG}^{\text{CG}} \approx \frac{g_{m1}}{\omega C_{gd1}} \times \frac{g_{m2}}{g_{d2}} \quad (3)$$

where g_{d2} is straightforward drain transconductance of CG device and the factor g_{m2}/g_{d2} can be in excess of 10. The maximum gain available of cascode HEMT is also can given by

$$\text{MAG}^{\text{cascode}} = \text{MSG}^{\text{cascode}}\left[k - (k^2 - 1)^{1/2}\right] \quad (4)$$

MAG is close related to MSG: the higher the MSG

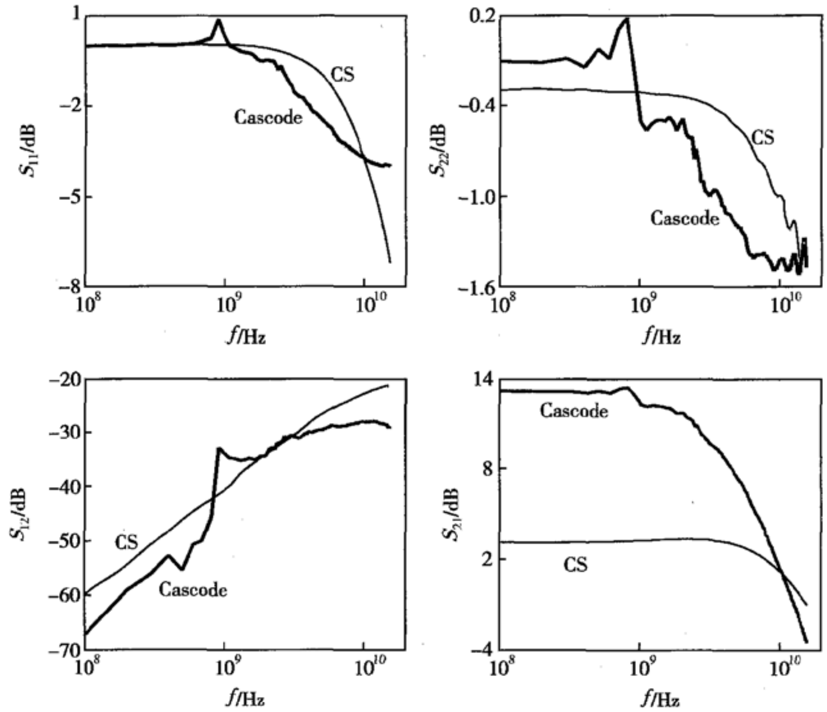

Fig. 4 S-parameter of cascode AlGaN/GaN HEMT

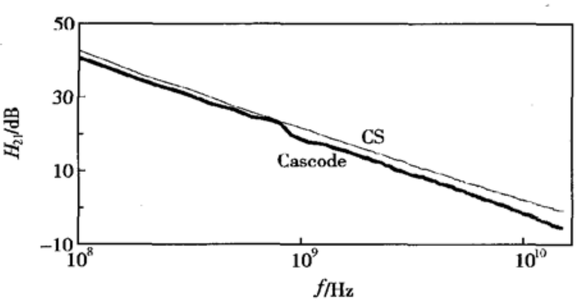

Fig. 5 Comparisons of H_{21} for cascode device and common source device

is, the higher the MAG is. The equation also means stability factor k may play an important role in power gain whereas k factor of cascode device can be approximately calculated by

$$k^{\text{cascode}} = k^{\text{single}} + 2 \times \frac{f}{f_{T2}} \quad (5)$$

where $f_{T2} = g_{m2}/2\pi C_{gs2}$, and stable factor k is largely affected by reverse gain. We have mentioned above that cascode device has relative smaller reverse gain, so k increased faster than that of common source device, and it can be much higher than unit in a relative low frequency.

So because of the effect of high k and high g_{m2}/g_{d2} ratio, it is very possible to obtain a high MAG in a wide frequency range as shown in Fig. 6. The cascode connected device exhibits more than 10dB power gain below 1GHz and 5dB below 10GHz than single-gate device. That makes cascode device look more attractive for use at such frequency below 10GHz, while single-gate device is apparently superior in and above X-band.

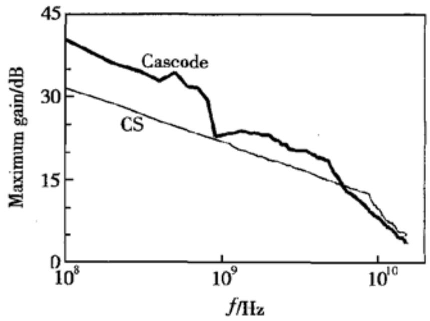

Fig. 6 Maximum available gain of CS and cascode device

Power gain control can also be realized by changing gate voltage of second device, for cascode configuration, V_{g2} varied from 2V to − 0.5V only lead to an output reflection moves from 0.803∠−18.23 to 0.88∠−23.57 at 4GHz, while the power gain changes from 19.6dB to 5.87dB. If we try to control the power gain by varying the gate bias of CS device, the phase angle of S_{22} and S_{11} will rotate too much to maintain matching. Therefore, cascode configuration device is particularly suitable for building a broadband amplifier with gain control.

5 Conclusion

AlGaN/GaN cascode connected device has been fabricated and studied. DC measurement shows, changing of the second CG device gate voltage will remarkably affect saturation current and transconductance. Compared to traditional single-gate device, cascode configuration display somewhat decrease of current cutoff frequency f_T, but high output impedance, small feedback between input and output and more than 10dB extra forward power gain in a wideband can be obtained, little impedance rotation in wide band and easy power gain control can also be realized. Such feature of merits will facilitate matching network design and made AlGaN/GaN cascode device itself a good candidate for high power, broadband, gain control block operate below 10GHz.

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蓝宝石衬底 AlGaN/GaN 共栅共源微波 HEMTs 器件*

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摘要: 报道了蓝宝石衬底 AlGaN/GaN 共栅共源器件的制备与特性. 该器件包括栅长为 0.8μm 共源器件与栅长为 1μm 的共栅器件. 实验表明, 共栅器件的第二栅压会显著影响器件饱和电流与跨导特性, 从而控制功率增益. 与共源器件相比, 共栅共源器件表现出稍低的 f_T、较低的反馈、显著增加的功率资用增益及较高的端口阻抗.

关键词: 共栅共源; 宽带; AlGaN/GaN; HEMTs; 蓝宝石

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