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Low Noise Characteristics of 0.2 μm $Al_{0.24}Ga_{0.76}As/In_{0.15}Ga_{0.85}As/GaAs$ Pseudomorphic HEMTs with Wide Head T-Shaped Multifinger Gate

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The fully passivated 0.2 μm pseudomorphic HEMTs(PHEMT) were fabricated by combining the wide head T-shaped gate formed using dose split method of electron beam lithography(DSM) and the multifinger structure with drain-airbridges for the interconnection of the drain pads . The device exhibited a minimum noise figure as low as 0.38 dB with an associated gain of 10.5 dB at 12 GHz. This result corresponds to the drastic reduction of gate resistance due to a combination of the multifinger gate structure and the wide head T-shaped gate.

1. INTRODUCTION

At present, the low noise high electron mobility transistors(HEMTs) are widely used in the front end of satellite communications, radio astronomy, and satellite direct broadcasting receiver systems. To achieve the low noise performance of HEMTs, it has been found that reducing the gate length and parasitic resistance simultaneously is effective [1-2]. However, a simple reduction of gate length to reduce the gate-to-source capacitance and improve transconductance unfortunately results in a much increased gate resistance. To this purpose, T-shaped gates composed of a wide head length and short footprint length to reduce the gate resistance and capacitance, are required for subquarter micrometer gate HEMTs. Also the airbridged structure with more gate fingers are applied for reducing the gate resistance. In this gate fabrication process, it is thought that a combination of T-shaped gates and multifinger structure is very adequate for reducing gate resistance. Until now, few papers have been reported for the multifinger gate structure with a wide head T-shaped gate fabricated by adopting dose split method of electron beam lithography(DSM).

In this study, for the first time the low noise AlGaAs/InGaAs/GaAs pseudomorphic HEMT with 0.2 μm T-shaped multifinger gate has been successfully fabricated by combining the wide head T-shaped gate defined with the DSM and the drain-airbridges for the interconnection of the drain pads. The device exhibited a minimum noise figure as low as 0.38 dB with an associated gain of 10.5 dB at 12 GHz. This noise performance improvement is attributed to the drastic reduction of gate resistance by adopting multifinger structure with a wide head T-shaped gate fabricated with the DSM.

2. HEMT STRUCTURE AND FABRICATION

The layer sequence for the pseudomorphic HEMT devices have been grown by using molecular beam epitaxy (MBE). An 80 nm thick undoped GaAs buffer are grown on 3-inch diameter semi-insulating GaAs substrates, followed by a 600 nm thick undoped GaAs layer. The channel layer consists of 12 nm $In_{0.15}Ga_{0.85}As$. The planar doping layer with a doping density of 5×10^{12} cm^{-2} of Si is separated from the active layer by thin undoped $Al_{0.24}Ga_{0.76}As$ spacer and 30 nm thick undoped $Al_{0.24}Ga_{0.76}As$ Schottky layer. The 50 nm thick GaAs cap layer was highly doped with Si (5×10^{18} cm^{-3}). The sheet carrier density of two-dimensional electron gas and the electron mobility measured from Hall measurements at room temperature are 2.2×10^{12} cm^{-2} and 5,900 $cm^2/V \cdot s$, respectively. Fig.1(a) shows that a multifinger gate layout is used in which four single gates of 0.2 μm gate length and a unit gate width of 50 μm are connected in parallel. The drain pads are connected with an airbriges. The sequence for device fabrication is as follows. After mesa isolation by wet chemical etching in $H_3PO_4 : H_2O_2 : H_2O = 4 : 1 : 90$, ohmic contacts were formed by evaporating Ni/Ge/Au/Ti/Au metallic layers, and then alloyed using a rapid thermal annealing. T- gate process using a dose split method of electron beam lithography (DSM) [3] with two-layer resists systems was newly developed to form wide head T-shaped gate having large cross-sectional gate head on the fine gate footprint. In T-gate process, we have used a P(MMA-MAA) for the top layer and a PMMA for the bottom layer. After coating 0.3 μm thick PMMA and prebaking, 0.6 μm thick P(MAA-MAA) was coated and prebaked. These patterns were exposed by Leica EBML 300 system with 30 kV acceleration voltage. The top and bottom resists were developed by the 1:3 solution of MIBK and IPA. The overhang of the top resist was suitable for the following lift-off process. After selective wet gate recess etching, Ti/Pt/Au layers were deposited and lifted-off. As shown in Fig. 1(b), a wide head T-shaped gate formed by

DSM exhibited large cross-sectional area having the aspect ratio of gate head length (1.25 μm) to gate footprint (0.2 μm) of 6. After opening the contact windows for posts of the airbridge with an RIE process, the airbridges are formed by using a two mask level process and the final gold thickness is obtained by electroplating. Finally, the device was passivated with Si_XN_Y deposited at low temperature PECVD.

3. DEVICE PERFORMANCE

The drain I-V characteristics have been measured for the fully passivated 0.2 μm x 200 μm gate length $Al_{0.24}Ga_{0.76}As/In_{0.15}Ga_{0.85}As$ pseudomorphic HEMT with a wide head T-shaped multifinger gate. PHEMT devices exhibit excellent dc characteristics, and drain saturation current I_{dss} measured at V_{ds} = 2 V and V_{gs} = 0 V was 40 mA. Transconductance and drain current as a function of source-to-gate voltage, Vgs, for 0.2 μm x 200 μm pseudomorphic HEMT with a wide head T-shaped multifinger gate are shown in Fig. 2. The threshold voltage ,V_{th} , measured at V_{ds} = 2 V was - 0.74 V and the maximum extrinsic transconductance measured at V_{gs} = 0 V and V_{ds} = 2.0 V was 490 mS/mm. The S - parameters for the fabricated HEMTs was measured on wafer from 1 to 20 GHz using Cascade microwave probe station and an HP 8510B network analyzer. Typical current gain, $|h_{21}|$, as a function of frequency for 0.2 μm x 200 μm pseudomorphic HEMT is shown in Fig. 3. The cut-off frequency f_T was obtained from the extrapolation of the current gain, $|h_{21}|$, to unity using a - 6 dB/octave slope and the maximum frequency of oscillation, f_{max} , was extracted from small signal parameters. The cut-off frequency and maximum frequency of oscillation in a 0.2 μm x 200 μm gate pseudomorphic HEMT device are 75 GHz and 158 GHz, respectively.

Noise figure measurements have been carried out in the frequency range between 2 GHz and 18 GHz by using an HP 8510B network analyzer, HP 8970B noise figure meter and an ATN NP5 noise parameter test set. Fig. 4 shows the minimum noise figure, NF_{min}, and the associated gain, G_a , as a function of the percent drain current, % I_{dss}, for the fully passivated 0.2 μm x 200 μm gate HEMT device. At 12 GHz and V_{ds} = 2.0 V, the lowest NF_{min} was observed around 40 % I_{dss}(I_{ds}). Fig. 5 exhibits the NF_{min} and G_a as a function of frequency measured at 40 % I_{dss} (16mA) and V_{ds} = 2 V for HEMT device. The NF_{min} measured at 12 GHz, including passivation loss with this bias condition (V_{ds} = 2 V, I_{ds} = 16 mA) is 0.38dB with associated gain of 10.5dB. At 18 GHz, the NF_{min} is 0.6 dB with associated gain of 9.2 dB. To our knowledge, these noise figures are the lowest values ever reported for the same gate length GaAs-based HEMTs with multifinger structure. The R_g of the conventional T-shaped gate and the multifinger gate structure with wide head T-shape as determined from S- parameter measurements are 2.8 Ω and 0.2Ω, respectively. The R_g of the multifinger gate structure with a wide head T-shape formed by the DSM was drastically reduced by a factor of 10 less than that of the conventional T-shaped gate. In PHEMT device with current multifinger gate structure, the improvements of NF_{min} due to the reduction of R_g were 0.35 dB and 0.46dB at 12 GHz and 18 GHz, respectively. As a result, this noise performance improvement is attributed to the drastic reduction of R_g by adopting multifinger gate structure with wide head T-shape fabricated by DSM.

The equivalent circuit model was used to extract the small signal parameters for calculation of the minimum noise figure using the following equation [4-5]:

$$NF_{min} = 10\cdot\log[1 + K_f \cdot f_M/f_T\cdot\{g_m\cdot(R_g + R_s) + K_i\}^{1/2}]$$

where f_M is the operational frequency, f_T is the cut-off frequency, K_f and K_i are Fukui constant, g_m is the transconductance, R_g and R_s are gate and source resistance, respectively. The measured and calculated NF_{min} are 0.38 and 0.37 dB at 12GHz , respectively. The measured NF_{min} is well consistent with the calculated data.

4. CONCLUSION

We developed a passivated AlGaAs/InGaAs/GaAs PHEMTs with 0.2 μm a wide head T-shaped multifinger gate fabricated by combining the dose split method of electron beam lithography(DSM) and the drain-airbridges for the interconnection of the drain pads. This device exhibited very low noise figures of 0.38 dB and 0.6 dB at 12 GHz and 18 GHz, respectively. To our knowledge, this noise figure of HEMTs fabricated in this work shows the lowest value ever reported for passivated PHEMTs with the same gate length and multifinger gate structure. These data were due to extremely low gate resistance obtained by adopting a combination of the multifinger gate structure and the wide head T-shaped gate.

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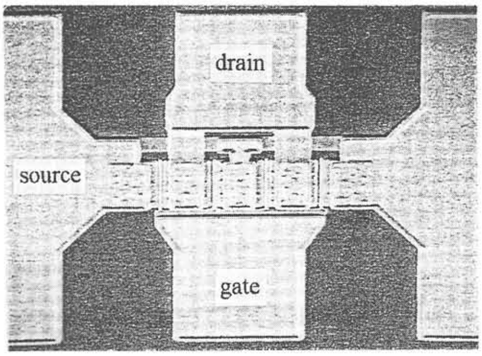
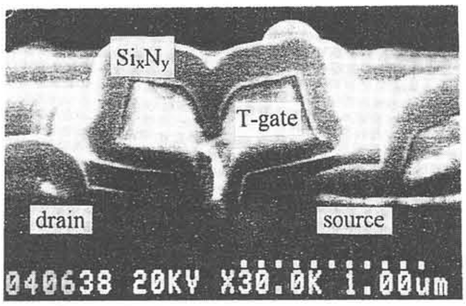


(a)



(b)

Fig. 1. (a) plane and (b) cross-sectional view for Si_xN_y passivated AlGaAs/InGaAs pseudomorphic HEMT with a wide head T- shaped multifinger-type gate.

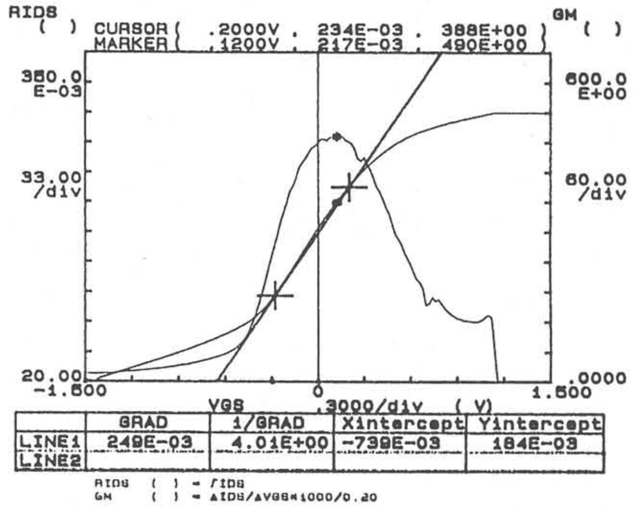


Fig. 2. The transconductance and drain current characteristics as a function of gate bias measured at Vds=2V.

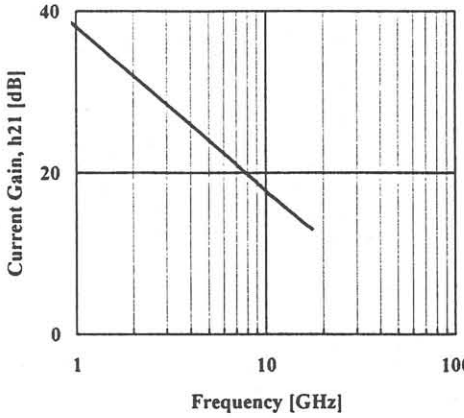


Fig. 3. Current gain, $|h_{21}|$, as a function of frequency of 0.2 μm x 200 μm pseudomorphic HEMT with a wide head T-shaped multifinger gate.

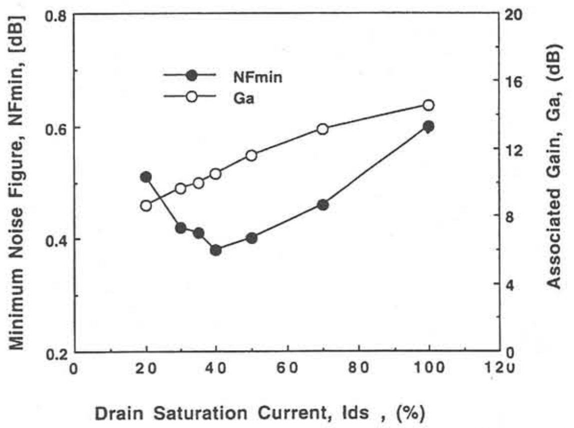


Fig. 4. The minimum noise figures and associated gain as a function of drain current measured at 12 GHz (I_{dss}= 40 mA).

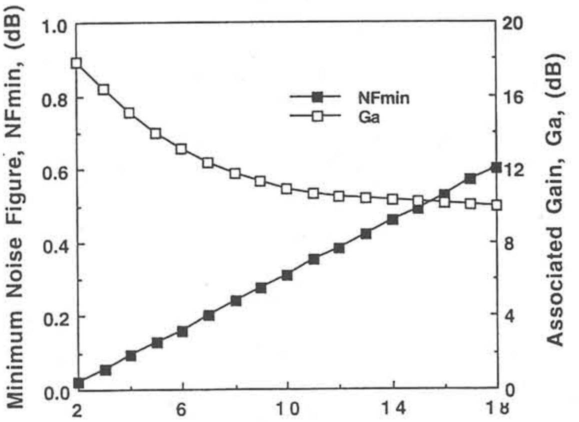


Fig.5. The minimum noise figures and associated gain as a function of frequency at V_{ds} = 2 V and I_{ds} = 40 % I_{dss} (I_{dss}= 40 mA).