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The fabric enhancement-mode metamorphic InAlAs/InGaAs HEMT by Pt Schottky metal diffusion

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1. Introduction

InAlAs/InGaAs enhancement-mode HEMT's (E-HEMT's) on InP substrates have provided promising characteristics and rf performance [1~2], which are very attractive to the wireless front-end applications, where a single positive voltage supply is preferred. However, manufacturing these devices is difficult due to the limited size, high cost, and brittle nature of the InP substrates. Growing the InAlAs/InGaAs structure metamorphically on a GaAs substrate can eliminate these substrate issues, and the metamorphic InAlAs/InGaAs HEMT's on GaAs substrate have achieved very good performance [3~4]. In this study, we developed the enhancement-mode InAlAs/InGaAs metamorphic HEMT's (m-HEMT's) on GaAs substrates by using the thermally diffused Schottky metal diffusion approach. This method in conjunction with the selective gate recess etching provides an easy way to fabricate InAlAs/InGaAs enhancement-mode HEMTs

2. Device structure and fabrication

Fig. 1 shows the schematic cross section of the epitaxial structure. The grown GaAs wafer consists of the InAlAs buffer layer with an Indium content varying from 0.0 to 0.52, a thick layer of InAlAs, a InGaAs channel layer followed by a InAlAs spacer layer, a delta doped layer, a 150 Å InAlAs Schottky layer, and a doped InGaAs cap layer.

Device fabrication was realized by the use of conventional lithography and lift-off techniques. An $H_3PO_4/H_2O_2/H_2O$ (1:1:40) solution was used for mesa etching.. Ohmic contacts were formed by electron beam evaporating Ge/Ni/Au metallization, followed by a 330 ^oC, 2 min hot plate annealing. TLM measurements show a typical ohmic contact resistance of 0.2 ohm-mm. The 1μm gate length was defined and selective gate recess etching was performed using a solution of citric acid and hydrogen peroxide [5]. The gate metal, Pt/Ti/Pt/Au (50 Å / 200 Å / 200 Å / 1500 Å), was then deposited. After gate metal liftoff, the devices were annealed in nitrogen ambient to enhance the threshold voltage [2].

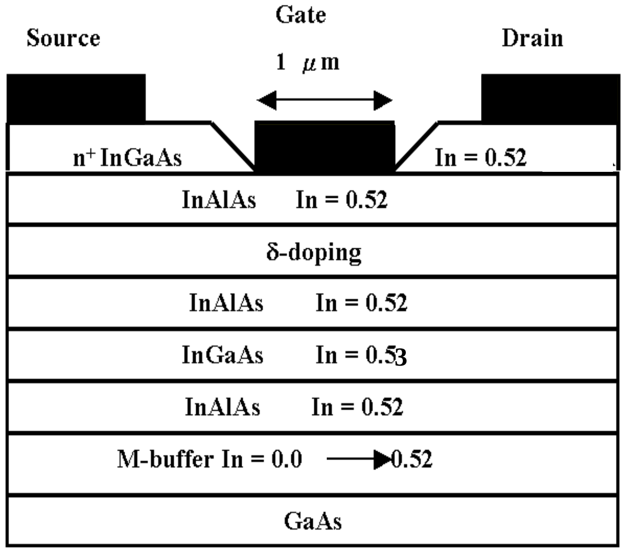


Fig. 1 A cross-sectional schematic of the metamorphic InAlAs/InGaAs metamorphic HEMT on GaAs substrate.

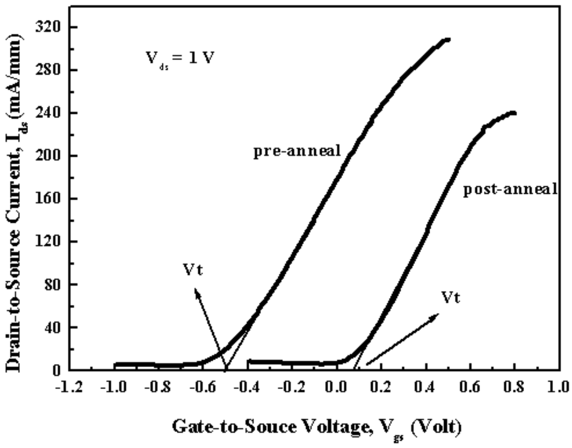
2. Results and discussion

Fig. 2 shows the transfer characteristics of a 50 μm gate width E-mode metamorphic HEMTs. Prior to the Schottky metal anneal, the devices exhibit depletion-mode performance with a threshold voltage of - 0.5 V and the maximum extrinsic transconductance is 364 mS/mm. After annealing the devices in a N_2 ambient at 320 ^OC for 2 min, the threshold voltage and maximum extrinsic transconductance shift to 0.1 V and 454 mS/mm, respectively. Fig. 3 shows the dc I-V characteristics for post-annealed devices. The E-mode device exhibits a high voltage gain (g_m/g_o) of 58, where no significant kink effect is observed.

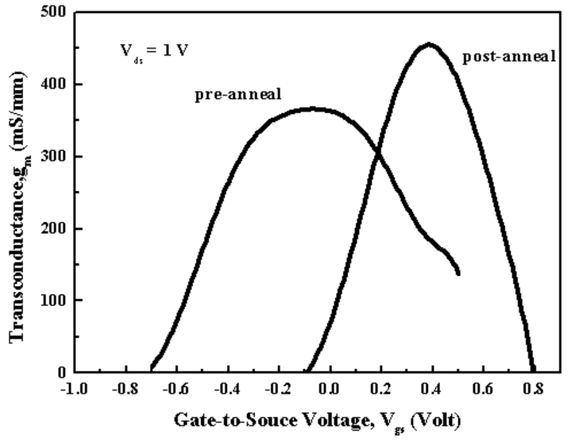
The positive shift of threshold voltage results from the interdiffusion of In and Al atoms into the Pt gate metallization, and the Pt reacts with the remaining As atoms in the Schottky layer [2]. This anneal is thought effectively to cause the gate front moving toward the channel, therefore reducing the gate-to-channel separation. The Ti atoms in the gate metallization sequence serve to limit the interdiffusion of the underlined In and Al atoms where the bottom Pt atoms can effectively intact with the As atoms, forming a $PtAs_2$ compound and resulting in a Schottky metal recess. The second Pt layer prevents the diffusion of the final Au atoms into the devices. The threshold voltage (*Vt*) of a conventional delta-doped HEMT can be obtained by solving the Poisson's equation in one dimension, which can be expressed as [6]

$$Vt = \Phi_b - \frac{\Delta E_c}{q} - \frac{qN_d D_d}{\varepsilon}$$

wher Φ_b :Schottky barrier hei ΔE_c; : conduction band discontinuity between the high-bandgap of Schottky layer and the low-bandgap channel layer; N_d :delta-doping sheet concentration; D_d :distance betwee ε he gate and the doping plane; : permittivity of the Schottky layer. From the above equation and threshold voltage variation of our E-mode m-HEMT, we observe the Pt involved in the anneal reaction to cause the interface penetration of InAlAs Schottky layer, and the estimated depth is about 40 Å.



(a)



(b)

Fig. 2 Drain current (a) and the extrinsic transconductance (b) versus gate voltage of a 50 um gate width E-mode metamorphic HEMTs with a bottom Pt thickness of 50 Å annealed at 320 ^{O}C for 2 min.

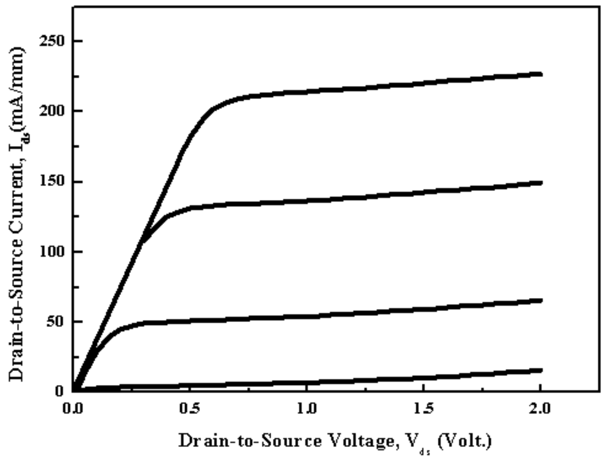


Fig 3 dc I-V characteristics for the post-annealed mHEMT. The gate voltage varies from 0 to 0.6 V in 0.2 V steps.

3. Conclusions

We have developed enhancement-mode metamorphic InAlAs/InGaAs HEMT by using a buried Pt gate approach. The devices exhibit the threshold voltages of 0.1 V and the maximum extrinsic transconductances of 454 mS/mm. The high transconductance coupled with the relatively low output conductance yields a maximum voltage gain of 58. The performances of these E-HEMT's make them excellent candidates for microwave circuit applications.

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