Recessed JPHEMT Technology for Low Distortion and Low Insertion Loss Switch

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Keywords: JPHEMT, Switch, Recess, SP10T

Abstract

We have developed a novel junction pseudomorphic high electron mobility transistor (JPHEMT) with a gate-drain and gate-source (gate-drain/source) recessed structure, Recessed JPHEMT (R-JPHEMT), and achieved the small off-capacitance (Coff) of 161fF/mm by using the recessed structure as well as keeping the low on-resistance (Ron) of 1.4ohm-mm with a buried pn junction gate. In Addition, we achieved a significant improvement in harmonics and inter-modulation distortions (IMD) compared with the ones in a conventional JPHEMT. Thus, this device has an excellent Quality factor (Q), the product of Ron-Coff, and low distortion characteristics as a switching device. The very low Q makes it possible to design a multi-throw switch, SP10T. The IMD2 and IMD3 of this SP10T switch are below -110dBm with low insertion loss. This novel device has been developed by using the low cost, 6inch, high-volume mass production technology.

INTRODUCTION

We have developed a junction pseudomorphic high electron mobility transistor (JPHEMT) for power amplifiers (PA) [1]. This device has low on-resistance (Ron) due to a buried pn junction gate compared with a normal Schottky gate PHEMT. Because the JPHEMT has the feature of low Ron, we have adopted it for the application of an antenna switch in order to lower the low insertion loss [2]. The antenna switch requires low distortion and low insertion loss characteristics. To achieve these, it is important to reduce the Ron, off-capacitance (Coff) and Quality factor (Q), the product of Ron-Coff. In recent years, the antenna switch has been required to support many kinds of communication systems such as GSM, UMTS and CDMA at once. Therefore, its circuit has become complex and large-scale, increases the insertion loss, and its distortion becomes worse. However, because the demand for low distortion in the antenna switch has not changed, various methods have been devised to develop the antenna switch to lower the distortion characteristics [3-5]. To achieve the demand, we have developed a novel structure of low distortion and low insertion loss device.

DEVICE DESIGN

There are a lot of off-state FETs in a multi-throw antenna switch IC. Therefore, it is necessary to improve the characteristics of off-state devices. We have achieved the gain enhancement in a PA device by reducing its gate-drain capacitance (Cgd) [6]. The device has a recessed structure between a gate and a drain. Using this structure, the carrier density in a barrier layer around the recessed region was reduced by the influence of a surface depletion layer. As a result, the Cgd was reduced as well. We adopted this concept, the recessed structure, to the region between a gate and a source to reduce the gate-source capacitance (Cgs). Then we came up with a solution of adopting the same concept to the gate-drain and gate-source (gate-drain/source) regions in order to reduce Coff. The cross section of the gate-drain/source recessed structure in a Recessed JPHEMT (R-JPHEMT) is shown in Figure 1. Carrier densities around a channel region were two-dimensionally calculated by using a drift-diffusion model for carrier transportation model. Moreover, we assumed that traps would exist in an interface between the SiN film and the AlGaAs layer as well as there would be no damage in the channel under the recessed region. The simulation results of the carrier concentration distribution of off-state JPHEMT and off-state R-JPHEMT are shown in Figure 2. In the state of the same gate voltage, the carrier density close to the gate has been much more depleted in the depletion layer in R-JPHEMT compared with the density in the same layer of the conventional JPHEMT. It is clear that applying the recessed structure to the gate-drain/source regions of the device is effective to reduce Coff. In this report, we describe R-JPHEMT, a novel device that has a gate-drain/source recessed structure, for the switch IC.

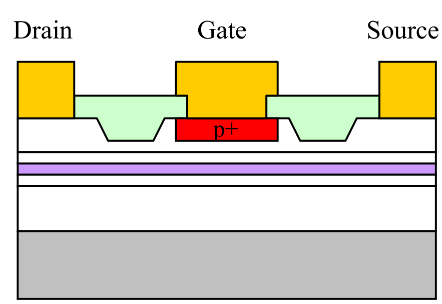
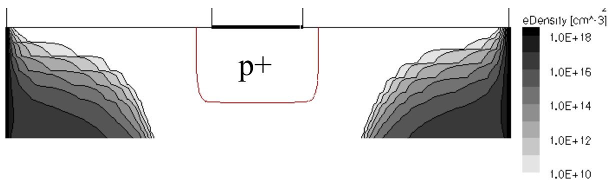
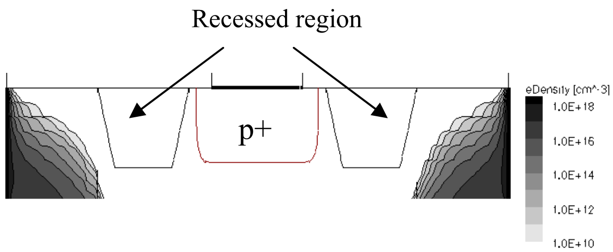


Fig.1 Device structure



(a) JPHEMT



(b) R-JPHEMT

Fig. 2 Carrier concentration distribution of off-state JPHEMT and off-state R-JPHEMT

FABRICATION

Next, we describe about the fabrication method of R-JPHEMT. First, layers of its epitaxial structure are composed sequentially on a semi-insulated GaAs substrate. The layers are, starting from the bottom, an AlGaAs/GaAs multiple buffer layer, a n-AlGaAs doping layer, undoped AlGaAs lower spacer layer, an undoped InGaAs channel layer, an undoped AlGaAs upper spacer layer, a n+AlGaAs doping layer, and a n-AlGaAs layer. Second, the recessed structure is formed by reactive ion etching (RIE) with the use of resist for an etching mask. Third, the SiN film, used as a mask of the Zn diffusion of p-type dopant, is deposited, and the gate is opened. Then, Zn is diffused to the n-AlGaAs doping layer, and the gate metal is formed. Finally, the drain and the source are formed, and the new R-JPHEMT structure is completed.

RESULTS AND DISCUSSIONS

We show characteristics of Ron and Coff in R-JPHEMT in comparison with the characteristics in conventional JPHEMT in TABLE I. The deterioration of Ron was suppressed and very small, and Coff was improved more than 20%. The Quality factor also achieved a 17% improvement compared with the conventional JPHEMT. Small Coff was achieved by using the recessed structure as well as keeping low Ron with a buried pn junction gate. This result emphasizes the strong point of both JPHEMT and R-JPHEMT.

TABLE I Comparison of Ron, Coff

	Device structure	
	JPHEMT	R-JPHEMT
Ron	1.3ohm-mm	1.4ohm-mm
Coff	208fF/mm	161fF/mm

As mentioned above, it is important to improve off-state FETs for multi-throw switches. We measured harmonics and distortions of 3-stacked off-state FETs connected to the GND and signal lines in Figure 3. The gate width of the FETs was 4mm and the gate bias voltage was -6V. Each Figures 4 and 5 shows the relation between the 2nd harmonics and the 3rd harmonics corresponding to the input power and 900MHz. In R-JPHEMT, the 2nd harmonics and the 3rd harmonics at the input power of 34dBm were -57dBm, and -66dBm respectively. The 2nd harmonics and the 3rd harmonics achieved the improvement of 4dB and 11dB compared with those in the conventional JPHEMT respectively. Next, the 2nd inter-modulation distortion (IMD2) and the 3rd inter-modulation distortion (IMD3) measurement results are shown in Table II. In R-JPHEMT, the IMD2 and the IMD3 were -113dBm and less than -130dBm, respectively, thus the achieved improvements were 9dB for IMD2 and more than 17dB for IMD3.

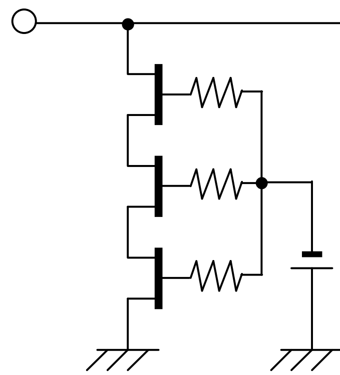


Fig.3 Schematic of distortion measurement of off-state device

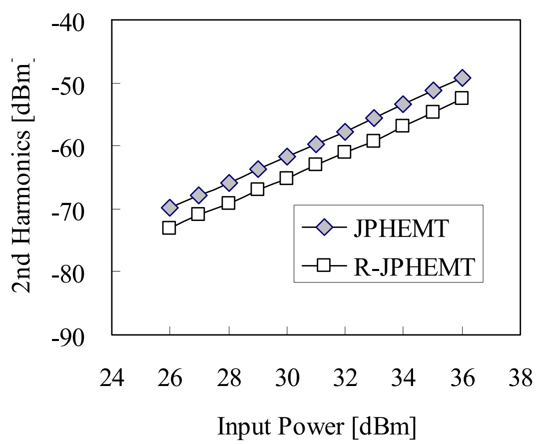


Fig.4 The relation of the 2nd harmonics to an input power@900MHz

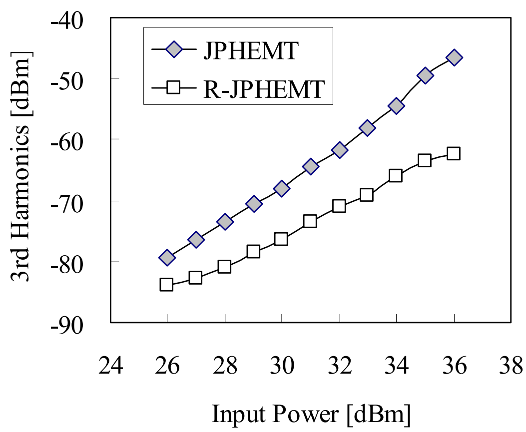


Fig.5 The relation of the 3rd harmonics to an input power@900MHz

TABLE II Comparison of IMD characteristics

	Device structure	
	JPHEMT	R-JPHEMT
IMD2@2140MHz Tx=20dBm@1950MHz Blocker=-15dBm@190MHz	-104dBm	-113dBm
IMD3@2140MHz Tx=20dBm@1950MHz Blocker=-15dBm@1760MHz	-113dBm	<-130dBm*

*Resolution of measurement system is -130dBm.

Finally, we report on the characteristics of SP10T antenna switch using R-JPHEMT. Figure 2 shows the schematic of SP10T antenna switch configuration. This switch is for GSM and UMTS/CDMA dual-mode handsets, and has a built-in dual low pass filter on Tx paths. The measurement results are summarized in Table III. The 2nd and 3rd harmonics were -56dBm and -45dBm respectively at the input power of 34dBm and 900MHz. The IMD2 and the IMD3 were below -110dBm which was low enough for the IMD spec of UMTS switch, -105dBm. The low distortion and low insertion loss characteristics were also achieved in the antenna switch IC.

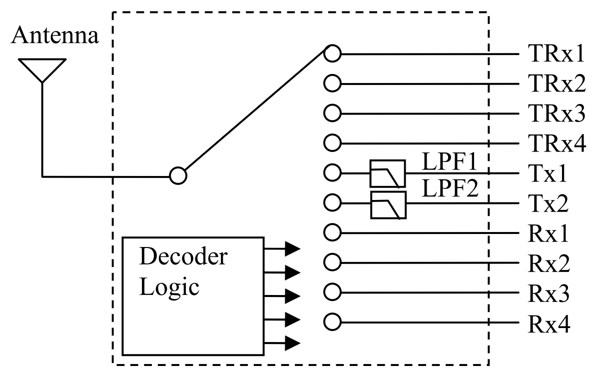


Fig.2 Schematic of SP10T antenna switch Configuration

TABLE III Characteristics of SP10T antenna switch

Item		Typical Value
Insertion Loss	Tx1(GSM Low Band)	0.85 dB
	Tx2(GSM High Band)	0.90 dB
	TRx(UMTS Band I)	0.55 dB
Harmonics	2nd harmonics(Tx2)	-56 dBm
	3rd harmonics(Tx2)	-45 dBm
IMD Tx=20dBm @1950MHz	IMD2 (Blocker=-15dBm@190MHz)	-112 dBm
	IMD2 (Blocker=-15dBm@4090MHz)	-114 dBm
	IMD3 (Blocker=-15dBm@1760MHz)	-116 dBm
	IMD3 (Blocker=-15dBm@6040MHz)	-118 dBm

CONCLUSIONS

We have developed a novel R-JPHEMT for antenna switches. This device has achieved the small Coff of 161fF/mm by using the recessed structure as well as keeping the low Ron of 1.4ohm-mm with a buried pn junction gate. Moreover, a significant improvement of characteristics has been made in the harmonics and the IMD compared with the ones in a conventional JPHEMT. As a result, we have successfully developed the complex circuit, SP10T antenna switch, which has low distortion and low insertion loss characteristics.

ACKNOWLEDGEMENTS

The authors would like to thank K. Kohama and H. Kawasaki for their discussion and encouragements. This work was supported by the SCK fabrication team, whose members we also would like to thank.

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ACRONYMS

JPHEMT: Junction Pseudomorphic High Electron Mobility Transistor
GSM: Global System for Mobile Communications
UMTS: Universal Mobile Telecommunications System
CDMA: Code Division Multiple Access
IMD: Inter-modulation Distortion
LPF: Low Pass Filter
GaAs: Gallium Arsenide
RIE: Reactive Ion Etching
SiN: Silicon Nitride