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Optimal design of P-buffer layer for GaAs power MESFET

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Indexing terms: MESFET, Power MESFET, Power transistors, Ion implantation

The mechanisms for current conduction in the substrate of planar ion-implanted GaAs power MESFETs for wireless communication are investigated by 2D simulation. A properly doped *p*-buffer layer can eliminate the substrate conduction, but a too heavily doped *p*-buffer can reduce the saturation current (I_{ds}) and the breakdown voltage significantly. Optimal design for the *p*-buffer of the MESFETs is described.

Introduction: Ion-implanted planar GaAs power MESFETs have been widely used in commercial wireless communication [1, 2]. This structure intrinsically can be of low cost and manufactured in high volume. The power device is normally biased at low bias current for dual mode operation. The resulting power devices have high power-added-efficiency in the analogue mode, and have high linearity and good efficiency in the digital mode at the same bias voltage. However, the MESFET without the *p*-buffer has large leakage current in the substrate when the device is biased near pinch-off. This leakage current reduces the transconductance, drain efficiency and linearity. Hence, we need to know the physics of the leakage current by performing a 2D simulation.

In this study, two different mechanisms for leakage current in the substrate have been identified. One is called the 'electron-push-out' effect and the other is the 'drain-induce-barrier-lowering (DIBL)' effect. The 'electron-push-out' effect happens just after the channel is pinched off. It acts as a resistor that is connected in parallel to the channel. The DIBL effect occurs as the gate is strongly reverse-biased. In the DIBL effect, the leakage current depends on the drain voltage exponentially. Both effects can be eliminated by a properly doped *p*-buffer in the substrate.

Simulation and results: 80keV 4.2×10^{12} /cm² Si implanted GaAs MESFETs with/without a 120 keV 6×10^{11} /cm² Be implanted *p*-buffer were analysed by 2D simulation. The devices had a gate length of 1 μ m and the gates had planar contours (i.e. there was no gate recess etching). Surface depletion of the devices was also accounted for in the simulation. The doping profile in the devices was as follows: A Gaussian distribution with $R_p = 0.065 \mu$ m and $\Delta R_p = 0.037 \mu$ m was used to simulate 80keV implanted Si (80% activation ratio); and a uniform distribution - 0.25 to 0.35 μ m from the surface with a $\Delta R_p = 0.05 \mu$ m Gaussian tail used to simulate the 120keV implanted Be (100% activation ratio). The parameters used here were based on the SIMS measurement.

The I-V curves simulated of an 80 keV, 4.2×10^{12} /cm² Si implanted MESFET without the *p*-buffer are shown in Fig. 1. This device has a large leakage current near pinch-off as shown in region I of Fig. 1 and beyond pinch-off in region II. First, in region I, the mechanism of the leakage current can be clearly understood in Fig. 2, which shows the plot of the contours representing the distribution of different electron concentrations in the device for $V_{gs} = -3$ V and $V_{ds} = 4$ V (just pinched-off condition). In Fig. 2, we can see that some electrons in the order of 10^{14} to 10^{15} /cm³ are pushed out from the depletion region under the gate and form an extra current path. We call it the 'electron-pushout' effect. This effect is not pronounced when the channel is opened but becomes significant when the channel is near pinch-off as can be seen in region I of Fig. 1. This undesired effect makes the substrate act as a parallel resistor and it smears out the knee voltage when the channel is near pinch-off.

Fig. 1 I-V curves of 80keV, 4.2×10^{12} /cm² Si implanted MESFET without *p*-buffer

Fig. 2 Electron concentration contours of MESFET without *p*-buffer for $V_{gs} = -3$ V and $V_{ds} = 4$ V (just pinched-off condition)

Fig. 3 I-V curves of 80keV, 4.2×10^{12} /cm² Si implanted MESFET without *p*-buffer

I_{ds} in log scale

Secondly, when the reverse gate bias is well beyond pinch-off, the device without the p -buffer still suffers from some small leakage current at large drain biases as shown in region II of Fig. 1. This can be interpreted by the DIBL effect as seen in Fig. 3. It shows the I-V curves of the same device as in Fig. 1, but its y -axis (I_{ds}) is changed from a linear scale in Fig. 1, to a logarithmic scale. In Fig. 3, the DIBL effect is obvious, because the drain leakage current increases exponentially as the drain voltage increases. This exponential dependence is evidence of the DIBL effect. Since the gate potential barrier is lowered by the drain voltage, the leakage current increases exponentially. The DIBL effect can be also verified in the 2D simulation by observing the difference of the potential contours between different drain biases beyond pinch-off. Detailed descriptions for these are not included in this Letter.

Fig. 4 I-V curves of 80keV, $4.2 \times 10^{12}/\text{cm}^2$ Si implanted MESFET with 120keV, $6 \times 10^{11}/\text{cm}^2$ Be implanted p -buffer

As for the MESFET with the p -buffer, the 'electron pushed out' and the DIBL effect both disappear. Fig. 4 shows the I-V curves for the device with 120keV $6 \times 10^{11}/\text{cm}^2$ Be implanted p -buffer. In Fig. 4, we can see that there is no leakage current near pinch-off and the I-V characteristics have well-defined knee voltages even near pinch-off. Moreover, the electron concentration contours of the device are also plotted. It can be seen that the electrons were confined in the channel very well by the p -buffer, both for the before-pinch-off condition and the beyond-pinch-off condition. The p -buffer can prevent electrons from being pushed out into the substrate when the gate voltage is before or near pinch-off; and can strengthen the potential barrier and consequently reduce the DIBL effect when the gate voltage is beyond pinch-off.

Fig. 5 I-V curves of 100keV, $6 \times 10^{12}/\text{cm}^2$ Si implanted MESFET

— MESFET with $1.5 \times 10^{12}/\text{cm}^2$ Be implanted p -buffer
 --- MESFET with $2.2 \times 10^{12}/\text{cm}^2$ Be implanted p -buffer
 top line: $V_g = 0$
 -0.5V/step

There are some disadvantages of the p -buffer. Although the p -buffer can eliminate the substrate leakage, the I_{ds} of the MESFET is also reduced by the p -buffer. For example, the I_{ds} of the two

devices discussed above is reduced from 230 (without p -buffer) to 100mA/min (with p -buffer). To obtain the desired I_{ds} (~200–250mA/mm), we should try a heavier dosage of the Si n -type dopant. In addition, the energy of the implanted Si ion must also be increased in order to obtain nearly the same peak concentration of doping. Therefore, 100keV $6 \times 10^{12}/\text{cm}^2$ Si implanted MESFETs with a 120keV Be implanted p -buffer were used. Two Be dosages were chosen, a $1.5 \times 10^{12}/\text{cm}^2$ and b $2.2 \times 10^{12}/\text{cm}^2$. The I-V curves of the two MESFETs are shown in Fig. 5. The I_{ds} of the two devices are a 240mA/mm and b 220mA/mm. Both devices show very little leakage current.

The p -buffer also affects the breakdown phenomena. If the p -buffer was not totally depleted, we found by simulation that the avalanche breakdown occurred easily at the junction of the n -channel and the p -buffer. Hence, it was called 'substrate breakdown'. Whenever the substrate breakdown occurred, as a result, the breakdown voltage was greatly reduced. For example, in device a , in which we found by simulation that the p -buffer was totally depleted under drain, no substrate breakdown occurred. The breakdown phenomenon was just like the phenomena in devices without p -buffer, which occur at the gate edge close to the drain. Conversely, in device b , in which the p -buffer was not totally depleted under the drain, avalanche breakdown occurred at the pn junction under the drain. Thus, substrate breakdown occurred. Consequently, the breakdown voltage was greatly reduced. Therefore, the breakdown phenomenon puts an upper limit on the Be dosage of the p -buffer.

Conclusion: Determined by 2D simulation, the optimal p -buffer for a GaAs MESFET can be obtained by carrying out 120keV $6 \times 10^{11}/\text{cm}^2$ silicon ion implantation with 100keV $1.5 \times 10^{11}/\text{cm}^2$ beryllium ion implantation. The resulting device has no substrate breakdown because the p -buffer is totally depleted. In addition, the device does not have substrate leakage. In conclusion, an ion-implanted planar power MESFET with adequate I_{ds} , high breakdown voltage and little substrate leakage current, has been successfully achieved by carrying out a 2D simulation.

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Quasi-Schottky contacts on $n\text{-In}_{0.35}\text{Ga}_{0.65}\text{As}$ epitaxial layers deposited on GaAs substrates

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Indexing terms: Schottky barriers, Indium compounds, Gallium arsenide

Al Schottky barriers have been prepared on $n\text{-In}_{0.35}\text{Ga}_{0.65}\text{As}$ /buffer/GaAs structures using $\text{In}_x\text{Ga}_{1-x}\text{As}$ buffers with different grading laws to reduce the defect density induced by lattice mismatch in the active $\text{In}_{0.35}\text{Ga}_{0.65}\text{As}$ layer. Counter doped p^+ cap layers have been used to enhance the barriers. Using suitable cap and buffer parameters, barrier heights up to 0.67eV and ideality factors of 1.15 have been obtained.