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V_T-V_{SUB} Characterization of AlGaN/GaN HFET with Regrown Epi-layer on p-GaN

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1. Introduction

Silicon technology fully uses p-type region to enhance the breakdown voltage. To utilize the mature technologies of Si-based power devices, such as hole sink [1], we tried to fabricate AlGaN/GaN heterojunction field effect transistors (HFETs) with p-GaN epi-layer on sapphire substrate and made substrate contact to the p-GaN (p-sub HFET).

Due to serious memory effect of Mg dopants in MOCVD systems, we tried to regrow the AlGaN/GaN heterostructure on the p-GaN layer grown in another MOCVD system. Before the regrowth process, a half of each p-GaN wafer was etched about 30nm by inductively coupled plasma (ICP) of $SiCl_4$. Therefore, we can compare the HFET devices with ICP-etched and as-grown regrowth interface.

In this work, utilizing the contact on p-GaN substrate, we compared the influence of the two different regrowth interfaces on the doping profile in i-GaN through threshold voltage(V_T)-sub voltage(V_{SUB}) measurements. Furthermore, with sub-bias stress and UV-light stress measurement, we measured the concentration of traps in the i-GaN layer.

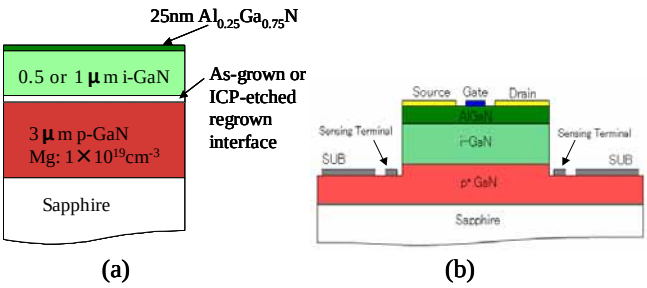


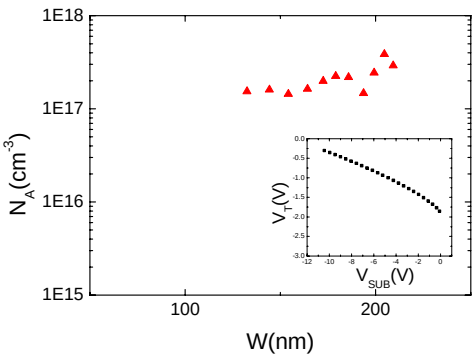
Fig.1 Epitaxial structure(a) and device structure(b) of AlGaN/GaN HFET with regrown epi-layer on p-GaN

2. Acceptor Concentration Measurement

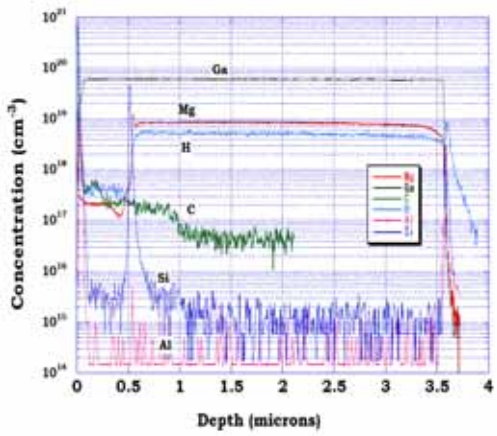
Fig. 1 shows the epitaxial layers and the device structure of our samples. Two wafers were used. Before the regrowth process, A half of each wafer was etched by 30nm by ICP of $SiCl_4$. Therefore, each wafer had two kinds of regrowth interfaces at the same time. After the regrowth process, one wafer has 0.5 μm regrown i-GaN layer and the other has 1 μm regrown i-GaN layer.

To accurately measure the substrate voltage (V_{SUB}), we used sensing terminal contact on the p-GaN layer (Fig. 1(b)).

Fig.2 shows the measured doping concentration of i-GaN in p-sub HFET with 500nm thick i-GaN regrown layer on as-grown p-GaN, from (a) V_T-V_{SUB} measurement and (b) SIMS. Two methods show similar results, indicating our V_T-V_{SUB} analysis seems accurate. To avoid the effects of gate and substrate leakage current, the data used were the ones which were obtained only when the drain current equals to the source current.



(a)



(b)

Fig.2 Doping concentration profiles of i-GaN layer in p-sub AlGaN/GaN HFET with 500nm i-GaN regrown on as-grown p-GaN, measured by V_T-V_{SUB}(a) and SIMS (b). The inset in (a) shows the V_T-V_{SUB} profile.

Fig.3 shows the measured V_T-V_{SUB} characteristics of p-sub HFET with as-grown and ICP-etched p-GaN inter-

faces. As expected from the backgate-bias-effect theory [2], V_T was increased with increasing negative substrate bias. From these V_T-V_{SUB} profiles, the calculated acceptor concentration profile was shown in Fig. 4.The out diffusion of Mg dopants was more severe in the samples with as-grown p-GaN interface. The measured acceptor concentration was as high as $1\times10^{17}cm^{-3}$. However, this value was as low as $1\times10^{16}cm^{-3}$ in the samples with ICP-etched p-GaN interface.

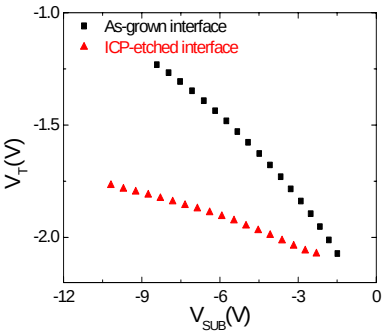


Fig.3 V_T-V_{SUB} profile of p-sub HFET with as-grown and ICP-etched p-GaN interface

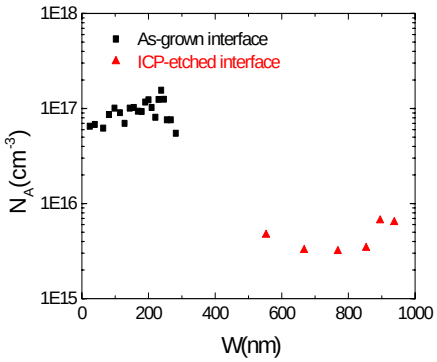


Fig.4 Doping concentration profile of i-GaN layer in p-sub HFET with as-grown and ICP-etched p-GaN interface

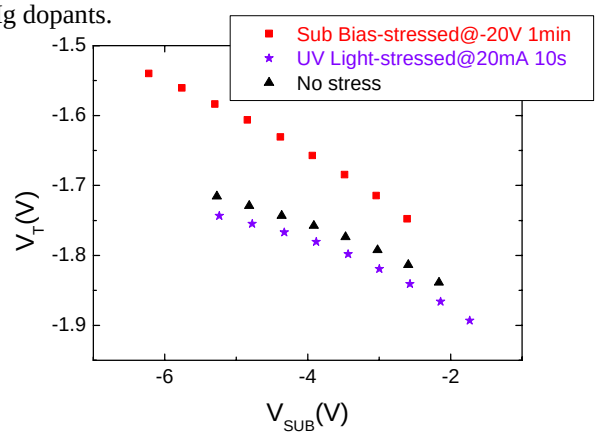
3. Bias and UV Stress Measurement

To electrically investigate the traps in the i-GaN layer, we used negative substrate-bias stress for depletion condition and UV-light stress for injection condition (Fig. 5).

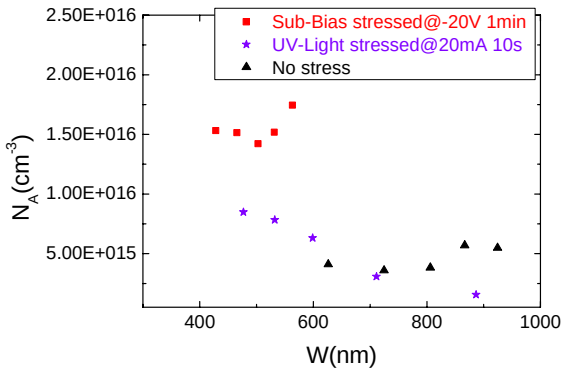
With –20V substrate-bias stress, the measured acceptor concentration (negative space charge density) was increased to 1.5×10^{16} cm^{-3}, indicating that the traps in the i-GaN layer captured electrons under the negative substrate bias. Since both electrons and holes were depleted in the negative substrate bias, the traps are hole traps, where electron occupancy is mainly influenced by hole concentration.

With UV-light illumination with no gate bias, both electron and hole concentrations are higher than their equilibrium values. Since negative charge density was slightly decreased by UV stress, again, the traps follow the hole concentration. The charge difference between the negative substrate-bias and UV irradiation may reflect deep level concentration, which was calculated to be $0.5\sim1\times10^{16}$ cm^{-3}.

The measured acceptor concentration under UV light is almost similar to that in thermal equilibrium, which indicates the traps are occupied by holes in equilibrium. We applied the same analysis to the sample with as-grown p-GaN interface, but no noticeable difference is obtained due to the high background concentration of out-diffused Mg dopants.



(a)



(b)

Fig.5 Sub-Bias stressed and UV-light stressed V_T-V_{SUB} profile (a) and doping concentration profile (b) of p-sub HFET with ICP-etched regrowth interface

4. Conclusions

In conclusion, for p-type substrate AlGaN/GaN HFETs, utilizing V_T-V_{SUB} analysis, we measured the doping concentration and trap density in i-GaN, which can not be measured in conventional HFET without substrate terminal. We also found severe outdiffusion of Mg on as-grown p-layer sample.

References

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