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AlGaN/GaN MOS-HFETs Exhibiting Improved Hysteresis in Transfer Characteristics with Recessed Gate Structures Formed by Selective Regrowth

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Abstract

A normally-off AlGaN/GaN MOS-HFET with recessed gate structure formed by selective area growth is demonstrated. The fabricated MOS-HFET exhibits an improved hysteresis of 0.5 V in the transfer characteristics. The *C-V* characteristics reveal that low interface state density is attained by the selective area growth, which results in the improved hysteresis.

1. Introduction

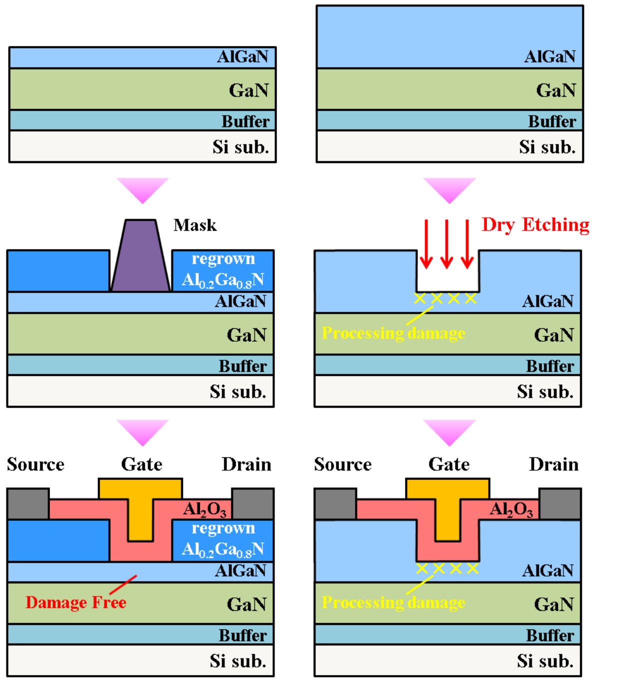
AlGaN/GaN heterojunction field effect transistors (HFETs) are very promising for power switching applications taking advantages of the superior material properties. Among various gate structures aiming at the normally-off operations, metal-oxide-semiconductor (MOS)-gate should be the most promising since it would make the gate-driving compatible with existing Si power devices. However, the interface between the AlGaN/GaN and the oxide has never been stable enough to apply the GaN-based MOS transistor for practical applications because of a lack of good thermal oxide as in Si devices. Various effects from deposition and processing especially by dry etching cause undesired hysteresis in the transfer characteristics, which needs to be solved for the practical use.

In this paper, a normally-off AlGaN/GaN MOS-HFET with an improved hysteresis is demonstrated. It is found out that the dry etching increases the interface state density leading to a large hysteresis. Using selective area growth technique for formation of the recessed gate structures leads to reduction of the interface state density at Al_2O_3/AlGaN layer, resulting in the improved hysteresis.

2. Device Fabrication and Epitaxial Design

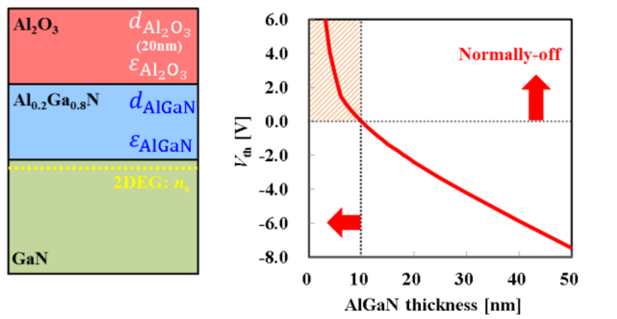
Fig.1 shows the fabrication process of AlGaN/GaN MOS-HFETs by using selective area growth (a) in comparison with the conventional dry etching process (b). The selective area growth is carried out by metal organic chemical vapor deposition (MOCVD) with the gate recess area on the AlGaN surface masked, while the dry etching is carried out by Cl-based inductively coupled plasma (ICP) etching.

Thickness of the AlGaN layer is designed by calculating threshold voltage of the MOS-HFETs to enable the normally-off operation, which is obtained below 10 nm as shown in Fig.2. The cross sectional transmission electron microscopic (TEM) image of the recessed gate structure formed by selective regrowth is shown in Fig.3.



(a) This work (b) Conventional

Fig. 1 The fabrication process of MOS-HFETs (a) by using selective area growth and (b) by dry etching



$$n_s = \frac{\sigma}{q} - \frac{\varepsilon_{AlGaN}}{q^2 d_{AlGaN}}(q\varphi + E_F - \Delta E_C)^{[1]} \quad V_{th} = \varphi' - \Delta E_{C(Al_2O_3\_GaN)} - q n_s \left(\frac{d_{AlGaN}}{\varepsilon_{AlGaN}} + \frac{d_{Al_2O_3}}{\varepsilon_{Al_2O_3}}\right)$$

Fig. 2 Calculation of threshold voltage and the calculated threshold voltage of AlGaN/GaN MOS structure as a function of AlGaN thickness.

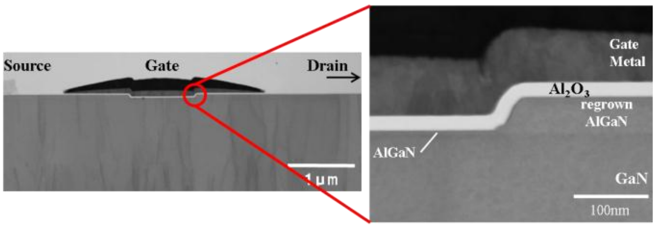


Fig. 3 The cross sectional TEM image of the recessed gate structure of the fabricated AlGaN/GaN MOS-HFET formed by selective area growth.

3. Results and Discussions

Fig. 4 shows the capacitance-voltage (C-V) characteristics of the fabricated AlGaN/GaN MOS diodes. The steeper slope of C-V curve near threshold voltage of the MOS diodes without dry etching suggests the lower trap density at the Al_2O_3/AlGaN interface. Note that the Fermi level is crossing the interface state at the threshold voltage in the MOS diodes with thin AlGaN layer, which enables the estimation of the interface state density from the slope of C-V curves near the threshold voltage. The estimation of the interface state density by the numerical fitting of C-V curves [2, 3] confirms that low interface state density of 6.0×10^{11} cm^{-2} eV^{-1} is attained in the MOS diode of which AlGaN layer is grown thin, while higher interface state density of 1.2×10^{12} cm^{-2} eV^{-1} is exhibited by the MOS diode of which AlGaN layer is thinned by dry etching. Fig. 5(a) shows the transfer characteristics of the fabricated AlGaN/GaN MOS-HFETs using selective area growth. An improved hysteresis (ΔV_{gs}) of 0.5 V is observed between the forward and backward sweeps for transfer curves in contrast to the larger hysteresis of 1.3 V exhibited by the conventional AlGaN/GaN MOS-HFETs shown in Fig. 5(b), corresponding to each interface state density. The low interface state density is also confirmed by the smaller subthreshold swing exhibited the MOS-HFET fabricated by selective area growth as shown in Fig.6.

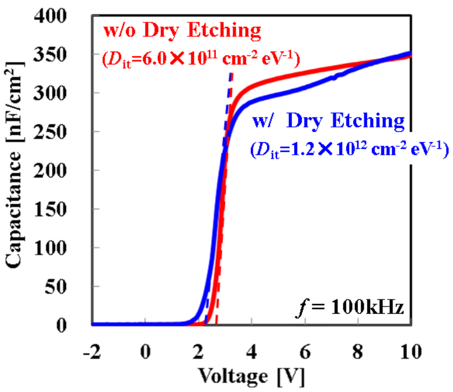
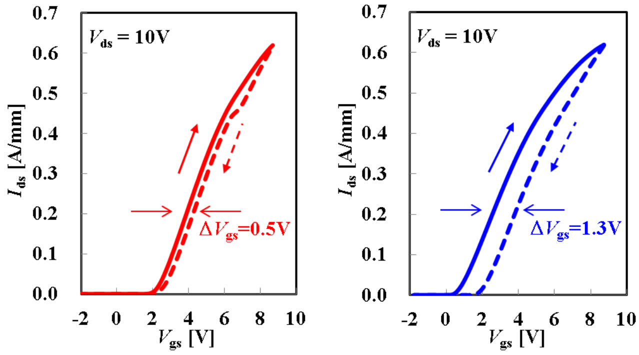


Fig. 4 C-V characteristics of Al_2O_3/AlGaN/GaN MOS diodes of which AlGaN layer is as-grown (denoted by "w/o Dry Etching") and is exposed to dry etching (denoted by "w/ Dry Etching"), respectively.



(a) Selective area growth (b) Dry etching

Fig. 5 The transfer characteristics of the fabricated AlGaN/GaN MOS-HFETs of which AlGaN layer is formed (a) by selective area gtrowth and (b) by dry etching.

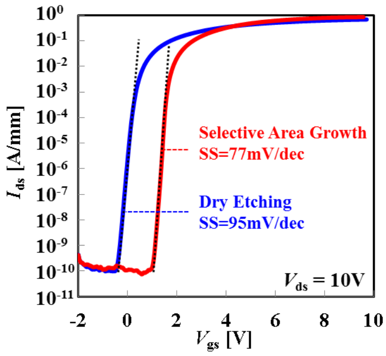


Fig.6 The comparison of the subthreshold characteristics between the fabricated AlGaN/GaN MOS-HFETs by selective area growth and by dry etching.

4. Conclusions

A normally-off AlGaN/GaN MOS-HFET with recessed gate structure formed by selective area growth is demonstrated. A threshold voltage of 1.7 V with an improved hysteresis of 0.5 V is attained. C-V characteristics reveal that using the selective area growth to form the recessed gate structures effectively reduces the interface state density, which results in the small hysteresis. The performances of the presented device imply that selective regrowth technique is promising for the fabrication of normally-off AlGaN/GaN MOS-HFETs.

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