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Nonvolatile memory effects in GaN Metal-Oxide-Semiconductor Heterostructure FETs with thin AlGaN barrier

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Abstract

We have fabricated gate-recessed AlGaN/GaN metal-oxide-semiconductor heterostructure field effect transistors (MOSHFETs) employing PECVD SiO_2 gate insulator. Gate recess process was adjusted to obtain very thin AlGaN barrier of 2 nm thickness to enable nonvolatile memory operation. Electrons were stored in and released from interface states at SiO_2/thin AlGaN layer by positive and negative gate biases, respectively. The threshold voltage shift was ~3.6 V between the program and the erase modes. The gate leakage characteristic was not degraded after 1000 cycles of program/erase modes. The retention characteristics were stable over 100,000 s.

1. Introduction

Field effect transistors based on AlGaN/GaN heterostructures have been strong candidates for high speed and high power applications owing to excellent material properties such as high electron mobility and large breakdown field. [1, 2]

Nonvolatile memory application is an important area of semiconductor technology. Two major criteria must be met to realize nonvolatile memory devices. One should secure enough sensing margin between the program and the erase modes. In addition, electrons must remain trapped for a long time in the program mode.

The charge storage in AlGaN/GaN-based metal floating gate devices, which enabled normally-off operation, was recently reported. [3, 4] Charge trapping devices using the interface states between Al_2O_3 and GaN were also reported. [5] GaN capping layer was used as charge storage layer for nonvolatile memory operation. [6]

In this work, the nonvolatile memory device was fabricated using SiO_2/thin AlGaN/GaN heterostructure on Si substrate. The devices demonstrated the positive shift of threshold voltage after charging by the positive gate voltage. This shift was reversible by the negative gate voltage. The device exhibited good retention and repetition characteristics compared with previous reports.

2. Device Fabrication

Fig. 1 shows the schematic cross-sectional view of fabricated SiO_2/ultra-thin AlGaN/GaN MOSHFETs on Si substrate. Ohmic contacts were formed by an e-beam evaporated Si/Ti/Al/Mo/Au (5/20/60/35/50 nm) metal stack and alloyed by rapid thermal annealing at 800 ℃ for 30 s. After ohmic process, mesa isolation and gate recess were followed. As shown in fig. 2, remaining thickness of AlGaN barrier was around 2 nm. A 33 nm SiO_2 was deposited using plasma enhanced chemical vapor deposition (PECVD), and a Ni/Au (20/200 nm) was evaporated for the gate contact. The gate length/width, gate-to-drain distance, and gate-to-source distance were 2/100 um, 15 um, and 3 um, respectively.

3. Experiment and Result

The transfer characteristics of the fabricated devices are shown in fig. 3. Normally-off operation was enabled by gate-recessed MOS approach. After charging by maintaining the gate voltage at 10 V for 300 ms, threshold voltage was shifted to a positive direction about 3.6 V so that the device was in the program mode. The memory device returned to before-charging (erase) mode after charging by the gate voltage at -10 V. Gate leakage currents before and after charging are also seen in fig. 3. Negligible changes in gate leakage were observed before and after programming. The change of threshold voltage as a function of charging time is shown in fig. 4.

After the device was set into the program mode, the retention characteristics were monitored and shown in fig. 5. The read current, I_D measured at V_G=2 V and V_D=1 V, was retained at ~ 10 pA/mm for over 10^5 s indicating excellent capability of charge storage.

Fig. 6 shows the repetition characteristics of the program/erase cycles. The memory device was biased at iterative bias conditions of the program and the erase modes aforementioned. After repetition of 1000 cycles, the read current of the memory device was maintained at initial current level of charging and discharging mode, respectively. Fig. 7 shows the transfer and gate leakage characteristics of the memory device were not degraded after 1000 cycles.

3. Conclusions

Nonvolatile memory devices based on SiO_2/ultra-thin AlGaN/GaN heterostructure have been fabricated. In the charging mode, electrons were injected into interface states between oxide and thin AlGaN barrier by a positive gate voltage, inducing the positive shift of the threshold voltage. The threshold voltage was shifted back to the initial value by applying the negative gate voltage. This structure demonstrated the retention characteristics over 10^5 s and the reliability after 1000 cycle repetition of the program/erase operations suggesting the feasibility of GaN-based devices for nonvolatile memory applications.

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References

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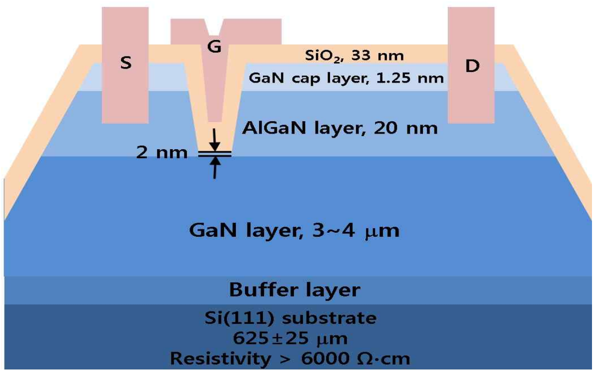

Fig. 1. The schematic cross-sectional view of fabricated SiO_2/ultra-thin AlGaN/GaN MOSHFETs.

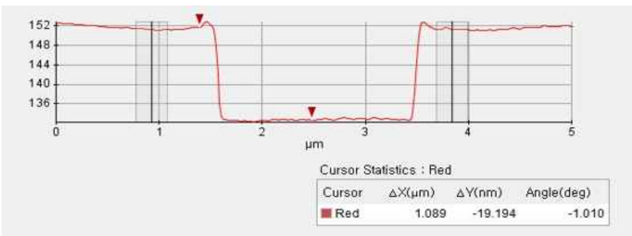

Fig. 2. AFM scan result for gate recess depth of 19 nm.

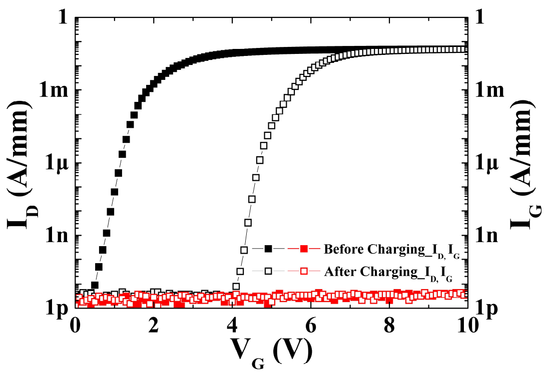

Fig. 3. The transfer characteristics at V_D=1 V of the memory device before and after charging by V_G=10 V.

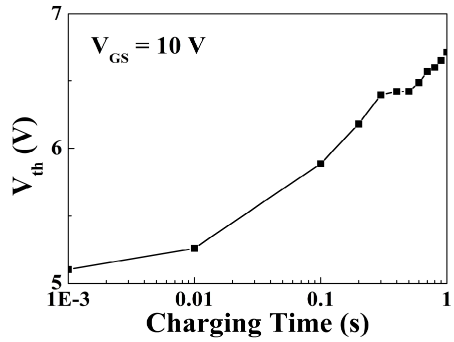

Fig. 4. The change of threshold voltage as a function of charging time.

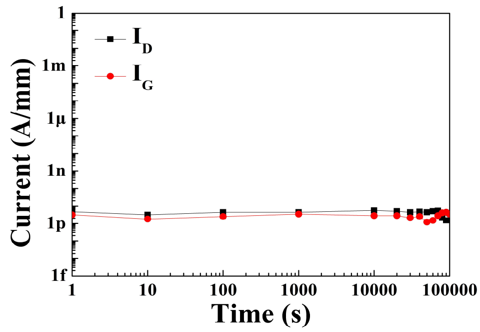

Fig. 5. The retention characteristics of SiO_2/AlGaN/GaN MOSHFET memory devices. I_D read at V_G=2 V, V_D=1 V in the program mode.

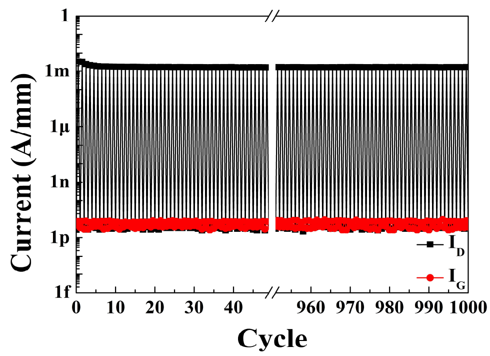

Fig. 6. The repetition characteristics of 1000 cycles of program/erase operation.

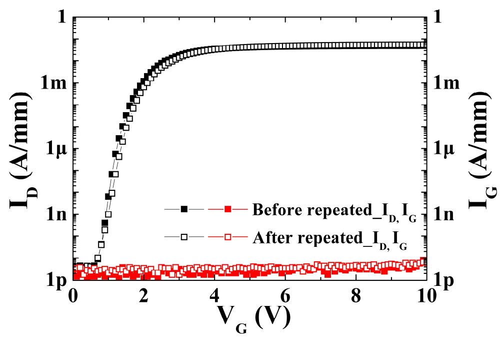

Fig. 7. The transfer characteristics of the memory device before and after repeated at V_D=1 V.