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Performance Improvement using Diluted KOH Passivation on Recessed-gate AlGaN/GaN Metal-oxide-semiconductor High-electron-mobility Transistors Grown on 8-inch Silicon(111) Substrates

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Abstract

In this letter, an effective surface recovery treatment by diluted KOH passivation is demonstrated. With this treatment, an enhanced-mode (threshold voltage =0.61V), high on-state current (175 mA/mm at overdrive voltage = 2 V), low on resistance (9.29 Ω-mm), less hysteresis (from 0.8V to 0.6V) AlGaN/GaN MOSHEMT is achieved.

INTRODUCTION

Gallium nitride (GaN) has attracted plenty of attentions due to its superior physical properties. Wide bandgap, high breakdown voltage, high frequency response and high saturation velocity provide AlGaN/GaN based high-electron-mobility transistors (HEMTs) much potential to be a promising candidate for electronic power devices [1]. To save the circuit area and power consumption, an enhanced-mode (E-mode) device is desperately desired. Because of the origin two-dimensional electron gas (2DEG) induced by strong spontaneous and piezoelectric polarization charges, the conventional AlGaN/GaN HEMTs are characterized by normally-on devices. A fully recessed, insulated gate structure GaN MOSHEMT has been demonstrated to achieve E-mode device [2-3]. However, the recess process will also induce bombarded damages on recessed area due to the ion impacts and cause scattering effect to reduce the carrier mobility. Therefore, the suppression of bombarded damage is a critical issue to the recess-related device.

Here we introduce a recess treatment with diluted KOH passivation. By means of this treatment, we obtain apparent improvements on device performance such as threshold voltage (V_{TH}, from 0.47 V to 0.61 V), on-state current (from 165 mA/mm to 202 mA/mm), on resistance (from 11.49 Ω-mm to 9.29 Ω-mm) and hysteresis (from 0.8 V to 0.6 V) compared to the device without the diluted KOH passivation.

LAYER STRUCTURE AND FABRICATION PROCESS

The wafer was grown by metal organic chemical vapor deposition on 8-inch Si(111) substrate which is more suitable for the mass production. It includes a 3.7 μm AlN/AlGaN buffer, a 1 μm undoped GaN layer, a 13 nm $Al_{0.57}Ga_{0.43}N$ barrier layer and a 1 nm undoped GaN cap layer. Here is our fabrication process. First of all, we use inductively coupled plasma reactive-ion etching (ICP-RIE) with Cl_2/BCl_3 plasma to etch the mesa with Cl_2/BCl_3 to isolate the devices from each other. The mesa height is about 200nm. Second, we deposit Ti/Al/Ni/Au by e-beam evaporator as the source/drain metal, then annealing at 850°C, 30s in N_2 for low contact resistance. Then, we use plasma-enhanced chemical vapor deposition (PECVD) to deposit 200nm SiN_x as the passivation layer. To define the gate recess region, reactive-ion etching (RIE) is used to etch SiN_x passivation layer. It should be noted that the diluted KOH passivation is conducted after gate recessed etch to recover the recessed area. The sample is treated in diluted KOH solution at 120ºC for 5 minutes. Next, we choose Al_2O_3 deposited by atomic layer deposition (ALD) as the gate oxide for its high dielectric constant. Subsequently, Ni/Au is evaporated by e-beam evaporator as the gate electrode. Last, we use BOE to remove Al_2O_3 and RIE to etch the SiN_x on the source/drain metal to open the contact via hole. Finally, our devices are finished. The full fabrication process is shown below.

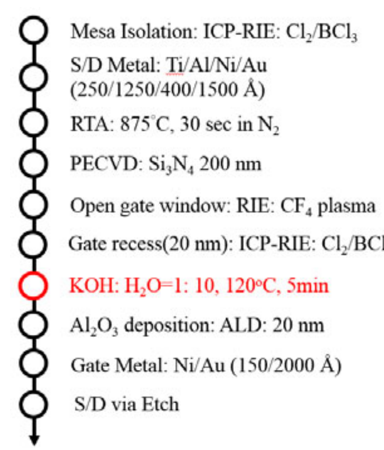

Fig. 1. Process flow: the KOH passivation is conducted after gate recessed etch.

Extremely slow etching rate (about 1 Å per second) of gate-recessed process is delivered by ICP-RIE with Cl_2/BCl_3 plasma (shown in fig. 2.), and this is the reason why we can control the recessed depth precisely. Since the KOH has an extremely slow etching rate to GaN [4], the KOH passivation can smoothen the recessed surface and ease the scattering effect.

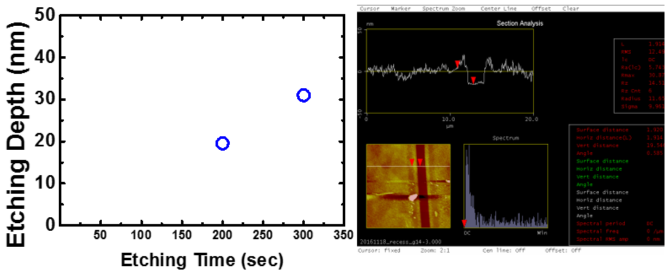

Fig. 2. For 200s etching time, the etching depth is 19.5 nm, and for 300s etching time, the etching depth is 30.9 nm.

DEVICE CHARACTERISTICS AND DISCUSSION

Devices characterized 2-µm-recessed width as gate length (L_G), The distance of gate-to-source (L_{GS}) and gate-to-drain (L_{GD}) are both 3µm. To prove that our KOH treatment provides obvious improvement to our device, we prepare another MOSHEMT device with the same layer structure and fabrication process except the KOH passivation as our control group.

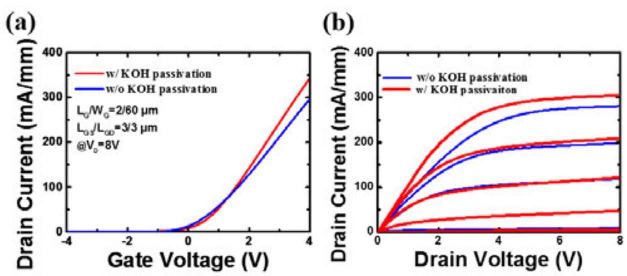

Fig. 3. (a) The transfer curve indicates a positive V_{TH} shift after KOH passivation. (b) I_D-V_D plot indicates that lower R_{ON} and higher I_{ON} are obtained with KOH passivation.

The transfer curve is shown in fig. 3(a). The V_{TH} is 0.61V (through the KOH passivation) and 0.47V (without the KOH passivation) by linear extraction, respectively. At overdrive voltage = 2 V, the on-state current is also larger after the treatment (202 mA/mm vs. 165 mA/mm). In fig. 3(b), lower on resistance (9.29 Ω-mm) is achieved by this treatment, too. To investigate whether the KOH passivation improves the channel resistance, we compare the on resistance with different gate length, and the plot is shown in fig. 4. The sheet resistivity of channel is 3596 Ω/□ without the KOH passivation. After our treatment, the sheet resistivity decreases to 2777 Ω/□. This significant reduction of the channel sheet resistivity presents a convincing evidence that the KOH passivation optimizes the recessed area.

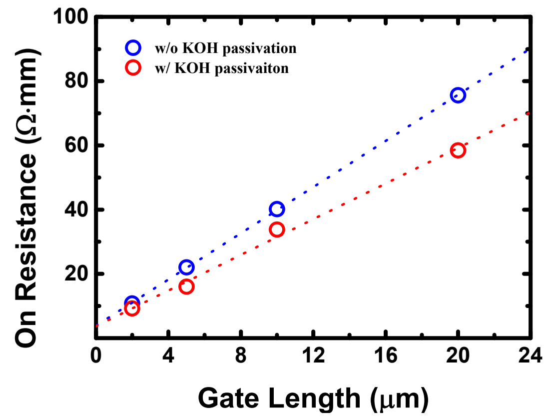

Fig. 4. On resistance vs. gate length. The sheet resistivity under the gate is 3596 Ω/□ without the KOH passivation. Through our treatment, the sheet resistivity reduced to 2777 Ω/□.

CV measurement at 1 MHz is conducted in order to observe the hysteresis, shown in fig. 5. The hysteresis reduced from 0.8 V to 0.6 V with KOH passivation, and it shows the interface of the oxide and GaN becomes better. The split-CV method is used to extract the carrier mobility, as shown in fig. 6. The peak carrier mobility is about 300 cm^2/V-s for the device with KOH passivation, while the peak carrier mobility of the other device is only 195 cm^2/V-s. The KOH passivation treatment shows significant improvement for the carrier mobility, and it proves that the scattering effect is obviously eliminated.

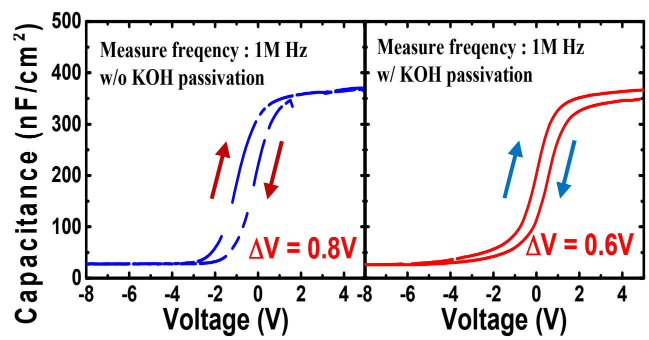

Fig. 5. Hysteresis reduced from 0.8V to 0.6V through the diluted KOH passivation.

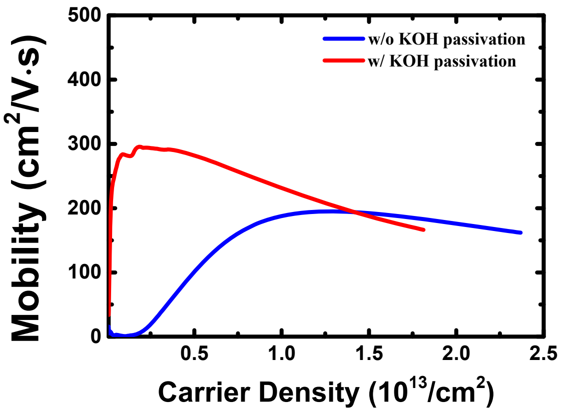

Fig. 6. Without KOH passivation, the carrier mobility is only 195 $cm^2/V \cdot s$. However, the carrier mobility has great increase (up to 300 $cm^2/V \cdot s$) after the recessed surface recovery by diluted KOH.

CONCLUSIONS

We introduce a convenient, simple and effective treatment to optimize the performance of AlGaN/GaN MOSHEMTs. The diluted KOH solution is adopted to recover the recessed surface. The scattering effect is apparently eased with diluted KOH passivation. More positive V_{TH} (0.61 V), higher on-state current (202 mA/mm), lower on resistance (9.29 Ω-mm) and less hysteresis (0.6 V) are obtained by this recessed-area treatment. This treatment shows promising potentials to be a standard process for AlGaN/GaN HEMTs with recessed-gate structure to eliminate the bombarded damage induced by ICP-RIE.

TABLE I
Comparison with the device performance with and without the KOH passivation

	V_{TH} (V)	I_{ON} (mA/mm)	R_{ON} (Ω-mm)	Hysteresis (V)
w/o KOH passivation	0.47	165	11.49	0.8
w/ KOH passivation	0.61	202	9.29	0.6

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