Suppression of Anomalous Electrochemical Etching by Reducing Dissolved Oxygen in Deionized Water for HEMT Process

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Abstract

In the InGaAs/AlGaAs HEMT fabrication process, we found an anomalous etching phenomena of the recess region during rinse process in deionized water. The anomalous etching occurred at the boundary between the n-type channel region and the isolation region, and at the gate recess region around the Al/Ti gate. This can be understood as an electrochemical etching effect caused by metal electrodes(cathode) and GaAs surface in the recess region(anode). In this paper, we describe such a phenomenon then propose a method to suppress that.

Introduction

RF performance of P-HEMT strongly depends on the cross-sectional profile of the gate recess region[1], and it has been reported that an electrochemical effect during recess etching results in non-uniform profile, which causes a serious degradation of the performance of the device and its uniformity[2-4]. Such an electrochemical effect has been observed under the condition that both of the GaAs surface and the ohmic electrode are electrically connected to each other and exposed to an etching solution. To avoid this problem, it is effective not to expose the ohmic electrode during recess etching process.

However, we have recently observed the phenomena not only during the wet chemical etching but also during the rinse process using deionized water[5,6]. In this paper, we clear the mechanism of the anomalous electrochemical etching in P-HEMT then propose to suppress such a problem.

Fabrication Process

The layer structure of P-HEMT was 100nm GaAs/100nm AlGaAs buffers, 10nm AlGaAs doped layer, 3nm AlGaAs spacer, 10nm InGaAs channel, 5nm GaAs spacer, 26nm AlGaAs doped layer, 50nm GaAs Schottky layer and 50nm GaAs cap layer. The layers were grown by MBE on a GaAs substrate. Fig.1 shows the fabrication process of p-HEMT. At first, the device was isolated by oxygen ion implantation at 80keV and 160keV, and Au/Ni/Au-Ge ohmic electrodes were formed. Next, silicon nitride film of 0.1µm thick was deposited by the plasma enhanced CVD, and 0.1µm gate pattern was formed by RIE using EB resist as a mask.

Fig.1 Fabrication process of 0.1µm gate P-HEMT

Then photo resist pattern for T-gate top portion was formed using i-line lithography. The gate recess etching using SiN opening was performed by H_3PO_4 and H_2O_2-based etchant with monitoring Idss. In the recess etching, only the gate recess region was exposed to the etching solution and the other region including ohmic metal was covered with photo resist. Finally Al/Ti gate electrode was formed by lift-off technique. In the rinse process, deionized water of the resistivity of 18Mohm with the dissolved oxygen of 8ppm(incorporated from air) was used.

Anomalous Etching Phenomenon and its Mechanism

After the recess etching, we have found that the threshold voltage of P-HEMT “with” SiN opening on the ohmic electrode was about 1V higher than “without” SiN opening. Such a threshold voltage difference resulted from the difference of the recess region profile, as shown in Fig.2. The profile for P-HEMT “without” SiN opening was flat and smooth. On the other hand, for P-HEMT “with” SiN opening, anomalous etching was observed at the boundary between the channel region and the isolated region. Because the ohmic electrode of both P-HEMTs was covered with the photo resist during the recess etching, such a profile difference is thought to be occurred before the recess etching process.

Fig.3 shows the profile of the gate recess region before and after recess etching process. It was found that an anomalous etching profile formed before the recess etching i.e. after the photo resist removal followed by RIE of SiN film. The resist removal accomplished by immersing into an organic solvent then rinsing in the deionized water. The profile just after the organic solvent immersing was confirmed flat. Therefore the anomalous etching shouled be occurred in the deionized water rinsing.

This phenomenon can be understood as an electrochemical etching effect caused by ohmic electrodes(cathode) and GaAs surface in the recess region(anode)[7]. The mechanism is as follows; on the ohmic electrode, the OH^- ions are generated from the cathode reaction between water(H_2O) and dissolved oxygen(O_2), while the anode reaction occurs on the GaAs surface of the recess region and consequently the GaAs is oxidized and etched. The isolated region is etched deeper than the channel n-type region, because hole in the isolated region enhances the anode reaction.

Fig.2 Recess region profiles “with” and “without” SiN opening on ohmic electrode

Fig.3 Recess region profiles before and after recess etching

Fig.4 Cross sectional imageof the recess region around Al/Ti gate

There is another case of anomalous etching occurred. Fig.4(a) shows the cross-sectional TEM image of the gate recess region around the Al/Ti gate. The GaAs surface beside the gate is etched anomalously during the Al/Ti lift-off process. This etching is also understood as an electrochemical etching effect. In this case, the gate metal operates as a cathode.

Fig.5 Dependence of the etching depth after water rinse on dissolved oxygen concentration

Suppression of Anomalous Electrochemical Etching

In order to suppress such an anomalous etching in water rinse process, it thought to be effective to reduce the concentration of OH^- ions, which generated from the dissolved oxygen in the deionized water. To prove that, we used deionized water with reduced dissolved oxygen by the menbrane degassing apparatus, which can reduce the dissolved oxygen concentration(N_{DO}) to less than 1ppb. The rinsing process was performed in the N_2 ambiance to prevent from oxygen solving into the water.Fig.5 shows the dependence of the etching depth at the boundary between the channel and the isolation region on N_{DO}. It is clear that the etching depth decreases as N_{DO} is reduced. As a consequence of the rinse process using 2ppb water, the profile of the gate recess region was ideal compare to that treated by 8ppm as shown in Fig.6. The SiN opening area on the ohmic electrode(S_{OM}) of the sample was 100 x 100 μm^2.

Fig.6 Recess region profiles after deionized water rinse with dissolved oxygen concentration of 8ppm and 2ppb

Fig.7 Dependence of etching depth after water rinse on SiN opening area on ohmic electrode

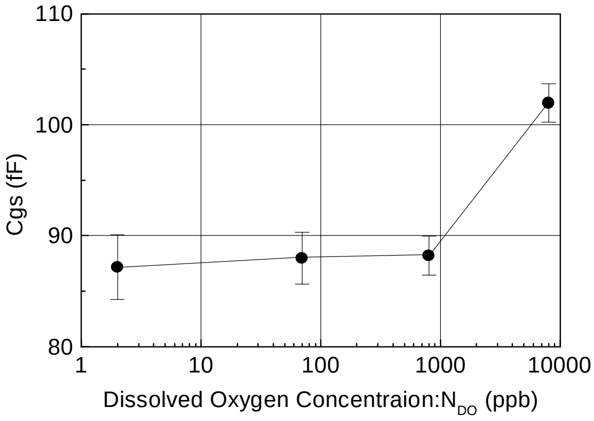

Fig.8 Dependence of gate source capacitance on dissolved oxygen concentration

We investigated the relationship between the etching depth and S_{OM} as shown Fig.7. In case of the water rinse at N_{DO} of 8ppm, the etching depth increased as S_{OM} increased. On the other hand, at N_{DO} of 2ppb, the etching depth was almost zero regardless of S_{OM}.

Fig.8 shows N_{DO} dependence of the gate source capacitance(Cgs), which should be affected by the etching depth of GaAs surface beside the gate. It is found that Cgs decreases as N_{DO} reduces, which means the etching depth decreases as N_{DO} reduces. As shown in Fig.4(b), the anomalous etching beside the gate has been successfully suppressed.

Then we fabricated 0.1µm gate P-HEMT using the deionized water of reduced dissolved oxygen in the rinse process. As a result, the cut-off frequency has been improved from 86GHz to 110GHz because of suppressed anomalous etching around the gate region.

Conclusion

In the HEMT device, the anomalous etching was found at the boundary between the channel region and the isolation region, and also at the gate recess region around the gate. This phenomenon occurred during the deonized water rinse process and it can be understood as an electrochemical effect caused by metal electrodes(cathode) and GaAs surface in the recess region(anode). The etching depth depended on the dissolved oxygen concentration in the deionized water. To suppress it, we have reduced the dissolved oxygen in the deionized water used for rinse process, and have successfully suppressed the anomalous electrochemical etching improving cut-off frequency of P-HEMT more than 20 %.

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