Damage Free Etching for Gate Process of GaAs MESFET by ICP Method

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Abstract

Damage free etching is required for the gate etching process in GaAs IC fabrication. While inductively coupled plasma (ICP) is thought to be the low damage etching technique, the degradation of DC characteristics was observed in our GaAs MESFETs. Threshold voltage shifts and Schottky barrier height is decreased. It was confirmed that the control of the antenna power (i.e. applied power to the upper electrode) is essential to obtain damage free etching by ICP. These properties are different from the case of reactive ion etching. We have successfully realized damage free etching by controlling the antenna power, which offers good uniformity and reproducibility of device characteristics.

INTRODUCTION

Dry etching technology has been widely used for GaAs IC fabrication. While reactive ion etching (RIE) is the conventional technique for the gate electrode formation of GaAs MESFET, plasma-induced damage derived from ion bombardment causes the degradation of device performance, such as the degradation of Schottky barrier height and reverse breakdown voltage and the reduction of the drain current [1-2]. Damage free etching is needed to realize suitable device performance.

On the other hand inductively coupled plasma (ICP) is thought to be the low damage etching technique. Since the region of the plasma source and ion acceleration area is separated from each other, incident ion bombardment to GaAs is easily controlled and low damage etching is obtained. However, it was found that the electric property shifts occurred in our GaAs MESFET using ICP for the gate etching process. There has been little discussion on the plasma-induced damage of ICP compared with that of RIE and studies on the mechanism of plasma damage has not been actively pursued. We report that the damage from the antenna power (i.e. applied power to the upper electrode) is dominant compared with the bias power (i.e. applied power to the bottom electrode) by means of ICP. It was found that the control of antenna power is important to obtain damage free etching.

DEVICE FABRICATION AND EXPERIMENTAL

The fabrication of GaAs IC for optic telecommunications has been previously published in detail [3]. The main process of the gate formation of GaAs MESFET is explained as follows.

Figure 1 shows the process flow of gate electrode formation of GaAs MESFET. A silicon nitride film (SiNx) is deposited to the GaAs surface by plasma enhanced chemical vapor deposition (PECVD). The SiNx is the role of the surface passivation and annealing cap for the activation of the implanted ion. The multilevel resist mask is used to define the gate area and the role of the lift-off of the gate metal. The SiNx film was etched off using CF4 gases by means of ICP. The selectivity of SiNx and SiO2 is required for producing an objective size of the gate length. In addition, damage free etching for GaAs is also important to obtain a desirable performance of the device. The ICP reactor consists of the upper electrode using a radio frequency bias 13.56MHz and the bottom electrode using 12.5MHz. After the etching of SiNx, a Ti/Pt/Au gate electrode was formed by electron-beam evaporation and the lift-off process. In order to obtain good Schottky junction, thermal annealing is performed at the temperature of 300 .

The influence of the plasma damage is evaluated by the DC characteristics, such as threshold voltage (Vth) and Schottky barrier height (BH) and so on. The GaAs MESFET has a gate length of 0.8 um and gate width of 20 um. The etching amount of GaAs was measured by a profile-meter. The state of plasma discharge during SiNx etching was investigated by optical emission spectroscopy.

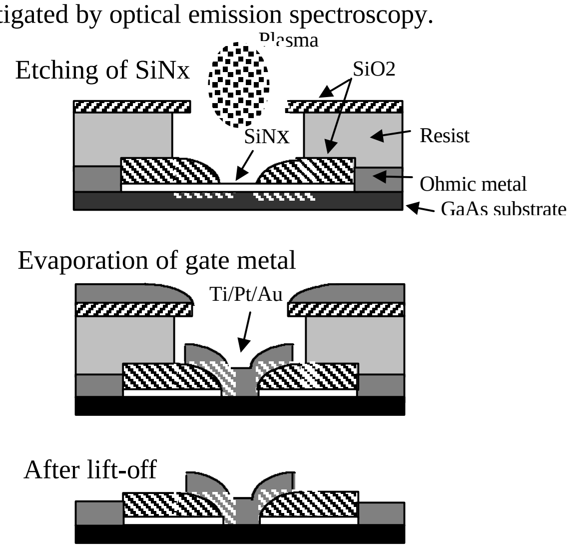

Fig.1 Process flow of gate electrode formation.

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THRESHOLD VOLTAGE SHIFT

Figure 2 shows the dependence of Vth on the bias power in GaAs MESFET. Vth is almost constant at the bias power from 5W to 15W, when the antenna power is constant for 150W. On the other hand Vth is strongly dependent on the antenna power as shown in Figure 3. Vth is shifted to more than +20mV in the positive direction, when the antenna power is 600W and the bias power is 5W. As the bias power generally accelerates the ion activity in plasma, the damage derived from ion bombardment is thought to increase by the increase of bias power. In the case of RIE, the damage is strongly influenced by the bias power. However the properties of ICP are different from those of RIE. Plasma damage may possibly be caused by the antenna power.

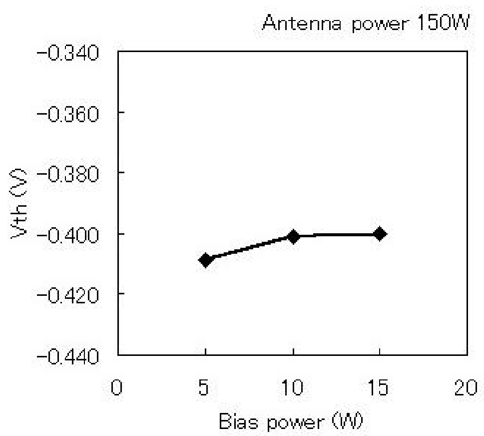

Fig.2 Dependence of Vth on bias power.

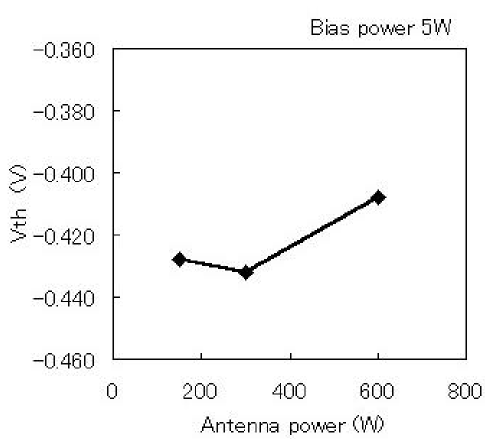

Fig.3 Dependence of Vth on antenna power.

Figure 4 shows the comparisons of the dependency of Vth on the amount of over etching between different ICP conditions. In the gate etching process, over etching time (i.e. GaAs is exposed plasma during that time) is necessary to prevent SiNx from remaining on GaAs surface. When the antenna power is 300W, Vth is clearly changed in proportion to the over etching amount. The absolute value of Vth is changed about +30mV as the over etch amount from 30% to 90%. To the contrary, Vth is almost constant when the antenna power is 150W. These results indicate that the plasma damage is related to the antenna power.

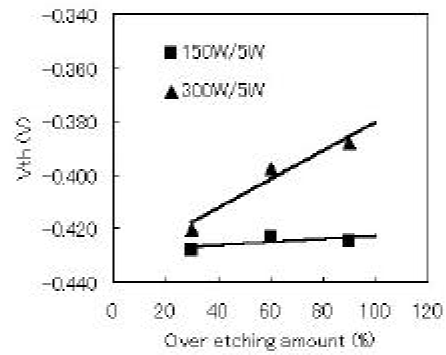

Fig.4 Dependence of Vth on over etchig amount of GaAs substrate.

GAAS SUBSTRATE ETCHING

Vth shift phenomenon usually occurs by the thinning of the channel or the decrease of carrier concentration in the gate region of GaAs MESFET. In order to investigate the mechanism of Vth shifts, we first studied the thinning of the channel due to GaAs etching. The etching rate of GaAs is estimated by a sample with a photo-resist pattern. After etching the sample the etching rate is calculated from the etched GaAs amount measured by a profile-meter.

When the antenna power and the bias power are 300W and 5W respectively, the etching amount of GaAs is not detected by the profile-meter, despite the GaAs's exposure by ICP discharge during 30 minutes. This result indicates that the Vth shift at the antenna power at 300W as shown in Figure 4 is not caused by the thinning of the channel for GaAs MESFET, because the maximum time for GaAs surface to be exposed plasma is less than 2 minutes.

On the other hand the etching rate is about 2.0 nm/min, when the antenna power and the bias power are 600W and 5W, respectively. The etching amount of GaAs as shown in Figure 3 is thought to be negligible, because the over etching time is less than 1 minute. However Vth is shifted more than +20mV at that plasma condition. Plasma damage obviously exists when the antenna power is larger than 300W.

Since the thinning of the channel for GaAs MESFET by the etched GaAs substrate does not cause Vth shift, we have investigated DC characteristics to study the plasma-induced damage. Schottky property is widely used to estimate the interface between the gate metal and GaAs substrate. With the decrease of carrier concentration at the surface of GaAs, there occurs a sensitive change in electric properties. We have measured Schottky forward and reverse current-voltage curves to estimate barrier height (BH), n-value and gate leak current.

SHOTTKY CHARACTERISTICS

Figure 5 shows the correlation between Vth and BH, when the bias power is changed by 5W, 10W and 15W, when the antenna power is constant 150W. There are 15 points data across a 4-inch wafer for each etching condition. BH is slightly decreased depending on the increase of the bias power. Figure 6 shows the correlation between Vth and BH, when the antenna power is changed by 150W, 300W and 600W, when the bias power is constant 5W. The over etching amount is constant for 30% in order to eliminate the time dependent induced damage. BH is obviously decreased in the case of the antenna power for 600W. N-value of Shottky property is also degraded at the condition. It is found that the surface of GaAs is damaged by plasma exposure.

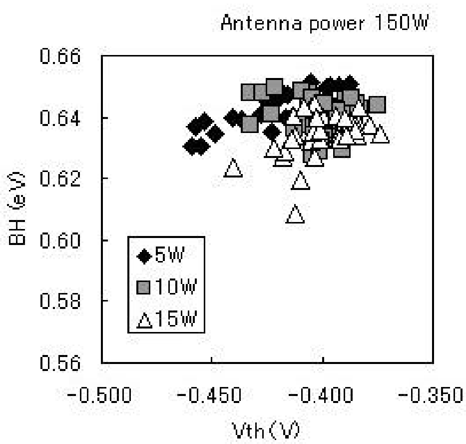

Fig.5 Correlation between Vth and BH with the change of bias power.

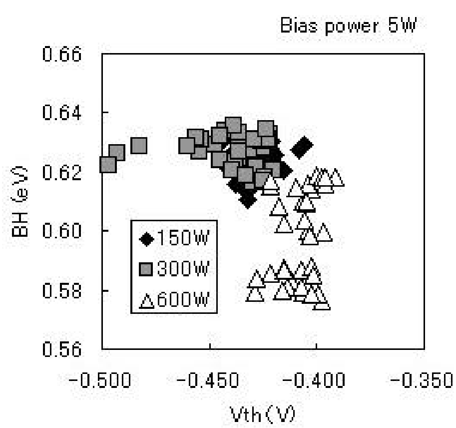

Fig.6 Correlation between Vth and BH with the change of antenna power.

OPTICAL EMISSION SPECTROSCOPY

In order to analyze the state of plasma discharge when the antenna power is 600W, we have investigated the reaction between plasma species and SiNx film by means of optical emission spectroscopy (OES). Plasma emission spectra during and after SiNx etching are shown in Figures 7 and 8, respectively. The vertical axis is the intensity of plasma and horizontal axis is the wavelength of plasma emission.

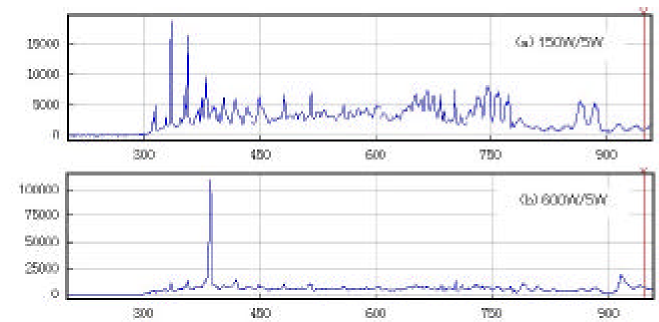

Fig.7 Plasma emitting spectra during etching of SiNx film. (a) antenna power is 150W and bias power is 5W. (b) antenna power is 600W and bias power is 5W.

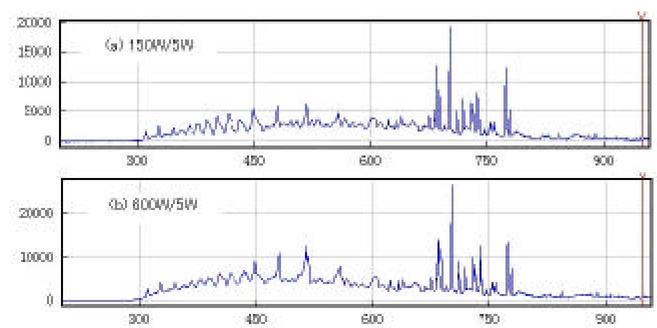

Fig.8 Plasma emitting spectra after etching of SiNx film. (a) the antenna power is 150W and the bias power is 5W. (b) the antenna power is 600W and the bias power is 5W.

In Figure 7(a), the peak of 337 nm is thought to be N2 or CO2 gases. The peaks of 670 nm and the satellite peak around it are mainly N2 gases. The peaks of 704 nm and the satellite peak around it are mainly F gases. In the case of the antenna power for 600W, there is a sharp peak around 390 nm as shown in Figure 7(b). The intensity of plasma emission is very strong compared with other peaks and about ten times higher than the peaks observed in Figure 7(a). The peak around 390 nm is identified as N2 or SiF2. The results of these spectra show that the etching mechanism is different between the two conditions. On the other hand the spectrum is similar to after etching of the SiNx film as shown in Figure 8. The plasma damage then appears to be induced during SiNx etching. The reaction between the plasma species and SiNx film is different in the case of 150W and 600W. This suggests that other plasma species or reactions related to the peak around 390 nm damages the GaAs crystalline or fluorine residue remains on GaAs as surface contamination. These factors are thought to influence the degradation of Shottky property and Vth shifts.

DISTRIBUTION MAP OF THRESHOLD VOLTAGE

The results of this study reveal the importance of damage free etching in GaAs IC fabrication to control the antenna power of ICP. We have determined the etching condition for gate process; the antenna power and the bias power are 150W and 5W, respectively. Figure 9 shows the distribution map of Vth across a 4-inch wafer. Test patterns of GaAs MESFET are placed in a rectangle area (i.e. shot) as shown in Figure 9.

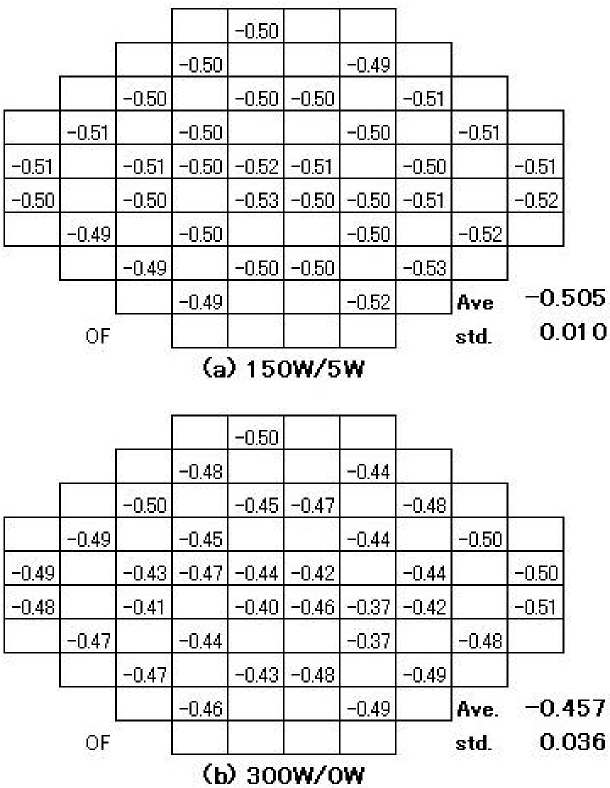

Fig.9 Distribution map of Vth across a 4-inch wafer. (a) antenna power is 150W and power is 5W. (b) antenna power is 300W and bias power is 0W.

In the case of the antenna power for 150W and the bias power for 5W, the uniformity of Vth is good, that is the standard deviation is 10mV for GaAs MESFET of the gate length 0.8 um. To the contrary the uniformity of Vth is degraded, when the antenna power and the bias power are 300W and 0W, respectively. Although the bias power is 0W, Vth is affected by the antenna power for 300W. The distribution of Vth is like concentric circles. The etching rate of GaAs is faster at the center of the wafer. As shown in Figure 4, Vth shift is dependent on the over etching amount of GaAs. This means that plasma-induced damage by the antenna power should be reduced to avoid the Vth shift. We have successfully demonstrated a quite stable etching process by controlling the antenna power of ICP. Therefore the reproducibility of Vth from lot to lot is accomplished within ±40mV and the through-put of the gate process by ICP is higher than that using RIE for the high-density plasma in GaAs IC fabrication.

CONCLUSIONS

Plasma-induced damage occurs in the gate etching process of GaAs IC by using ICP. Vth shifts and the degradation of BH are observed in GaAs MESFET. This degradation of DC characteristics is strongly influenced by the antenna power of ICP. It is different from the mechanism of RIE, in that ion bombardment derived from the bias power with the bottom electrode is mainly dominant. In the case of the antenna power for 600W compared with 150W, the plasma emission spectrum shows sharper peak around 390nm, which is identified as N2 or SiF2. This suggests that the different reaction between SiNx and plasma species occurred at the antenna power of 600W. It was found that the control of antenna power is important to obtain damage free etching. We accomplished quite stable etching process by the antenna power of ICP decrease to 150W.

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