Recessing Process for Au-free Ohmic Contacts Formation on AlGaN/GaN Heterostructures with AlN Spacer

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Abstract

The formation of recessed Au–free ohmic contacts on AlGaN/GaN heterostructures having an AlN spacer layer is investigated for a wide range of etch conditions using BCl_3 chemistry and an ICP etch system. The impact of the AlGaN recess depth and profile is characterized as a function of etch time, bias and ICP powers. The best ohmic contact performance of about 0.5 Ohm.mm is obtained for a low bias power together with a high ICP power when the AlGaN barrier is thinned down to a few nanometers and the recessed contacts have a rounded edge profile. However, further recess of the AlGaN barrier leads to a degradation of the ohmic contact performance.

INTRODUCTION

HEMT's based on AlGaN/GaN heterostructures are the devices of choice for the next generation of high power electronics. The introduction of a thin AlN spacer layer in between the GaN channel layer and the AlGaN barrier layer has been proven to be one possible solution to further decrease the on−resistance of the HEMT devices by increasing both the sheet carrier concentration and the electron mobility in the 2−DEG [1]. However, the presence of an AlN spacer layer which is having a wide band gap 6.1eV makes the formation of ohmic contacts difficult. To overcome this problem, partial or complete AlGaN recess prior to metallization has been shown to significantly facilitate the formation of Au−based [2] and Au−free [3, 4] ohmic contacts on AlGaN/GaN heterostructures with an AlN spacer. Cl−based dry etching techniques are generally applied to the AlGaN and AlN recess. However, during dry etching, plasma damage can generate defects in the AlGaN layer and as a result can degrade the electrical properties of the ohmic contacts.

In this work, we investigate the formation of recessed Au−free ohmic contacts on AlGaN/GaN heterostructures over a wide range of recess conditions using an ICP etch system. In order to evaluate any plasma damage, ohmic contacts were processed on heterostructures with an AlN spacer and compared to those fabricated on heterostructures without an AlN spacer. The role of the recessing profile on the formation of Au−free ohmic contacts is then discussed.

EXPERIMENTAL DETAILS

The undoped AlGaN/GaN heterostructures were grown on (111) Si wafers by MOCVD. Two epitaxial structures were investigated: with or without an AlN spacer layer in between the GaN channel layer and the AlGaN barrier layer. An in−situ grown Si_3N_4 was used as a capping layer. The openings for ohmic contacts were formed by ICP etching. Si_3N_4 was etched using CF_4−based chemistry end pointing on AlGaN. Then, the AlGaN barrier was recessed in BCl_3−based chemistry using 10 W bias power, 1300 W ICP power and etch times ranging from ~ 100 to 250s leading to different recess depths. Once the optimal recess depth determined, the bias power was varied from 10 to 60 W, and the ICP power was changed from 300 to 1800 W and the etch time was adjusted to reach the same targeted depth. The metallization was done by sputter deposition of Ti/Al/TiN annealed at 850°C under Nitrogen ambient in a RTP furnace [4]. Finally, device isolation was performed by Nitrogen implantation.

The recessing profile and surface morphology of the etched AlGaN layer were characterized by AFM. The electrical characteristics of the contacts were assessed by TLM structures from which the ohmic contact resistance and the 2−DEG sheet resistance were extracted using the four−point probe method. The contact width is 100 µm, the contact length is varying from 2 to 6 µm, and the contact spacing is ranging from 2 to 18 µm.

RESULTS AND DISCUSSION

Etching layers with multiple compositions in the AlGaN/GaN heterostructures is challenging because the etch rate depends on the Al content. An etch approach which is non−selective would be beneficial from uniformity and repeatability aspects. Therefore, we developed a slow and non−selective etch process based on BCl_3 chemistry. The etch rate of AlGaN was examined as a function of bias and ICP powers, and compared to GaN and AlN etch rates (Fig. 1). Etch rates were determined by measuring the depth of the etch features with AFM. The AlGaN layer used in this study etches ~ 0.08nm/s at a relatively low bias power of 10W and for 800W ICP power. Similar removal rates were achieved for GaN and AlN layer under identical conditions. At a higher bias power of 60 W, AlN etches slightly slower than GaN and AlGaN (Fig. 1a). The linear correlation between bias power variation and etch rate indicates a physical etch component next to a chemical component. By increasing the bias power, the physical component of the etch process is enhanced and the etch process tends to become selective towards AlN. On the other hand, for a bias power of 30 W an increase of the ICP power does not have an influence on the etch selectivity (Fig. 1b). The linear correlation between ICP power variation and etch rate indicates a chemical etch component next to the physical component. By increasing the ICP power, the amount of etch species (ions and radicals) is increased.

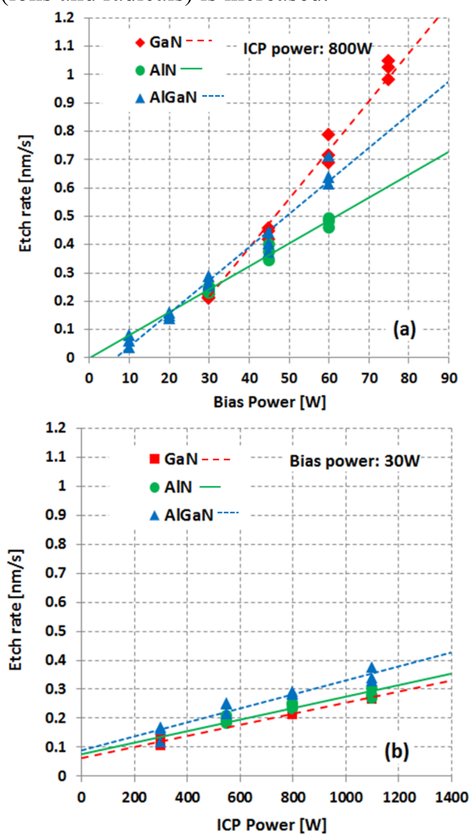

Fig. 1. Etch rate of AlGaN compared to GaN and AlN as a function of (a) bias power and (b) ICP power for BCl_3 etching process.

To determine the optimum recess depth resulting in low contact resistance, ohmic contacts were first processed on AlGaN/GaN heterostructures without an AlN spacer. While keeping the etch conditions unchanged (10 W bias power and 1300 W ICP power), the etch time was increased from 105 to 250s leading to different recess depths (Fig. 2). In the case of 200s and 250s, the recess etch was done till below the 2−DEG and the AlGaN barrier was completely removed in the center of the contacts. Moreover, the etch time has an impact on the recessing profile especially for narrow contacts. By increasing the etch time, the rounding of the bottom profile increases for narrow contacts (Fig. 2b) while the profile remains straight for large contacts with some roughness over 400 nm close to the contact edges (Fig. 2a).

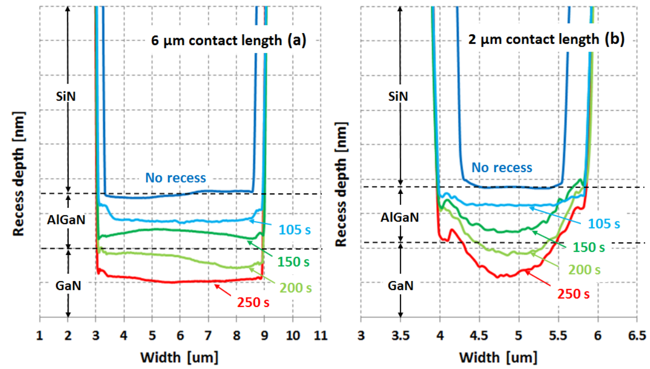

Fig. 2. AFM scans of the recessing profile after BCl_3 etching process as a function of etch time with 10 W bias power and 1300 W ICP power.

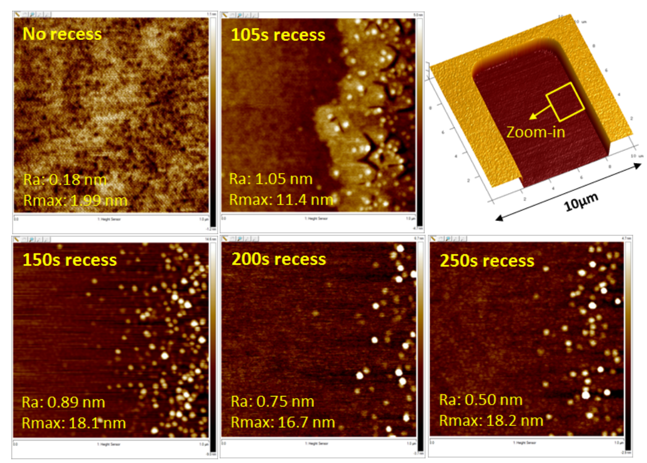

Fig. 3. AFM images (1 µm x 1 µm scan) of the AlGaN and GaN surfaces after BCl_3 etching process as a function of etch time with 10 W bias power and 1300 W ICP power.

Fig. 3 shows the corresponding AFM images of the AlGaN and GaN surfaces at the contact edges after BCl_3 etching for the different etch times.

Fig. 4 shows the contact resistance as a function of etch time for different contact lengths, and Fig. 5 reports the corresponding saturation current. Low resistive ohmic contacts were successfully obtained ~ 0.2−0.5 Ohm.mm without any AlGaN recess. Further recess etching leads to a clear increase of the contact resistance by 40% and in general to a degradation of the contact performance. It is believed that carrier transport by tunneling through the AlGaN barrier is more efficient than sidewall contact of the ohmic metal to the 2−DEG at the edges of the contacts.

The same variation in etch times was performed on AlGaN/GaN heterostructures with an AlN spacer. Fig. 6 shows the corresponding contact resistance values. While low resistive ohmic contacts were successfully obtained without AlGaN recess on heterostructures without an AlN spacer, significantly higher contact resistance values were achieved without AlGaN recess on heterostructures with an AlN spacer.

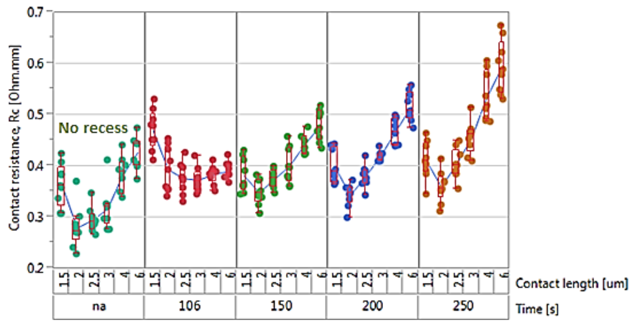

Fig. 4. Contact resistance of ohmic contacts on AlGaN/GaN heterostructures without an AlN spacer as a function of etch time with 10 W bias power and 1300 W ICP power.

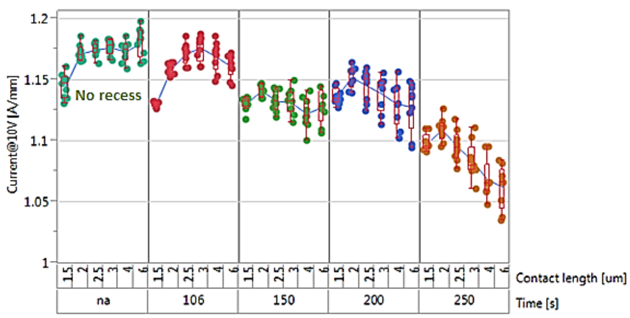

Fig. 5. Saturation current measured at 10 V on ohmic contacts on AlGaN/GaN heterostructures without an AlN spacer as a function of etch time with 10 W bias power and 1300 W ICP power.

The best ohmic contact performance of about 0.5 Ohm.mm was obtained when the AlGaN barrier was recessed down to several nanometers (105s and 150s etch times). The barrier is thick enough to generate 2−DEG and thin enough to allow tunneling through the barrier, contributing to low contact resistance values [2, 4]. Therefore, direct sidewall contact made by the ohmic metal to the 2−DEG around the edges of the contacts appears to be a more efficient carrier transport mechanism than through the full contacts, which is opposite for ohmic contacts processed on heterostructures without an AlN spacer. However, further recess of the AlGaN barrier resulted in the degradation of the ohmic contact performance as seen in Fig. 7. This is due to the complete removal of the AlGaN barrier: the 2−DEG cannot accumulate at the interface anymore, so there is no more tunneling possible especially for large contact openings.

In order to define the optimum ICP power having the lowest plasma damage and leading to the lowest contact resistance, ohmic contacts were first processed on AlGaN/GaN heterostructures without an AlN spacer. The etch times were adjusted as a function of ICP power for keeping the AlGaN recess depth constant (~ 6 nm of remaining AlGaN). As shown in Fig. 8, the ICP power has an impact on the recessing profile. By increasing the ICP power the rounding of the recessing profile increases for narrow contacts (Fig. 8b) while the profile remains unchanged for large contacts (Fig. 8a).

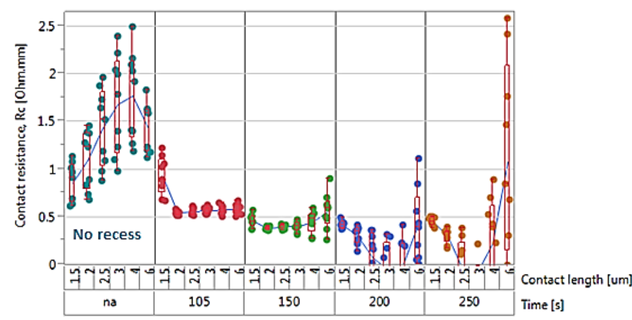

Fig. 6. Contact resistance of ohmic contacts on AlGaN/GaN heterostructures with an AlN spacer as a function of etch time with 10 W bias power and 1300 W ICP power.

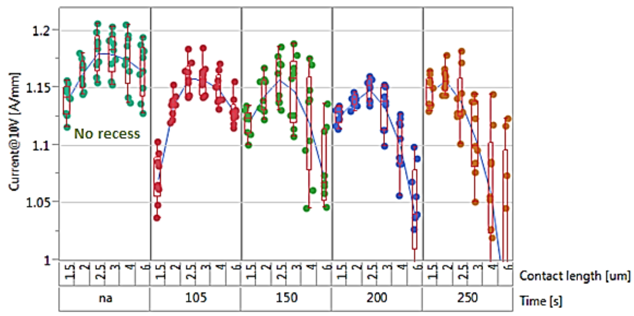

Fig. 7. Saturation current measured at 10 V on ohmic contacts on AlGaN/GaN heterostructures with an AlN spacer as a function of etch time with 10 W bias power and 1300 W ICP power.

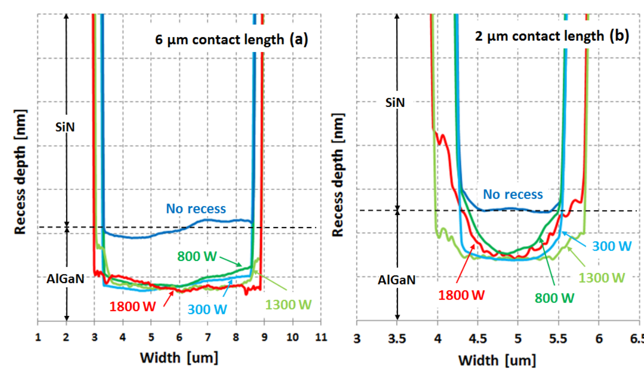

Fig. 8. AFM scans of the recessing profile after BCl_3 etching process as a function of ICP power with a bias power of 10 W.

Fig. 9 and Fig. 10 show the corresponding contact resistance and saturation current for different contact lengths. The optimum etch conditions were obtained with a bias power of 10 W and an ICP power of 1800 W. Low resistive ohmic contacts were successfully obtained ~ 0.4 Ohm.mm and almost equivalent to that on heterostructures without AlGaN recess ~ 0.35 Ohm.mm.

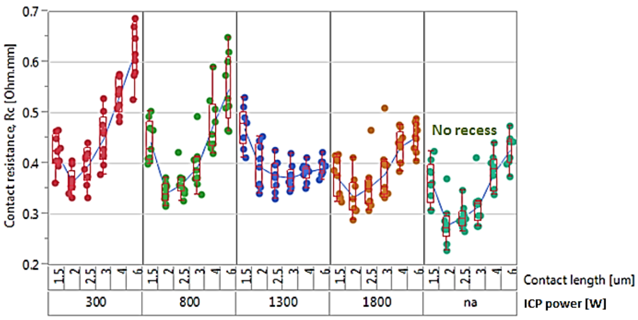

Fig. 9. Contact resistance of ohmic contacts on AlGaN/GaN heterostructures without an AlN spacer as a function of ICP power under a bias power of 10 W.

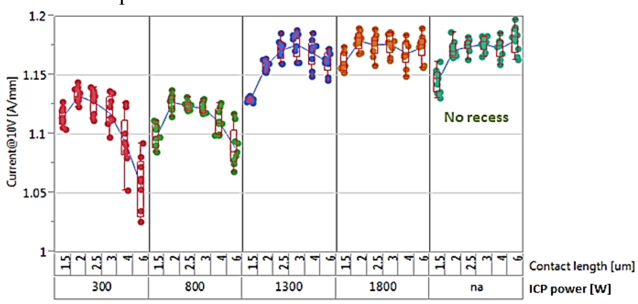

Fig. 10. Saturation current measured at 10 V on ohmic contacts on AlGaN/GaN heterostructures without an AlN spacer as a function of ICP power under a bias power of 10 W.

The same variation in etch conditions was performed on AlGaN/GaN heterostructures with an AlN spacer, and Fig. 11 shows the corresponding contact resistance values. Low resistive ohmic contacts were obtained around 0.5 Ohm.mm sufficiently equivalent to that on heterostructures without an AlN spacer layer. The best ohmic contact performance of about 0.5 Ohm.mm was obtained for a low bias power together with a low ICP power, in contradiction to heterostructures without an AlN spacer. By decreasing the ICP power, the AlGaN barrier around the edges of the contacts is thinned down enough to allow tunneling through the barrier. Furthermore, for both types of heterostructures, a decrease in saturation current was observed when decreasing the ICP power (Figs. 10 and 12). It is most probably related to plasma damage because of the high bias voltage applied at low ICP power [6].

CONCLUSIONS

In this work, ohmic contacts on AlGaN/GaN heterostructures having a thin AlN spacer layer were investigated over a wide range of etch conditions. It was shown that the contact resistance is controlled by the AlGaN recess depth and the recessing profile. Using the optimum etch conditions, ohmic contacts fabricated on heterostructures with an AlN spacer exhibit low contact resistance values ~ 0.5 Ohm.mm comparable to those processed on heterostructures without an AlN spacer, which is essential to achieve high performance devices.

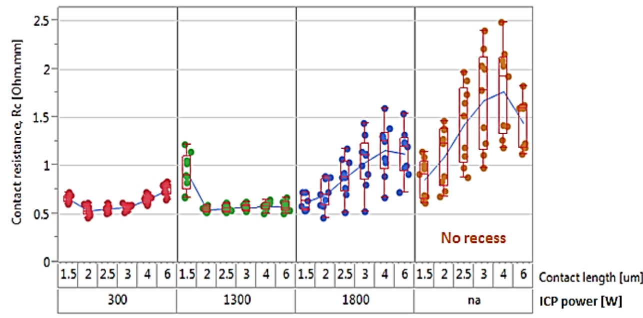

Fig. 11. Contact resistance of ohmic contacts on AlGaN/GaN heterostructures with an AlN spacer as a function of ICP power under a bias power of 10 W.

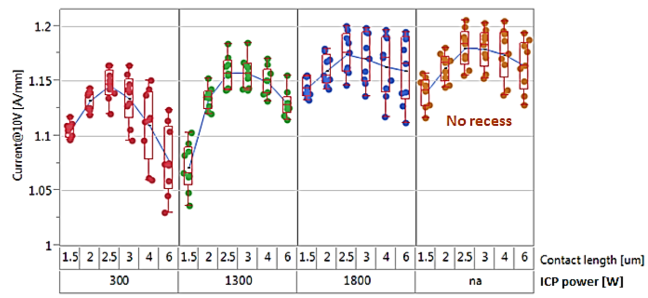

Fig. 12. Saturation current measured at 10 V on ohmic contacts on AlGaN/GaN heterostructures with an AlN spacer as a function of ICP power under a bias power of 10 W.

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ACRONYMS

2−DEG: Two−Dimensional Electron Gas
AFM: Atomic Force Microscopy
ICP: Inductively Coupled Plasma
HEMT: High−Electron−Mobility Transistors
MOCVD: Metal Organic Chemical Vapor Deposition
RTP: Rapid Thermal Processing
TLM: Transmission Line Method