Application of $Cl_2/BCl_3/Ar$ Plasma Tretment in the Improvent of Ti/Ai/Mo/Au Ohmic Contacts

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Abstract. *Significant improvement of Ti/Al/Mo/Au ohmic contacts deposited on previously $Cl_2/BCl_3/Ar$ plasma treated surface was observed. The standard deviation of contact resistance was crucially reduced due to the incorporation of $Cl_2/BCl_3/Ar$ plasma treatment. The Cl_2:BCl_3:Ar gas mixture was used in order to thin the top of AlGaN layer prior to deposition of Ti/Al/Mo/Au ohmic contacts. The surface morphology of AlGaN was investigated using scanning electron microscopy and atomic force microscopy. TLM measurements revealed a consequential decrease of contact resistivity.*

Keywords

AlGaN, GaN, ohmic metallization, recess, Ti/Al/Mo/Au.

1. Introduction

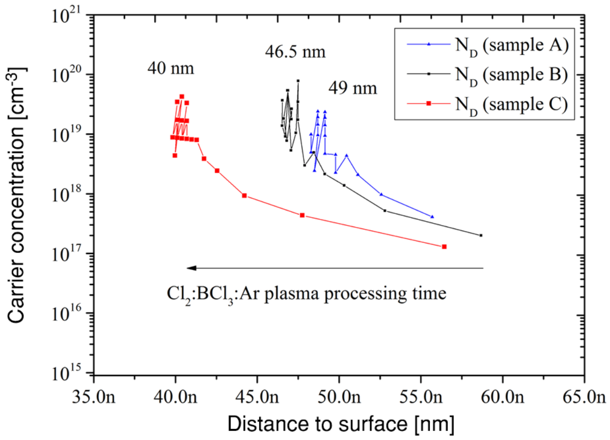
Gallium nitride and aluminium gallium nitride are the materials used for high frequency power devices including high electron mobility transistors (AlGaN/GaN HEMTs). The fabrication of advanced AlGaN/GaN HEMTs requires elaborating of low-resistance ohmic contacts to AlGaN/GaN heterostructures [1]. In spite of technological advance achieved in recent years [2] there are still some challenges regarding the improvement of ohmic contacts parameters, especially in case of Ti/Al based contacts. It is a common practice to introduce thin AlN layer to suppress Al alloy scattering in HEMTs. However, by incorporation of wide band gap material it is even more difficult to create high quality ohmic metallization. One of the available technological approaches is BCl_3-based plasma treatment [1], [2], [3], [4] due to deoxidizing of heterostructure surface. Without sputter desorption it is possible to deposit B_x-Cl_y which contributes to the increase of contact resistance [5]. The addition of Cl_2/Ar enhances the process of AlGaN etching due to sputtering effect. In result, the distance between the metallization and two dimensional electron gas (2DEG) is decreased which affects contact resistance.

2. Experiment

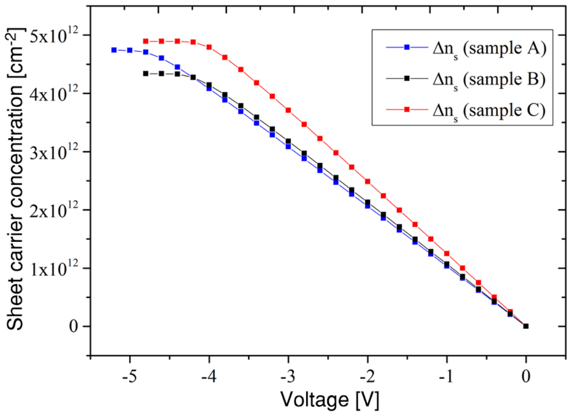
The $Al_{0.2}Ga_{0.8}N$/GaN heterostructures were deposited on 2" sapphire substrates using low pressure MOVPE process (3×2"). The heterostructures consisted of about 50 nm thick $Al_xGa_{1-x}N$, AlN spacer (1.6 nm) and 2.35 µm thick unintentionally doped GaN layer. The surface was etched in H_2SO_4 ($t = 3$ min), then exposed to N_2O ($t = 3$ min) and N_2 ($t = 3$ min) plasma in order to get rid of contamination.

After surface pre-treatment the heterostructures were exposed to plasma in RIE system using the following conditions: $P = 150$ W, $p = 20$ mTorr (2.66 Pa), $T = 7$ °C, Cl_2:BCl_3:Ar (7:3:5) in parallel plate reactor. The etch rate evaluation was based on measuring etch depth using atomic force microscope (AFM). For mentioned conditions the etch rate of $Al_{0.2}Ga_{0.8}N$ was 5±1 nm·min^{-1} [3]. By modifying processing time, the thickness of the top AlGaN layer was varied for $Al_{0.2}Ga_{0.8}N$/GaN heterostructures.

Three samples (A, B, C) were etched in such conditions in order to decrease AlGaN thickness and to strip the native oxide of the surface. For reference, sample O (unetched) was examined. The remaining thicknesses of plasma treated AlGaN layers were presented



(a) Carrier concentration (N_D).



(b) Sheet carrier concentration.

Fig. 1: Carrier concentration (N_D) in function of distance to surface and sheet carrier concentration of 2DEG in function of applied voltage. Evaluation was based on C-V Hg-probe measurement.

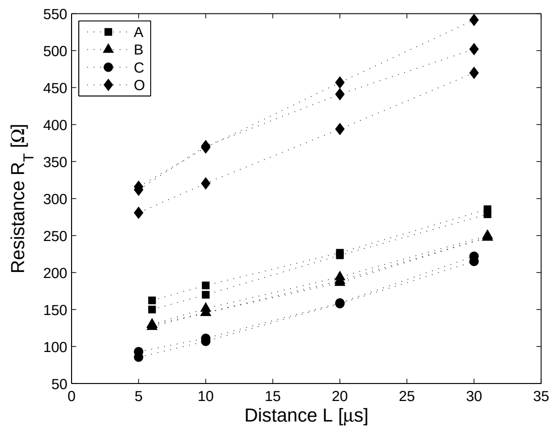
in Fig. 1. The C-V measurement of carrier concentration and sheet charge concentration using Hg probe gave an information about remaining thicknesses for investigated heterostructures. The heterostructures were annealed in a nitrogen ambient at 825 °C ($t = 60$ s) in order to improve heterostructure properties.

After the definition of an active region (mesa etching), the TLM (Transfer Length Method) [6] structures were deposited on previously etched AlGaN surface. The metallization consisted of Ti/Al/Mo/Au (230/1000/ 450/1700) [7]. After that, the heterostructures were annealed once again in a nitrogen ambient at 825 °C in order to form ohmic contacts.

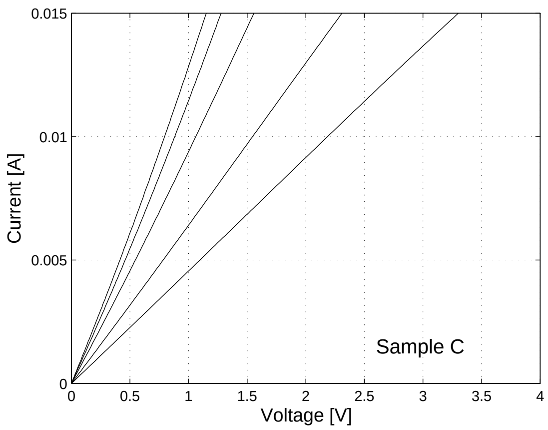
3. Results and Discussion

The evaluation of etch depth was based on AFM measurements and performed C-V measurements. From C-V curve it was possible to derive carrier concentration profile (Fig. 1(a)). The width of depletion region under mercury probe was evaluated under assuming it was a parallel plate capacitor. The sheet carrier concentration (n_s) was evaluated using the integration of carrier concentration profile. From the slope of the variation of 2DEG sheet carrier concentration (Fig. 1(b)) it was also possible to evaluate thickness of AlGaN layer after etching.

Significant improvement of Ti/Al/Mo/Au contact resistance was observed for contacts deposited on previously plasma treated and pre-annealed $Al_{0.2}Ga_{0.8}N$/GaN heterostructures. Contact resistance (R_c), contact resistivity (ρ_c) and transfer length (L_T) were calculated using TLM method which relies on calculation of total resistance (R_T) in function of distance (L) between adjacent metallization pads (Fig. 2(a)) from I-V characteristics (Fig. 2(b)). Values of contact resistance (R_c) and corresponding standard error calculated from linear fitting of curves (Fig. 2(a)) for investigated heterostructures were presented in Tab. 1.



(a) Total resistance R_T.



(b) I-V charasteristic.

Fig. 2: Total resistance (R_T) in function of adjacent Ti/Al/Mo/Au pads and corresponding I-V characteristic of sample C.

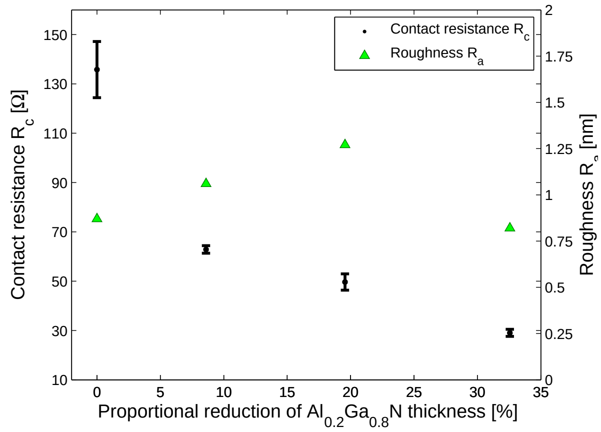
Tab. 1: Contact resistance (R_c) and corresponding standard error along with proportional reduction of thickness for investigated samples size.

Sample	Contact resistance R_c (Ω)	Standard Error (Ω)	Proportional reduction of $Al_{0.2}Ga_{0.8}N$ thickness (%)
O	135.78	5.70	0 (unetched)
A	62.85	1.53	8.7
B	49.65	3.32	19.5
C	29.02	1.43	32.6

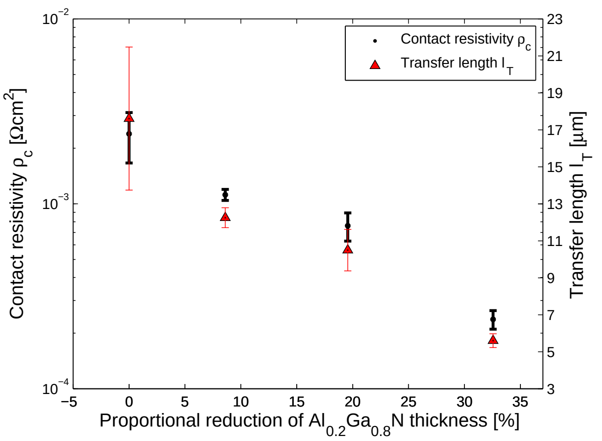
Even though proportional reduction of AlGaN thickness was significant (32.6 %), the surface roughness of plasma treated and as-grown samples was similar ($R_a < 1.5$ nm) as it was depicted in Fig. 3(a). Surface roughness deterioration of AlGaN caused by ion bombarding did not affect contact resistance (R_c). Similar non-affecting influence of surface roughness was observed for specific contact resistivity (ρ_c) and transfer length (L_T) (Fig. 3(b)). Surface of $Al_{0.2}Ga_{0.8}N$ prior and after etching was depicted in Fig. 4.

It was observed that even insignificant reduction of the AlGaN thickness (8.7 %) gives promising results in achieving lower contact resistivity, contact resistance as well as transfer length improvement. Thinning of AlGaN layer caused by deeper etch depths resulted in further decrease of Ti/Al/Mo/Au contact resistance.

Boron trichloride plasma surface treatment not only removes surface oxide efficiently, but it also introduces surface donor states that contribute to the improvement of ohmic resistance [3]. BCl_x radicals generated

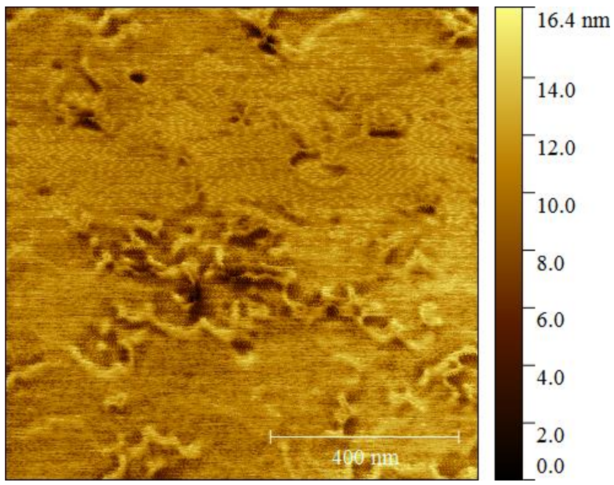


(a) Contact resistance R_c.

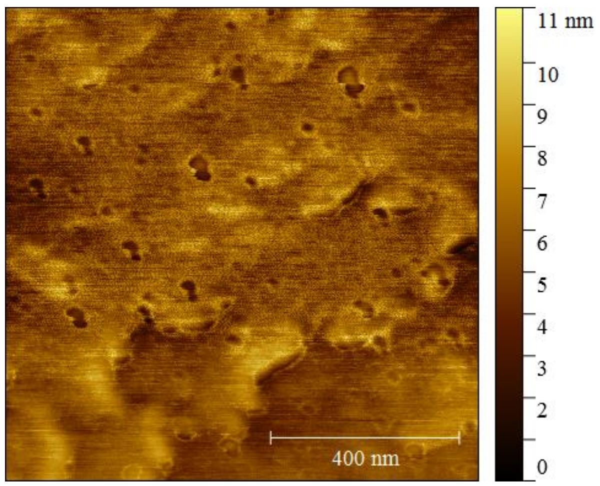


(b) Contact resistivity ρ_c.

Fig. 3: Contact resistance R_c and contact resistivity ρ_c in function of proportional reduction of $Al_{0.2}Ga_{0.8}N$ thickness.



(a) Unetched surface.



(b) Etched surface.

Fig. 4: AFM pictures of unetched (a) and etched (b) surface of Al0.2Ga0.8N/GaN heterostructure (sample B).

by cascade electron impact ionization enhance oxide layer etching by forming volatile B_xOCl_y and B_xO_y etch products which are removed from surface by accompanying ion bombardment. To increase the ion bombardment contribution, Cl_2/Ar gas mixture was added, which helped in preventing from the deposition of B_x–Cl_y passivation layer reported elsewhere [5]. Results presented in Fig. 3 indicate on dependency that predominant factor in the improvement of contact resistance was the reduction of AlGaN thickness. Further improvement of contact resistance can be obtained by forming Ti/Al/Mo/Au contacts at 850 °C [8].

4. Conclusion

The influence of AlGaN layer etching in Cl2:BCl3:Ar plasma on the parameters of Ti/Al/Mo/Au ohmic contacts to AlGaN/GaN heterostructure was investigated. By reducing AlGaN thickness and subsequent annealing at 825 °C in nitrogen ambient we observed the significant improvement of Ti/Al/Mo/Au ohmic contact resistance. Although etching caused gentle deterioration of surface roughness, it is believed that surface roughness did not affect contact resistance significantly. Shrinking the distance between Ti/Al/Mo/Au metallization and two.

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