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Low Ohmic Contact Resistance on AlGaN/GaN Heterostructures Based on Ti/Al/Ti/TiN Metal Stacks

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Abstract

Ti/Al/Ti/TiN based Au-free ohmic contact to AlGaN/GaN heterostructures is investigated by analyzing the influences of contact pre-treatment and barrier thickness on ohmic contact resistance (R_C). With appropriate contact treatment (cleaning) and pre-ohmic recess etching of the AlGaN barrier down to several nanometers are demonstrated to be effective methods to reduce the contact resistance between Ti/Al/Ti/TiN (25/120/20/20 nm) ohmic metals and AlGaN/GaN heterostructures. An extremely low R_C of 0.31 Ω· mm is obtained when 4 nm AlGaN barrier is left with HF (2%), SC1 (H_2O: H_2O_2: NH_4OH=6:1:1) and SC_2 (H_2O: H_2O_2: HCl=6:1:1) pre-cleaning orderly and 45 s annealing at 850 ℃.

1. Introduction

AlGaN/GaN high electron mobility transistors (HEMTs) exhibit excellent device performance because of their inherent material properties [1]. Low resistance ohmic contacts (R_C) are essential for the efficient operation of high power electronic device. At present, the ability to manufacture GaN-on-Si power devices in existing fully depreciated 6-or 8-inch silicon fabrication facilities offers further cost competitiveness to the GaN-on-Si power technology [1]. Therefore, Au-free ohmic contacts to GaN-HEMTs are compatible with standard Si CMOS technologies which are meaningful to developed to satisfy the need of industry production [2]. For now, Ti/Al [2, 3] based and Ta/Si [4] based Au-free metal stacks have been investigated systematically and low resistance (Rc<1 Ω· mm) have achieved. However, ohmic contact based on Ta/Si system should be annealing above 900 ℃, which will result in high density of deep surface/interface states [5]. Ti/Al based ohmic contact metal systems are more widely used, especially for Ti/Al/(Ti)/W and Ti/Al/Ni/Pt, because of low annealing temperature. Nevertheless, there are still some disadvantage for these two metal stacks. (1) Metal W is usually deposited by CVD in Si CMOS fabs, which cannot be deposited together with Ti/Al/(Ti) in the same machine. This may cause oxidation of Al/(Ti) and result in bad connection interface between Al/(Ti) and W. (2) Metal Pt plays the role of deep-level trap in Si CMOS devices, so it is prohibited in Si CMOS fabs.

Recently, we propose Ti/Al/Ti/TiN metal stacks with barrier recessed ohmic contact on AlGaN/GaN HEMTs, enabling the resistance (R_C) decrease to 0.31 Ω·mm. This is much lower than 1.25 Ω·mm reported before [3] and comparable with Ti/Al/W [6] and Ti/Al/Ni/Pt [7] based ohmic contact resistance.

2. Experiment Process

The AlGaN/GaN heterostructure layers were grown on by metalorganic chemical vapor deposition (MOCVD). The epistack consists of a 25-nm $Al_{0.25}Ga_{0.75}N$ barrier layer, a 1-nm AlN insert layer, a 150-nm GaN Channel layer, a 2.8-μm GaN buffer layer, and a 200-nm AlN nucleation layer on Si (111) substrate. The passivation cap layer of the wafers is 2 nm GaN. After ohmic contact patterned, we etched the cap layer and AlGaN barrier layer using BCl_3/Cl_2 based ICP etcher leaving 4nm AlGaN barrier. Before metal deposition, we treated the surface using HF (2%), SC1 (H_2O: H_2O_2: NH_4OH=6:1:1) and SC2 (H_2O: H_2O_2: HCl=6:1:1) solution sequentially for 20 s, 300 s and 300 s, respectively. The Ti/Al/Ti/TiN (25/120/20/20nm) metal stacks were deposited by PVD without any interruption avoiding pollution at metal interface. For comparison, we treated the surface with HF, SC1 and SC2 individually for 600 s as well. Followed metal patterned, the wafer was annealed at 850℃ for 45 s. It should be pointed out that the thickness optimization of the AlGaN layer was also performed on the same wafer with AlGaN layer thicknesses of 0, 4, 8, 15, and 25 nm.

3. Result and Discussion

The I-V characteristics of ohmic contacts with different pre-treatments were measured on the TLM patterns with a gap of 11 μm. From the I-V characteristics shown in Fig. 1(a), we can tell that the hybrid treatment with HF, SC1 and SC2 is the best in all of the treatments. The phenomenon can be explained that the metal particles (Al, Ti etc., coming from etching equipment), organics (coming from photoresist) and oxide particles (created during photoresist removing by oxygen plasma and other oxidation process) at surface of contact are removed by HF, SC1 and SC2, respectively [1]. Fig. 1(b) shows the linear fitting of the measured resistance versus gap-spacing curves at center, bottom and top of the same 150mm wafer with 4 nm AlGaN barrier left after 850 °C, 45 s annealing. RC (and specific contact resistivity ρ_C) of center, bottom, and top are determined to be 0.31 Ω· mm (2.61×10-6 Ω·

cm2), 0.39 Ω· mm (3.95×10-6 Ω· cm2), and 0.36 Ω· mm (3.28×10^{-6} Ω· cm2), respectively, as shown in Table II. The extracted 2DEG sheet resistances (R_{SH}) for ohmic contacts are 369 Ω/sq, 379 Ω/sq and 398 Ω/sq, indicating outstanding quality of the AlGaN/GaN epi wafer. It should be pointed out that the transfer length of ohmic contacts are similar (1um), which means concentrative distribution of current in Ti/Al/Ti/TiN contact.

The relationship between remained AlGaN thickness and R_C was also investigated as shown in Fig. 2(a). The lowest resistance value 0.31 Ω·mm is obtained when the remained AlGaN thickness is 4 nm. Before that, the ohmic contact resistance reduces with the reduction of AlGaN thickness. This is because tunneling (field emission) is the dominant conduction mechanism in ohmic contact at room temperature [8].

Table I
Parameters Values of Ti/Al/Ti/TiN Based Ohmic Contacts

Sample	RC (Ω·mm)	ρC (Ω·cm^2)	LT (μm)	RSH (Ω/□)
Center of Wafer	0.31	2.61×10-6	0.84	369
Bottom of Wafer	0.39	3.95×10-6	1.02	379
Top of Wafer	0.36	3.28×10-6	0.91	398

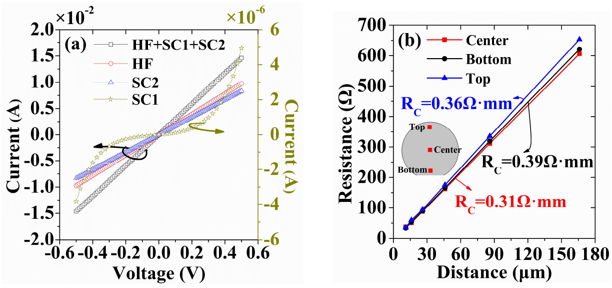

Fig. 1 (a) I–V characteristics of the ohmic contact with different surface treatments. (b) Ti/Al/Ti/TiN based ohmic contact resistance (R_C) extracted by transmission line method.

According to field emission theory, ρ_C depends primarily on the effective metal-semiconductor barrier height Φ_B. It is given by

$$\rho_C = K_B/\pi A^* T^2 \sin(\pi K_B T C)\, exp(\emptyset_B/E_{00}) \qquad (1)$$

where

$$E_{00} = (hq/4\pi)\sqrt{N_D/m_n^* \varepsilon}, \qquad (2)$$

$$C = \ln(4\emptyset_B/E_n)/2E_{00}, \qquad (3)$$

$$E_n = (K_B T/q)\ln(N_C/N_D), \qquad (4)$$

N_C is the effective density of states for electrons in the conduction-band of AlGaN barrier, me is the electron mass, $m_n{}^*=0.25m_e$ is the corresponding effective electron mass, $\varepsilon=9.2\varepsilon_0$ is the corresponding dielectric constant. $A^*=4\pi m_n{}^*kB^2/h^3$ is the Richardon constant, Φ_B is the Schottky barrier height. N_D is the doping conduction, and E_n is the energy difference between the conduction-band edge and the Fermi level. All other parameters have their usual meanings. With the AlGaN recessed down to several nanometers, the tunneling probability is significantly enhanced (tunneling easily occurring at nanoscale). Thus, contacting barrier height (Φ_B) can be reduced [8]. However, for all-recessed sample, due to the lack of the underneath 2DEG channel, tunneling only takes place in a very small area around the sidewall of the recessed barrier, resulting in a high R_C value (4.66 Ω·mm). Of course, more detailed researches and experiments should be down to verify the mechanism. Fig. 2(b) summarizes the best R_C values of Ti/Al based metal scheme reported before. The extremely low R_C of 0.31 Ω·mm achieved in this work is one of the best results among the published reports.

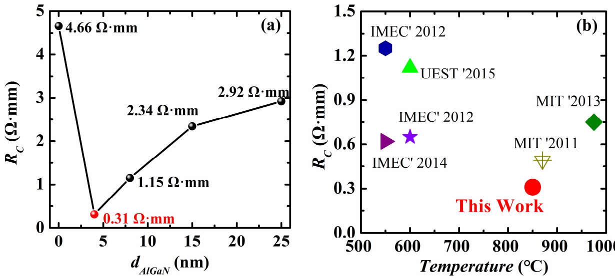

Fig. 2 (a) Ohmic contact resistance RC with different AlGaN barrier thickness. (b) Benchmark of Ti/Al Based ohmic contact resistance (R_C) on AlGaN/GaN heterostructures

4. Conclusions

An extremely low Rc of 0.31 Ω· mm is obtained on Ti/Al/Ti/TiN based Ay-free ohmic contact with HF, SC1 and SC2 pre-cleaning and 850 °C annealing when pre-ohmic recess etching of the AlGaN barrier down to 4 nm. The optimized Si compatible ohmic contact with the specific designed gate structure enable high power and low energy consumption application.

References

[1] H. Sun, M. Liu, P. Liu, X. Lin, J. Chen, M. Wang, and D. Chen, IEEE Trans. Electron Devices **65** (2018) 622.

[2] H. Lee, D. S. Lee, T. Palacios, and A. This, IEEE Electron Device Lett. **32**, (2011) 623.

[3] B. Jaeger, M. Hove, G. Mannaert, K. Geens, S. Decoutere, Proc. Int. Symp. Power Semicond. Devices ICs (2012) 49.

[4] Y. Li, G. Ng, S. Arulkumaran, C. Kumar, K. Ang, M. Anand, H. Wang, R. Hofstetter, and G. Ye, Appl. Phys. Express **6** (2013) 116501.

[5] T. Hashizume and H. Hasegawa, Appl. Surf. Sci. **234** (2004) 387.

[6] M. Hove, S. Boulay, S. Bahl, S. Stoffels, X. Kang, D. Wellekens, K. Geens, A. Delabie, and S. Decoutere, IEEE Electron Device Lett. **33** (2012) 667.

[7] Z. Liu, M. Sun, H. S. Lee, M. Heuken, and T. Palacios, Appl. Phys. Express **6** (2013) 096502.

[8] J. Zhang, S. Huang, Q. Bao, X. Wang, K. Wei, Y. Zheng, Y. Li, C. Zhao, X. Liu, Q. Zhou, W. Chen, and B. Zhang, Appl. Phys. Lett. **107** (2015) 262109