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A Low Turn-On Voltage and High Breakdown Voltage AlGaN/GaN Dual Metal Schottky Barrier Diode

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Abstract

An AlGaN/GaN Dual Metal Schottky Barrier Diode (SBD) was proposed and fabricated on a Si substrate. Two different metals were utilized to form the anode electrode. One is titanium which has a lower work function and the other is nickel which has a higher work function. Schottky barrier height (SBH) would be lowered by the presence of Ti which will reduce the turn-on voltage so that the forward current would be increased. And the higher SBH formed by Ni will help reducing the leakage current so that the breakdown voltage would be higher. From the experiments, the specific on-resistance is 5.27 mΩ·cm^2 and breakdown voltage is 1020 V with an anode-cathode spacing of 12 μm.

1. Introduction

In recent years, GaN devices have become a promising candidate for high-power applications. Attributed to the strong spontaneous and piezoelectric polarization, AlGaN/GaN devices can provide a high two dimensional electron gas (2DEG) concentration of ~ 1×10^{13} cm^{-2}, and mobility could be higher than 1500 cm^2/V·s, both can contribute to a low on-state resistance. On the other hand, the wide band gap of 3.4 eV and the high critical electric field of 3.3 MV/cm lead to a high breakdown voltage.

Schottky barrier diode has the advantages of a low turn-on voltage, a high current density and a low reverse recovery time, which is quite suitable for fast switching applications. There were some new SBD structures proposed such as a floating metal ring which was placed between anode and cathode [3], a recess hybrid anode structure [4], and a p-GaN layer which was located at the anode edge [5]. These structures were designed to lower the turn-on voltage, reduce the reverse leakage and even increase the breakdown voltage. In this study, we demonstrate a novel dual metal SBD which can make the turn-on voltage significantly lower to gain a higher forward current density without any compromise in breakdown voltage.

2. Experiments and results

The AlGaN/GaN sample wafer was grown on a Si (111) substrate by MOCVD. The epitaxial layers consist of a 1 μm-thick nucleation layer, a 4.2 μm-thick highly resistive GaN buffer layer, a 1.6 μm-thick undoped GaN layer, a 25 nm-thick AlGaN barrier layer, and a 1 nm-thick undoped GaN cap layer. The Al content of the AlGaN barrier is 20 %.

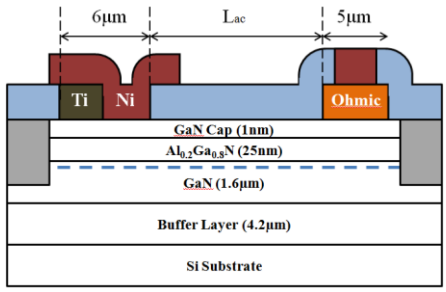


Fig. 1 Cross-sectional schematic of an AlGaN/GaN dual metal SBD. The width of the device is 140 μm.

For the device fabrication, a Ti/Al/Ti/Au (25/125/45/55 nm) ohmic metal stack was deposited by a thermal evaporator and followed by rapid thermal annealing at 850 ℃ for 30 s in a N_2 ambient. Next, the device isolation was achieved by a sequence of oxygen implant. The implant depth ranged from surface to 300 nm deep. The implantation creates a high resistive region and thus resulting in a good isolation between devices. Then the SiO_2 surface passivation layer with a thickness of 300 nm was deposited by PECVD. Next, ohmic contact holes were over etched by RIE. Schottky contact windows were first dry etched by RIE and then wet etched by BOE to avoid the surface damage by plasma. Before the Schottky metal deposition, the surface treatment was done by dipping samples in diluted HCl for 30 s and then BOE for 5 s. The low work function metal Ti was deposited (30 nm) immediately and following by a 50 nm-thick Au for good conductivity. At last, Ni/Au (30/300 nm) was deposited as the high work function metal and also the pad metal. The conventional Ti and Ni single metal SBD were also fabricated at the same time for comparison.

The current-voltage and breakdown characteristics were measured by an Agilent B1505A analyzer. Fig. 2 indicates the comparison of the forward characteristics of three kinds of SBD with an anode-to-cathode distance (Lac) of 12 μm. The turn-on voltage of the dual metal SBD was reduced from 1.6 V of the Ni-SBD to 0.92 V which is close to the turn-on voltage of the Ti-SBD. When biasing at a forward voltage of 2 V, the current density of the dual metal SBD is 192.7 A/cm^2, which is 2.6 times higher than the Ni-SBD.

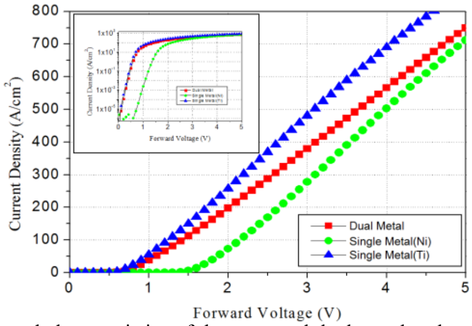


Fig. 2 Forward characteristics of the proposed dual metal and conventional single metal Ni and Ti SBD. The length of Lac is 12 µm.

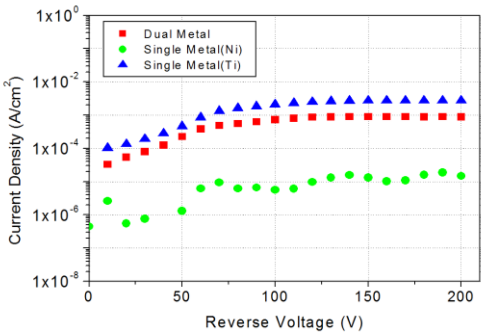
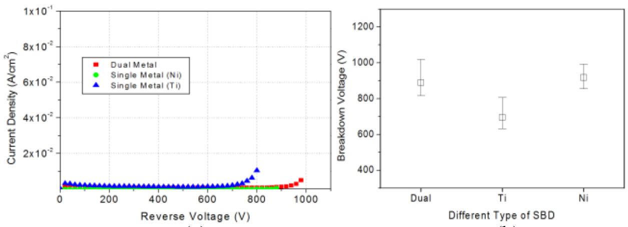


Fig. 3 Reverse characteristics of the proposed dual metal and conventional single metal Ni and Ti SBDs. (Lac = 12 µm)



(a) (b)

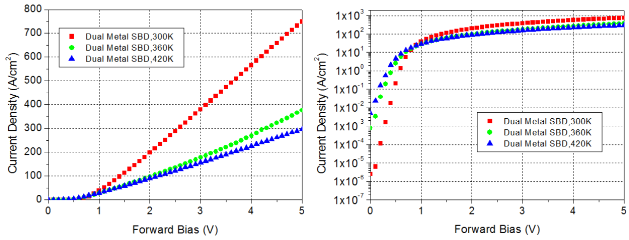
Fig. 4 (a) Breakdown characteristics of the proposed dual metal and single metal Ni and Ti SBDs. (b) Statistics of breakdown voltage obtained from 5 devices in different dies. (Lac = 12 µm)

The Ti-SBD has the lowest Schottky barrier height of 0.69 eV, Ni-SBD is 1.07 eV and dual metal SBD has a SBH of 0.73 eV which is similar to Ti-SBD.

The reverse characteristics of the three kinds of SBDs are shown in Fig. 3. The leakage level of the dual metal SBD is 8.9×10^{-4} A/cm^2 at a reverse voltage of 200V. The Schottky barrier height of the dual metal SBD is close to that of the Ti-SBD, but due to the higher SBH in the Ni metal in dual metal SBD, the leakage level can be 2 to 4 times lower than Ti-SBD. It indicates that the presence of a high work function metal at the location of the peak electric field could effectively reduce the leakage current even at a small reverse bias.

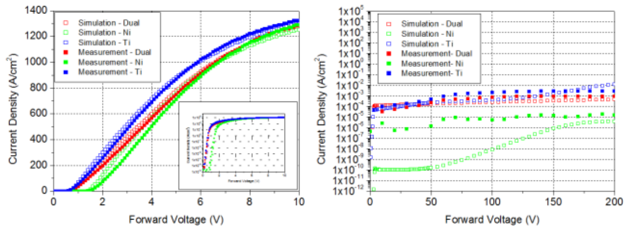
Fig. 4(a) and (b) shows the breakdown statistics of three kinds of SBDs. The mean value of the breakdown voltage of dual metal SBD is 890V which is slightly lower than 910V of Ni-SBD but is significantly higher than 700V of Ti-SBD, which is again owing to the high SBH formed by Ni metal at the anode edge where the peak electric field is located when breakdown.

In AlGaN/GaN material, the mobility of 2DEG would decreases with increasing temperatures, which can be explained by the phonon scattering effect. As a result,



(a) (b)

Fig. 5 Temperature dependent analysis of the dual metal SBD in forward characteristics. (a) linear scale (b) semi-log scale



(a) (b)

Fig. 6 Comparison between simulation and measurement results of the dual metal SBD and single metal SBDs. (a) forward characteristics. (b) reverse characteristics.

forward current degrades at a higher temperature, as shown in Fig. 5(a). Fig. 5(b) shows the same IVs in a semi-log plot. The SBH would be decreased with increasing temperature.

The simulation results were carried out by a TCAD tool Silvaco. As shown in Fig. 6(a) and (b), with adjusted models such as polarization effects and effective mass in tunneling, the experimental IV-curves in both forward and reverse biases can be fitted quite well.

3. Conclusions

In this work, we demonstrated an AlGaN/GaN dual metal Schottky barrier diode. The low work function metal Ti was inserted to lower the turn-on voltage to 0.9V. As a result, the forward current is 2.6 times higher than the conventional Ni SBD when operating at 1.5 V. The high work function metal Ni was inserted at the location of the peak electric field is to reduce the leakage current. The leakage current level is reduced 2 to 4 times lower than the conventional Ti SBD. And the degradation of breakdown voltage was not found in this metal structure even with the presence of Ti. These results validate that the dual metal SBD is a promising device for power applications.

References

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