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Analysis of Electrical Characteristics of AlGaN/GaN on Si Large SBD by Changing Structure

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Abstract

The improvement in electrical characteristics of large AlGaN/GaN on Si SBD induced by structural change was investigated to achieve a better trade-off between the forward and the reverse performance. Using the optimized dry etch condition for a large device, we fabricated three-types of SBD with 63 mm channel length: conventional, recessed, recessed dual anode metal SBD. The recessed dual anode metal SBD exhibited a very low turn-on voltage of 0.34 V, a high forward current of 1.63 A at 1.5 V, a leakage current of 114 µA, a breakdown voltage of 794 V.

1. Introduction

Recently, various studies have been carried out to improve characteristics of AlGaN/GaN Schottky Barrier Diode (SBD). In one case, the anode region was etched using dry etching process to reduce on-resistance [1], [2]. In another study, the anode of the SBD was replaced with a dual anode metal to take advantage of the different work functions of the two metals [3]. However, although the forward characteristics of dual anode metal SBD were improved, the reverse characteristics were degraded. So, to improve both the forward and the reverse characteristics, a gated ohmic anode SBD together with a recessed and dual metal was suggested [4]. However, finding a dry etch condition that can achieve uniform etching profile with a reproducible etch rate and little plasma damage is very difficult. So, fabrication of large dimension device needed for power conversion application is challenging.

Here, using the optimized dry etch condition for a large device, we fabricated AlGaN/GaN on Si SBD with 63 mm channel length and demonstrated the electrical characteristics by structural change.

2. Device fabrication

The epitaxial layers of the AlGaN/GaN SBD were grown on a 4-in Si (111) wafer with a wafer median sheet resistance of 527 Ω/□. This wafer consists of a 3-to-4-µm GaN buffer layer, a 20-nm $Al_{0.25}G_{0.75}N$ barrier, a 1.25-nm undoped GaN layer. A mesa isolation with an etching depth of 300 nm was etched by inductively coupled plasma reactive ion etching (ICP RIE) using a BCl_3/Cl_2 gas mixture. To measure electrical characteristics of AlGaN/GaN SBD in a consistent manner, SBDs of different structure, Type 1(=Conventional SBD), Type 2(=Recessed SBD), and Type 3(=Recessed dual anode metal SBD) were fabricated on the same wafer. The structure of a completed AlGaN/GaN SBD is shown in Fig. 1. To form an ohmic contact in cathode and anode, a Ti/Al/Ni/Au ohmic metal was deposited using e-beam evaporation in a cathode and anode at the same time, followed by rapid thermal annealing at 900 ˚C for 50 s in N_2 ambient. The transfer contact and specific contact resistivity were 1.08 Ω·mm and 2.4 × 10^{-5} Ω·cm^2, respectively. AFM measurement results of small devices verified that the etching profile is very uniform and the etch rate reproducible. Usually, etching profile is not uniform in larger devices, and therefore we expect high device-to-device variation. Also, uneven etch surface morphology can result in increased surface leakage current. So, in order to obtain ICP RIE dry etch condition with a uniform etch profile, accurate etch rate, very low plasma damage, and even surface morphology, we optimized dry etch condition by changing the ICP power, the RF power, the gas feed rate, the chamber pressure. The ICP RIE con-

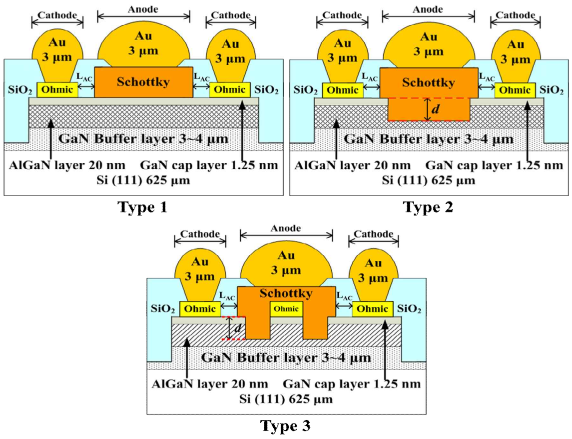


Fig. 1 The fabricated SBD structure (Type 1 = conventional SBD, Type 2 = recessed SBD, Type 3 = recessed dual anode SBD)

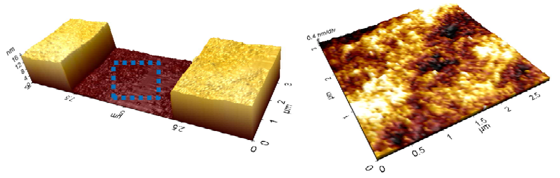


Fig. 2 AFM image of recessed region (left), rms roughness of recessed surface (right)

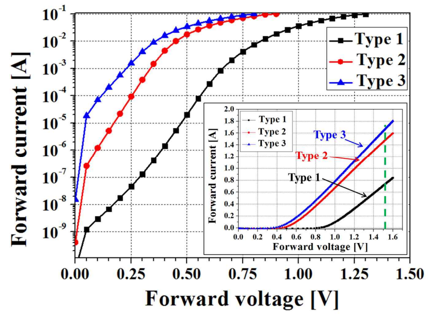
dition used to fabricate a large GaN SBD was following: ICP power = 50 W, RF power = 3 W, flow (BCl_3/Cl_2) = (16/3) sccm, pressure = 10 mTorr. The rms roughness of the etched surface was measured by AFM to be 0.29 nm. Type 2, 3 devices were etched using the same etch condition. The recess depth *d* measured by AFM was 16 nm. Fig. 2 shows measured AFM profile of the recessed region and recess surface morphology. Next, a Ni/Au Schottky metal for the anode was deposited, and then, a SiO_2 passivation layer of 700 nm was deposited by PECVD. The distance between anode and cathode, L_{AC}, is 15 µm. After removing the SiO_2 passivation layer in the anode and cathode region using BOE etch, finally, a 3-µm-thick Ti/Au metal was plated as the contact metal.

3. Results and Discussion

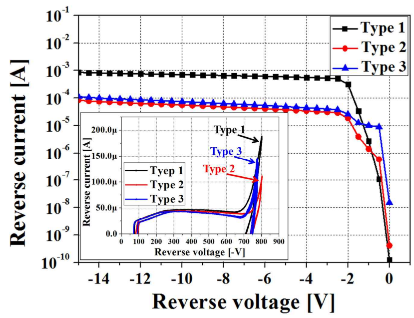
As shown in Fig. 2, the anode region dry etched using the optimized etch condition with uniform etch profile and low plasma damage and accurate etch rate. Large devices were free of adverse effect that can arise from the dry etching process. Fig. 3 is a comparison of the I-V curve of the fabricated devices. In Fig. 3(a), Type 2 device by comparison with Type 1 device exhibited a reduced turn-on voltage and on-resistance by having the Schottky metal near 2DEG channel [1]. On the other hand, by having the ohmic contact region in the anode to flow electrons at a small bias, the turn-on voltage is greatly improved in Type 3 device in comparison to Type 2 device. When the forward bias voltage is increased above a threshold value, electrons can flow through the Schottky contact region as well. When the device is completely turned on, extra current flowing through the ohmic contact region in the anode increases the total forward current [4]. We also observed that, as shown in Fig. 3(b), Type 2 device exhibited the lowest leakage current due to effective control of the Schottky metal by close to 2DEG channel. In Type 3 devices, the majority of the voltage drop develops across the Schottky recess metal and the cathode metal. Therefore, the additional ohmic contact region introduced in the anode does not contribute much to increasing the leakage current. Also, the breakdown voltages were not changed by changing the anode structure. The electrical characteristics of the fabricated devices are summarized in Table. 1.

4. Conclusion

The most of traditional structures of SBD were realized in small devices that could not be readily used in a power conversion system because the same structure could not scale up to a larger dimension. Problems such as epitaxial defects, non-uniform and uneven etch condition have plagued larger devices. In this study, using the optimized dry etch condition, such as uniform etch profile, accurate etch rate, very low plasma damage in anode region, we fabricated three different structure type GaN-SBD with 63mm channel. This device is suitable for high power frequency application which is required for the high conversion efficiency.



(a)



(b)

Fig. 3 Electrical Characteristics (a) Forward Log scale I-V, Linear scale (Inset) (b) Reverse I-V, Breakdown voltage (Inset)

TABLE 1
DEVICE CHARACTERISTICS

Characteristics	Type 1	Type 2	Type 3
V_{th}	0.85 V	0.45 V	0.34 V
I_F (at 1.5 V)	0.7 A	1.45 A	1.63 A
V_B	803 V	802 V	794 V
I_R (at -15 V)	865 µA	84 µA	114 µA

Acknowledgements

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References

[1] E. Bahat-Treidel, et al., IEEE Electron Device Letters, 33, (2012) 357.

[2] Yao Yao, et al., Japanese Journal of Applied Physics, 54, (2015) 011001.

[3] Ting-Fu Chang et, al., Solid-State Electronics, 105, (2015) 12

[4] Jae-Gil Lee, et al., IEEE Electron Device Letters, 34, (2013) 214