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High Thermal Stability AlGaN/GaN Schottky Barrier Diode with Diamond-like Carbon (DLC) Heat Dissipation Anode Design

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I. Introduction

GaN-base materials have attracted a lot of attentions for the next generation of high power electronic applications because of the superior material properties such as high breakdown electric field, wide bandgap, and high saturated electron velocity [1]. They can keep device operation characteristics at high temperatures and high voltage conditions because their superior material properties. Recently GaN on Si (111) growth technology was developed application because its low cost and superior scalability of large wafer size [2]. However, there is an obvious thermal effect observed from the GaN HEMTs on Si substrate because of poor thermal conductivity of the Si substrate . The current density was limited due to thermal effect and the current crowding operated at high current condition.In this study, we propose Ni/DLC replace tradition Ni/Au anode due to DLC layers provide excellent thermal conductivity (600 $Wm^{-1} K^{-1}$) to reduce the thermal effect.

II. Device Structure and Fabrication

The sample used in this work was a commercial AlGaN/GaN HEMT wafer grown by MOCVD on (111) silicon substrate. The epitaxial structure includes a 1 µm-thick undoped GaN channel layer was grown on top of a 2 µm-thick undoped AlN/GaN buffer/transition layer and an 29 nm-thick undoped $Al_{0.25}GaN$ Schottky layer was sandwiched between the GaN channel layer and the 1.5 nm undoped GaN cap layer. This structure exhibits a sheet charge density of 9.8×10^{12} cm^{-2} and a Hall mobility of 1420 $cm^2/V{\cdot}s$ at 300 K. Devices were processed by conventional optical lithography and lift-off process. To define an active region by a photoresist, and the mesa isolation region was removed in a reactive ion etching (RIE) chamber using BCl_3+Cl_2 mixed gas plasma. The cathode ohmic contacts were prepared by the electron beam evaporation of a multilayered Ti/Al/Ni/Au sequence, followed by rapid thermal annealing at 850 °C for 30 s in a N_2 ambient. The ohmic contact resistance is 8.6×10^{-5} $\Omega{\cdot}cm^2$, as measured by the transmission-line method. And then, we deposited Ni/DLC as the anode metal by sputter system. Finally, a 100-nm-thick Si_3N_4 layer was deposited as passivation layer. Figure 1(a) presents the device structure and cross-section and the device with a L_a = 20 µm, L_{ca} = 20 µm and L_{ac} = 20 µm. Figure 1(b) show the OM image of Ni/DLC SBD HEMT. In this work, we compare tradition Ni/Au SBD and Ni/DLC SBD. The active region of both devices is 6.84 mm^2.

III. Results and Discussion

Figure 2 displays forward current voltage characteristics of Ni/Au and Ni/DLC SBDs. The on-resistance (R_{on}) and turn–on (V_{on}) voltage can be observed from Fig2. A lower Ron of 170 mΩ is obtained from Ni/DLC Anode SBD due to its superior thermal dissipation ability of the DLC layer. The turn-on voltage is defined at the current at 1mA/mm. The turn-on voltage (V_{on}) were 1.1 V for Ni/Au SBD and 1.3 V for Ni/DLC SBDs.

Fig. 3 shows I_{DS} variations of both SBDs at temperatures from 25 to 175 °C at V = 4 V. At 175°C environment, the normalized I for the standard device demonstrates an average of 28.7 % reduction. This value is only 18.9 % for the Ni/DLC SBDs. It pointed out the Ni/DLC had better thermal stability.

Figure 4 shows the reverse-bias current-voltage characteristics at room temperature for the both SBDs. The breakdown voltage is defined at the leakage current at 100 µA. The breakdown voltage (V_{BK}) of Ni/Au and Ni/DLC SBDs were 665 V and 690, respectively. The breakdown voltage with the Ni/Au SBDs is better than DLC/Au SBDs, because deposited Ni/DLC using sputter system to make the surface damage and leakage current raise by plasma deposition. The inset shows the 1/f spectra noise characteristic for both device. To investigate further the surface relationship, a low-frequency noise measurement was made because at low frequency, is sensitive to the semiconductor surface [3]. The bias point of low-frequency noise measurement was I= 1mA/mm for both devices. Since the measurement was dominated by the series resistance of each device, identical Ids bias point importantly confirm the flicker noise characteristics. The Ni/DLC SBDs had a higher 1/f spectra noise than Ni/Au SBDs due to the surface damage was increased.

The thermal images of (a) multi-finger SBDs with Ni/Au Anode, (b) multi-finger SBDs with Ni/DLC Anode which drain current is limited at 1 A, and continuous time is 1min are shown in Figure 5. The average temperature of Ni/Au SBD is 192.2 °C. The average temperature of Ni/DLC SBDs is reduced to 142.5 °C. It can be concluded that the DLC layer significantly eliminates the self-heating effect which biases at high current.

IV. Conclusion

In summary, the temperature-dependent performance of AlGaN/GaN Ni/Au Anode and Ni/DLC power SBDs was estimated. We have successfully improved SBDs performance and eliminated the self-heating effect by using Ni/DLC Anode. For Ni/DLC SBDs, the forward current is improved from 7.2A to 14.5A at V=4V and the device temperature which biased at I=1A and operation time was 30s can be reduced from 192.2 to 142.5 °C. The Ni/DLC Anode SBDs exhibited the better thermal stability because their device dc was less affected by temperature. These superior thermal stability and high current driving capability prove that Ni/ DLC technology has great potential for power device applications.

V. Reference

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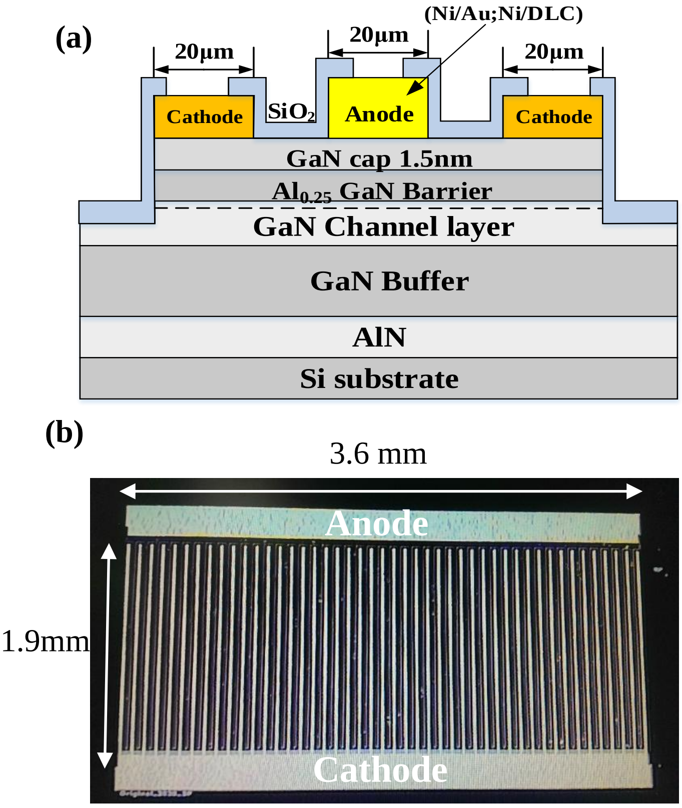

Fig.1(a) Device structure and cross-section of AlGaN/GaN HEMT with a L_a = 20 μm, L_c = 20 μm and L_{ac} = 20 μm. (b) OM image of multi-finger Ni/DLC SBDs.

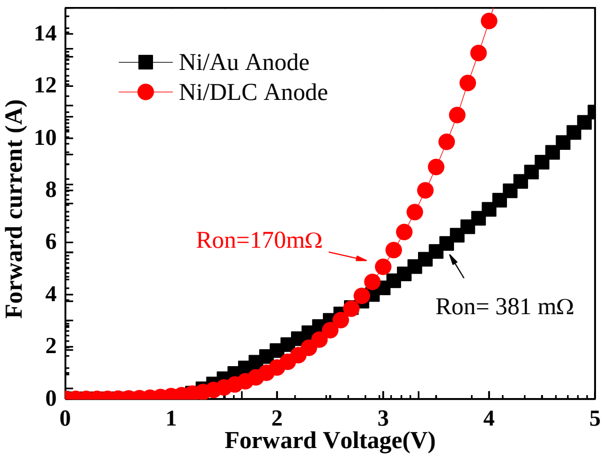

Figure 2 displays forward current voltage characteristics of Ni/Au and Ni/DLC SBDs

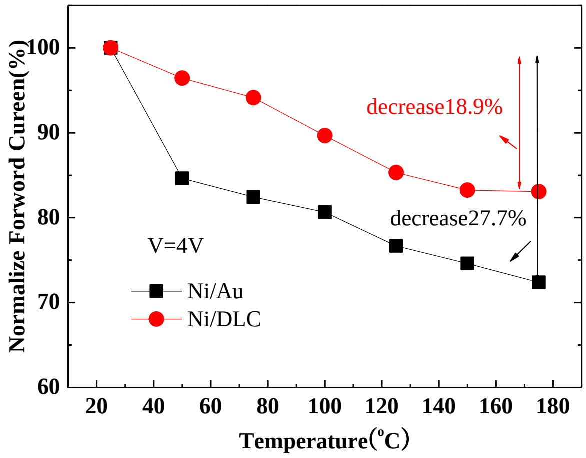

Fig. 3 shows I_{DS} variations of both SBDs at temperatures from 25 to 175 °C at V = 4 V

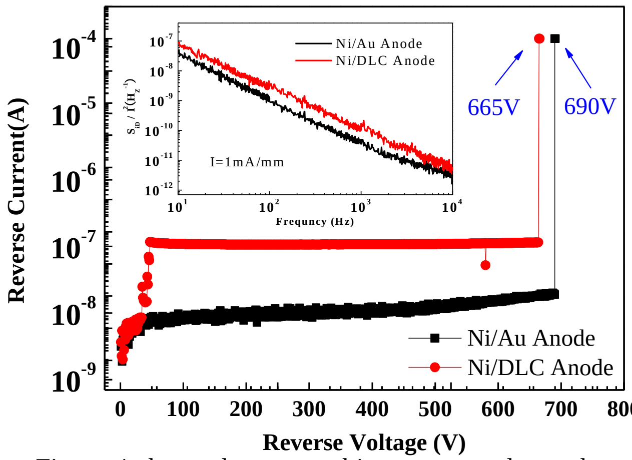

Figure 4 shows the reverse-bias current-voltage characteristics at room temperature for the both SBDs. The inset shows the 1/f spectra noise characteristic for both devices.

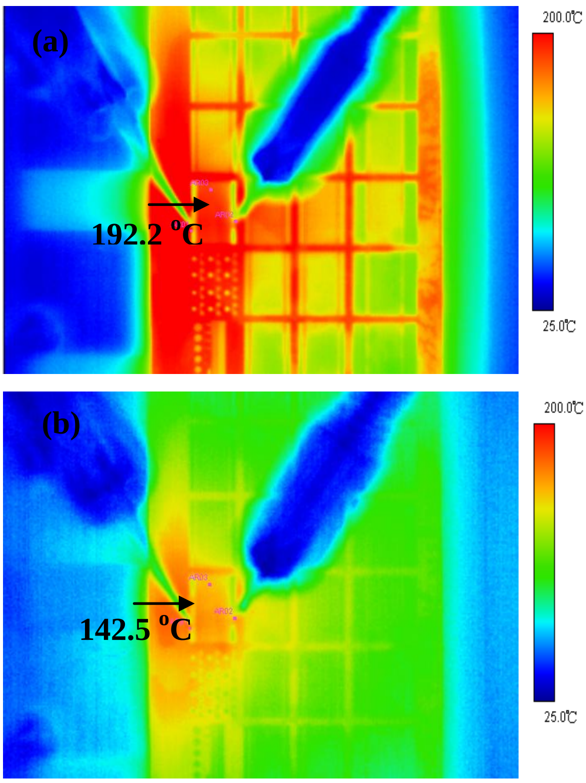

Fig.5 Thermal images of (a) multi-finger SBD with Ni/Au Anode, (b) multi-finger SBD with Ni/DLC Anode which current is limited at 1 A, and continuous time is 1min.