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Electroluminescence under the gate region using AlGaN/GaN HEMT with a transparent gate electrode

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Abstract

AlGaN/GaN high electron mobility transistors with a transparent gate electrode are studied by means of electroluminescence (EL) to investigate under the gate region. We successfully observed EL emissions under the gate at off-state conditions and the gate edge at on-state conditions. We believe the EL through the transparent gate electrode is contributed to gate leakage path. Hence, this transparent gate technology is useful for future evaluation of localized gate leakage paths.

1. Introduction

GaN-based high electron mobility transistors (HEMTs) are attractive for high power and high frequency applications due to their material properties. One of the problems preventing widespread use is reliability of these devices [1-3].

In the off state Electroluminescence (EL) is useful tools to monitor device degradation in AlGaN/GaN HEMT devices. To investigate the active channel under the gate is important in understanding of the failure mechanisms and the mechanisms of gate leakage current [4]. However, this region is generally covered by the metal.

In this paper, we report on EL of AlGaN/GaN HEMT with a transparent gate to investigate under the gate region.

2. Device fabrication

An AlGaN/GaN HEMT with a transparent gate used in this study is schematically shown in Fig. 1[5]. For the gate electrode a conductive indium tin oxide (ITO) film was used instead of the conventional metal electrode. The AlGaN/GaN heterostructure was grown on a high resistivity (111) oriented Si substrate by metal organic chemical vapor deposition (MOCVD). The Epitaxial structure consisted of a buffer layer, a 1.0-μm-thick unintentionally doped (UID) GaN channel layer, a 1-nm-thick AlN spacer and a 25-nm-thick UID $Al_{0.26}Ga_{0.74}N$ layer. By van der Pauw method, the electron mobility and the sheet carrier density of the epitaxial wafer were evaluated as 1515 $cm^2\ V^{-1}\ s^{-1}$ and $1.1\times10^{13}\ cm^{-2}$ at 300 K, respectively. In the first step of the device-fabrication process, each device was isolated by reactive ion etching (RIE). Then a Ti/Al-based ohmic electrode was formed by conventional electron-beam evaporation and lift-off techniques. After which, the device was annealed at 850 °C in N_2 ambient for ohmic contact in rapid thermal annealing system. Finally, the ITO film for the transparent gate was deposited by radio-frequency (RF) sputtering at room temperature through a patterned photo-resist, and lifted-off. As a target of sputtering, a mixture of 90% of indium oxide (In_2O_3) and 10% of tin oxide (SnO_2) was used. The thickness of the ITO film was approximately 60 nm.

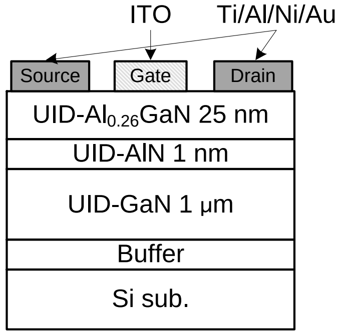

Fig. 1. Cross-sections of the transparent gate AlGaN/GaN HEMT on Si substrate.

3. Results and Discussion

To observe the luminescence through the gate electrode, we have chosen the transparent material at the energy less than a bandgap of GaN (3.4 eV). Figure 2 shows the transmittance of the ITO film as a function of wavelength. For example, at a wavelength of 360 nm, a transmittance of the film was 61%.

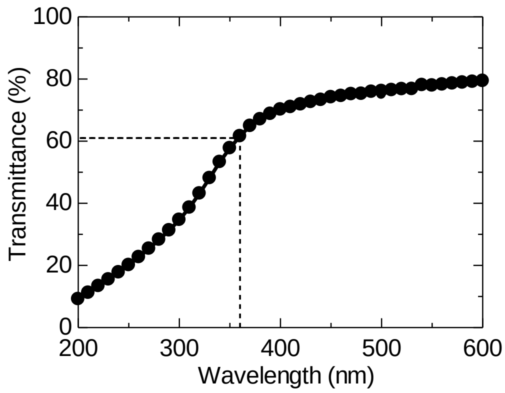

Fig. 2. Transmittance of ITO film as a function of wavelength.

Typical drain *I-V* characteristics of the transparent gate AlGaN/GaN HEMT with a 3 μm gate length are shown in Fig. 3. The developed device showed good pinch-off characteristics. A threshold voltage of this HEMT is −1.8 V. The leakage current below pinch-off voltage for the transparent gate HEMT of a ~2×10^{-6} A/mm has been ranged to match our conventional metal-gate HEMT with the same epitaxial structure under the same V_{ds} of 6 V (around 10^{-6} A/mm). Therefore, the developed transparent-gate device can be concluded ready for evaluation.

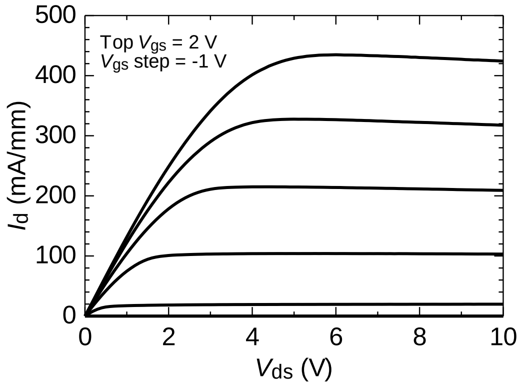

Fig. 3. Typical drain *I-V* characteristics of the transparent gate HEMT with a gate length of 3 µm.

Figure 4 shows transfer characteristics at V_{ds} of 45 V near pinch off region. At a V_{gs} of less than pinch-off voltage (−3 V), I_d and I_g are comparable each other, indicating that a current in the device dominantly flows from the drain to the gate electrode.

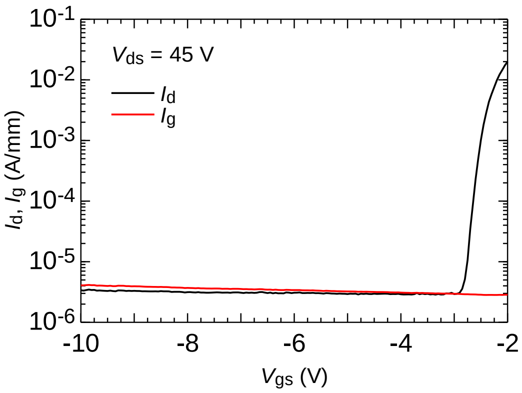

Fig. 4. Drain and gate current as a function of gate voltage for the transparent gate HEMT.

EL measurements were performed using an Emission Microscope Hamamatsu PHEMOS-1000. EL images from the devices were taken by means of a silicon-intensified charge-coupled device (SI-CCD) camera. The spectral response extends from visible (400 nm) to near infrared (1100 nm).

Figure 5(a) shows EL images at an off-state condition (V_{ds} = 45 V, V_{gs} = −10 V). EL emission was observed through the transparent gate electrode. We have successfully observed the EL under the gate region which might not been observed using the conventional metal gate HEMT because of an opaque metal stack.

In addition, during observing EL emission, gate current was stable (4.7×10^{-6} A/mm) without any abrupt increase in gate current. This EL emission reappeared at the same points and same bias condition. Also, *I-V* characteristics were identical before and after EL measurement. Therefore the EL emission beneath the gate region was not formation of defects or localized damage induced during device continuously stressed.

We also carried out on-state EL at V_{ds} = 45 V and V_{gs} = −2 V. The on-state condition, EL emission occurs at the edge of the gate toward drain where the electric field is supposed to be maximum. This result agrees with previous reports using the metal gate [2,6-7]. Therfore, we belive that EL emission under the gate shown in Fig. 5(a) may occur for both the metal gate and the transparent gate HEMTs. However, only in the case of the transparent gate, we are able to observe it.

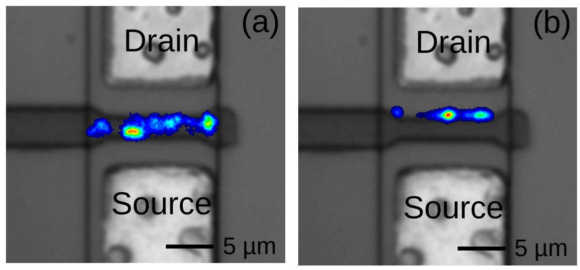

Fig. 5. False color image reporting the distribution of EL of the transparent gate AlGaN/GaN HEMT. Image were taken when the device was continuously stressed at V_{ds} = 45 V and (a) V_{gs} = −10 V (off-state condition), (b) V_{gs} = −2V (on-state condition).

3. Conclusions

An AlGaN/GaN HEMT with a transparent gate electrode has studied by means of EL to investigate under the gate region. We successfully observed EL emissions under the gate at off-state conditions and the gate edge at on-state conditions. At this moment, we believe the EL through the transparent gate electrode is contributed to gate leakage path. Hence, this transparent gate technology is useful for future evaluation of localized gate leakage paths.

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