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Electro Static Discharge effects on AlGaN/GaN HEMTs on sapphire substrates

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1. Introduction

GaN is a promising material for HEMTs for high temperature, high power and high frequency applications due to its wide band-gap properties [1]. AlGaN/GaN HEMTs have several merits such as high sheet carrier density (~1e13cm^{-2}) and high electron mobility (~1300 cm^2/Vs) which enable high current density and high cutoff frequency [1]. Also, high breakdown voltage can be obtained due to high breakdown field strength (>3MV/cm).

It is well known that Electro Static Discharge (ESD) is a crucial phenomenon which influences reliability of silicon device. ESD issues in compound semiconductor such as GaAs and InP have also been reported recently [2,3]. Although effects of ESD stress on AlGaN/GaN HEMTs are also critical, it has not been reported yet. It may be noted that only a few data have been reported about effects of ESD for GaN LEDs.

The purpose of this work is to report degradation and failure of AlGaN/GaN HEMTs under ESD stress. In order to investigate ESD behavior of AlGaN/GaN HEMTs we have used transmission line pulsing (TLP) method which is widely used in ESD stress experiments.

2. Experiments

We have fabricated HEMTs on doped and undoped AlGaN/GaN HEMT structures which were grown on sapphire substrates by MOCVD method. Mesa was formed by RIE plasma etching for isolation. Ohmic contact metals (Ti/Al/Ni/Au=20nm/80nm/20nm/100nm) were deposited in a sequence by e-gun evaporator and annealed in 840^{o}C by using RTA for 30s. Schottky contact metals (Ni/Au=20nm/300nm) were deposited. A cross sectional view of fabricated HEMT is shown in Fig. 1.

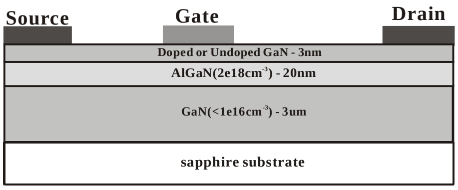


Fig. 1. Cross-sectional view of AlGaN/GaN HEMT (gate length=2μm, gate width=75μm, L_{gd}=3μm,)

ESD stress was applied to AlGaN/GaN HEMTs by TLP equipment in order to investigate degradation and failure in ESD stress. The pulse duration generated by TLP is 100ns and rise time is 10ns. ESD stress has been applied in three cases entitled experiment 1, 2, and 3. In experiment 1, we have induced ESD stress on drain when source and gate are grounded. In experiment 2, ESD stress was applied on drain when only gate is grounded and in experiment 3, ESD stress was induced on gate when drain and source are grounded. We have measured electrical characteristics before and after ESD stress.

3. Results and Discussions

In experiment 1, HEMTs are in turn-on operation mode and ESD current passes through the channel because gate is grounded. However, metal migration occurs due to high electrical field and high temperature by ESD stress [2], so that the space between drain and source is narrowed. Therefore, on-current (@ V_d=5V, V_g=-1.5V) after inducing ESD stress is increased and on-current ratio before and after ESD stress is increased when higher ESD stress is induced as shown in Fig. 2.

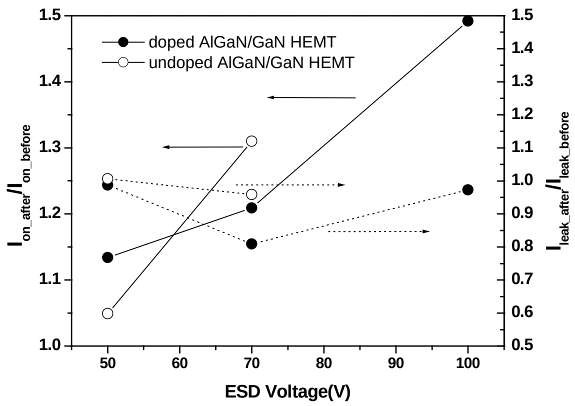


Fig. 2. On-current and leakage current ratio before and after ESD stress in experiment 1

Variation of characteristics in undoped HEMTs was larger than doped HEMTs and almost undoped HEMTs were failed less than below 70V ESD stress while doped HEMTs were failed over 100V ESD stress as shown in Fig. 2. Severe change of undoped HEMTs was caused by higher electric field and temperature due to higher ohmic contact resistance. The g_m was slightly decreased and the leakage current (@V_{gd}=-4.5V) was also decreased.

ESD stress was induced on drain when only gate was grounded and source was floated in experiment 2. On-current is increased (on-current ratio=1.14 @ 50V ESD) and leakage current is decreased and all devices were failed around 70V ESD voltage due to high temperature under gate. Because heat is easily concentrated under the gate due to low thermal conductivity of sapphire substrate, AlGaN/GaN HEMTs are very weak for ESD compared with GaAs HEMTs which were reported before [2].

In experiment 3, because ESD current pass through forward bias direction of the schottky diode, on characteristics and g_m were changed slightly. However, leakage current was reduced due to annealing effect by high passing current through schottky contact under 70V ESD stress as shown in Fig. 3 and devices was failed over 70V due to high ESD current.

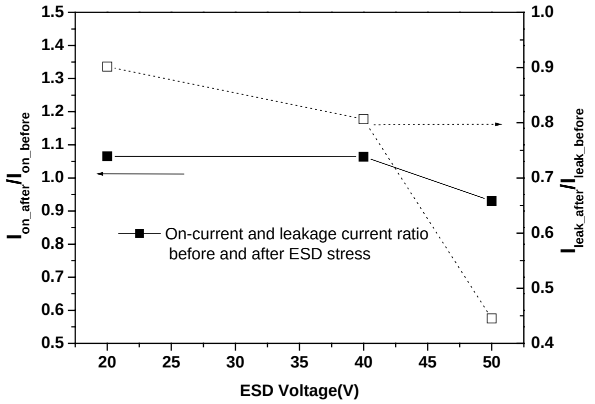


Fig. 3. On-current and leakage current ratio before and after ESD stress in experiment 3

In order to verify failure points in three cases, we have applied step-up ESD stress on HEMTs and the results are shown in Fig. 4. Avalanche breakdown can occur under snap-back voltage and contact metals are melted and migrate due to high electric field and temperature caused by ESD stress in the HEMTs [2], so that electric characteristics are changed. When gate and drain electrode are shorted by metal migration due to ESD, snap-back occurs and the device is failed over snap-back voltage.

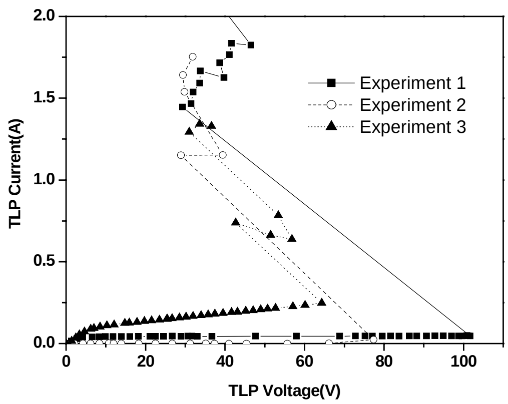
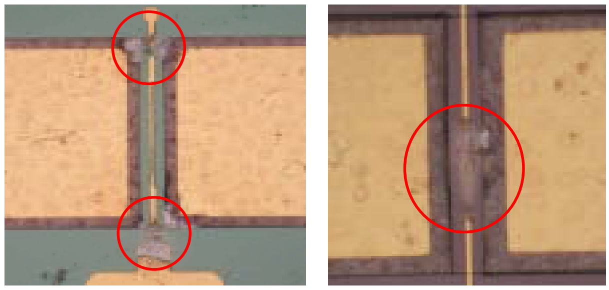


Fig. 4. Snap-back curves of HEMTs using TLP

In experiment 1, ESD stress passes from drain to source in low ESD voltage (<100V) because HEMT is in on operation mode. Therefore, snap-back point in experiment 1 was higher than other condition and failure occurred in higher ESD stress. However, in the case of experiment 2, device was failed in lower ESD stress (~80V) while ESD current was not increased under 80V ESD stress because ESD stress is applied on reverse schottky diode without ESD current path. In experiment 3, because ESD stress is induced to forward direction of gate-drain forward direction, ESD current passes through gate-drain schottky diode. However, the device was failed by high ESD current at 60V because ohmic and schottky metals were easily blown off due to the heat by high ESD current. As a result, AlGaN/GaN HEMTs are almost failed below 100V ESD stress.



(a) (b)

Fig. 5. Failure points of HEMTs by ESD stress

We observed that failure due to ESD stress occurs mainly in both side of gate (Fig. 5-a) and middle of gate (Fig. 5-b). Failure in the middle of gate is cause by concentration of heat during ESD stress because heat is concentrated in the middle of the gate in AlGaN/GaN HEMTs and heat concentration is accelerated by low thermal conductivity of sapphire substrate. Other main failure point is each side of gate due to concentration of ESD current on the side of gate. Current concentration on each side of gate is caused by narrowing of channel which occurs due to shrink effect of metal in the middle of ohmic pad during ohmic metal annealing.

4. Conclusions

We have investigated the degradation and failure of AlGaN/GaN HEMTs due to ESD stress using TLP. The on-current is increased because the space between drain and gate is narrowed due to migration of metal by high electric field and temperature under ESD stress. The leakage current is decreased and g_m is changed slightly. The failure points are located mainly in the middle and side of the gate and AlGaN/GaN HEMT have been easily failed due to poor thermal characteristics caused by sapphire substrate compared with GaAs HEMTs.

References

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