Current Collapse and Deep Levels of AlGaN/GaN Heterostructures monitored by LFN Measurements

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Abstract: The correlation between the current collapse in the IV characteristics of AlGaN/GaN HFETs and the traps monitored through the unpassivated and SiN-passivation processes of the AlGaN/GaN heterostructures by the low frequency noise measurements is reported: the noise level of E_1(47 meV) trap decreased by 10 dBA/√Hz by the SiN passivation process together with the current collapse recovery in IV curves, while E_2(131 meV) and E_3(235 meV) levels became apparent after SiN passivation, indicating the remarkable suppression of the E1 trap by the passivation. The commercially available AlGaAs/GaAs LED heads for the page and FAX printers found several deep levels introduced during the contact formation processes, which could not be assigned by the DLTS measurements.
Keywords:AlGaN/GaN HFETs, AlGaAs/GaAs LED Arrays, Low Frequency Noise, Arrenius plots without DLTS
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Introduction

Best performances of AlGaN/GaN high-electron-mobility transistors (HEMTs) are obtained by growing the heterostructure on the lattice matched SiC substrates, and improved device structures obtained 550 W pulse output at 3.5 GHz, and the via hole drain structure realized the breakdown voltage of over 10 KV for power devices, approaching GaN device properties to those of the vacuum power devices, the cutoff frequency of 190 GHz and g_m of 420 mS/mm with the 60 nm gate length was also obtained. The growth technology of wide gap semiconductors, however, still needs years to put these promising materials for the practical use. The drain current collapse is the serious problem in the AlGaN/GaN heterostructures. This is induced by the traps within the AlGaN and GaN layers, and can easily be monitored by the LFN measurement without using the DLTS measurements. We have the generation-recombination noise at the corresponding time constant in addition to the intrinsic $1/f$ noise level in the noise spectroscopy. We report here the simultaneous deep level assignments of the AlGaN/GaN heterostructures by the LFN measurement with the drain current collapses in the HFET drain currents. LFN measurement technology is also applied to an AlGaAs/GaAs PNPN junction LED, to which the DLTS measurements cannot be applied to monitor the deep level traps in the too much complicated structures.

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Experiments and Results

1) AlGaN/GaN Heterostructure HFET

The layer structure was prepared for a high-breakdown-voltage AlGaN/GaN metal-insulator-semiconductor HEMT (MIS-HEMT), consisting of a 4-μm-thick undoped GaN layer and a 15-nm-thick undoped $Al_{0.25}Ga_{0.75}N$ barrier layer on a 2-inch c-face sapphire substrate by the metal organic chemical vapor deposition (MOCVD). The sheet carrier mobility and the density were 480 cm^2/Vs and 1.3×10^{13} $/cm^2$ at room temperature, respectively. The Ohmic electrodes were formed at the drain and source by depositing Ti (25 nm thick), Al (100 nm), Ni (40 nm) and Au (50 nm) by an electron-beam deposition and annealing by the rapid thermal annealing at 700°C for 120s in N_2 gas. The minimum specific contact resistance was 2.6×10^{-6} $\Omega\cdot cm^2$. The gate length and source-drain distance were 2 and 6 μm, respectively, formed Ni (25 nm) and Au (500 nm) deposition. A 120-nm-thick SiN layer was deposited on the completed device for surface passivation by ECR sputtering. The current collapse in the device the *I-V* characteristics were evaluated after applying the drain bias of V_d = 10 V. Figure 1 shows both the un-passivated drain current of 184 mA/mm (dashed lines) and that of the passivated devices 264 mA/mm (solid lines) at the drain and the gate voltages of V_d =10 V and V_g =1 V, respectively. SiN film is known to reduce the surface state density, resulting in the drain current recovery in AlGaN/GaN HEMTs. The LFN measurements were done on the same wafer as the HEMTs and Hall elements. The device was mounted in a cryostat with the minimum noise level of -245 dBA/√Hz up to 100 KHz. Figure 2 shows temperature dependence of noise density S_I at different frequencies for the unpassivated (a) and passivated (b) devices. The peak in Fig. 2(a) corresponds to the generation-recombination (G-R) noise by the electron trap, E_1=47 meV. Fig. 2(b) indicates -12 dBA/√Hz suppession by the SiN passivation and those by the traps E_2=131 meV and E_3=235 meV becomes apparent. The Arrhenius plots of G-R noise at E_1, E_2 and E_3 are shown in Fig. 3, indicating the E_1 trap the main source of the current collapse in AlGaN/GaN HFETs.

2) AlGaAs/GaAs Heterostructure LED Array

The semiconductors GaAs and AlGaAs/GaAs are the fore-runners of GaN, and great many works on the deep levels are studied, too, both by the DLTS and LFN measurements[13]. Many of the deep levels in AlGaAs/GaAs LEDs, LDs and HEMTs are now deleted to have sufficient life times of the order of 10^6 hrs as the practical devices, and various new applications are devised. One of the stacked LED array became commercially available as the light source for the page/FAX printers. This light source array can make more compact light system compared with those made by the laser diode, suitable for the compact size color page printers or FAX printers.

Figure 4 shows the schematic diagram and its expected IV curves of a light emitting thyristor, during the on-state of which the light is emitted and led to the collecting lens. Each of this thyristor is arrayed to make the LED printer. The LFN measurements of the anode noise can determine the deep levels existing within these complicated device structure, which cannot be done by the conventional DLTS measurements, i.e., most powerful way in this case. Two kinds of substrates are compared by the LFN measurements in Fig. 5. We knowthat similar deep levels are induced in these substrates, independent of the wafer preparations. Well prepared GaAlAs/GaAs HEMT has no deep levels, and observed deep levels might be introduced in the Ohmic contacting process.

Conclusion

1) AlGaN/GaN Heterostructure HFET

Low frequency noise measurements both before and after the SiN passivation of AlGaN/GaN HFETs made it possible to trace the reduction of deep level(47 meV) trap density corresponds to the dramatic decrease of the drain current collapse. This passivation also revealed another two deep levels E_2=131 meV and E_3=235 meV in addition to the reduction of the trap density of the deep level E_1=47 meV. These traps need to be diminished by improving the substrate growth technology. We need also to make enhanced temperature measurement hopefully up to 200 C so that we can assign another huge trap just above the room temperature, which could affect much on the drain current at room temperature.

2) AlGaAs/GaAs Heterostructure Thyristor

Light emitting thyristor is a kind of new practical application of AlGaAs/GaAs heterostructure devices, and is now commercially available as the page printer head LED. Low frequency noise measurements of this complicated structure made it possible to assign the deep levels induced within the structure. These levels were observed independent of the substrate preparation and of the substrate lots, indicating the deep level introduction through the Ohmic contacting processes, just as typically observed in AlInAs/InGaAs heterostructures. Improvements of the contacting processes must be procecuted to diminish the deep levels. The thin film passivation on AlGaAs surface could improve the reliability of the device.

Low Frequency noise measurements have shown a valuable tool to assign the deep level trap energy and density of hard electronics devices made of SiC or GaN as well as those made of the shallow band gap devices like InGaAs and InAs as well as those of the conventional devices like GaAs and Si, and of the complicated device structures.

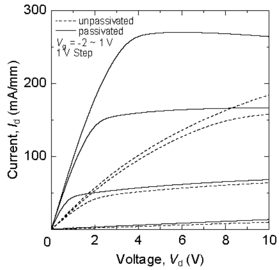

Fig. 1. Drain IV characteristics of AlGaN/GaN HFET before (dashed) and after(solid) SiN passivation.

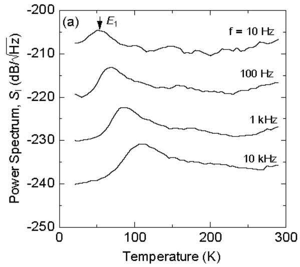

Fig. 2a. Temperature dependences of current noise characteristics for HFET without SiN passivation at 5 mA.

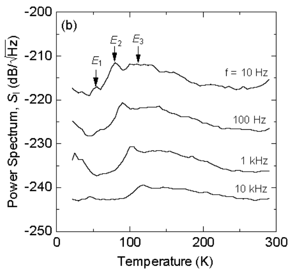

Fig. 2b. Temperature dependences of current noise characteristics for HFET with SiN passivation at 5 mA.

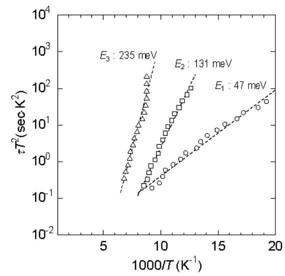

Fig. 3 Arrhenius plots of the fluctuation time constant, τ, for AlGaN/GaN HFET.

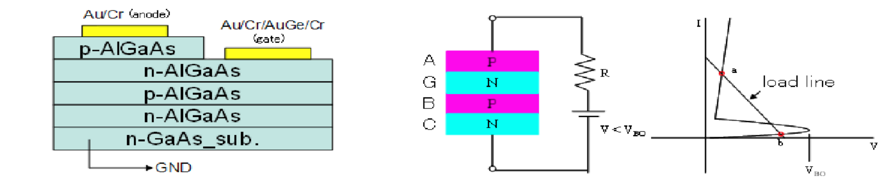

Fig. 4 Schematic diagram of light emitting thyristor

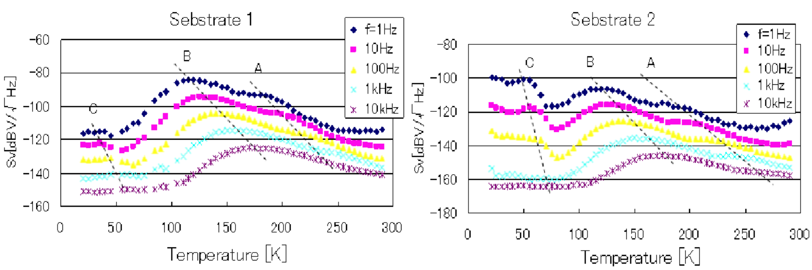

Fig. 5 LFN measurements of AlGaAs/GaAs light emitting thyristor