Trapping Characteristics and Reverse Leakage Current Mechanism ofAlGaN/GaN and AlGaN/InGaN/GaN Heterostructures

Abstract

Nitride Based Semiconductor devices are considered to be the next promising candidate for future high speed and high power applications. Heterostructure based on gallium nitride (GaN) and its related compound (like aluminium gallium nitride (AlGaN), Indium gallium nitride (InGaN) etc.) can induce higher Two dimensional electron gas (2DEG) concentration (~ 10^{13} cm^{-2}) without any intentional doping due to its inherent polarization property. In this research, trapping characteristics and reverse leakage current mechanism of AlGaN/GaN and AlGaN/InGaN/GaN are investigated. First, the simulation based study has been carried to see the electron distribution and trap recombination phenomena in these structures. It is found that the AlGaN/GaN structure suffers from large distribution of electron below the gate contact in gate-drain side. This is because of the higher electric field and carrier energy formation in the same region. The transient simulation reveals that the on-state drain bias gives higher recombination of channel electron in the GaN buffer region below the gate contact.

Before analysing the AlGaN/InGaN/GaNheterostructure, the InGaN growth investigation on silicon substrate is carried out. Indium nitride (InN) segregation is found to be a most common problem in constant flux growth regime which degrades the quality of the crystal. So the shutter modulation scheme is adapted to grow InGaN, where the Indium, gallium are shuttered simultaneously and periodically in the constant ambience of nitrogen. Indium incorporation is dependent on In/(In+Ga) ratio in which the Gallium flux is changed keeping the indium flux constant. In this way, 16% and 23% indium are incorporated in the InGaN layer without any InN segregation. The FESEM image reveals that the surface of InGaN contains many V-shaped pits due to the lattice relaxation. Also, trench formation is seen in the cross sectional images of heterostructures mainly due to the basal stacking fault.

Now, frequency dependent conductance measurement is carried out to observe the trapping effect in the grown $Al_{0.3}Ga_{0.7}N/In_{0.02}Ga_{0.98}N/GaN$ double heterostructure and compared that with conventional $Al_{0.3}Ga_{0.7}N/GaN$ single heterostructure. The surface and interface trapping characteristics are investigated separately by conductance measurement in the depletion and accumulation region of voltage biases. It is found that the AlGaN/InGaN/GaN diode structure does not show any interface trapping effect, whereas single heterostructureAlGaN/GaN diode suffers from two kinds of trap energy states. This conductance behaviour of AlGaN/InGaN/GaNheterostructure is owing to more Fermi energy level shift from trap energy states at AlGaN/InGaN junction compare to single AlGaN/GaNheterostructure and eliminates the trapping effects. Analysis yielded interface trap energy state in AlGaN/ /GaN is to be with time constant of (33.8-76.5)μs and trap density of (2.38-0.656) $\times 10^{12} \mathrm{eV}^{-1}\mathrm{cm}^{-2}$in -3.2 to -4.8 V bias region, whereas for AlGaN/InGaN/GaN structure no interface energy states are found. But, the surface trap energy of AlGaN/InGaN/GaN is extracted with concentrations and time constants of (5.87-4.39)$\times 10^{12} \mathrm{eV}^{-1}\mathrm{cm}^{-2}$and (17.8-11.3) μs respectively in bias range -0.8 to 0.0 V.

Next, the reverse gate leakage current mechanism is investigated in the same device structures. Two types of reverse leakage current mechanism are investigated: one is Frenkel-Poole (FP)emission and other is Fowler-Nordheim (FN) tunnelling. The conduction band simulation shows that the band bending at the interface is higher in AlGaN/InGaN/GaNheterostructure due to the higher polarization charge which results in higher electric field across the AlGaNbarrier compare to single heterostructure. Hence, the single heterostructureAlGaN/GaN shows only FP emission leakage current whereas the double AlGaN/InGaN/GaNheterstructure follows FP and FN both. The FP analysis reveals that the trap energy levels of 0.37eVand 0.34eVare contributing for AlGaN/GaN and AlGaN/InGaN/GaNheterostructure respectively.However, the FN tunnelling in AlGaN/InGaN/GaN is dominating for electric field higher than 2.63 MV/cm.