Title	AlTiO絶縁膜を用いたGaN系MISデバイスにおけるノーマリーオフ動作のための界面電荷エンジニアリング
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Citation	
Issue Date	2022-03
Type	Thesis or Dissertation
Text version	ETD
URL	http://hdl.handle.net/10119/17767
Rights	
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Abstract

Wide-gap semiconductor GaN is anticipated for its potential to overcome the trade-off between speed and power in semiconductor devices. In particular, GaN-based metal-insulator-semiconductor heterojuction field-effect transistors (MIS-HFETs) have been investigated extensively owing to the merits of gate leakage reduction and passivation to suppress the current collapse. As a gate insulator of GaN-based MIS-HFETs, various materials such as Al_2O_3, TiO_2, TaON, AlN, BN, and so on have been employed and investigated. Although a wide energy gap E_g and a high dielectric constant k_{ins} are preferable for a gate insulator, a trade-off between E_g and k_{ins} generally exists for insulators. Aluminum titanium oxide Al_xTi_yO (AlTiO), an alloy of Al_2O_3 (E_g ~ 7 eV, k_{ins} ~ 10) and TiO_2 (E_g ~ 3 eV, k_{ins} ~ 60) is a versatile insulator since its properties can be modified for energy gap engineering (E_g control) and dielectric constant engineering (k_{ins} control) via its composition. Although there still exists a trade-off between E_g and k_{ins}, we can choose an AlTiO composition according to applications, considering the trade-off. On the other hand, at the interface between an oxide gate insulator and a negatively polarized semiconductor surface, such as a Ga-face (Al)GaN surface, a positive fixed charge tends to be generated and to neutralize the negative polarization charge. The positive interface fixed charge has a significant impact on threshold voltages; a high-density positive interface fixed charge shifts the threshold voltage negatively. The technology aiming to control the threshold voltage by controlling the positive interface charge is called “interface charge engineering”.

In this work, we investigated interface charge engineering in AlTiO/AlGaN/GaN MIS devices by evaluating the positive interface fixed charge density depending on the composition of AlTiO obtained by atomic layer deposition. We found a trend that the interface fixed charge density decreases with a decrease in the Al composition ratio, i.e. increase in the Ti composition ratio. Moreover, X-ray photoelectron spectroscopy characterization of AlTiO/AlGaN reveals a relation between the positive interface fixed charge density and the bonding states of Ga: an increase in Ga-N bonding state or a decrease in Ga-O bonding state leads to an increase in the positive interface fixed charge density.

In order to realize normally-off operations with good transport properties in AlTiO/AlGaN/GaN MIS-FETs, we investigated combining the interface charge engineering and partial gate recess method with a thick remaining

AlGaN layer. For a composition of $x/(x+y) = 0.73$, the positive fixed charge at AlTiO/recessed-AlGaN is significantly suppressed compared to that at Al_2O_3/recessed-AlGaN, leading to a positive slope in the relation between the threshold voltage and the AlTiO insulator thickness. As a result, we successfully obtained normally-off operations in partially-gate-recessed AlTiO/AlGaN/GaN MIS-FETs with a threshold voltage of 1.7 V and good transport properties. For a composition of $x/(x + y) = 0.73$, low-frequency noise characterization of AlTiO/AlGaN/GaN MIS-FETs with different remaining AlGaN thickness reveals two trap levels in AlTiO, independent of AlGaN thickness. Moreover, the noise magnitude increases with a decrease in the remaining AlGaN thickness, owing a decrease in the channel electron mobility.

In summary, we successfully obtained normally-off operation in GaN-based MIS devices by interface charge engineering using AlTiO insulators and investigated the AlTiO/AlGaN interface by X-ray photoelectron spectroscopy and low-frequency noise.

Keywords: III-V compound semiconductor, AlGaN/GaN, AlTiO, interface charge engineering, normally-off operation