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Inversion Layer Mobility of SiC MOSFETs with Thermally Grown Oxide : Effect of Post-Oxidation Nitridation and Gate Oxide Thickness

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Abstract

Inversion layer mobility of 4H-SiC MOSFETs with thermally grown gate oxide was investigated. To clarify fundamental scattering properties of inversion layer mobility in SiO_2/4H-SiC systems, we examined the effects of post-oxidation nitridation and gate oxide thickness on Hall effect mobility (μ_{Hall}) in inversion layer of 4H-SiC MOSFETs. It was revealed to be a common feature for thermally grown SiO_2/4H-SiC systems that dominant scatterings in inversion layer are phonon and Coulomb scattering, not surface roughness scattering.

1. Introduction

4H-SiC MOSFETs have been widely developed owing to its high breakdown electric field and thermal conductivity, which are suitable for power devices. To improve the channel characteristics and maintain stability of the gate oxide, post-oxidation nitridation is commonly used for 4H-SiC MOSFETs [1, 2]. As the field effect mobility of 4H-SiC MOSFETs still remains as low as 30 cm^2/V·s, extensive research of μ_{Hall} in inversion layer has been carried out to understand the mobility-limiting factors in 4H-SiC MOS inversion layer [3-10]. The mobility-limiting factors are considered to be phonon, Coulomb, and surface roughness scattering on the basis of the inversion layer mobility model of Si MOSFETs [11]. In the case of 4H-SiC MOSFETs, it was suggested that a dominant scattering changes from Coulomb scattering to phonon scattering when lowing acceptor concentration (N_A) of p-type well region from 5×10^{17} to 1×10^{15} cm^{-3} [6]. Although scattering components have long been distinguished by adjusting numerical formulae [3-5] or mobility models in TCAD [6], carrier scatterings in 4H-SiC MOS inversion layer were experimentally investigated in a recent study [10]. The gate oxide used in this previous experiment was a single condition, that is, 50 nm-thick thermally grown SiO_2 followed by post-oxidation nitridation. Therefore, it is still unclear whether the reported carrier transport properties of 4H-SiC MOS inversion layer are a common feature of 4H-SiC MOSFETs or not.

In this study, we focus on the behavior of μ_{Hall} in inversion layer with thermally grown SiO_2/4H-SiC systems. To understand fundamental scattering properties of 4H-SiC MOSFETs with the thermally grown gate oxide, we examined the effects of post-oxidation nitridation and/or gate oxide thickness on μ_{Hall} in inversion layer of 4H-SiC MOSFETs.

2. Experimental

Planar-type Si-face 4H-SiC MOSFETs were fabricated on uniformly doped p-type epitaxial layers grown on an n-type substrate. The acceptor was aluminum (Al), and N_A was designed to be around 3×10^{14} and 1×10^{16} cm^{-3}. Thin and thick gate oxide were formed by thermal oxidation. Here, the thickness before post-oxidation nitridation were around 5 nm and 50 nm, respectively. Post-oxidation nitridation was carried out in NO (10% diluted in N_2) at 1250 ºC for 1 hour. The Hall effect measurement was carried out under a magnetic field of 1.1 T.

3. Results and Discussion

3.1. Phonon-limited mobility

For the experimental evaluation of carrier transport properties in 4H-SiC MOS inversion layer, it is important to lower N_A down to the order of 1×10^{14} cm^{-3} to discuss phonon-limited mobility (μ_{phonon}) [10]. In this previous study, phonon and Coulomb scattering are found to mainly dominate the inversion layer mobility of 4H-SiC MOSFETs, while surface roughness scattering has little effect (**Fig. 1**).

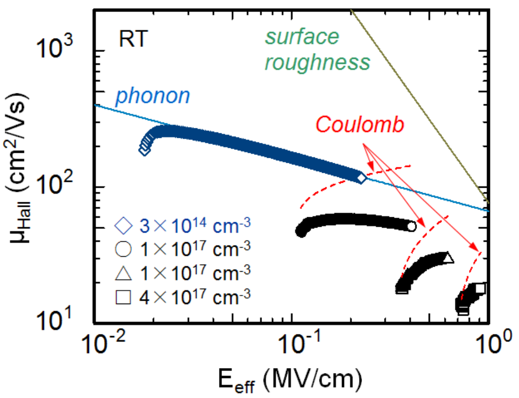

Fig. 1 μ_{Hall} as a function of E_{eff}. Here, η for calculating E_{eff} was set to be 1/3. N_A was 3×10^{14}, 1×10^{16}, 1×10^{17}, and 4×10^{17} cm^{-3}, respectively. Red, blue, and green lines represent Coulomb-, phonon-, and surface roughness-limited mobility, respectively.

We examined the effect of post-oxidation nitridation and gate oxide thickness on μ_{Hall} in inversion layer of 4H-SiC MOSFETs using N_A around 3×10^{14} cm^{-3}. It was found that μ_{Hall} as a function of effective electric field (E_{eff}) was plotted on the same line for 4H-SiC MOSFETs with thick gate oxide regardless of post-oxidation nitridation in E_{eff} region higher than 0.03 MV/cm (**Fig. 2**). Note that E_{eff} is at most 0.05 MV/cm for the sample without post-oxidation nitridation because of significantly more severe carrier trapping at MOS interface. This result suggests that post-oxidation nitridation does not affect μ_{phonon} for 4H-SiC MOSFETs with thick gate oxide. Moreover, although the oxidation mechanism might be different at the early stage oxidation [12], μ_{Hall} as a function of E_{eff} was plotted on the same line regardless of post-oxidation nitridation and/or gate oxide thickness (**Fig. 2**). Thus, **Fig. 2** represents a fundamental feature of μ_{phonon} in thermally grown SiO_2/4H-SiC systems when the gate oxide is thicker than 5 nm.

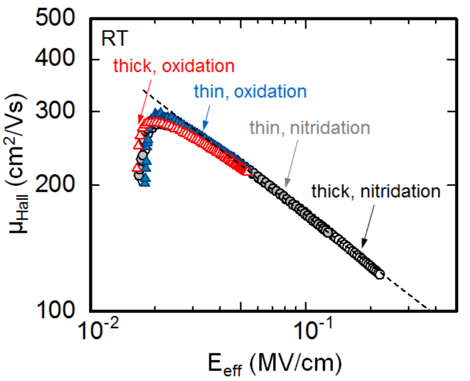

Fig. 2 Gate oxide process dependence of μ_{Hall} as a function of E_{eff}. Here, η for calculating E_{eff} was set to be 1/3. N_A was around 3×10^{14} cm^{-3}. The effect of post-oxidation nitridation was examined for 4H-SiC MOSFETs with thin and thick gate oxide.

3.2. Coulomb- and surface roughness-limited mobility

As it was found that μ_{phonon} for 4H-SiC MOSFETs with SiO_2/4H-SiC systems was independent of gate oxide processes used in this study, carrier transport properties can be evaluated using the method described in Ref. 10. For the 4H-SiC MOSFETs with N_A of 1×10^{16} cm^{-3}, we examined the effect of post-oxidation nitridation and gate oxide thickness. Regardless of gate oxide thickness, μ_{Hall} as a function of surface carrier density (N_S) is almost the same when post-oxidation nitridation was carried out (**Fig. 3**).

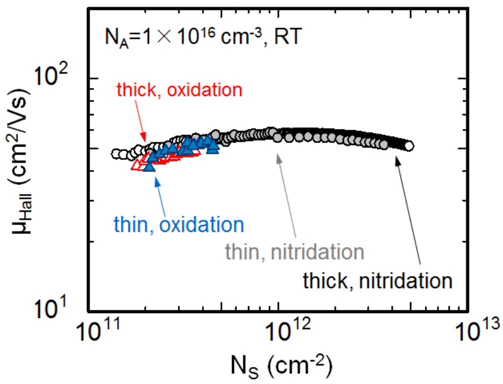

Fig. 3 Gate oxide process dependence of μ_{Hall} as a function of N_S. The effect of post-oxidation nitridation was examined for 4H-SiC MOSFETs with thin and thick gate oxide.

By subtracting the effect of phonon scattering from μ_{Hall} on the basis of Matthiessen's rule, the effect of Coulomb and surface roughness scattering can be evaluated. Regardless of the gate oxide processes, μ_{Hall} without the effect of phonon scattering is proportionally increasing to the power of N_S in low N_S region (**Fig. 4**). This feature possibly represents Coulomb-limited mobility ($\mu_{Coulomb}$) in 4H-SiC MOS inversion layer [8]. In high N_S region more than 2×10^{12} cm^{-2}, μ_{Hall} without the effect phonon scattering is slightly lower than the expected $\mu_{Coulomb}$. This decrease means that surface roughness slightly affects inversion layer mobility in high N_S region, but the effect is limited. Thus, regardless of post-oxidation nitridation and gate oxide thickness, dominant scattering mechanisms in 4H-SiC MOS inversion layer were found to be phonon and Coulomb scattering, not surface roughness scattering.

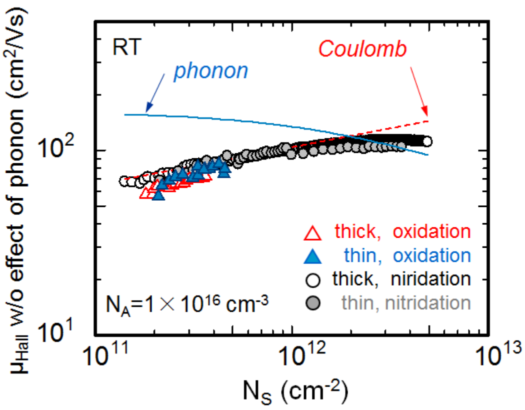

Fig. 4 Gate oxide process dependence of μ_{Hall} without the effect of phonon as a function of N_S. The effect of post-oxidation nitridation was examined for 4H-SiC MOSFETs with thin and thick gate oxide.

4. Conclusions

Inversion layer mobility of 4H-SiC MOSFETs with thermally grown gate oxide was investigated. The effect of post-oxidation nitridation and gate oxide thickness on μ_{Hall} of 4H-SiC MOSFETs was examined. It was found that μ_{phonon} was determined at the early stage of oxidation regardless of post-oxidation nitridation. Also, it was revealed to be a common feature for thermally grown SiO_2/4H-SiC systems that dominant scatterings in inversion layer are phonon and Coulomb scattering, not surface roughness scattering.

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