Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 1058-1059

H-9-2

Influence of High Dielectric Constant in Gate Insulator on Remote Coulomb Scattering due to Gate Impurities in Si MOS Inversion Layer

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1. Introduction

It has been reported that inversion-layer mobility (μ_{eff}) is significantly degraded in gate oxides thinner than critical thickness [1]. Although reliable experimental results [2,3] suggest that this mobility lowering can be associated with remote Coulomb scattering (RCS) due to ionized impurities in poly-Si gate, the mechanism of RCS has not been fully understood yet. Recent calculation [4] suggested that the dependence of remote Coulomb scattering potential ϕ on dielectric constant ε in stacked-gate structure can have a maximum with increasing ε (Fig.1(a)).

In this paper, we experimentally examine μ_{eff} of MOSFEETs with SiON gate insulator, in order to clarify the influence of high dielectric constant ε in gate insulator on remote Coulomb scattering due to gate impurities. We discuss how is the trade-off between the "ε effect" and "r effect" under EOT=const. (Fig.(b)).

2. Experimental

Since SiON gate insulator has large amount of trap charges and interface states, characterization of mobility in SiON has not been sufficient as compared to that in pure SiO_2, and hence it is not easy to extract the RCS component (μ_{RCS}). In this study, we fabricated MOSFETs with different poly-Si gate impurity concentration (N_{poly}) values of $5x10^{15}cm^{-2}$ (high dose) and $2x10^{15}cm^{-2}$ (low dose) (Fig.2). Since μ_{RCS} has strong N_{poly} dependence [3], the comparison of μ_{eff} between different N_{poly} samples enables us to detect the behavior of RCS due to gate impurities, even in SiON case.

The devices used in this study were conventional n-MOSFETs with gate insulators of SiO_2 (1.5-2.1nm) and SiON (1.8-2.4nm). The thickness of gate insulators was determined with high resolution TEM.

3. Results and discussion

3.1. Influence of dielectric constant on RCS

In order to examine the influence of dielectric constant on RCS (ε effect), inversion-layer mobility in the SiON sample was compared to that in the SiO_2 sample with almost the same insulator thickness (Fig.3). Although μ_{eff} in SiON is degraded compared to that in SiO_2, there is no N_{poly} dependence of μ_{eff} at 300K (Fig.4). The μ_{eff} degradation in SiON is due to trap charges (μ_{trap}) and/or interface sates (μ_{it}). Since μ_{RCS} has stronger temperature dependence than μ_{trap}/μ_{it} (Fig.5) [5], the influence of μ_{RCS} becomes significant at low temperatures, compared to other components. The SiON sample shows strong N_{poly} dependence at 100K, while the SiO_2 sample still has little N_{poly} dependence (Fig.6). This is the direct experimental evidence that the increase in dielectric constant can enhance RCS due to gate impurities (ε effect), though it is not so critical at 300K in our SiON samples.

3.2. Influence of physical thickness on RCS

Next, the influence of physical thickness on RCS (r effect) under constant EOT is discussed. μ_{eff} in samples with the same EOT of 1.5nm (Fig.7) was compared at 300K (Fig.8). Although μ_{eff} in SiO_2 has clear N_{poly} dependence, similar as previously reported [3], μ_{eff} in SiON is almost independent of N_{poly}, even at the same EOT. The same behaviors were observed in SiON samples with higher EOT. The ratio of μ_{eff} at high N_{poly} to that at low N_{poly} is shown as a function of EOT (Fig.9(a)) and physical thickness (Fig.9(b)). Although the ε effect can influence RCS, it is concluded that RCS is mainly dominated by the r effect from a practical viewpoint.

The relationship between remote Coulomb scattering potential ϕ and dielectric constant ε was calculated (Fig.10). When the distance r is constant, ϕ has a maximum at/around the dielectric constant of substrate, which leads to the enhancement of RCS as shown in Fig.6. On the other hand, under constant EOT, ϕ decreases monotonously, which corresponds to suppression of RCS (Figs.8, 9). From these results, RCS due to gate impurities on inversion-layer mobility will become less influential in MOSFETs with high-k materials, in which sufficient physical thickness is required to reduce gate leakage current.

3. Conclusions

The influence of high dielectric constant in gate insulator on remote Coulomb scattering due to gate impurities was examined. Experimental evidence that the increase in dielectric constant can enhance RCS was obtained. However, since the physical thickness also increase with increasing ε for a practical use, RCS will be rather suppressed. Our new findings will contribute to an accurate modeling of mobility limited by remote Coulomb scattering.

References
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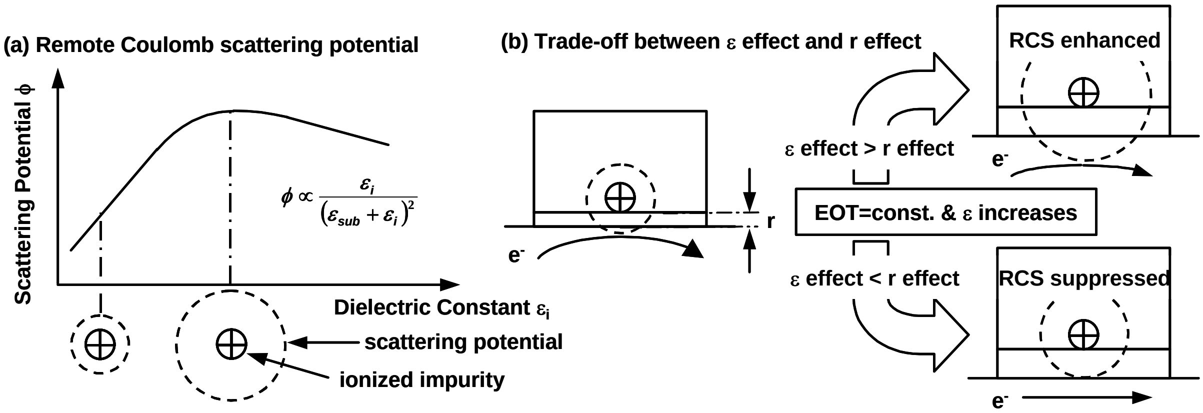


Fig.1 (a) Schematic diagram for dielectric constant dependence of RCS potential. Dashed circle indicates the strength of scattering potential. (b) Trade-off between ε effect and r effect. "ε effect" means that the increase in ε leads to stronger ϕ. "r effect" means that the distance between surface carriers and ionized impurities in the gate becomes long with increasing ε under constant EOT.

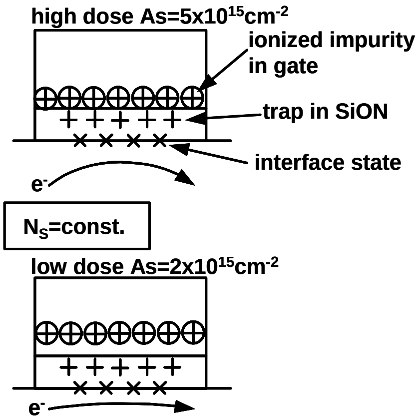


Fig.2 Schematic diagram for origin of gate impurity concentration dependence of RCS.

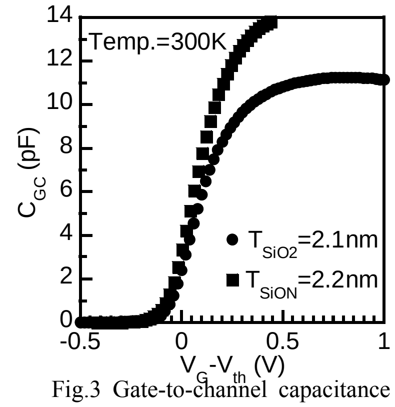


Fig.3 Gate-to-channel capacitance characteristic. Dielectric constant in SiON is higher than that in SiO_2.

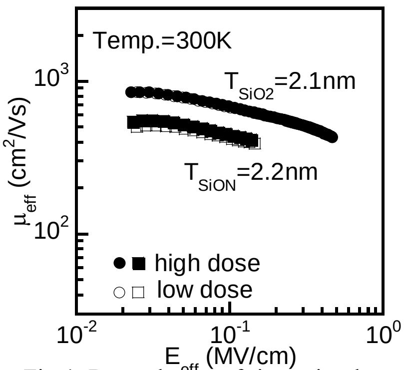


Fig.4 Dependence of inversion-layer mobility (μ_{eff}) on effective field (E_{eff}) at 300K.

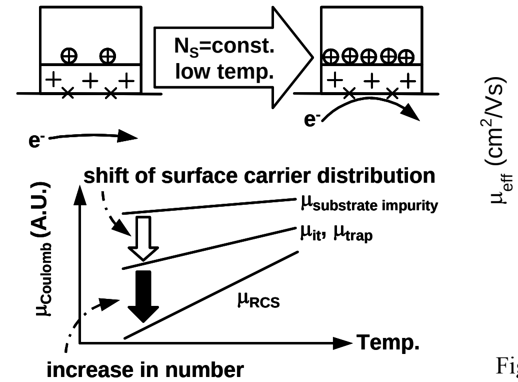


Fig.5 Schematic diagram for temperature dependence of each Coulomb scattering component [5].

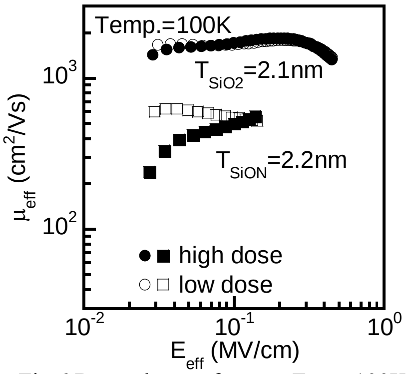


Fig.6 Dependence of μ_{eff} on E_{eff} at 100K.

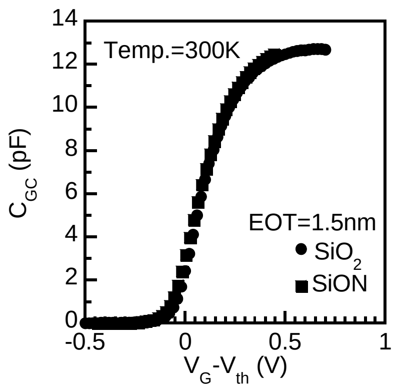


Fig.7 Gate-to-channel capacitance characteristic at EOT=1.5nm.

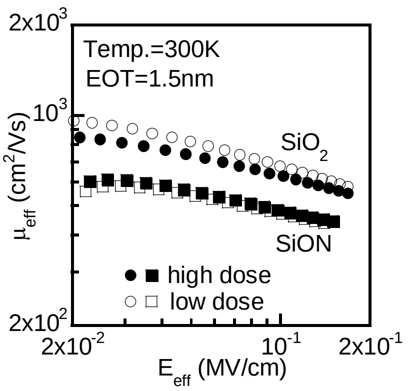


Fig.8 Dependence of μ_{eff} on E_{eff} at 300K at EOT=1.5nm.

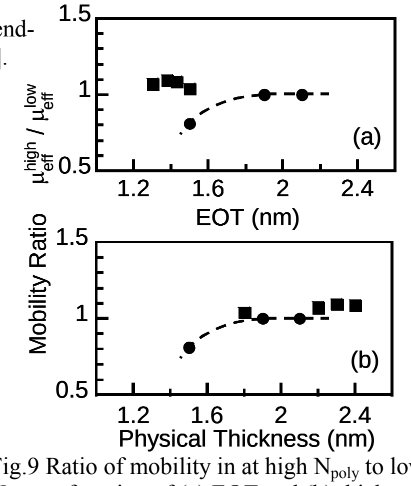
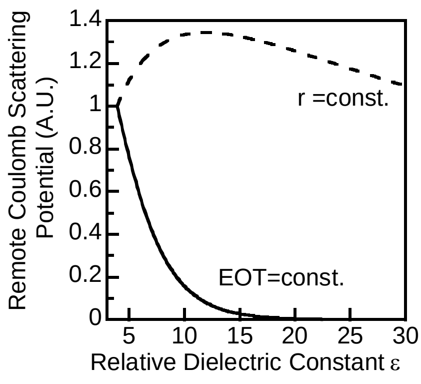


Fig.9 Ratio of mobility in at high N_{poly} to low N_{poly} as function of (a) EOT and (b) thickness. N_S=3x10^{11}cm^{-2}, (●) SiO_2, (■) SiON.



Fi.10 Relationship between scattering potential and dielectric constant.