Remote Coulomb Scattering Limited Mobility in MOSFET with CeO_2/ La_2O_3 Gate Stacks

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Introduction

Downsizing of the Metal-Oxide–Semiconductor Field-Effect Transistors (MOSFETs) has required the use of high-k material to replace the conventional SiO_2. The problem of mobility degradation of high-k MOSFETs has been well modeled and as a result, the main reason has been regarded as Remote Coulomb Scattering (RCS) [1-5]. It has been demonstrated that a direct contact structure between La_2O_3, one of the most promising high-k, and Si substrate can be obtained by forming La-silicate, a silicate which has a relatively higher k value, at the interface as a result of the reaction of La_2O_3 with Si substrate. Forming a higher k value silicate is advantageous for gate dielectric scaling, but the mobility degradation due to RCS still remains as one of the major concern. Recently, CeO_2 capping on La_2O_3 has revealed an improvement in mobility mostly at low electric field. In this paper, we studied RCS limited mobility in CeO_2 capped La_2O_3 high-k MOSFETs.

RCS Theory

We used the relaxation time approximation to calculate the RCS-limited mobility,

$$\mu_{RCS} = e\tau^*_{RCS} / m^* \text{, (1)}$$

τ^*_{RCS} is the averaged relaxation time over the kinetic energy, and can be find by the well-known Fermi golden rule,

$$\frac{1}{\tau_{RCS}(\varepsilon)} = \frac{2\pi m^*}{\hbar^3}\int_0^{2\pi} d\theta \int_{-\infty}^{\infty} dz_0 N_{RCS}(z_0) \left|< A_q(z_0) >\right|^2 (1-\cos\theta) \text{ ,(2)}$$

where $< A_q(Z_o) >$ is an average of wave vector related RCS potential. By considering finite oxide thickness of the layers into account, applying the Fang-Howard method, and the Green's function method, one can find RCS potential by analytically solving the Poisson equation

$$\nabla \cdot [\varepsilon(z)\nabla\phi(\bar{r},z)] = -\rho(\bar{r},z) \text{. (3)}$$

Here □(z) is the spatial dependent permittivity. Once get RCS potential, we can calculate RCS limited mobility by using the Eq.(1),and Eq.(2).

Experimental details

nMOSFET was fabricated on a S/D preformed Si(100) substrate. High-k thin films were deposited by e-beam evaporation followed by the substrate cleaning. After metal gate formation by dry etching process, the samples were annealed in forming gas ambient at 500 °C for 30 min. The effective mobility of electrons was measured for both La_2O_3 single and CeO_2 / La_2O_3 stacked MOSFETs.

Results and discussion

Fig.1 shows the average scattering potential due to the remote charge. While the distance of the fixed charges from inversion layer is increasing, the average scattering potential is decreasing. Fig.2 shows the experimentally extracted effective mobility of electrons in both of La_2O_3 and CeO_2/ La_2O_3 gate stack samples. The effective mobility was improved nearly 30% by using stacked CeO_2 layer. Since no shift in threshold voltage has been observed, the improvement in mobility might be due to the reduction of the scattering charge density inside the gate stack by using multivalent CeO_2 material. Comparison of an analytically calculated RCS limited mobility with experimental one is shown in Fig.3. Since RCS limited mobility is dominant in low effective electric field region, we extract RCS limited mobility by using Matthiessen's rule. The effective oxide thickness was 1.5nm. We find there was a good agreement between measured mobility and calculated mobility.

Conclusion

In summary, the RCS limited electron mobility in the inversion layers in MOSFETs with CeO_2/ La_2O_3 gate stacks have been investigated. Our results show that the possibility of the improvement of the RCS limited mobility by introducing multivalent CeO_2 material to reduce fixed charge density in the gate stack.

Acknowledgement

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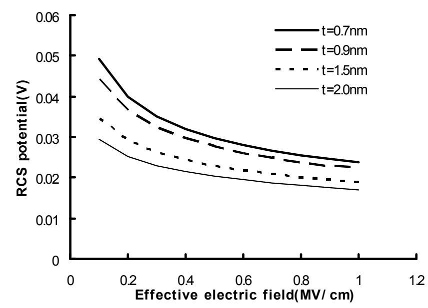

Fig. 1: Calculated RCS average potential versus applied effective electric field. Here t is physical thickness of the La_2O_3 layer, fixed charge density is 4E+13/cm^2;

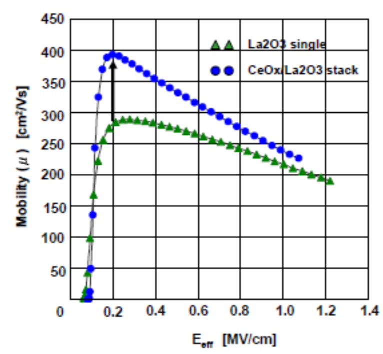

Fig. 2: Experimentally measured mobility versus effective field (W/WO CeO_2 layer on La_3O_3).

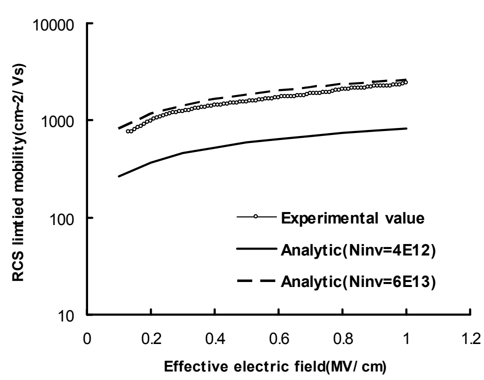

Fig.3: Calculated RCS limited mobility comparison to experimental one (semi log plot, with 1.5nm EOT).

References

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