Study on Remote Coulomb Scattering Limited Mobility in MOSFETs with CeO_2/ La_2O_3 Gate Stacks

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Introduction: The problem of mobility degradation of high-k MOSFETs has been well modeled and as a result, one of the main reasons has been regarded as Remote Coulomb Scattering (RCS). In high-k/SiO_2 MOSFETs, SiO_2 layer plays important role to improve the mobility. But, the SiO_2 interfacial layer should be removed in the future for further scaling of the transistor size. Therefore, the mobility degradation is a main concern when high-k and the silicon substrate directly contacted. Recently, it has been demonstrated that the direct contact structure between La_2O_3, and Si substrate can be obtained by forming La-silicate. Forming a higher k value silicate is advantageous for gate dielectric scaling, and the mechanism of the mobility degradation needed to study. In this report, we studied RCS limited mobility in CeO_2 capped La_2O_3 high-k MOSFETs, and try to explain the mobility degradation by the RCS which is induced by the fixed charges in the gate stacks.

Numerical Calculation: We started from to solving the Shrödinger equation, self consistent Poisson equation and then applied the relaxation time approximation to calculate the RCS-limited mobility. The relaxation time is averaged by the kinetic energy, and found by the well-known Fermi golden rule.

Experiment: nMOSFET was fabricated (fabrication process see at Fig.1-a) on a S/D preformed Si (100) substrate with the annealing condition of forming gas ambient at 500℃ for 30 min. In the gate stack, the physical thickness of the La_2O_3 is 3-5nm, and the physical thickness of the CeO_2 is 1nm (See at Fig.1-b). The effective mobility of electrons was measured for both La_2O_3 single and CeO_2 / La_2O_3 stacked MOSFETs.

Result: From experimental result (See at Fig. 2-a) we see that for CeO_2 / La_2O_3 stacked MOSFETs, mobility is increasing while EOT increasing. Fig.2-b shows that, the mobility of carrier in the CeO_2 / La_2O_3 gate stack MOSFEt is higher than the single layer La_2O_3 MOSFETs, i.e., the mobility of the single layer MOSFETs is degraded compare to gate stack MOSFETs. This can be understood as that the fixed charge in the gate stack might be main reason for mobility degradation. In Fig. 3-a, we show the RCS limited mobility by the analytic simulation. And in Fig.3-b, we compared an experimentally extracted the RCS limited mobility to an analytic one. We can see that the experimental result and analytic result are matching well. In conclusion, it is possible to improve the mobility by introducing a multivalent material(CeO_2) to reduce fixed charge density in the gate stack, i.e., one can able to reduce the RCS during in MOSFETs fabrication process by the controlling the amount of the fixed charges in the gate stacks.

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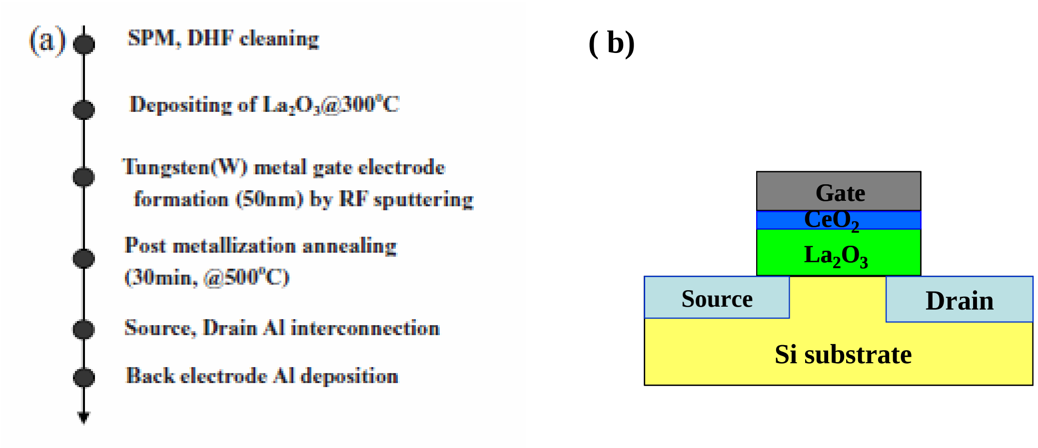

Fig 1. (a): Fabrication process of MOSFETs; (b) A structure of the fabricated MOSFETs.

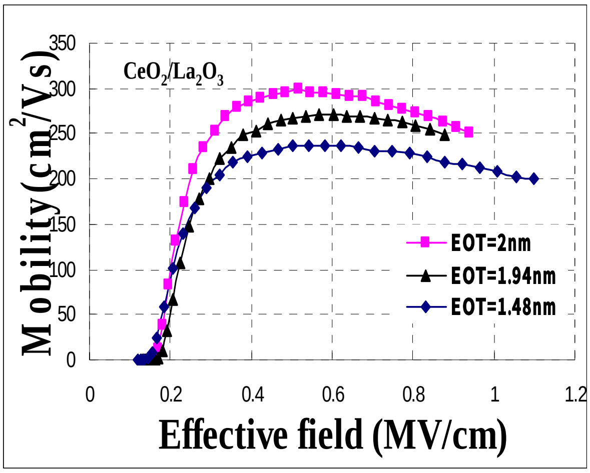

Fig 2. (a): Experimentally measured effective mobility of CeO_2/La_2O_3 gate stack MOSFETs.

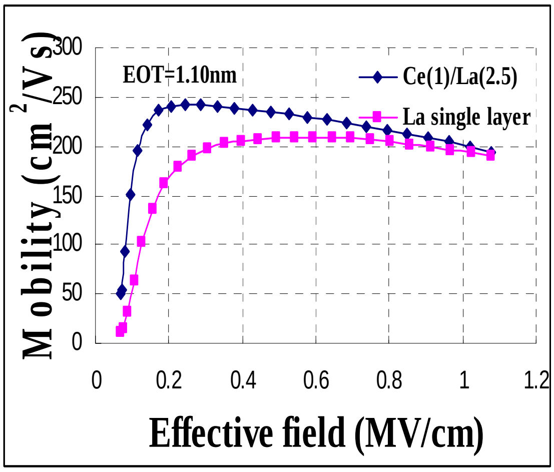

Fig 2. (b): Effective mobility of La_2O_3 single layer and gate stack MOSFETs, EOT is 1.10nm.

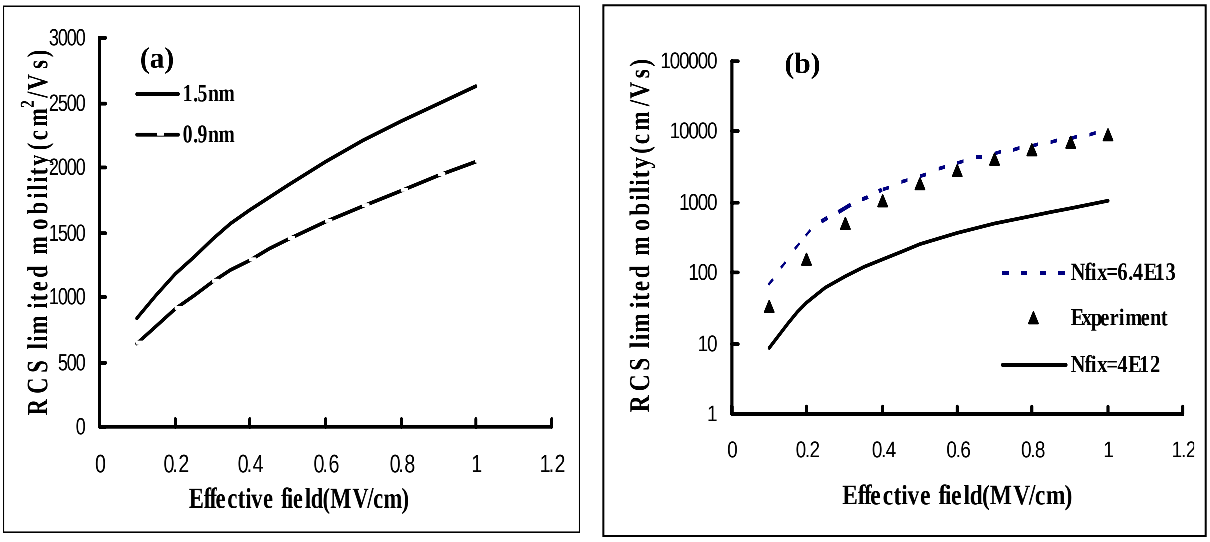

Fig 3. (a): Calculated RCS limited mobility versus applied effective electric field;

(b) Comparison of the RCS limited mobility of analytic and experimental results.