Extended Abstracts of the 2000 International Conference on Solid State Devices and Materials, Sendai, 2000, pp. 42-43

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Quantitative Understanding of Electron Mobility Limited by Coulomb Scattering in MOSFETs with N_2O and NO Oxynitrides

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1. Introduction

Oxynitride films with a few percent of nitrogen atoms are promising candidates for ultra-thin gate dielectrics in dual-gate CMOS technologies for their superior boron diffusion barrier characteristics. However, it is well known that oxynitridation leads to the degradation of the low field mobility μ_c, which is caused by the increase in Coulomb scattering due to the fixed charges. It has already been reported that fixed charges locate mainly at the MOS interface for N_2O oxynitrides, while those locate into oxynitride films around 5Å inner from the MOS interface for NO oxynitrides[1], as shown in Fig.1. The observed difference of mobility limited by Coulomb scattering, μ_c, between N_2O and NO oxynitrides has been attributed to this difference of the location of fixed charges[1]. However, the quantitative examination and the accurate model for μ_c in N_2O and NO oxynitrides have not been obtained yet. In this paper, we propose a new mobility model, where the effect of the location of fixed charges is appropriately taken into account. It is demonstrated that this model successfully represent the N_s(inversion layer electron density) dependence of μ_c for both N_2O and NO oxynitrides. The physical meaning of this model is discussed in terms of multi-subband transport.

2. Model

The mobility limited by Coulomb scattering, μ_c, is determined by subtracting phonon and surface roughness scattering components from the total mobility, according to the Matthiesen's rule. In order to explain the experimental data of electron mobility μ_c with oxynitride, we propose the following mobility model:

$$\mu_c = \alpha \mu_{woscr} + (1-\alpha)\mu_{wscr} \qquad (1)$$

where μ_{wscr} is the mobility with the screening effect and μ_{woscr} is the one without the screening effect. Both μ_{wscr} and μ_{woscr} are determined from the relaxation times given by Stern and Howard[2,3] under the assumption of the electron occupation of lowest subband only. The effect of the location of fixed charges has been incorporated into these relaxation times[2]. The weighting factor $\alpha(0<\alpha<1)$ in (1) is a fitting parameter.

3. Results and Discussion

Fig. 2 and Fig.3 show the calculated N_s dependence of μ_c by the proposed model eq.(1)(α =0.85). For comparison, μ_c with and without screening effect are also presented. The fixed charge density and the position of the charges have been taken to be the same values as those obtained from the experiment[1]. It is found that the present model successfully reproduces the experimental data for both N_2O and NO oxynitrides under a same value of the weighting parameter α, 0.85. Fig. 4 and Fig. 5 show the fixed charge density dependence of μ_c. Fig. 6 sows the comparison between the fixed charge density obtained by the calibration of the present model(eq. (1)) with the experimental data, shown in Fig. 4 and 5, and that extracted from the flat-band voltage shift[1]. It is found that the two values of the fixed charge density are in good agreement, only except for at low nitrogen concentration for NO oxynitride. This disagreement is explainable by the consideration of interface states, which increase the amount of the total Coulombic scattering center. The above results demonstrate that the present model accurately represent the experimental μ_c for both N_2O and NO oxynitrides by using physically appropriate parameters of fixed charges.

This mobility model has been incorporated into 2D device simulator. Fig.7 shows the comparison of the experimental and the simulated results of the drain current versus gate voltage for NO oxynitrides, showing very good agreement.

In order to investigate the physical meaning of α =0.85 in eq.(1), the effect of the multi subband occupation is studied. Fig. 8 and 9 show the calculated electron mobility μ_c based on the two-subband(0,0') screening model[4,5] using the fixed charge density obtained so as to be fitted to the experimental data. The two-subband approximation provides weaker N_s dependence than the only one-subband approximation, irrespective of N_2O and NO oxynitrides. Although the agreement with the experiment is still insufficient, the N_s dependence in the two-subband model is closer to the experimental one, particulary for N_2O oxynitrides. Thinking of the fact that the parameter α in (1) has been introduced to represent the weak N_s dependence of μ_c, experimentally observed, the value of α(=0.85), inherent to electron inversion layer, is considered to contain the effect of the multi-subband screening.

4. Conclusions

A new model for electron mobility milited by Coulomb scattering for MOSFETs with N_2O and NO oxynitrides has been proposed. It has been demonstrated that this model accurately represents the experimental mobility using physically appropriate parameters of Coulomb scattering centers. The weaker N_s dependence of μ_c, included into the new model, can be attributed to the effect of multi-subband screening at room temperature.

References

[1]M. Takayanagi-Takagi and Y. Toyoshima, IEDM. Technical Digest., pp.20.6.1-20.6.4, (1998).

[2]F. Stern and W. E. Howard, Phys. Rev. 163, 816(1967).

[3]T. Matsuoka *et. al.*, J. Appl. Phys.78, 3252(1995).

[4] F. Stern, Sur. Sci. 73, 197(1978).

[5] T. Ando, A. B. Fowler, and F.Stern, Rev. Mod. Phys. 54, 437(1982).

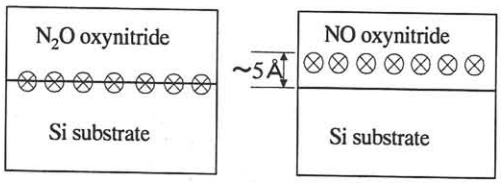

Fig.1 Schematic diagrams of the location of fixed charges for N_2O and NO oxynitrides[1].

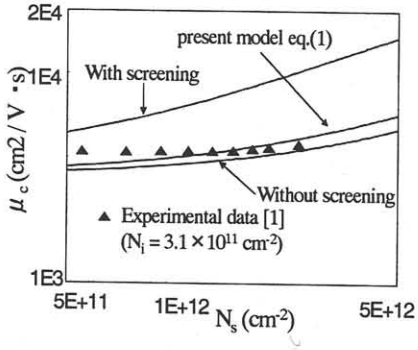

Fig. 2 N_s dependence of μ_c for N_2O oxynitride calculated by the model with screening and without screening and the present model eq. (1). Fixed charges are just at the interface.

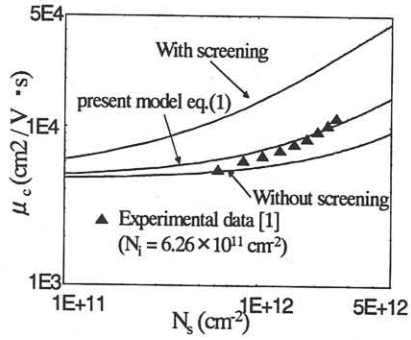

Fig. 3 N_s dependence of μ_c for NO oxynitride calculated by the model with screening and without screening and the present model eq. (1). Fixed charges locate into the oxynitride films around 5 Å inner from the MOS interface.

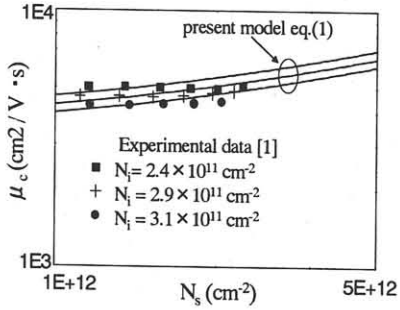

Fig. 4 N_s dependence of μ_c for N_2O oxynitride calculated by the present model eq. (1) with α =0.85 for various fixed charge densities.

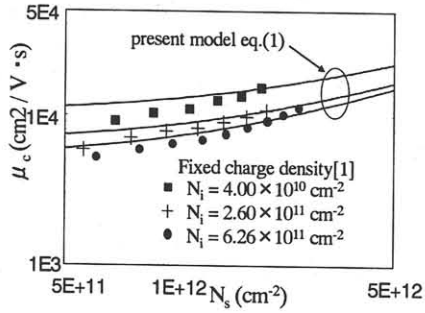

Fig. 5 N_s dependence of μ_c for NO oxynitride calculated by the present model eq. (1) with α =0.85 for various fixed charge densities.

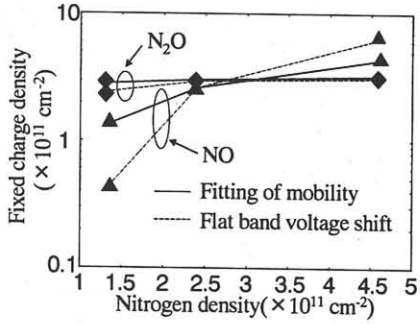

Fig. 6 Fixed charge densities obtained by flat band voltage shift and by the calibration of the present model (1) with the experimental data .

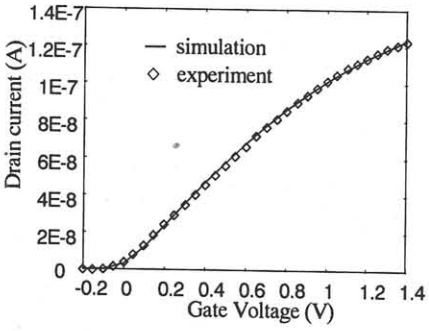

Fig. 7 Comparison of the experimental and simulated results of the drain current versus gate voltage for NO oxynitrides.

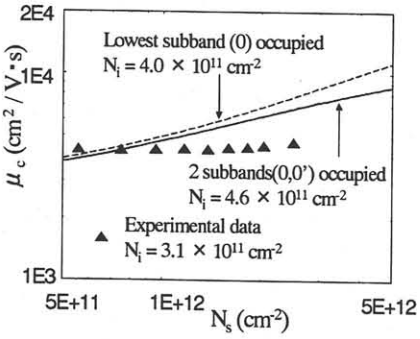

Fig. 8 N_s dependence of μ_c for N_2O oxynitride calculated by the two-subband model. For comparison, μ_c calculated by one-subband model (0) is also presented.

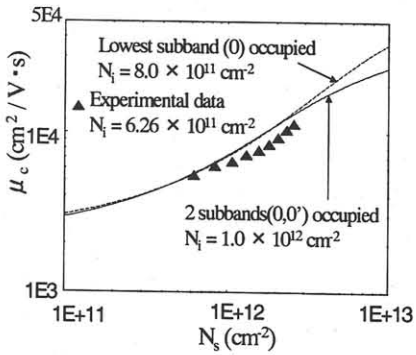

Fig. 9 N_s dependence of μ_c for NO oxynitride calculated by the two-subband model. For comparison, μ_c calculated by one-subband model(0) is also presented.