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Analysis of Boron Pile-up at the Si-SiO_2 Interface Using 2-D Process and Device Simulation

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Introduction

An accurate channel doping profile calculated by a process simulator is essential to the prediction of MOSFET threshold voltage (Vth). However it can not be easily calibrated to measurements, since SIMS which is believed to be the most accurate profiling technique at present, has ±10% error on the depth scale, ±15% on the concentration scale[1]. Moreover measured concentrations in the near-surface region is not reliable[2]. In this study the correction method for SIMS profile is presented. Also by using well-calibrated channel doping profiles, the boron pile-up layer situated on the Si side of the Si-SiO_2 interface is analyzed.

Analysis and Discussion

4 types of n-channel MOSFET's were fabricated (Table 1). Channel doping (boron) profiles of all samples were measured using SIMS. Hereafter type A MOSFET's are used to explain the analysis procedure. For the sake of simplicity of the analysis and accuracy of a 2-D device simulation, artificial modifications were done (Fig.1 and 2). A 2-D structure for the device simulation was created with a combination of a modified SIMS profile and a source/drain profile from a 2-D process simulation. The device simulation was performed using the work function of n^+polySi $\Phi_m = 4.17$ V obtained from measurements and the fixed charge density $Q_{ss} = 0$ in order to calculate the body effect. Fig.3 shows the comparison between the experimental data mearsured from type A MOSFET's (W/L = 25/25) and the calculated results. It is clearly seen that the shape of the calculated curve does not match with that of the experimental one. This means that the modified SIMS profile was different from the true channel doping profile since the body effect mainly depends on the channel doping profile. Therefore the modified SIMS profile needs to be corrected. Fig.4 shows a flow chart of the SIMS profile correction method used in this study. The flow begins with multiplying the correction factors by the concentration and the depth scale of the modified SIMS profile, respectively. Considering the errors on the scales of SIMS profile, the correction factors for the concentration scale and the depth scale should range from 0.85 to 1.15 and from 0.9 to 1.1, respectively. If the boron dose extracted from the corrected SIMS profile is less than the channel implant dose, the 2-D structure is created and the device simulation is performed as mentioned above. The calculated body effect is compared to the measured one, if the agreement is not acceptable, the correction factors are changed to improve the match. Fig.5 shows the result of the SIMS profile correction. The correction factors for the concentration scale and the depth scale are determined to be 1.1 and 0.9, respectively. Fig.6 shows the match between the measured and the calculated body effect using the corrected SIMS profile. The shape of the curve of the calculated body effect matches well with the measured one. This means that the corrected SIMS profile agrees with the true channel doping profile except the near-surface region. However the difference between the calculated Vth at zero substrate bias and the measured one ($\triangle Vth = Vth^{simulated} - Vth^{measured}$) is equal to -27 mV, if we use a more reasonable value of $Q_{ss}/q = 4 \times 10^{10} cm^{-2}$, △Vth leads to -47mV. This implies that an electrically active boron pile-up layer is situated on the Si side of the Si-SiO_2 interface (Fig.7). To estimate the amount of the boron pile-up, the process simulator was calibrated to reproduce the corrected SIMS profile except the near-surface region (Fig.8). Using the well-calibrated channel doping profile, △Vth is equal to -96 mV. If we assume the boron pile-up is confined in a very narrow region of the Si surface, it can be translated into Q_{ss} and then the corresponding value of Q_{ss}/q is equal to $1.84 \times 10^{11} cm^{-2}$. Thus the amount of the boron pile-up is estimated. The same procedure is applied to type B to D MOSFET's. The effects of process conditions on the amount of the boron pile-up are shown in Fig.9 to 11. It can be seen that the amount of the boron pile-up increases with channel implant dose or gate oxide thickness and is independent of gate oxidation temperature. In order to account for the boron pile-up, a more sophisticated model like, the three phase Si-SiO_2 system suggested by F. Lau et al. [3] needs to be incorporated in a process simulator. With this incorporation it is feasible to predict Vth more precisely over the wide range of process conditions by a process and a device simulation.

Acknowledgment

We would like to thank Assistant Professor K. Taniguchi of Osaka University for his helpful comments.

References

[1] W. Vandervorst, et al., J. Vac. Sci. Technol. B 10, 302 (1992)
[2] S. F. Corcoran, et al., J. Vac. Sci. Technol. B 10, 342 (1992)
[3] F. Lau, et al., Appl. Phys. A 49, 671 (1989)

Table 1. Process condition

process condition	type A	type B	type C	type D
channel implant	B 50keV,5×10^{12}cm^{-2}	B 50keV,5×10^{11}cm^{-2}	B 50keV,5×10^{12}cm^{-2}	B 50keV,5×10^{12}cm^{-2}
gate oxidation	850℃,11.1nm	850℃,11.3nm	850℃,18.6nm	920℃,11.0nm

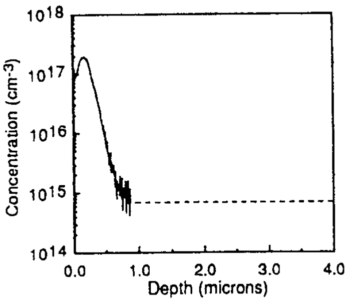

Fig.1. Boron profiles in the channel region of type A MOSFET's. Solid line denotes the experimental profile measured by SIMS and dashed line denotes the artificially modified SIMS profile.

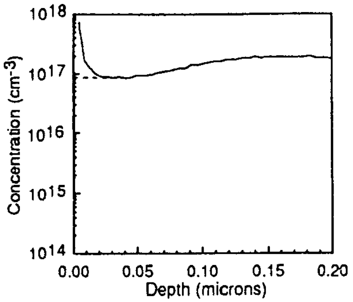

Fig.2. Boron profiles in the channel region of type A MOSFET's. Solid line denotes the experimental profile measured by SIMS and dashed line denotes the artificially modified SIMS profile.

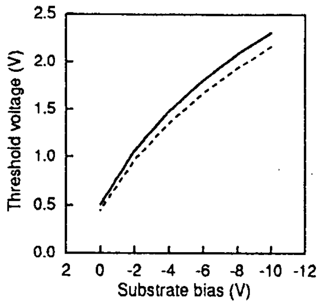

Fig.3. The body effect for type A MOSFET's. Solid line denotes the experimental data and dashed line denotes the simulated results with the artificially modified SIMS profile.

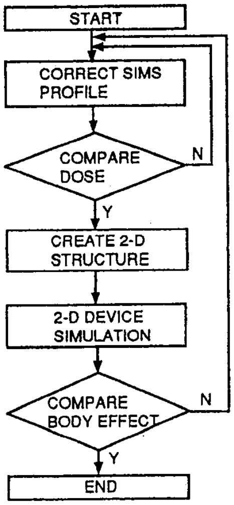

Fig.4. Flow chart of the SIMS profile correction

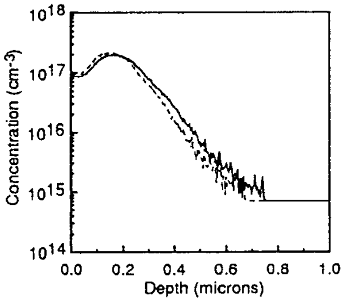

Fig.5. Boron profiles in the channel region of type A MOSFET's. Solid line denotes the artificially modified SIMS profile and dashed line denotes the corrected SIMS profile.

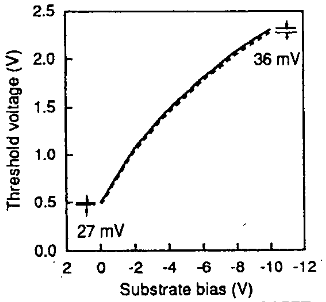

Fig.6. The body effect for type A MOSFET's. Solid line denotes the experimental data and dashed line denotes the simulated results with the corrected SIMS profile.

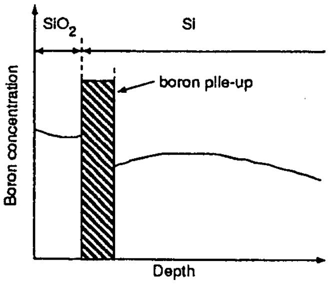

Fig.7. Conceptual schematic of the boron profile in the channel region.

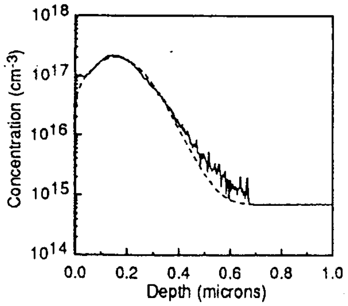

Fig.8. Boron profiles in the channel region of type A MOSFET's. Solid line denotes the corrected SIMS profile and dashed line denotes the simulated result.

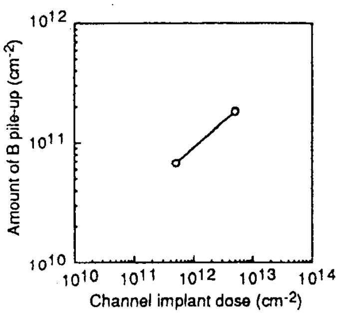

Fig.9. Amount of B pile-up as a function of channel implant dose.

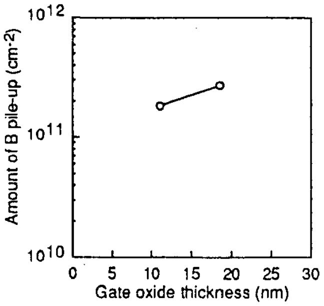

Fig.10. Amount of B pile-up as a function of gate oxide thickness.

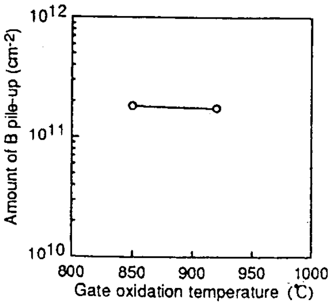

Fig.11. Amount of B pile-up as a function of gate oxidation temperature.