Ion implantation model for channeling through multi-layers

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Abstract— **A new implantation model which considers effects of covered layers to channeling effects in substrate is proposed. Physics of energy loss and scattering in covered layers are summarized to a simple expression. The model is easy to implement to any existing process simulators, and accuracy is drastically improved not only for advanced devices but also for legacy devices.**

Keywords Ion implantationn, Silicon, Modeling, Simulation, Monte Carlo model

I. INTRODUCTION

Ion implantation is one of the key processes in LSI fabrication, and its simulation of implanted dopant profile is very important. There are two approaches for implantation simulation. Although it is very slow in calculation, well-tuned Monte Carlo simulation (MCS) is excellent in accuracy including channeling effects and can deal with arbitrary structures. Analytical simulation (AS) is fast, and the parameters can be well-tuned for simple substrate structures. For implantation to Si substrate without any covered layers, well tuned parameters are available through simulation software vendors. For implantation to the substrate even with oxide-covered layers, Morris et al proposed[1], by using double Pearson distribution, accurate parameters depending on the oxide thickness.

Although channeling effects through covered layers can be tuned-up by MCS, it is difficult for AS approach to include variety of covered layers simultaneously. These include structures with non- uniform dielectric film including halo implantation and implantation through LOCOS as shown in Fig.1. In such cases, the parameters for AS cannot be tuned up for various film thicknesses at the same simulation.

In this paper, B implantation into SiO2/Si structure is studied by MCS and AS in ENEXSS software[2]. By extensive MCS and AS, we investigate dependence of B channeling in Si on the SiO2 thickness. By considering energy distribution at the SiO2/Si interface and subsequent channeling effects in crystalline Si, a new analytical model is proposed which explains SiO2 thickness effects well. The significance of the model is also discussed.

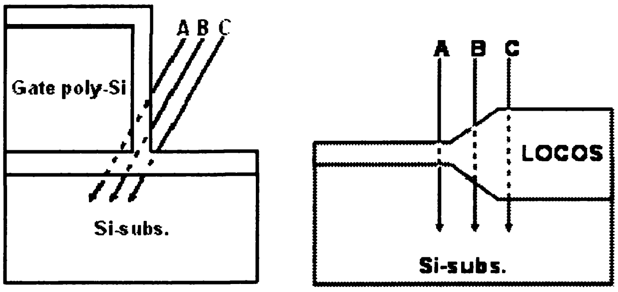

Fig.1: Typical cases where analytical simulation does not work: (a)Halo implantation and (b)implantation through LOCOS

II. SIMULATIONS

First, MCS results are compared with experiments. Fig.2 shows such comparison, and MCS reproduces experimental results excellently. In the following, MCS are used as a reference of AS. Extensive simulations of B implantation to the SiO2-covered Si are done with dose of 1E15cm-2. The energy of B ion ranges from 5 to 30[keV], and SiO2 thickness ranges from 0(non-oxide) to 30nm. Incident angle is fixed to 4 degrees throughout the following simulations.

Before the modeling, AS are tuned by MCS results for cases without any covered layers. When SiO2 is placed on top of Si substrate, however, they show differences. Fig.3 shows such examples with SiO2 thickness of 20nm. Errors are seen not in the surface side but in the deeper region. We plot the depth difference at B concentration of 1E17cm-3 against SiO2 thickness. Fig.4 shows such plot with parameter of B implantation energy. In all cases, the error increases with SiO2 thickness.

III. MODELING

The difference between MCS and AS is understood as follows. Parameters of AS for implantation into Si are optimized for non-SiO2 Si substrate. Due to crystalline nature of Si substrate, ion channeling always occurs and the

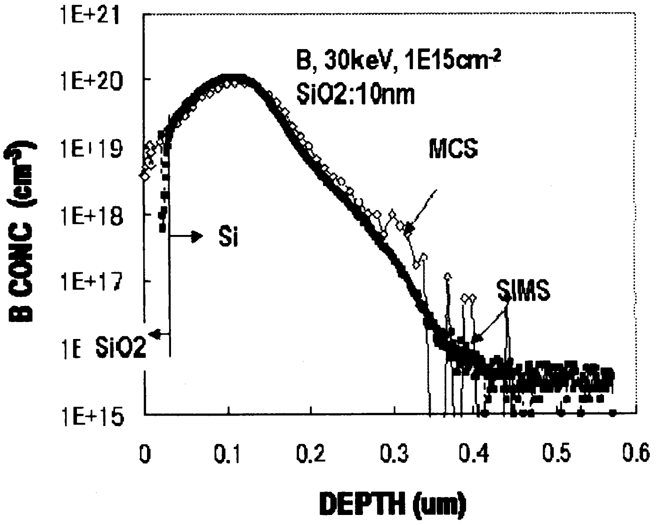

Fig.2:Comparison between MCS and experiments(SIMS).

parameters reflect these channeling effects. We point out that B ions which reach the deepest region are the ones which started channeling at rather shallow region with energy close to the original energy. On the other hand, when SiO2 is placed on top of Si, B ions already lost energy when they reach SiO2/Si interface. Some start channeling there only with less energy compared with non-SiO2 Si. Parameters for analytical modeling do not reflect these effects, and thus, resulting profiles by conventional analytical models yield deeper profile than MC simulations.

We analyzed energy profile of ions at specific depths of SiO2 as shown in Fig.5. Since ENEXSS is not equipped with the output of such energy profile, we calculated implanted profiles by varying the stopping energy. From these profiles, energy profiles at each depth of SiO2 can be obtained, and is shown in Fig.5. In Fig.5, each profile shows abrupt drop at higher energy. This energy is due to the minimum energy loss only by electron stopping power. On the other hand, the profile shows rather gentle slope at lower energy. Even at the depth of 0.01um, non-negligible amount of B is observed. at very low energy. This is because implanted B suffers lots of collision with SiO2 nuclei in a small distance.

Fig.6 shows average ion energy versus oxide thickness. Also plotted is the straight line which start at the original energy and crossing the lateral axis at the depth of projected range (Rp) of oxide. When ions penetrate deeper in the oxide, some portions of ions stop there by losing energy, and the average energy of remaining ions does not fall to zero. In general, however, the straight line reproduces the simulated average energy of ions excellently.

Thus, a new analytical model in Si is proposed, which reflects the average ion energy at the SiO2/Si interface. Here, we explain the case for single-Pearson since B profile in ENEXSS is represented by single-Pearson. The parameter, Rp, in Si has already been taken into consideration in the established parameter sets, and is not necessary to modify. However, the parameters reflecting channeling effects should be modified according to the ion energy at SiO2/Si interface. By using the average energy at the SiO2/Si interface, parameters concerning channeling effects are modified from those of implanted energy to the average energy at the SiO2/Si interface.

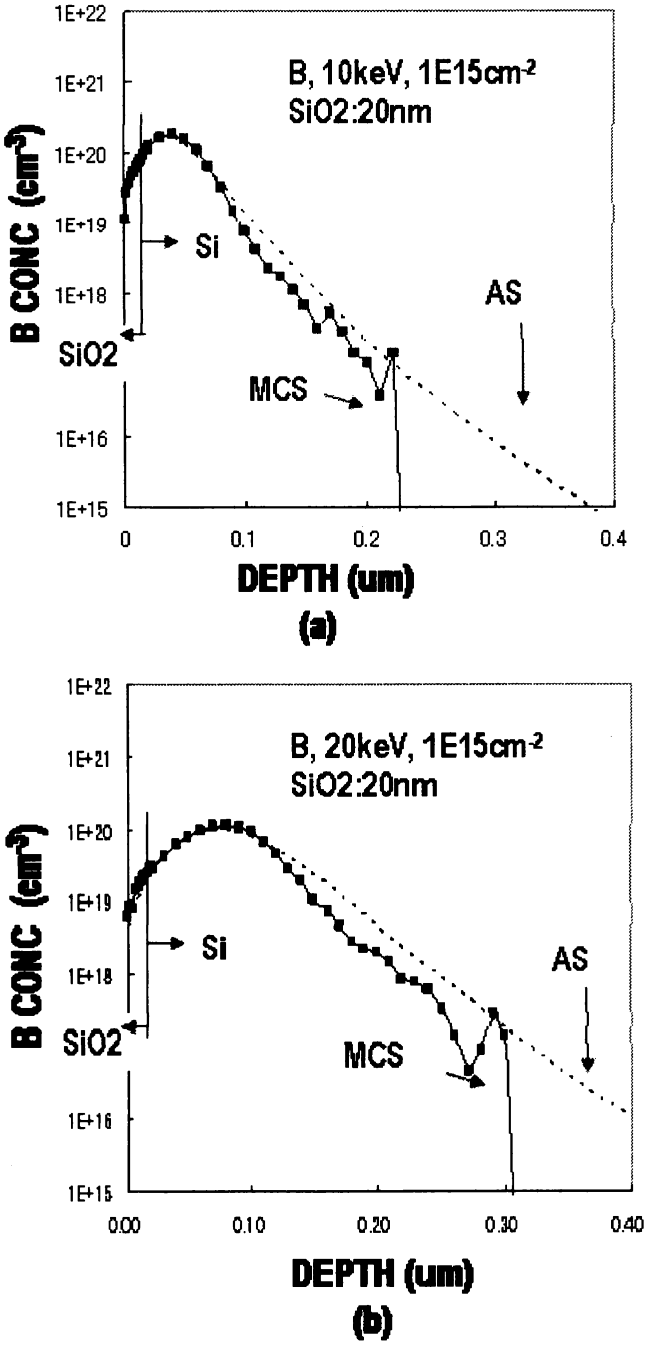

Fig.3: Comparison of MCS and AS. Implantation energies are: (a)10keV and (b)20keV.

The calculation flow is summarized in Fig.7. Here, the flow is only for SiO2-covered Si, but can be easily extended to multilayer films on top of Si..

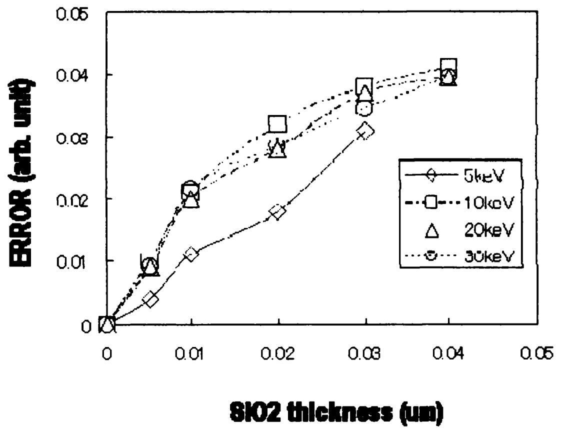

Fig.4: Dependence of the difference of depth on oxide thickness

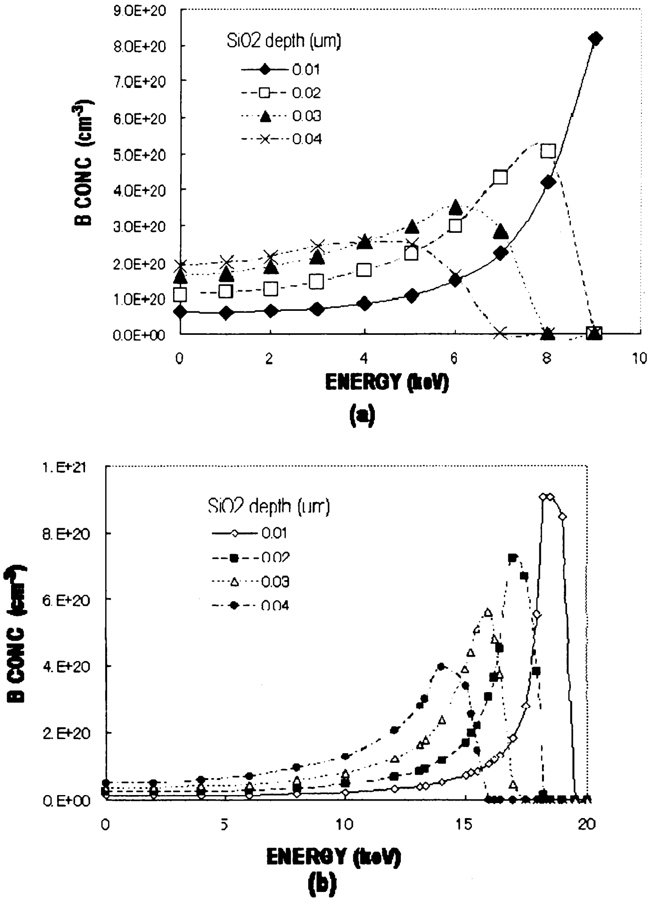

Fig.5: Energy distribution of B ions at specific depth of oxide. B is implanted with dose of 1E15cm-3 at 10keV(a) and 20keV(b), respectively . The parameter is SiO2 thickness.

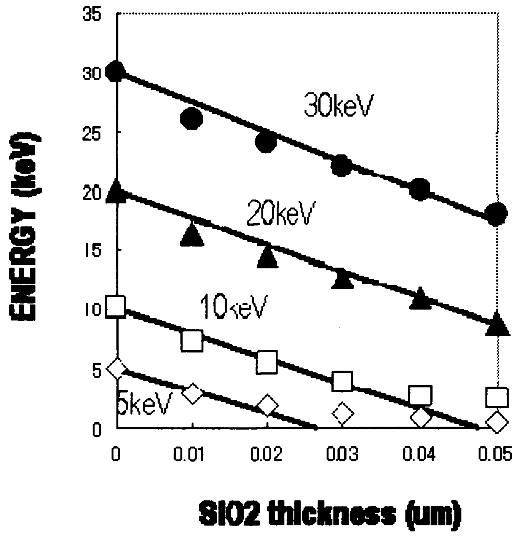

Fig.6: B energy vs. oxide thickness. The parameter is original B energy.

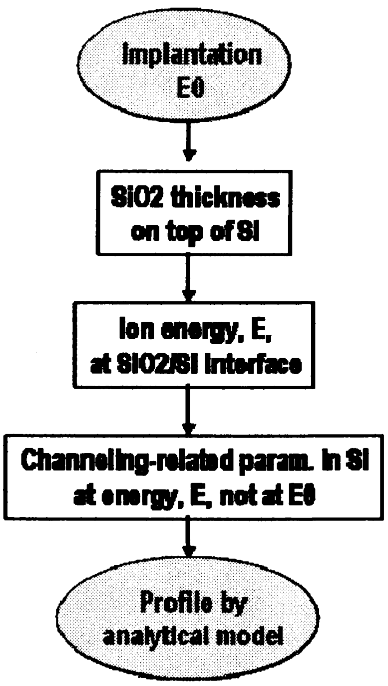

Fig.7: Calculation flow of the proposed models

The proposed model is checked in various conditions. Fig.8 shows such examples where B profiles implanted into 20nm-thick-SiO2-covered Si. Profiles calculated by the proposed model show excellent agreement with those by MCS. Channeling-related parameters may be those of 2nd Pearson distribution if the profiles are given in dual-Pearson distribution. In this case, however, parameters other than Rp are modified since original B profiles are given in single-Pearson distribution.

We also compare a film other than SiO2. Fig.9 shows an example of implantation into Si3N4-covered Si. Although the parameters for Si3N4 are different from those of SiO2 by 30%,

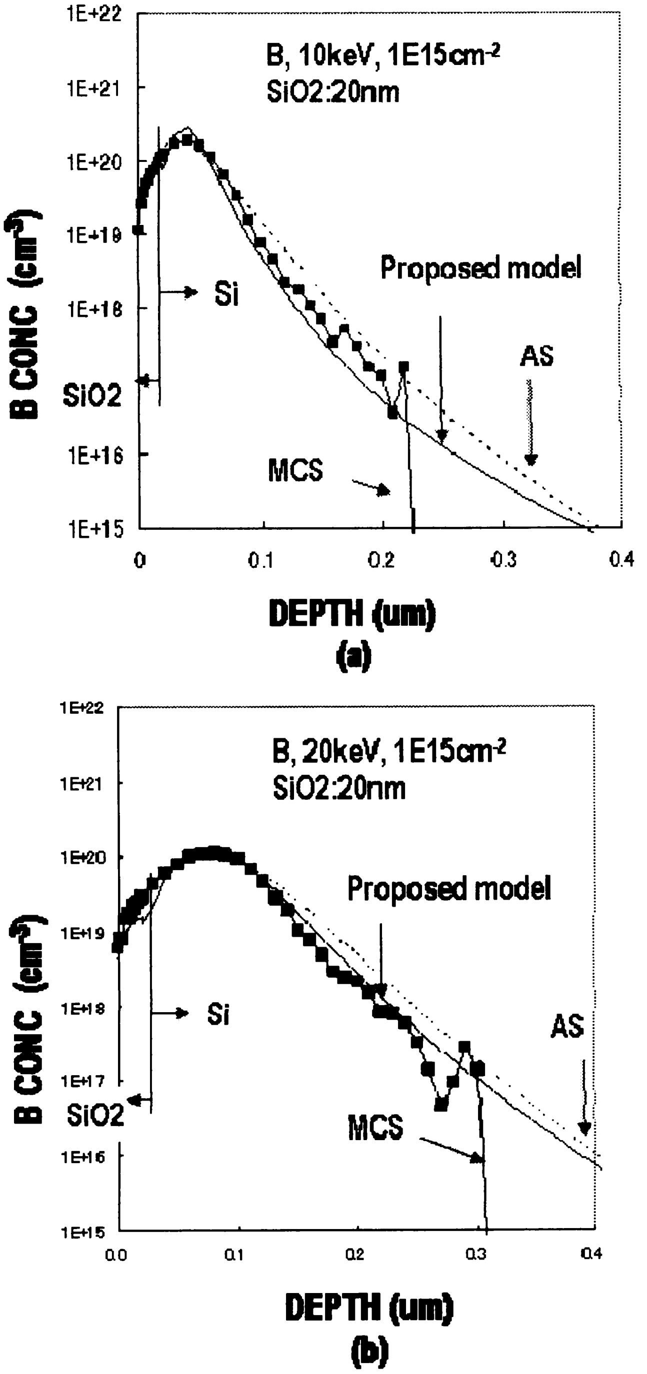

Fig.8: Comparison of MCS with proposed modified analytical models. Implantations energies are: (a)10keV and (b)20keV

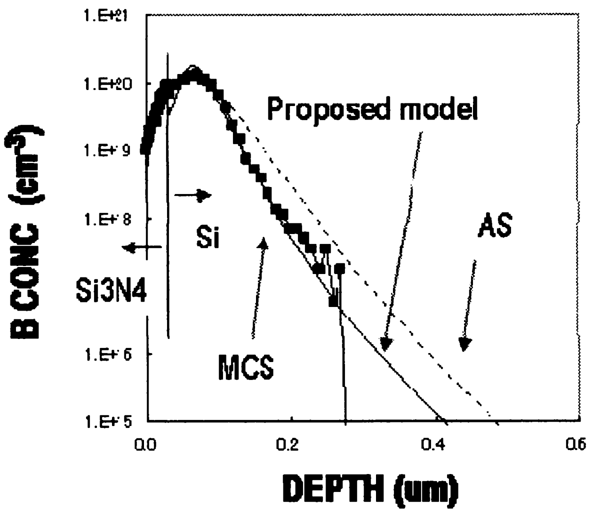

Fig.9: Comparison of MCS and proposed models on Si3N4-covered Si

calculation by the proposed model also shows excellent agreement with MCS.

The impact on the proposed model is checked with 45nm-level nMOSFET. Vth of nMOS differs as much as 10% by the new model as compared with the current model. We also comment that the proposed model is easy to implement in the existing process simulator.

IV. SUMMARY

A new analytical ion implantation model is proposed which accounts for implantation through multilayer films. The model, easy to implement into any process simulator, reflects energy distribution at SiO2/Si interface, and simulations using the new model show excellent agreement with MCS. The impact of the new model is discussed.

ACKNOWLEDGMENT

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References

[1] S.J.Morris et al, IEEE Trans. Semi. Manufacturing, vol.8, #4, pp.408-413, 1995

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