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Statistical Fluctuation Analysis by Monte Carlo Ion Implantation Method

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Abstract **- This paper shows a new statistical fluctuation analysis method by Monte Carlo ion implantation and investigates Vt fluctuations due to statistical variation of dopant profile by 3D process-device simulation system. This method is very useful to analyze a statistical fluctuation in sub-100nm MOSFETs efficiently.**

I. INTRODUCTION

As MOSFET devices are aggressively scaled into the sub-100nm regime, statistical threshold voltage (Vt) fluctuations due to random dopant effects become increasingly important (Table 1)[2,3]. This effect is very serious and essential in device design because the fluctuations cannot be suppressed by reducing process variations. Several analysis methods with different degrees of complexity, introducing the random dopant in MOSFET's, have been developed over the years [3,4,5,6,7,8]. One of the typical analysis methods is "atomistic" simulation method [7,8] and the other is particle simulation like MD (Molecular Dynamics) simulation. Nevertheless, atomistic simulation method need a special program to generate the random dopant profile and particle simulation method is usually very time consuming and still not popular.

In this paper, we present a new statistical fluctuation analysis method by use of Monte Carlo ion implantation method and investigate Vt fluctuations due to statistical variation of pocket (halo) dopant profile by 3-dimemsional process-device simulation system ENEXSS developed by Selete in Japan [9].

Table 1. Vt variation requirements (ITRS 1999[1]).

Year	2002	2005	2008	2011
Gate Length(nm)	85	65	45	32
Vt variation σ(mV)	14	11	8	6

II. SIMULATION METHOD

In the conventional "atomistic" simulation [10,11], to introduce the random dopant, the number of dopant in each mesh region (cell) is chosen from a Poisson distribution with a mean equal to the average dopant number in the region by using a continuous doping distribution of process simulation result for device simulation.

Our method uses a Monte Carlo (MC) ion implantation method with real dose (one MC particle corresponds to one actual implant ion) to introduce the realistic positional fluctuation of dopant. Moreover, we use different random number series with different seed of random number to realize a statistical fluctuation of dopant. For example, when we evaluate the random dopant effect of pocket implantation, the MC implantation method is only used for the pocket ion implantation process step and analytic model is used for the other implantation steps. Except for this dopant introduction method, we use three dimensional fluid type process simulator with realistic process condition and

conventional drift-diffusion type device simulator to calculate the threshold voltage. Fig.1 summarized our modeling and simulation methodology.

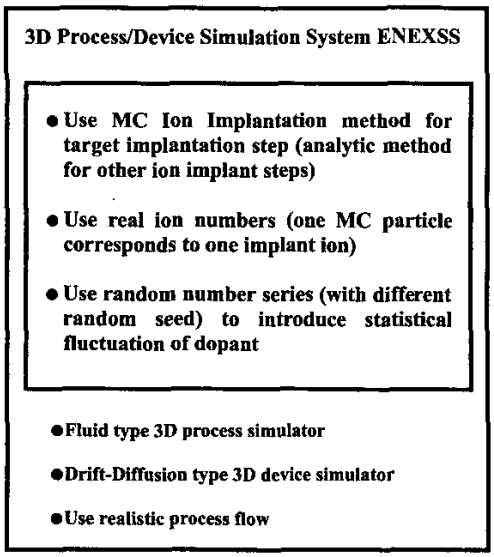

Fig.1. Our Modeling and Simulation methodology

The advantages of our method are

- short computation time (compared with atomic level simulation)
- accurate profile (especially, in complex structure)
- can evaluate specific (pocket and channel...) dopant fluctuation independently

The drawbacks of our method are

- under estimate fluctuation (Our method neglects randomness in diffusion process. But this point is the same when creating random discrete dopant by random number from continuous doping profile.)
- computation time depend on simulation structure size (e.g. for large channel width).

Fig. 2 shows a comparison of averaged threshold voltage by our method and the threshold voltage of devices with continuous doping profile by analytic model. Due to the descritized doping effects, the threshed voltages of our method are slightly lower than the threshed voltages from continuous doping profile.

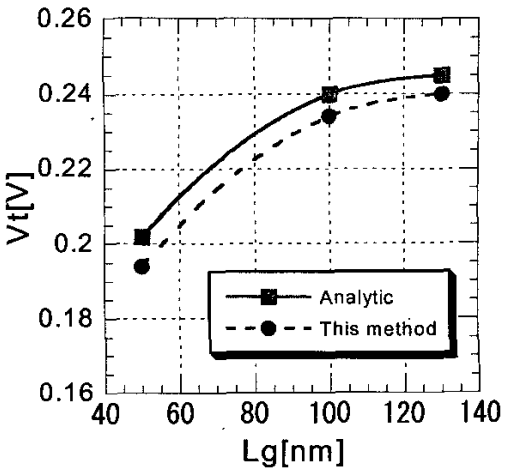

Fig. 2. Comparison of averaged threshold voltage by our method and the threshold voltage of devices with continuous doping by analytic model.

III. SIMULATION RESULTS

Fig.3 shows a typical final boron concentration profile of process simulation result for an nMOSFET (Lg=100nm, W=100nm, Depth=500nm) by using our method. Bright

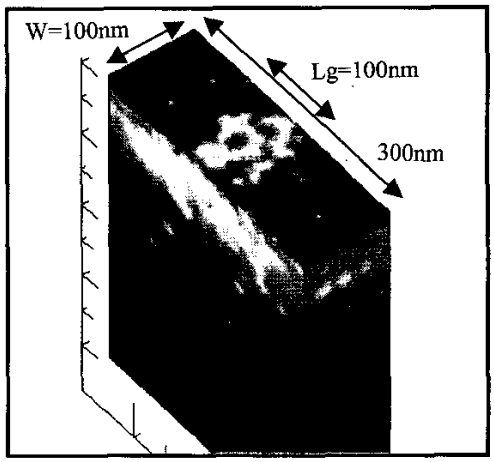

Fig. 3. Boron concentration profile of process simulation for a typical nMOSFET (Lg=100nm, W=100nm).

area shows a high concentration region. In this case, 4e12 atoms/cm2 pocket dose is implanted to 100nm(W direction) x 300nm(L direction) area by MC method, and this means 1200 ions into the simulation region. As seen from the Fig. 3, final profile still reflects the initial MC implant profile after diffusion steps.

In this simulation, uniform grid size (typically 4nm) is used in the channel and pocket region for the simulation Fig.4. This results, for example, in a grid with 81536 nodes to simulate a MOSFET with Lg = W = 100nm, depth = 500nm. Typical process conditions of this simulation are shown in Fig.5.

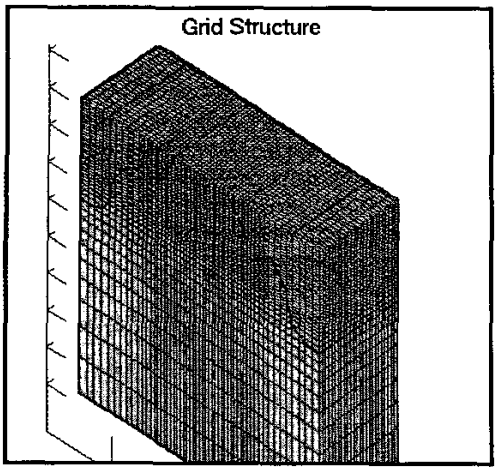

Fig. 4. Typical grid structure. Uniform grid size (typically 4nm) is used in the channel and pocket region.

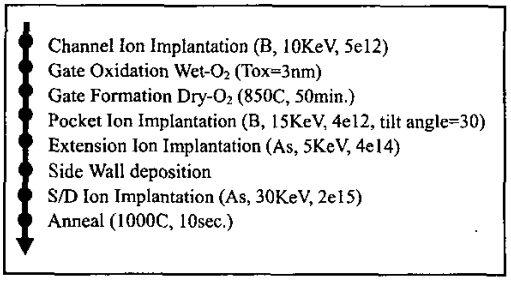

Fig.5. Process conditions.

A dose dependency of σVt (standard deviation) is shown in the Fig. 6. To calculate the standard deviation, we use 40

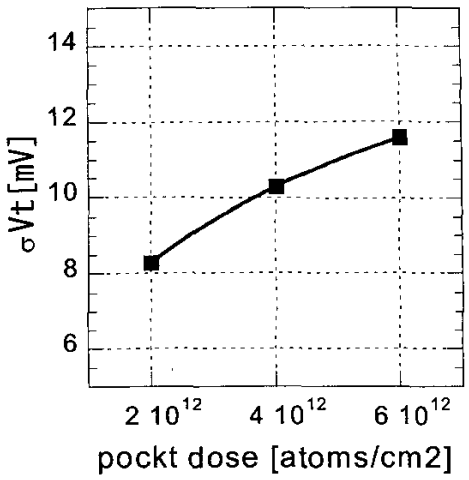

Fig. 6. Pocket dose dependencies of σVt (standard deviation).

simulations run with different random number seed. The σVt increases with the increase of the dose concentration. Fig. 7 shows an Lg length dependency of σVt. The σVt follow the $1/\sqrt{Leff}$ dependence predicted

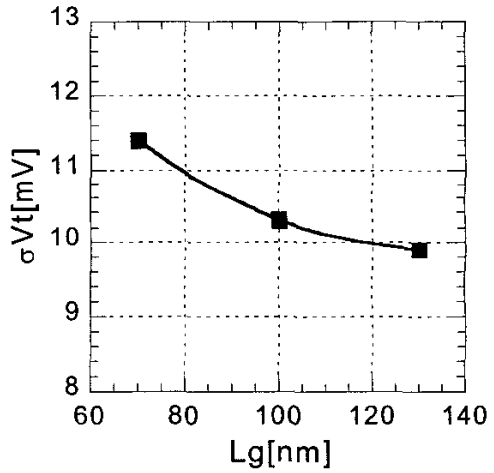

Fig. 7 Lg dependencies of σVt (standard deviation).

by the analytical model [12]. Fig.8 illustrates the dependency of the standard deviation σVt as a function of the channel width. Similarly to the channel length dependence, we observe a steady increase in the random dopant induced threshold voltage lowering with increase of channel width W [13].

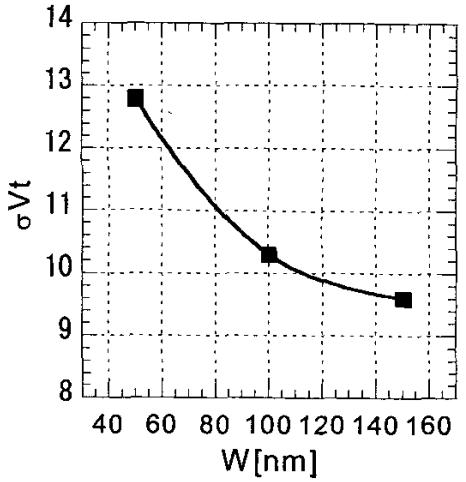

Fig. 8. W dependencies of σVt (standard deviation).

As we mentioned before, our method can evaluate pocket and channel dopant fluctuation independently. Fig. 9 shows a result of channel dose dependency of σVt. In this simulation, we use MC implantation only for channel implantation step.

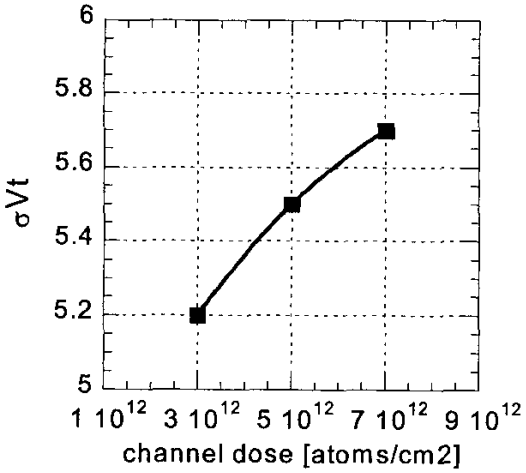

Fig. 9. Channel dose dependencies of σVt (standard deviation).

IV. CONCLUSION

A new and effective statistical fluctuation analysis method by use of Monte Carlo ion implantation method has been presented. The method was applied to investigate Vt fluctuations due to statistical variation of pocket dopant profile by 3D process-device simulation system. This method is very useful to analyze a statistical fluctuation in sub-100nm MOSFETs efficiently.

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