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Estimation of the Charge Collection for the Soft-Error Immunity by the 3D-Device Simulation and the Quantitative Investigation

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Abstract

The charge collection induced by incident particles was estimated by the 3-dimensional device simulation and the quantitative evaluation method using the nuclear microprobe. The role of the buried p $^+$layer was well analyzed in terms of the soft-error immunity of DRAMs. The methods developed here are applicable to optimize the well structure for the soft-error immunity of advanced DRAMs.

1, Introduction

The modification of well structure is important to get the soft-error immunity for advanced DRAMs. However, since soft-error events of DRAMs have been conventionally evaluated using energetic particles from a radioactive source such as Am which has the inherent distribution of incident energies and the amount of the incident particles, the evaluation result offers just a qualitative analysis.

In this study, the precise estimation of soft-error is demonstrated. The charge collection induced by incident particles was simulated by the 3-dimensional device simulation for the improvement of soft-error immunity. And the quantitative investigation of soft-errors was performed by using the nuclear microprobe with optional energy and controlled amount of incident particles[2]. The role of the buried p^+layer , which forms the retrograde well structure , against the charge collection into n^+ layer was evaluated by comparing the experimental results with the simulation result.

2, Estimation Methods

The charge collection efficiency was calculated using a general purpose 3-dimensional device simulator,"3D-MIDSIP (3 Dimensional-Mitsubishi Device SImulation Program)," in which a Poisson equation and continuity equations for electrons and holes were solved self-consistently. After steady state condition was calculated, electron-hole pairs created by an injected proton were distributed along the track of the particles to perform transient analysis. The depth of penetration or range of particles was determined by the initial energy E0[3]. The proton lost an average energy of 3.6eV at 3 00K for every electron-hole pair generation[4]. The total ionization produced by the proton was given by its initial energy E0 divided by the average energy loss. The pair generation per unit length was obtained by differentiation of the energy-range relation with the average energy loss.

Also, the new evaluation system with the proton microprobe was used for the quantitative investigation of the charge collection. Incident flux, energy and irradiated position can be easily controlled in this method. The proton energies were 1.3MeV~2.0MeV in this study. The proton with the energy of 1.3MeV almost has the same trajectory as that of the 5.0MeV alpha particle in the Si-substrate.

The measured samples had the retrograde well structure with n^+layer and buried p^+layer formed by the high energy ion implantation. The depth of the buried p^+layer is 0.4~1.7μm and the peak concentration of p^+layer is 4.2×10^{16}~$4.3\times10^{17}cm^{-3}$. The charge collection efficiency was defined as a ratio of collected charges in n^+layers with a well structure to that without a well structure.

3, Results

Fig.1 shows the simulation result of the induced current depending on the depth of the buried p^+ layer. For the stage of funneling effect (1psec.-1nsec.), the induced current into the n^+layer is reduced as the depth of the buried p^+layer decreases. The shallow buried p^+layer is so effective for the reduction of the funneling effect. However, for the stage of the diffusion effect (1nsec.-1μsec.), the induced current has no dependence on the depth of the buried p^+layer.

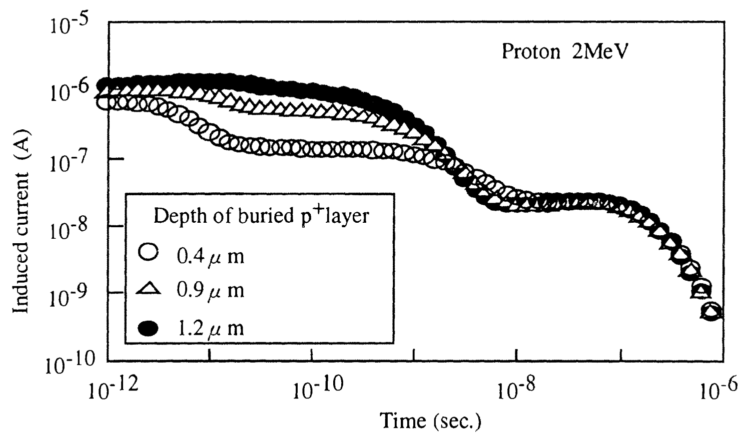

Fig.1: Dependence of the induced current on the depth of buried p^+layer

The simulation of accumulated charge collection into the n^+layer is shown in Fig.2. The amount of collected charges does not depend on the depth of buried p^+layers. The most of charges are collected for the stage of diffusion effect. The quantitative investigation of charge collection was performed by using the proton microprobe with the energy of 1.3 and 2.0MeV. Fig.3 shows the experimental result of the charge collection dependence on the depth of the buried p^+layer. The simulation result well coincides the experimental result. It is verified that the charge collection is mainly due to the diffusion of induced charges by high energy particles.

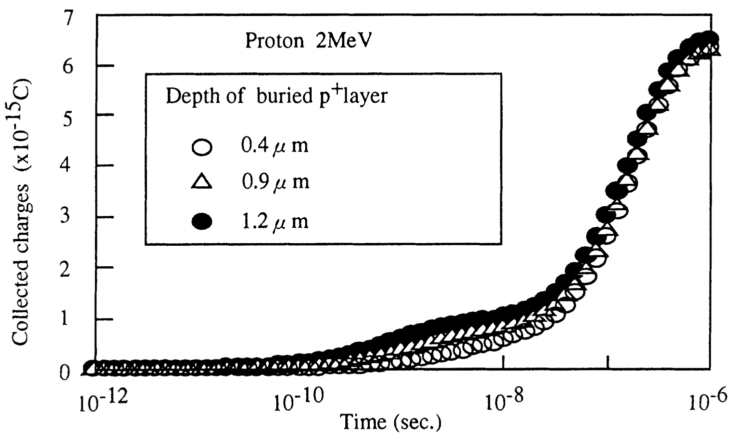

Fig.2 Dependence of the charge collection on the depth of buried p$^+$layer

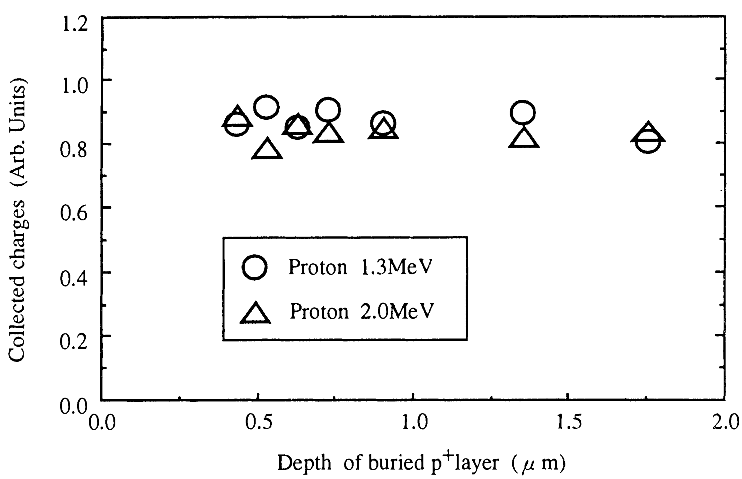

Fig.3 Relation between the depth of buried p$^+$ layer and the charge collection

Fig.4 shows the simulation of the induced current dependence on the concentration of the buried p$^+$layer. The induced current into the n$^+$layer is reduced as the concentration of the buried p$^+$layer increases for both stages of funneling and diffusion effects. Fig.5 shows the experimental result of the charge collection dependence on the concentration of buried p$^+$layer. The experimental result is well explained by the simulation. The buried p$^+$layer achieves as barrier against the charge collection caused by the diffusion and funneling effects.

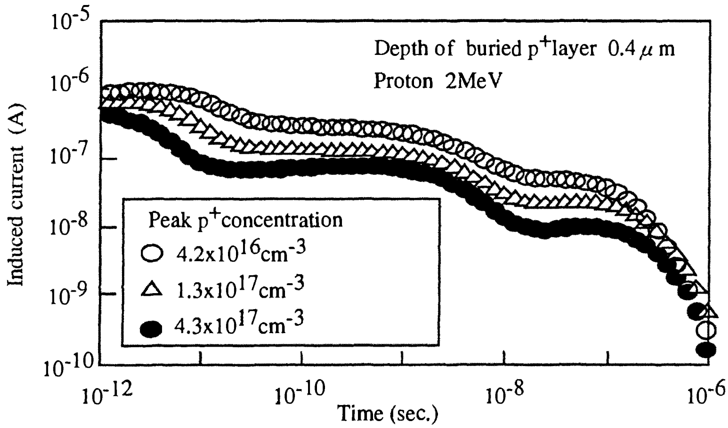

Fig.4 Dependence of the induced current on the concentration of the buried p$^+$layer

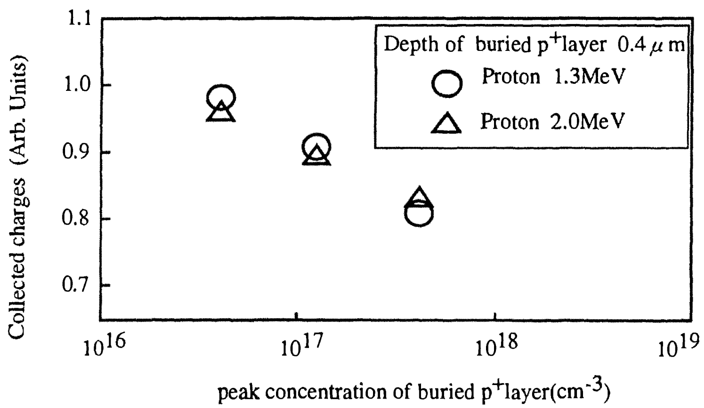

Fig.5 Relation between the concentration of the buried p$^+$layer and the charge collection

4, Summary

The 3-dimensional device simulation and the quantitative evaluation using the nuclear microprobe have been demonstrated. The quantitative study of the charge collection was realized by these investigations. The role of the buried p$^+$layer was well analyzed in terms of the soft-error immunity of DRAMs. The methods developed here are applicable to optimize the well structure for the soft-error immunity of advanced DRAMs.

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