Analysis of the asymmetric breakdown characteristics of trench isolation structure by using TCAD

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Abstract

Experimentally observed asymmetric breakdown characteristics of shallow trench isolation are investigated by using TCAD. Both transient enhanced diffusion of boron and phosphorus and deactivation of phosphorus piled up at the trench bottom are the main causes of the asymmetry. Several techniques which reduce the asymmetry are proposed and their effects are compared by using TCAD.

1. Introduction

Shallow Trench Isolation (STI) is an indispensable technology for deep sub-micron ULSI. However, neither the dominant factors which determine the breakdown voltage of STI nor the proper guidelines for the well profile design are well understood. In this paper, experimentally observed asymmetric breakdown characteristics of STI are investigated and dominant factors for the breakdown characteristics of STI are clarified by using TCAD.

2. Experiment and Simulation

Two types of STI structure were fabricated as shown in Fig. 1. In the type-(a) structure, the well was formed after STI fabrication by ion implantation tilted by 7 degrees to the n-well side. In contrast, the well ion implantation of the type-(b) structure was tilted to the p-well side. The conditions of the well ion implantation were phosphorus (P) 700 keV 1.5E13 cm^{-2} for the n-well and boron (B) 300 keV 2E13 cm^{-2} for the p-well. The trench depth was 550 nm and the width was varied from 200 nm to 1 μm. The breakdown characteristics due to the punch-through between the S/D region and the well on the opposite sides of the trench were measured by monitoring the leak current. The measurement condition is shown in Fig. 2. TCAD simulation was also performed for these STI structures. A process simulator which includes a crystal-mode Monte Carlo ion implantation model [1], a consistent point-defect pair diffusion model [2], and a P pile-up model [3] and a drift-diffusion type device simulator [4] were used. Fig. 3(a) shows the measured and the simulated leak current between the n-well and the n+ S/D region for the type-(a) structure. Neither the measured nor the simulated results show any sign of breakdown at the separation width (= half of the trench width) of 200 nm. On the other hand, for the type-(b) structure, both the measured and the simulated results show significant breakdown between the p-well and the p+ S/D region at the separation width of 300 nm as shown in Fig. 3(b).

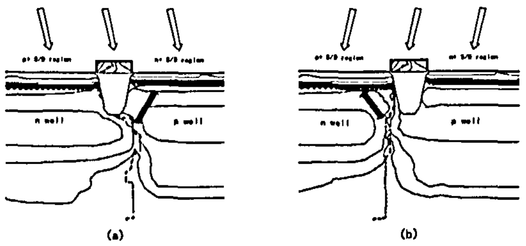

Fig. 1 Fabricated STI structures. (a) well I/I is tilted to the n-well side. (b) well I/I is tilted to the p-well side. Weak paths for breakdown are shown by the black arrows.

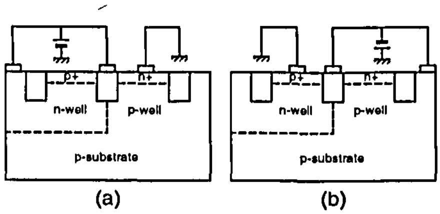

Fig. 2 Measurement condition for the leak current. (a) between n-well and n+ S/D region. (b) between p-well and p+ S/D region.

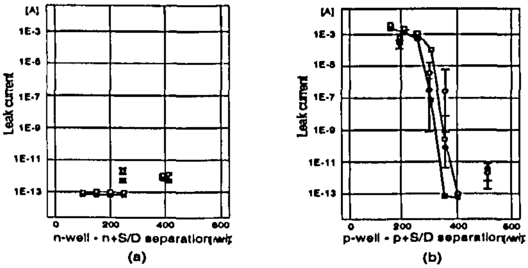

Fig. 3 Measured and simulated leak current for STI structures. (a) type-(a) structure. (b) type-(b) structure. Circles are measurement and squares are simulation. Open symbols are for 4 V bias and closed symbols are for 2 V bias.

3. Origin of the Asymmetry

According to the experiment and the simulation, it was found that there was significant asymmetry in the breakdown characteristics between the type-(a) and the type-(b) structures, while their structures were symmetric. The implanted dose of the well was the only structural difference. However, according to simulation, it was found that strong asymmetry still remained even if the P dose of the n-well was increased to 1E13 cm^{-2}. In order to clarify the origin of this asymmetry, a STI structure with the well formed by non-tilted and equally-dosed ion implantation (i.e. completely symmetric structure) was simulated. Figs. 4-6 are the simulation results. Fig. 4(a) shows the as-implanted total P and (b) shows the final active P profiles of the n-well. It is observed that the final active concentration of P around the bottom of the STI is smaller than the as-implanted concentration. Fig. 5(a) is the as-implanted total B and (b) is the final active B profiles of the p-well. In contrast to P, the final B concentration around the bottom of the STI is larger than the initial one. Fig. 6 shows the variation of P and B concentration along the horizontal line near the bottom of the STI. At the time of ion implantation, the n-well and the p-well meet almost in the middle of the STI. However, after device fabrication, the p-well becomes dominant around the bottom of the STI and this causes asymmetric breakdown characteristics. The mechanism of the re-distribution of B and P is as follows: (1) Well ion implantation generates point-defects, which induce Transient Enhanced Diffusion (TED) of B and P during the subsequent thermal process. (2) As a result of TED, B and P pile up at the trench-substrate interface which acts as a sink of point-defects. (3) The piled-up P becomes inactive, while the piled-up B remains active. Hence, B concentration becomes dominant around the bottom of the STI. In the conventional LOCOS process, an important factor for the well profile design is B dose loss from the substrate due to segregation during field oxidation. On the other hand, in the STI process, TED and pile up of dopant become important issues to be taken care of.

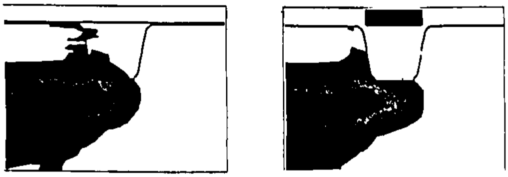
(a) (b)

Fig. 4 Simulated P profile. (a) as implanted total concentration. (b) final active concentration.

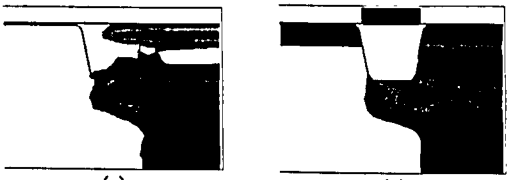
(a) (b)

Fig. 5 Simulated B profile. (a) as implanted total concentration. (b) final active concentration.

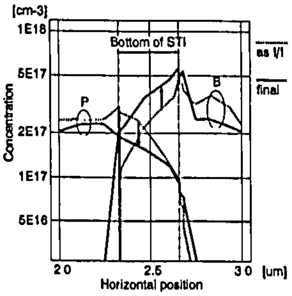

Fig. 6 B and P concentration at the bottom of STI. Broken line: as implanted total concentration. Solidline: final active concentration. At the time of ion implantation, n-well and p-well meets almost in the middle of STI. After device fabrication, p-well becomes dominant at the bottom.

4. Well Profile for Asymmetry Reduction

In order to reduce the asymmetry in the breakdown characteristics, the following methods are proposed. (1) Increase the P dose; that is, compensate the deactivated P concentration. (2) Reduce the B implantation energy; that is, let B pile up at the side of the STI rather than at the bottom. (3) Reduce the P implantation energy; that is, set high concentration region of P between the p+ S/D region and the bottom of the STI. (4) Use As with the same projection range of P; that is, reduce TED and pile up effects. Effects of these methods were compared by using TCAD and the results are shown in Figs. 7–10. Method (3) is found to be the most effective.

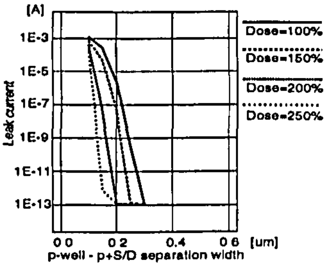

Fig. 7 Dependence of the leak current between p-well and p+ S/D region on P I/I dose.

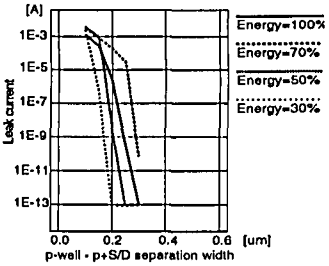

Fig. 8 Dependence of the leak current between p-well and p+ S/D region on B I/I energy.

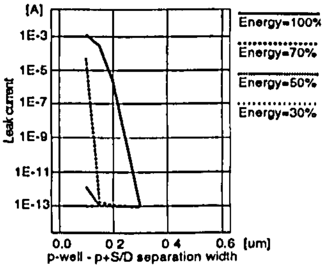

Fig. 9 Dependence of the leak current between p-well and p+ S/D region on P I/I energy.

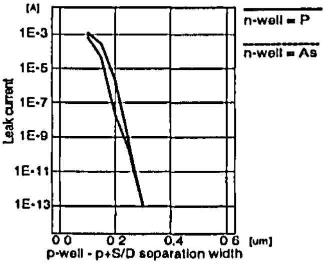

Fig. 10 Dependence of the leak current between p-well and p+ S/D region on I/I dopant.

5. Conclusion

It is shown that both TED of B and P and deactivation of P piled up at the trench bottom are the main causes of the asymmetric breakdown characteristics of the STI structure. Reduction of the P implantation energy is found to be effective in reducing the asymmetry.

References

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