Extended Abstracts of the 1996 International Conference on Solid State Devices and Materials, Yokohama, 1996, pp. 476–478

Analysis of the Charge Density at Field Oxide/SOI and SOI/Buried Oxide Interfaces in Partially Depleted SOI MOSFET's with and without Hydrogenation

T. Iwamatsu, T. Ipposhi, S. Miyamoto, Y. Yamaguchi, Y. Inoue, H. Miyoshi and A. Yasuoka
ULSI Laboratory, Mitsubishi Electric Corporation, 4-1, Mizuhara, Itami, Hyogo 664, Japan

Both the fixed charge at SOI/buried oxide (BOX) interface (Nf(BOX)) and the charge in LOCOS edge region (Nf(LOCOS)) have been analyzed by measurement of Id-Vg and Id-Vback characteristics of partially depleted SOI NMOSFET's with and without hydrogenation. Threshold voltage lowering of the parasitic MOSFET was caused by both Nf(BOX) and Nf(LOCOS). The density of Nf(LOCOS) generated during transistor fabrication process was almost the same in different vendor's SIMOX substrates. Moreover, it was found that the density of Nf(LOCOS) was reduced by hydrogenation but Nf(BOX) was not reduced by hydrogenation.

1. Introduction

Thin-film SOI MOSFET's are attractive devices for low-voltage and low-power operation due to low junction capacitance and little back-bias effect compared with bulk-Si MOSFET's. However, the subthreshold leakage current of LOCOS-isolated SOI MOSFET is a crucial problem because of the threshold voltage lowering of the parasitic MOSFET's [1][2]. For the realization of low power circuits, the threshold voltage of the parasitic MOSFET at the LOCOS edge region should be set higher than that of the main MOSFET. So far, several isolation techniques on the SOI MOSFET's have been proposed. The hump in the subthreshold region can be eliminated by increased the impurity concentration at the LOCOS edge, and other modified LOCOS isolation processes were adapted for the ideal characteristics [3]-[5]. It was pointed out recently that the threshold voltage of the parasitic MOSFET's was lowered by the fixed charge in LOCOS edge regions by three dimensional (3-D) numerical device simulation [6]. However, the experimental evaluation of the fixed charge density has not been reported.

In this report, the analysis of both the fixed charge at SOI/buried oxide (BOX) interface (Nf(BOX)) and the charge in LOCOS edge region (Nf(LOCOS)) were proposed by measurement of Id-Vg and Id-Vback characteristics with edgeless and LOCOS-isolated SOI MOSFET's. Moreover, the density of the Nf(BOX) was estimated in different vendor's SIMOX substrates. It was found that Nf(LOCOS) was generated during transistor fabrication process and was reduced by hydrogenation. On the other hand, the density of Nf(BOX) depended on SIMOX substrates and was not reduced by hydrogenation.

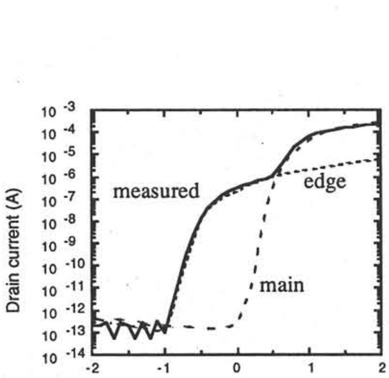

Fig.1 Id-Vg characteristic of LOCOS-isolated SOI MOSFET. Measured current is consisted from the currents of the main-transistor and the edge transistor.

2. Results and discussions

Fig. 1 shows typical Id-Vg characteristics in a LOCOS-isolated SOI MOSFET. A hump is observed in the subthreshold region due to the parasitic MOSFET. A 3-D device simulator was used to study the parasitic MOSFET. Fig. 2 illustrates a schematic diagram of the simulated LOCOS-isolated SOI MOSFET. The thicknesses of the gate oxide, SOI layer and buried oxide are 100, 1000 and 4000Å, respectively. N type polysilicon gate was used for the transistor. Fig. 3 shows calculated Id-Vg characteristics for various fixed charge conditions at LOCOS/SOI or SOI/BOX interfaces. The threshold voltage of the parasitic MOSFET is lowered by increased fixed charge. However, the position of the fixed charge does not significantly influence the threshold voltage of the parasitic MOSFET's. These results show that the threshold voltage of the parasitic MOSFET is mainly dominated by the quantity of the fixed charge, because the parasitic MOSFET is located at the tip of the SOI edge region. The SOI layer in the edge region is very thin, therefore the parasitic MOSFET operates in fully depleted mode and it is difficult to determine the position of the fixed charge in edge regions by the device simulation.

Fig. 4 shows measured Id-Vg characteristics of LOCOS-isolated MOSFET's fabricated on high-dose standard SIMOX substrate (SIMOX-1) with and without hydrogenation. The hump of the subthreshold

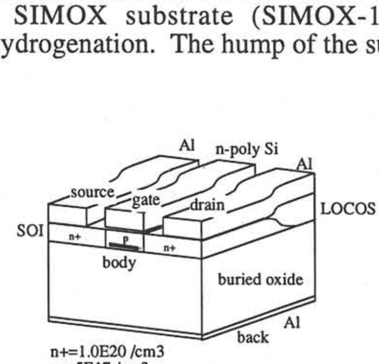

Fig.2 Schematic diagram of an SOI MOSFET analyzed by the 3-D simulation.

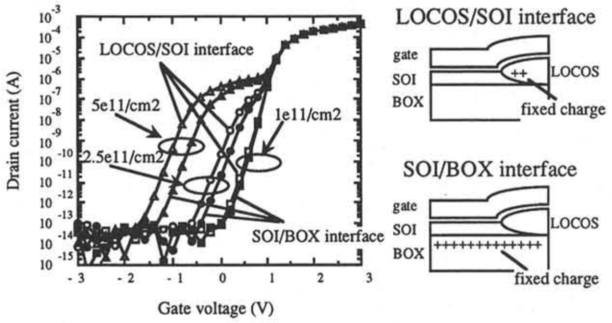

Fig.3 Simulated Id-Vg characteristics in LOCOS-isolated SOI MOSFET. Fixed charge is set in LOCOS/SOI or SOI/BOX interfaces. L=0.5 μ m

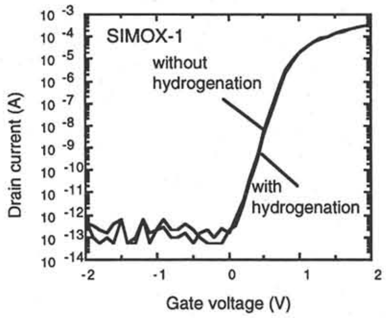

Fig.5 The comparison of measured Id-Vg characteristics in edgeless SOI MOSFET's with and without hydrogenation. L/W=1.0 μ m/4.0 μ m, Vf(body bias)=0V.

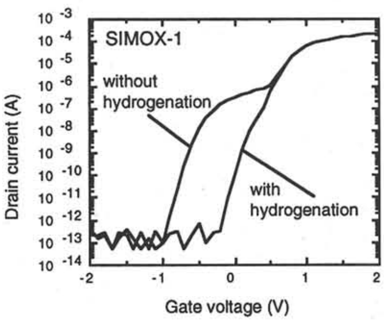

Fig.4 The comparison of measured Id-Vg characteristics in LOCOS-isolated SOI MOSFET's with and without hydrogenation. L/W=1.0 μ m/10 μ m

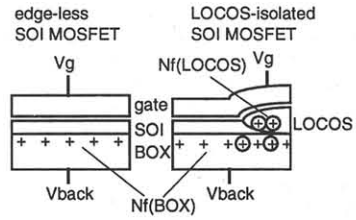

Fig. 6 Schematic diagram of edgeless and LOCOS-isolated SOI MOSFET's. By measuring of both devices, each fixed charges of Nf(BOX) and Nf(LOCOS) is able to be estimated.

region in the Id-Vg characteristics is reduced by hydrogenation. The subthreshold slop of the parasitic MOSFET is almost the same between the MOSFET's with and without hydrogenation. This suggests that only the fixed charge was reduced by hydrogenation. The density of the fixed charge in edge region without hydrogenation is estimated at about 5e11/cm2 by comparison of the results of 3-D device simulation. Fig. 5 shows Id-Vg characteristics of edgeless MOSFET's. The influence of the hydrogenation for the gate oxide is investigated by measurement of the MOSFET's. The threshold voltage and the subthreshold slope of the SOI MOSFET with hydrogenation are almost the same as those of the MOSFET without hydrogenation. It is indicated that the surface condition of the gate oxide was not influenced by the hydrogenation.

Fig. 6 shows schematic diagrams of edgeless and LOCOS-isolated MOSFET's. Nf(BOX) and Nf(LOCOS) can be estimated by measurement of both Id-Vg and Id-Vback characteristics of LOCOS-isolated and edgeless MOSFET's with and without hydrogenation. Table 1 complies the effect of Nf on I-V characteristics of each MOSFET. Nf(BOX) can be estimated by comparison between the device simulation results and the measured results of the back-surface characteristics in edgeless MOSFET's. The simulation was carried out with a uniform channel profile condition.

By back-surface characteristics in LOCOS-isolated MOSFET's, the density of Nf(LOCOS) can be also estimated with considering the results of Id-Vback characteristics of edgeless MOSFET's because the edge region is fully depleted. Id-Vback characteristics of the LOCOS-isolated MOSFET's are affected by Nf(LOCOS). Fig. 7 shows Id-Vback characteristics of edgeless MOSFET's. The threshold voltage and the subthreshold slope of MOSFET with hydrogenation are almost the same as those of the MOSFET without hydrogenation, and it is indicated that the density of Nf(BOX) does not largely change by the hydrogenation. It is estimated at about 3e11/cm2.

Fig. 8 shows Id-Vback characteristics of LOCOS-isolated MOSFET's. The threshold voltage of the parasitic MOSFET without hydrogenation is lower than that of the MOSFET with hydrogenation. On the other hand, the subthreshold slopes in both MOSFET's are almost the same. It is suggested that the fixed charge was reduced by hydrogenation, but the surface states density was not changed drastically.

The threshold voltage of the parasitic MOSFET is lower than the main MOSFET because the parasitic MOSFET operates in fully depleted condition. The density of Nf(LOCOS) is estimated at about 2e11/cm2. From these results, the threshold voltage of the parasitic MOSFET was lowered owing to both Nf(LOCOS) and Nf(BOX). Nf(LOCOS) can be reduced by hydrogenation, although Nf(BOX) is not influenced by hydrogenation, as shown in Fig. 9.

Fig. 10 shows Id-Vg characteristics of the MOSFET's fabricated in another vendor's high-dose SIMOX substrate (SIMOX-2). The hump is also reduced by hydrogenation. The subthreshold voltage of the parasitic MOSFET on the SIMOX-2 is higher than that of the MOSFET on SIMOX-1. It was reported that the threshold voltage of the parasitic MOSFET was

Table. 1 Nf : Affecting on I-V characteristics.

	LOCOS-isolated SOI MOSFET		edge-less SOI MOSFET
	main	edge	main
Id-Vg Characteristics	No	Nf(LOCOS) Nf(BOX)	No
Id-Vback Characteristics	Nf(BOX)	Nf(LOCOS) Nf(BOX)	Nf(BOX)

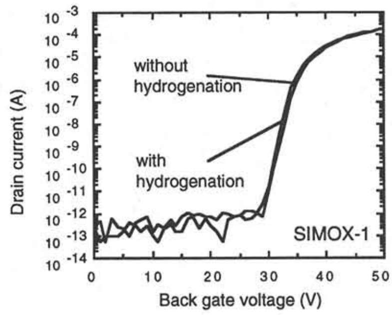

Fig.7 The comparison of measured Id-Vback characteristics in edgeless SOI MOSFET's with and without hydrogenation. L/W=1.0 μ m/4.0 μ m

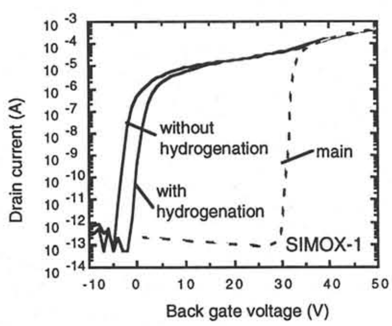

Fig.8 The comparison of measured Id-Vback characteristics in LOCOS-isolated SOI MOSFET's with and without hydrogenation. L/W=1.0 μ m/10 μ m

affected by the shape of the edge structure [6]. From SEM observation, however, the shapes of the SOI edge region of the MOSFET's in SIMOX-1 and SIMOX-2 were almost the same. It is indicated that the difference of the threshold voltage of the parasitic MOSFET is caused by the fixed charge and not by the shape of the SOI edge region. The density of the fixed charge in the edge region is estimated at about 3e11/cm2 by comparison of 3-D device simulation results. The difference of the fixed charge density in the edge region in SIMOX-1 and SIMOX-2 is estimated at about 2e11/cm2.

It was also found that the density of Nf(BOX) of SIMOX-2 was lower than that of SIMOX-1 by measurement of Id-Vback characteristics of the edgeless MOSFET's. The density of Nf(BOX) in SIMOX-2 is estimated at about 1e11/cm2, and the difference of the density of Nf(BOX) in SIMOX-1 and SIMOX-2 is estimated at about 2e11/cm2. These results indicate that Nf(LOCOS) induced during the transistor fabrication process was almost the same between SIMOX-1 and SIMOX-2, and it is estimated at about 2e11/cm2.

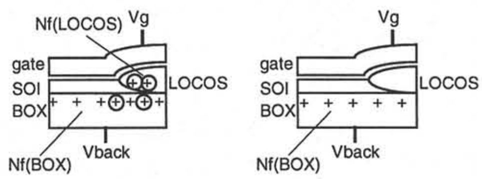

Fig. 9 Schematic diagram of LOCOS-isolated SOI MOSFET's with and without hydrogenation. Nf(LOCOS) is reduced by hydrogenation.

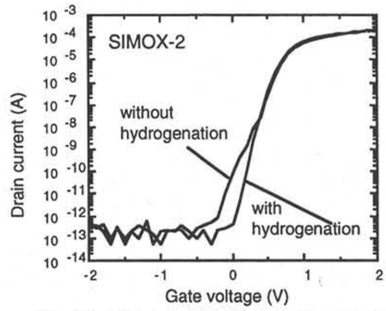

Fig.10 Measured Id-Vback characteristics of LOCOS-isolated SOI MOSFET's with and without hydrogenation. L/W=1.0 μ m/10 μ m

3. Conclusion

The method of estimation of the fixed charges at both LOCOS/SOI and SOI/BOX interfaces was determined by measurement of Id-Vg and Id-Vback characteristics of partially depleted NMOSFET's with and without hydrogenation. It was found that the hump in the subthreshold region was caused by fixed charges at both LOCOS/SOI and SOI/BOX interfaces. The density of the induced charge (Nf(LOCOS)) during the transistor fabrication process could be reduced by hydrogenation and was the same in different SIMOX substrates. However, the density of the fixed charge (Nf(BOX)) which was not largely changed by hydrogenation, depended on SIMOX substrates. These results suggest that the SOI substrate with low fixed charge at SOI/BOX interface and the hydrogenation process become key factors for low power SOI circuits using LOCOS isolation technology.

References

[1] T. Elewa, B. Kleveland, S. Cristoloveaun, B. Boubaker, and A. Chovet, IEEE Trans. Electron Devices, **39**, 874 (1992).

[2] J. W. Thomas, J. E. Chung, and C. L. Keast, Proceedings IEEE Intr. SOI conf., 116 (1995).

[3] H. S. Kim, S. B. Lee, D. U. Choi, J. H. Shim, K. C. Lee, K. P. Lee, K. N. Kim and J. W. Park, VLSI Symp. Tech, Dig.,143 (1995).

[4] M. Racanelli, W. M. Huang, H. C. Shin, J. Foerstner, B-Y Hwang, S. Cheng, P. L. Fejes, H. park, T. Wetteronth, S. Hong, H. Shin, and S. R. Wilson, Tech, Dig. IEDM, 855 (1995).

[5] T. Ohno, Y. Kado, M. Harada, and T. Tsuchiya, IEEE Trans. Electron Devices, **42**, 1481 (1995).

[6] T. Iwamatsu, S. Miyamoto, Y. Yamaguchi, T. Ipposhi, Y. Inoue and H. Miyoshi, ECS 7th International Symposium on SOI Technology and Devices, 318 (1996).