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Source/Drain Dopant Deactivation and Junction Degradation by Energetic Ions in Plasma Processes

Yukio Tamai[1] and Tadahiro Ohmi[2]
[1]Department of Electronic Engineering, Graduate School of Engineering, Tohoku University,
Aza-Aoba 05, Aramaki, Aoba-ku, Sendai 980-8579, Japan tamai@sse.ecei.tohoku.ac.jp
[2]New Industry Creation Hatchery Center, Tohoku University,
Aza-Aoba 05, Aramaki, Aoba-ku, Sendai 980-8579, Japan Phone: +81-22-217-7124 / Fax: +81-22-263-9395

1. Introduction

In the future scaled devices, one of the critical issues is parasitic series resistance of MIS transistors. The series resistance degrade the current drivability of the transistor. In the smaller devices, the contribution of the contact resistance to the series resistance will be enlarged, because the contact area decreases drastically with the device size shrinkage. In order to make contact resistance low the doping concentration of the semiconductor at the very interface between metal and the semiconductor must be as high as possible. Contrary to the requirement, contact resistance increase due to the damage caused by reactive ion etching (RIE) process have been reported [1,2]. Although many research on the damage caused by RIE, which is relatively complex system because of the employment of reactive mixture gases, have been reported, there has been few reports on detailed ion-bombardment-induced damage in simple system. Therefore, the purpose of this work is to clarify the detailed mechanism of dopant deactivation caused by energetic noble gas ion bombardment, which can help us understand the damage caused by complex RIE system. For this purpose we investigated dopant deactivation caused by energetic ions in noble gas (no etching gas included) discharge system. As a result, it was clarified that ion bombardment itself deactivates dopants. Form the obtained results, we have speculated that this phenomenon has a close relation to point defects. Furthermore, based on the speculation, we investigated the pn junction degradation, which is caused by generated point defects.

2. Ion-Bombardment-Induced Dopant Deactivation and Reactivation by Thermal Annealing

In order to investigate the ion-bombardment-induced dopant deactivation behavior, the experiments as shown in **Fig. 1** were conducted. p^+ or n^+ layers formed on silicon (100) were bombarded by Ar^+ in parallel plate RF(13.56Mhz) glow discharge plasma. The incident ions' energy was controlled by changing the self bias voltage (Vdc). We confirmed in advance that the amount of sputtering of the sample surface was small enough. **Figure 2** shows carrier profiles for As, P and B doped Layers. In each graph curves for both before and after-bombardment samples are plotted. It is clearly seen that in all the after-bombardment samples the dopants were deactivated by the bombardment. Since we can estimate the projected range of Ar with a energy of 400eV to be a few nano meter, it appears that the dopant deactivation within 40nm of the silicon surface is not due to the direct interaction between incident ion and dopant atom. We speculate this is due to the interaction between the dopant and point defect which generated at the surface and migrated into the bulk of silicon substrate, because it is well known that point defects migrate until forming stable state with dapant or etc [3] It is interesting that the dopant deactivation behaviors are different among B, As, P-doped samples. We believe that this is because the capture cross sections of point defect are different among these dopant atoms. **Figure 3** shows the annealing behavior of deactivated layer. It is observed that the deactivated dopants can be reactivated by thermal annealing at as low as 200-400°C. We believe that this result would be the proof that the deactivation has close relation to point defects, because there are results that dopant-ponit defect complex can be annealed out at these relatively low temperature range[4]. **Figure 4** shows the results of the experiments to investigate the influence of existence of surface oxide on the dopant deactivation. The amount of deactivated dopant per unit area is plotted as a function of the oxide thickness. Interestingly, the bombardment on the oxide of which thickness is thicker than the implanted-ion distribution still causes the dopant deactivation. The detailed analysis is under research at present. According to the result in **Fig. 3**, it seems that the deactivated dopants can be reactivated enough by thermal annealing at as low as 400°C. However, the key for the low contact resistivity is the high carrier concentration at the very surface of the semiconductor. The surface carrier concentrations of the samples in **Fig. 4** which were annealed at 400°C for 30 min are plotted in **Fig. 5** as a function of the surface oxide thickness. Only the sample which was bombarded directly with the ions exhibit low surface carrier concentration of $3x10^{19}cm^{-3}$, which is not high enough for low contact resistivity. Therefore, we concluded that implantation of noble gas ions into highly-doped surface must be avoided in order to realize low contact resistivity in the case of employing total low temperature processing in the future manufacturing. **Figure 6** is the illustration of the dopant deactivation by ion bombardment. The deactivated layer consists of two kinds of layers. One is the heavily-damaged region where the ions are implanted. The other is the layer where the dopants are deactivated forming dopant-point defect complex.

3. Junction Degradation Induced by Ion Bombardment

As described above, the energetic incident ions create point defects which diffuse into the bulk of silicon substrate, we have done an experiments similar to **Fig. 1** to clarify the influence of ion bombardment on the junction properties. Low leakage p^+n junction, which was formed by BF_2^+ implantation and post-implantation annealing at 800°C for 1h, was bombarded. Then Current-Voltage Characteristic of the junction was measured. Furthermore, we investigated the effect of thermal annealing on junction property recovery. **Figure 7** shows leakage current of the junctions bombarded with a dose of 10^{17} cm^{-2} as a function of self bias voltage. The bombarded junctions exhibit 3-4 order of magnitude higher leakage currents. This would be due to complex-type defect which relate to point defects. The leakage current decreases with the decrease in the self bias voltage. However, the junction bombarded with −100V of Vdc still exhibits 3 order of magnitude higher leakage current than the junction not bombarded. **Figure 8** shows leakage current of the junctions bombarded with –100V of Vdc as a function of ion dose. Although the leakage current decreases with the decrease in the ion dose, the leakage current bombarded with a dose of 10^{14} cm^{-2}, which is fairly low in typical plasma processes, still shows 2 order of magnitude higher leakage current than that of the junction not bombarded. Since 10^{9}-10^{10}cm^{-2} defects in the depletion region can cause leakage current of 10^{-8}-10^{-9}A/cm^{2}, the dose of 10^{14} would be enough to degrade the junction. The effect of thermal annealing on the junction property recovery is shown in **Fig. 9**. Although the thermal annealing at 400°C can reduce the leakage current, the effect is not sufficient to remove all of the damage. It should be noted that the employment of the annealing at relatively low temperature (400°C) in this experiment is for total low temperature processing which is essentially required in the future ULSI fabrication. Finally the threshold energy which causes no degradation must be clarified and this subject is under research.

4. Summary and Conclusions

It has been demonstrated that energetic ion causes dopant deactivation and this is due to the formation of dopant-point defects complex. The only dopants which exist in the region where the ion was not implanted into can be reactivated sufficiently by thermal annealing even at as low as 400°C. Furthermore, it was clarified that the point defects, which migrate from the bombarded surface into the vicinity of the junction, cause the junction degradation and only a part of the damage can be removed by thermal annealing at 400°C.

Acknowledgments

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Reference

[1] K. –H. Kwon et al., Jpn. J. Appl. Phys., **35**, 1611, (1996)

[2] K. Komeda et al., 3rd Int. Symp. Plamsma Process Induced Damage, pp.88-91, 1998.

[3] T. Sadoh et al., Jpn. J. Appl. Phys., **33**, 7151, (1994).

[4] M. Hirata et al., J. Phys. Soc. Jpn., **27**, 405, (1969).

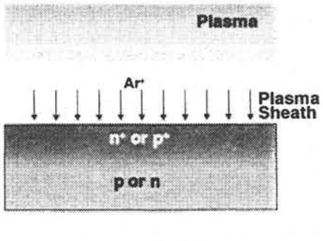

Fig. 1 Schematic diagram of ion bombardment experiment.

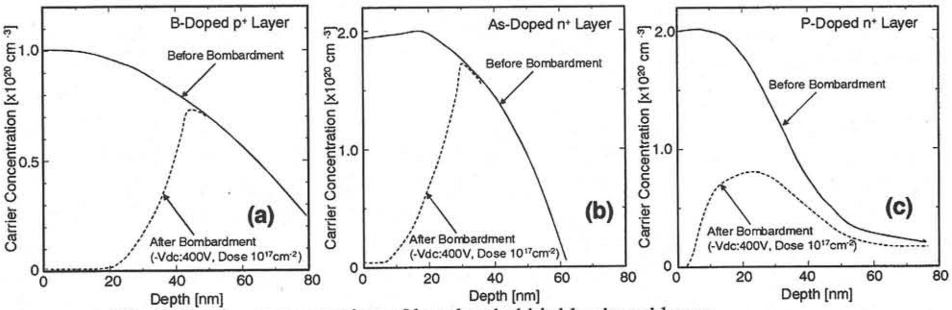

Fig. 2 Carrier concentration of bombarded highly-doped layer.
(a) Boron-Doped Layer (b) Arsenic-Doped Layer (c) Phosphorus-doped Layer

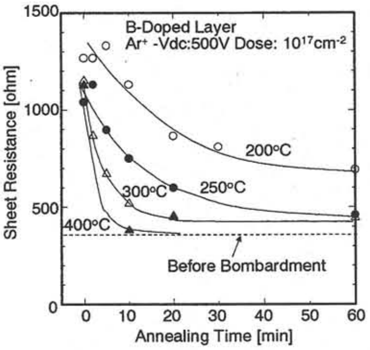

Fig. 3 Annealing behavior of deactivated B-doped layer.

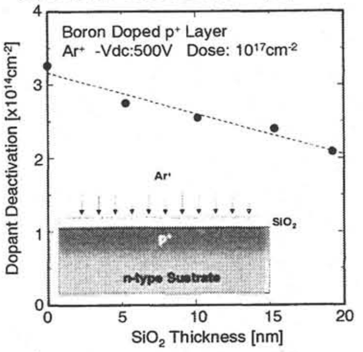

Fig. 4 Amount of deactivated dopants as a function of surface oxide thickness.

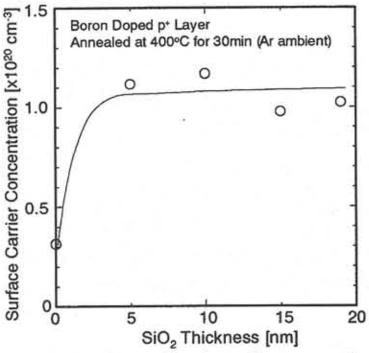

Fig. 5 Surface Carrier Concentration after annealing at 400°C for 30min as a function of surface oxide thickness

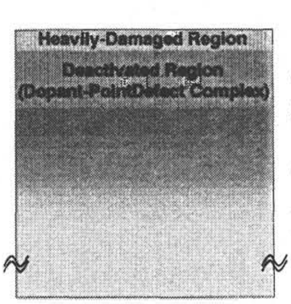

Fig. 6 Schematic diagram of deactivated region.

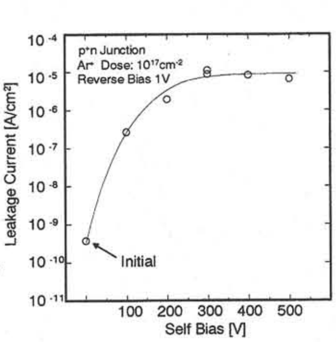

Fig. 7 Leakage current of bombarded p+n junction at reverse bias 1V as a function of self bias voltage. Dose: 10^{17}cm^{-2}

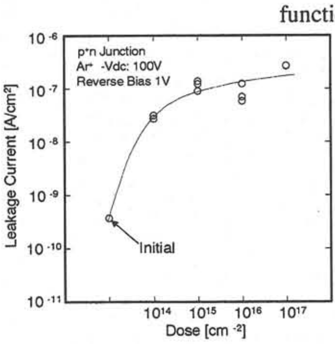

Fig. 8 Leakage current of bombarded p+n junction at reverse bias 1V as a function of dose. Self bias voltage: 100V

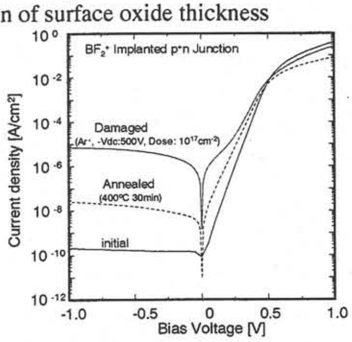

Fig. 9 Effect of thermal annealing at 400°C for 30min on the junction property recovery.