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Proximity Gettering of Micro-Defects by High Energy Ion Implantation

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We studied the proximity gettering of micro-defects intentionally introduced by silicon implantation above a gettering layer formed by high energy, high dose, ion implantation. The heavily damaged layer implanted with high energy boron, carbon, oxygen, fluorine and silicon ions acted as a gettering site of micro-defects induced by silicon implantation. The gettering ability of high energy silicon implantation was considered to be the strongest among the ion species studied. The gettering effects were observed by the heat treatment down to 900 °C, even if the gettering layer is apart more than 2.0 µm from the micro-defects region.

1. Introduction

High energy ion implantation technique has been widely used for VLSI fabrications such as a retrograde well and a buried layer [1]. Recently, a proximity gettering of heavy metals by using a high energy ion implantation was reported [2),3)]. We reported a remarkable decrease in leakage current of P-N junction at a certain implant conditions for a buried layer formation [4),5)]. It seemed that the formation of the secondary defects played an important role for gettering of micro-defects around the depletion layer which was formed in a course of high energy implantation for a buried layer formation. The interaction between the defects formed by low energy and high energy implantation was also reported [6)]. In this paper, we investigate the gettering of micro-defects which are intentionally introduced by silicon implantation above the heavily damaged region by high energy, high dose implantation. The leakage current of N^+-P diode formed in the micro-defects region is monitored to examine the gettering of micro-defects.

2. Experimental

After LOCOS isolation, a retrograde well was formed by multiple high energy boron implantation in a p-type 10 Ωcm (100) silicon wafer. Boron, carbon, oxygen, fluorine and silicon ions were implanted to form a gettering layer with $1x10^{15}$ ions/cm^2. The implantation energies were chosen to have almost the same projected range of 2.4 µm for all the above ion species. No increase in junction leakage current of N^+-P diodes was observed in these implantation conditions [5)]. The gettering effects were investigated by introducing the micro-defects by silicon implantation with doses from $1x10^{13}$ to $1x10^{14}$ ions/cm^2. Implantation energies of silicon to form micro-defects were varied from 100 keV (Rp=0.13 µm) to 2.4 MeV (Rp=2.07 µm), which located above the gettering layer. Subsequently some samples were annealed at 1000 °C for 1 hour. Finally arsenic ions were implanted at 50 keV and annealed at 900 °C for 20 mins to form N^+-P junction.

3. Results and discussion

Figure 1 shows the dependence of junction leakage current on silicon implantation dose for micro-defects formation with ion species to form a gettering layer as a parameter. The gettering layer was formed by boron, carbon, oxygen, fluorine and silicon implantation with a dose of $1x10^{15}$ ions/cm^2 at approximately 2.4 µm depth. The micro-defects were introduced by silicon implantation at 700 keV with doses from $1x10^{13}$ to $1x10^{14}$ ions/cm^2. These micro-defects can act as a generation-recombination center within the depletion layer, and thus increase the junction leakage current of N^+-P diode formed in a silicon implanted damage region. The junction leakage current starts to increase at a dose of $5x10^{13}$ ions/cm^2 in the case without gettering layer. In the case of boron implantation, almost no reduction in the leakage current is observed. However, a remarkable decrease in leakage current is observed for other gettering implantations at a dose of $5x10^{13}$ ions/cm^2 for micro-defects formation. Only fluorine and silicon implantations can reduce the junction leakage current of

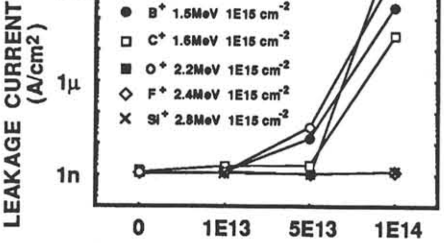

Figure 1 Dependence of junction leakage current on silicon implantation dose for micro-defects formation with and without a gettering implantation. All samples were annealed at 1000 °C for 1h.

diode with micro-defects induced by silicon implantation at a dose of $1x10^{14}$ ions/cm^2.

Figure 2 shows the junction leakage current of N^+-P diode as a function of annealing conditions with ion species to form a gettering layer as a parameter. The micro-defects were introduced by silicon implantation at 700 keV with $1x10^{14}$ ions/cm^2. The gettering layer was formed by fluorine implantation at 2.4 MeV and silicon implantation at 2.8 MeV with $1x10^{15}$ ions/cm^2. In the case of fluorine implantation, the reduction of leakage current can be observed at the annealing temperature of 1000 °C for 1 hour. However, silicon implantation for gettering layer formation can completely eliminate the increase in the junction leakage current for relatively low temperature heat treatment, such as 900 °C for 20 mins. Therefore the gettering ability of silicon implantation is considered to be the strongest among the ion species studied. From these reductions in junction leakage current, the gettering ability is thought to be in the order $B^+ < C^+, O^+ < F^+ < Si^+$. Silicon has, of course, no chemical reaction with micro-defects, and heavier ions have stronger gettering ability. These phenomena indicate that the gettering reaction of micro-defects is not a chemical reaction with implanted ion species but a physical reaction with implant damages.

Figure 3 gives the dependence of the junction leakage current on the process sequence for the formation of gettering sinks. Silicon ions were implanted for a gettering layer formation (step 1). The effect of the heat treatment for the secondary defects formation (step 2) was examined. The micro-defects were introduced by silicon implantation (step 3), after step 2 or without step 2. The annealing for gettering was performed at 1000 °C for 1 hour (step 4). The reduction of the leakage current was observed for both process sequences. The gettering effect was insensitive whether the secondary defects were existed before the introduction of micro-defects or not. The micro-defects introduced simultaneously with the gettering implantation was also gettered by the secondary defects which grew during the annealing for gettering. The gettering effects can be remained for a long time because the secondary defects are very stable against the heat treatment [7].

Figure 4 gives the junction leakage current of N^+-P diode as a function of silicon implantation energy for micro-defects formation. The micro-defects were introduced by silicon implantation at $1x10^{14}$ ions/cm^2 with energies from 100 keV (Rp=0.13 μm) to 2.4 MeV (Rp=2.07 μm). The gettering layer is formed by silicon implantation at 2.8 MeV (Rp=2.4 μm) with a dose of $1x10^{15}$ ions/cm^2. The junction leakage current increases with silicon implant energy in the case without a gettering implantation. However, the leakage current can clearly be reduced by the gettering layer formed by high energy silicon implantation for all the silicon implantation energies for micro-defects formation. This indicates that the range of gettering influence of heavily damaged region is very long. The gettering ability is still observed even if the gettering layer is apart more than 2.0 μm from the micro-defects region.

The cross-sectional TEM photographs for samples with and without gettering implantation at a dose of $1x10^{15}$ ions/cm^2 are shown in Fig. 5. The micro-defects are introduced to all samples by silicon implantation with 700 keV (Rp=0.94 μm) at a dose of $1x10^{14}$ ions/cm^2. The silicon implanted micro-defects, which would be the cause of increase in junction leakage current, can not be observed in the TEM photographs. In the case with gettering implantation of boron, oxygen, fluorine and silicon ions, secondary defects are densely formed around the projected range of ion species implanted to form a gettering layer. No extended dislocation loops toward the surface can be observed. The micro-defects are thought to be gettered by secondary defects induced by implantation. In the case of carbon implantation, the gettering sink is considered to be the silicon self-interstitial which densely exists around the projected range of carbon ions [8].

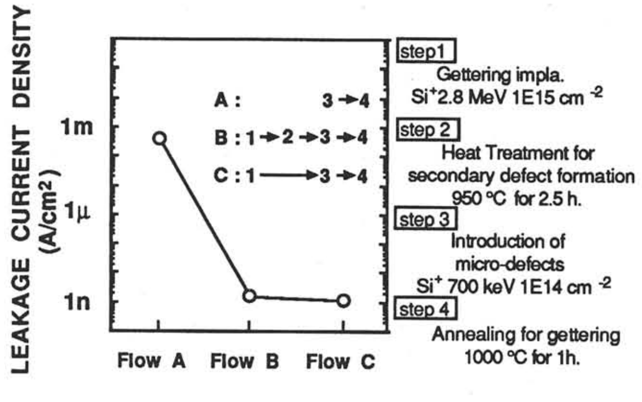

Figure 3 Dependence of junction leakage current on process sequence for the formation of gettering sinks.

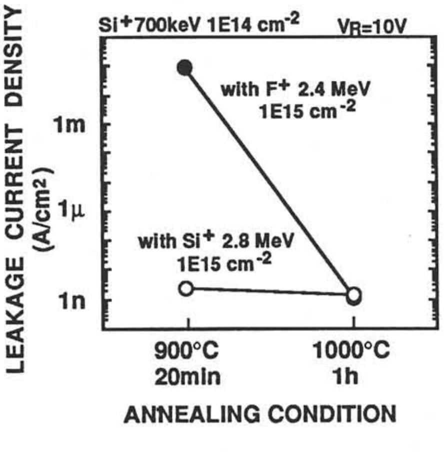

Figure 2 Dependence of junction leakage current on annealing conditions. The gettering layer is formed by fluorine and silicon implantation.

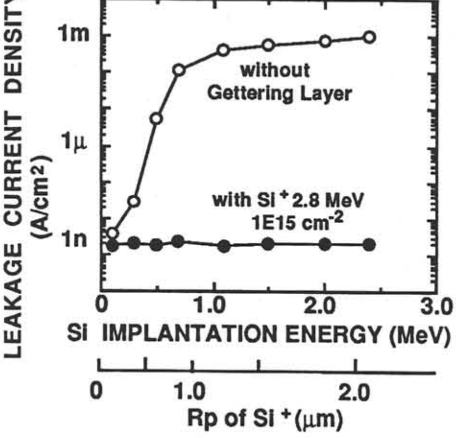

Figure 4 Dependence of junction leakage current on silicon implantation energy for micro-defects formation. The gettering layer is formed by silicon implantation at 2.8 MeV with a dose of 1E15 cm^{-2}.

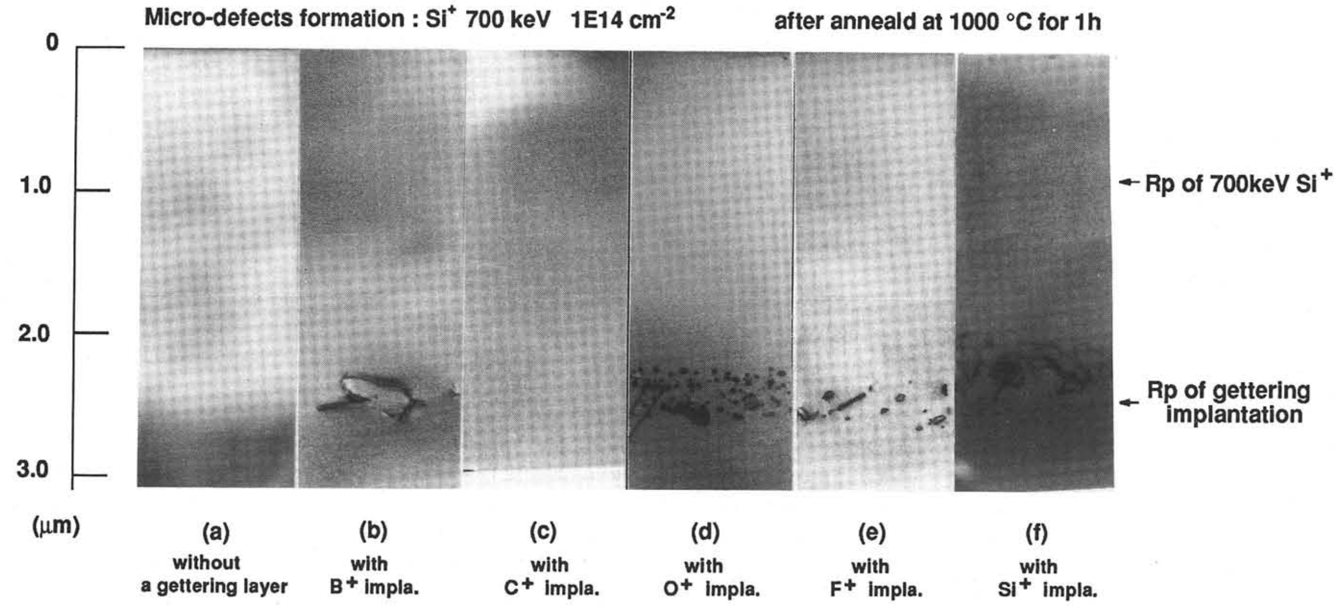

Figure 5 Cross-sectional TEM photographs of samples implanted with 700 keV Si^+ at a dose of 1E14 cm^{-2}. (a) without a gettering layer and with a gettering layer formed by (b) B^+ implantation at 1.5 MeV, (c) C^+ implantation at 1.6 MeV, (d) O^+ implantation at 2.2 MeV, (e) F^+ implantation at 2.4 MeV, and (f) Si^+ implantation at 2.8 MeV with a dose of 1E15 cm^{-2}. All samples were annealed at 1000 °C for 1 h.

The model for gettering of micro-defects gettering by secondary defects is shown in Fig.6. There are two defects regions, one is induced by silicon implantation for micro-defects formation, and the other is induced by implantation for gettering layer formation. The density of defects induced by gettering implantation is much higher than that of silicon implantation for micro-defects formation. After the annealing, the secondary defects are formed around the projected range of gettering implantation. At the same time, the micro-defects induced by silicon implantation are gettered by secondary defects. As a result no residual micro-defects exists in the depletion layer and the junction leakage current decreases.

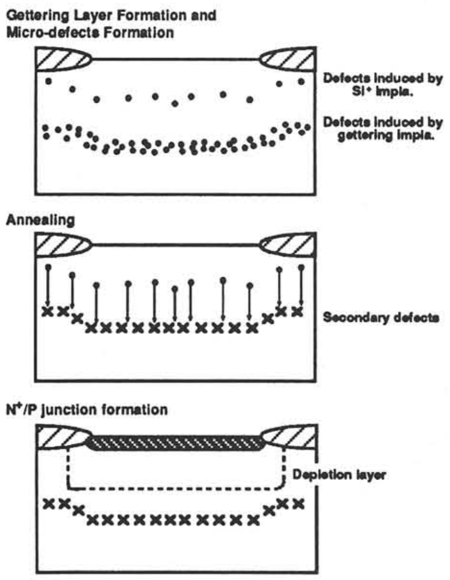

Figure 6 Model for gettering of micro-defects by secondary defects induced by high energy ion implantation.

4. Conclusion

Our extensive investigation concludes that a heavily damaged layer formed by high energy ion implantation can acts as a gettering site for micro-defects. The micro-defects, which would be the cause of increase in junction leakage current of P-N diode, could be completely eliminated by the gettering implantation. The gettering ability of high energy ion implantation was the order of $B^+ < C^+, O^+ < F^+ < Si^+$. The gettering effects were observed by the heat treatment down to 900 °C even if the gettering layer was apart more than 2.0 μm from the micro-defects region. This technique can be applied to the future ULSI devices as a new defect control method.

5. Acknowledgement

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