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Characteristics of Junction Leakage Current of Buried Layer Formed by High Energy Ion Implantation

T. Kuroi, S. Komori, H. Miyatake, K. Tsukamoto and Y. Akasaka

LSI R&D Lab. Mitsubishi Electric Corp.

4-1 Mizuhara, Itami, Hyogo 664, Japan

The characteristics of the junction leakage current of diodes that have a buried layer formed by high energy boron, phosphorus and arsenic ion implantation were studied. A reduction of the leakage current to the level comparable to that without a buried layer was observed with doses of over $3x10^{14}$ ions/cm^2. This drastic decrease in junction leakage current depends on the defect position (influenced by the implantation energy) and density of secondary defects (influenced by the dose and ion species). The self-gettering by secondary defects and the relative positioning of the defects with respect to the depletion layer are likely to be major causes for this phenomenon.

1. Introduction

In the past, many new device structures with superior performance have been reported by using high energy ion implantation. For example, a retrograde well is used to reduce latch up susceptibility[1)] and a buried layer is added for preventing soft error in memory devices[2)]. Detailed knowledge of defects induced by implantation and their annealing behavior are required for VLSI fabrication. The behavior of defects has commonly been studied by a cross-sectional transmission electron microscopy[3)]. However, no systematic studies have been conducted to establish the electrical properties of a buried layer formed by high energy ion implantation. In this paper, we investigate the characteristics of junction leakage current of n^+/p or p^+/n diodes that have a buried layer formed by high energy boron, phosphorus and arsenic ion implantation.

2. Experimental

We used boron, phosphorus and arsenic ions for implantation. After LOCOS isolation, we implanted ions of each type at 0.7 MeV to 3.0 MeV with doses of $1x10^{13}$ to $1x10^{15}$ ions/cm^2 for buried layer formation in the same type of substrate as the ion specie used. Subsequently samples were annealed at various conditions. Finally 50keV arsenic and 10keV boron ions were implanted to form n^+/p and p^+/n diodes, respectively, above the buried layer.

3. Results and discussion

Figure 1 shows the dependence of the leakage current of n^+/p diodes at V_R=5V on the boron implant dose with the implant energy as a parameter. As implant energy increases, the critical dose to maintain a small leakage current increases. In the case of 2.4 MeV implantations, almost no increase of the leakage current was observed with doses ranging from $1x10^{13}$ to $1x10^{15}$ ions/cm^2.

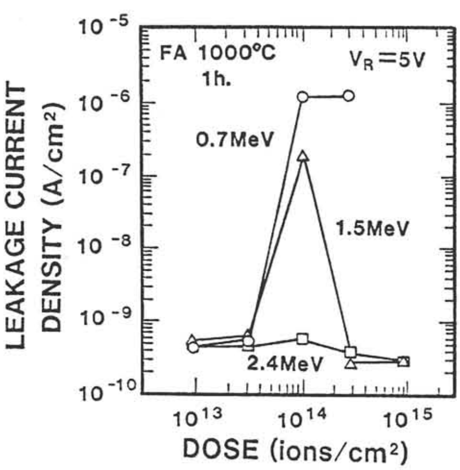

Fig. 1 Dose dependence of the junction leakage current at V_R=5V of diodes formed with a boron implanted buried layer at 0.7, 1.5 and 2.4 MeV.

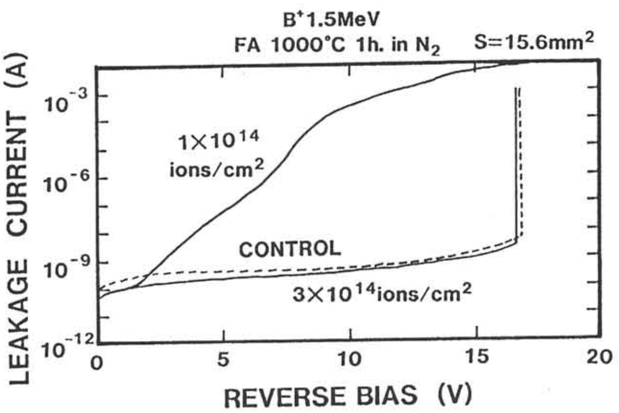

Fig. 2 Reverse bias I-V characteristics of n^+/p diodes with a boron implanted buried layer at 1.5 MeV

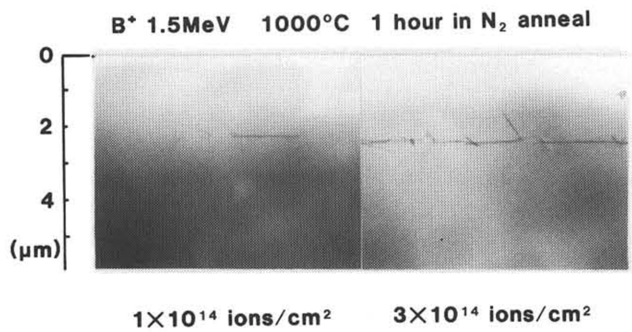

Fig. 3 Cross-sectional TEM photographs of secondary defects for boron implantation at 1.5 MeV with a dose of $1x10^{14}$ and $3x10^{14}$ ions/cm^2, and annealed at 1000 °C for 1 hour.

This is because the defect region induced by implantation becomes deeper than the depletion layer width. A drastic leakage current reduction occurred from the case of $1x10^{14}$ ions/cm^2 dose to that of $3x10^{14}$ ions/cm^2 dose for the 1.5MeV boron implantation.

Figure 2 depicts the reverse bias I-V characteristics of diodes implanted with 1.5 MeV boron, where the broken line represent the case for diode without a buried layer. In the case of $1x10^{14}$ ions/cm^2 implantation, the leakage current remarkably increases even at a small bias. On the other hand, the leakage current curve for the $3x10^{14}$ ions/cm^2 implantation is almost identical as the curve for the diode without a buried layer. Therefore, the junction breakdown for this case occurs quite sharply at V_R=17V.

A sudden decrease in leakage current occurred not only at the $3x10^{14}$ ions/cm^2 dose for boron as mentioned earlier, but also at doses for other ion species. We will call this type of doses "magic doses".

Figure 3 shows cross-sectional TEM photographs of the samples implanted with 1.5MeV boron at doses of $1x10^{14}$ and $3x10^{14}$ ions/cm^2 and annealed at 1000°C for 1 hour. In the sample with $3x10^{14}$ ions/cm^2 implantation where the junction leakage current remarkably decreases, dislocations are more densely formed near the boron projected range than in the sample with $1x10^{14}$ ions/cm^2. Therefore these results lead us to conclude that the leakage current does not correlate with dislocation formation. Figure 4 shows the SIMS depth profiles of boron, carbon and oxygen measured on the same two samples. They have almost the same carbon profiles, while they show quite different oxygen profiles. Oxygen precipitates around the same region as the boron projected range in the sample with $3x10^{14}$ ions/cm^2. It is likely that oxygen in the substrate is gettered by the secondary defects caused by boron implantation.

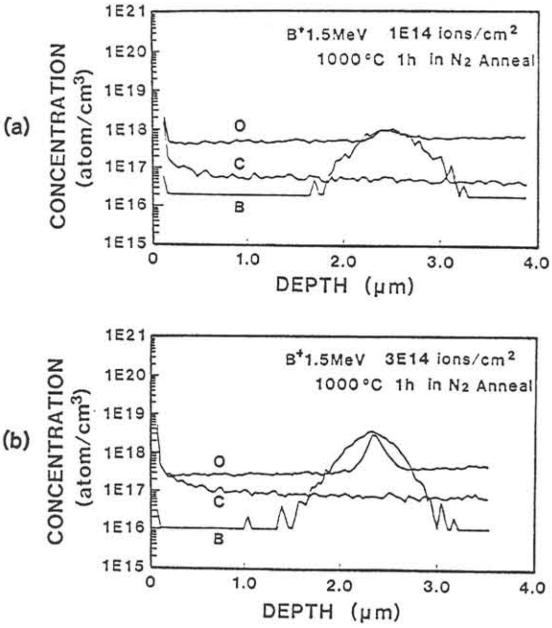

Fig. 4 SIMS depth profiles of boron, carbon and oxygen measured on samples implanted with (a) $1x10^{14}$ and (b) $3x10^{14}$ ions/cm^2 boron at 1.5 MeV and annealed at 1000 °C for 1 hour.

From C-V measurement, the depletion layer at V_R=5V is estimated to extend to 1.35 um and 1.15 um from the surface for boron implantation at 1.5 MeV with a dose of $1x10^{14}$ and $3x10^{14}$ ions/cm^2, respectively, and is shallower than the secondary defect region at around 2.4 um. In spite of the small difference in the depletion layer width, the leakage current is quite different as already shown in Figs.1 and 2. This is due to the

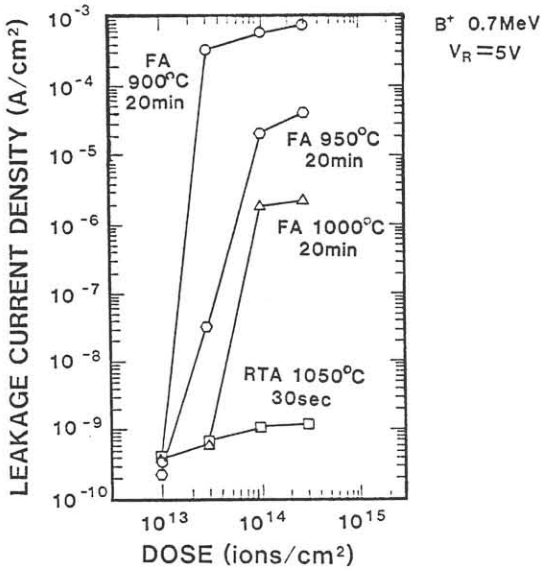

Fig. 5 Dose dependence of the junction leakage current at V_R=5V of diodes implanted with 0.7 MeV boron and annealed at 900°C, 950°C and 1000°C for 20 mins (FA) and at 1050°C for 30 secs (RTA).

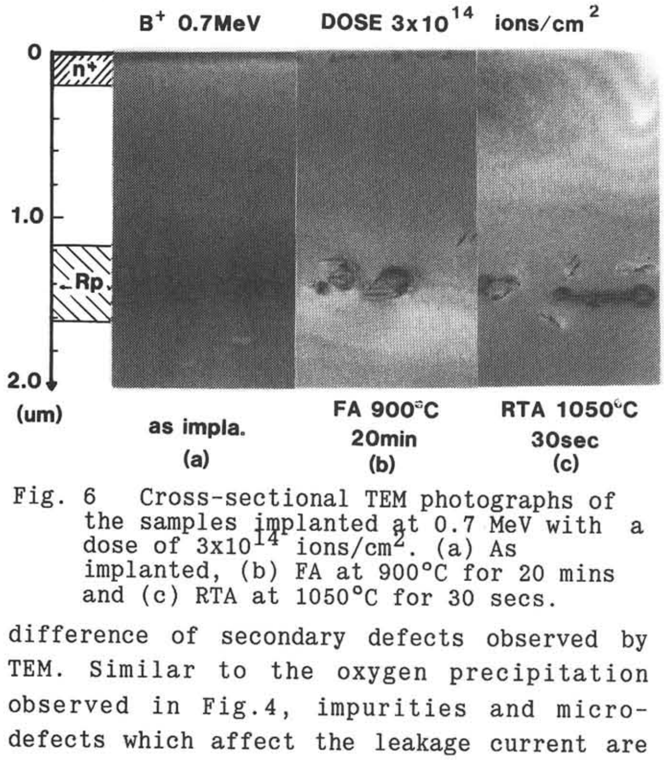

Fig. 6 Cross-sectional TEM photographs of the samples implanted at 0.7 MeV with a dose of $3x10^{14}$ ions/cm^2. (a) As implanted, (b) FA at 900°C for 20 mins and (c) RTA at 1050°C for 30 secs.

difference of secondary defects observed by TEM. Similar to the oxygen precipitation observed in Fig.4, impurities and micro-defects which affect the leakage current are also likely to be gettered by the secondary defects. However, in the case of boron implantation at 0.7 MeV with a dose of $3x10^{14}$ ions/cm^2, the depletion layer width is 1.00 um at V_R=5V and is close to the secondary defect region at around 1.4 um. As a result, the reduction of the leakage current can not be observed. From the above observations made for the two types of boron implantations, we concluded that the self-gettering by secondary defects and the relative positioning of the defects and the depletion layer are major causes for "magic doses," at which the leakage current remarkably decreases to the level comparable to that without a buried layer.

Figure 5 shows leakage current at V_R=5V as a function of boron implant dose at 0.7MeV, with the annealing conditions as a parameter. Compared with Furnace Anneal (FA), Rapid Thermal Anneal (RTA) is very effective in reducing the leakage current . Figure 6 shows the cross-sectional TEM photographs of silicon implanted with 0.7 MeV boron after FA at 900°C for 20 mins and RTA 1050°C for 30 secs. The secondary defects such as dislocations are formed in both samples and the density of defects is almost the same. This result also leads to conclusion that the

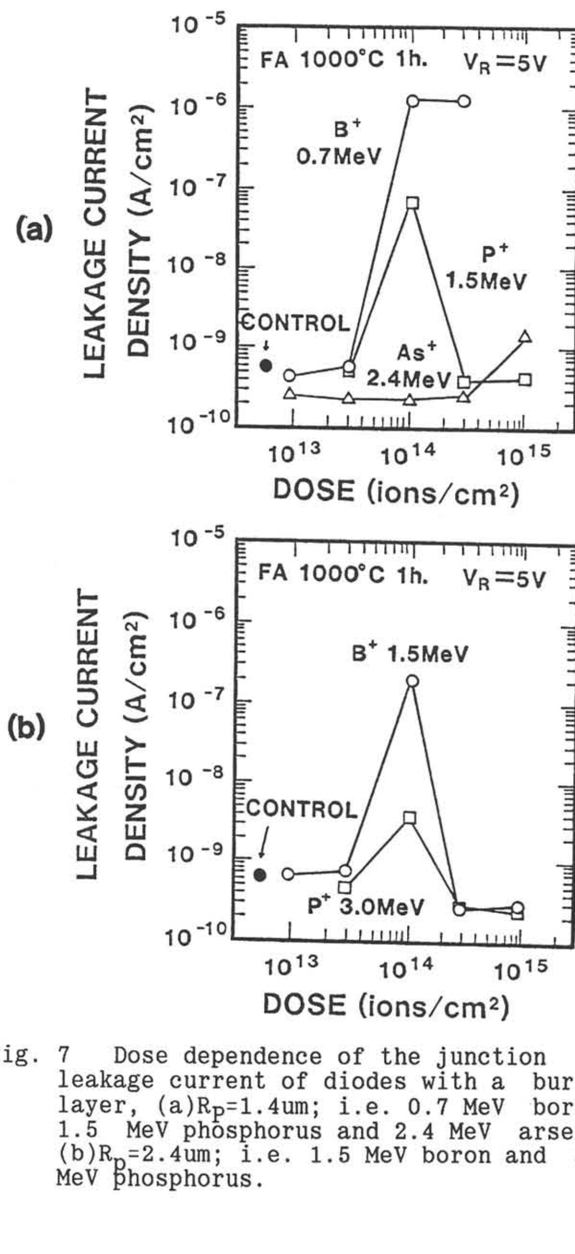

Fig. 7 Dose dependence of the junction leakage current of diodes with a buried layer, (a)R_p=1.4um; i.e. 0.7 MeV boron, 1.5 MeV phosphorus and 2.4 MeV arsenic (b)R_p=2.4um; i.e. 1.5 MeV boron and 3.0 MeV phosphorus.

increase in leakage current does not correlate with secondary defect formation.

Figure 7 shows the dependence of the leakage current at V_R=5V on implant dose with the type of ion species as a parameter. The implant energies of boron, phosphorus and arsenic are chosen to have almost the same projected range, 1.4 um for Fig.7a and 2.4 um for Fig.7b, respectively. In the case of R_p=1.4 um, reduction of the leakage current can not be observed for the boron implanted sample. "Magic doses" are clearly seen at over $3x10^{14}$ ions/cm^2 with phosphorus implantation for both projected ranges. The leakage current of phosphorus with R_p=1.4 um is found to increase when a reverse bias voltage is increased to V_R=10V. This phenomenon indicates that the depletion layer spreads to the secondary defect region at V_R=10V. In the case of arsenic implantation, the increase in leakage current can not be observed for doses up to 10^{15} ions/cm^2 under this experimental condition. Figure 8 shows the cross-sectional TEM photographs of the samples implanted with 1.5 MeV phosphorous and 2.4 MeV arsenic at dose of $3x10^{14}$ ions/cm^2. For phosphorus implantation, secondary defects are almost the same density compared with that of boron implantation as shown in Fig.3. For arsenic implantation, we observed much higher density of secondary defects than for phosphorus implantation. The ability of self-gettering by arsenic implantation is by far the strongest.

Figure 9 shows the temperature dependence of the leakage current of n^+/p diode with and without the p^+ buried layer formed at 1.5MeV boron with $3x10^{14}$ ions/cm^2. At high temperatures (>65 °C) where the leakage current is dominated by bulk diffusion mechanism, the leakage current of the sample with a buried layer is one order of magnitude smaller than that of the sample without the buried layer. Two explanation may follow. First, the minority carrier diffusion is suppressed by the p^+ buried layer where the carrier life time is quite short. And second, the minority carrier concentration at the depletion layer edge is reduced by the p^+ buried layer.

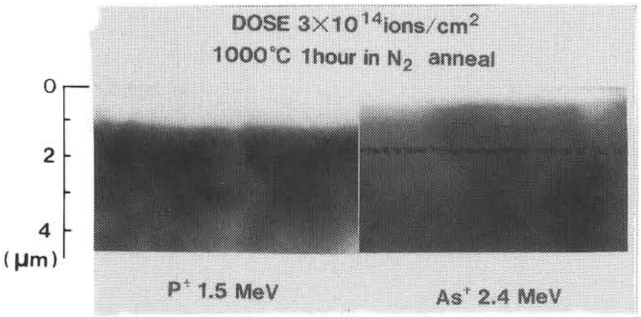

Fig. 8 Cross-sectional TEM photographs of the samples implanted with 1.5 MeV phosphorus and 2.4 MeV arsenic.

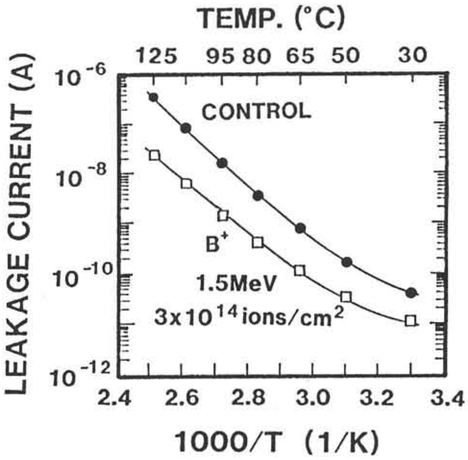

Fig. 9 Temperature dependence of the junction leakage current of diodes with and without a p^+ buried layer.

4. Conclusion

We have demonstrated that a heavily doped buried layer with higher implant dose than the so-called "magic doses," acts as a self-gettering layer, This results in a remarkable decreases in the leakage current of diodes to the level comparable to that without a buried layer. It is likely that the self-gettering by secondary defects and the relative positioning of these defects with respect to the depletion layer are main causes for this leakage current decrease.

5. Acknowledgment

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6. Reference

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