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Defect-Free Well Layer with High-Dose B^+ Implantation

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In CMOS-VLSIs, defect-free well layers with low resistivity have been eagerly anticipated. This paper analyzes defects resulting from high-dose Boron ion implantation and describes a new technique that realizes a defect-free well layer with low resistivity. This analysis of defects leads to new facts: (i) defects inherently included in the Si substrate, are gettered out by a new intrinsic gettering process, and (ii) defects depending on ion doses have specific threshold doses, Ndt. Based on these facts, a new "Plural Ion Implantation Method", that increases the threshold doses, Ndt, and offers the possibility of a defect-free P-well layer with about 40 ohm/□, is developed.

1 Introduction

Recently, such CMOS-VLSIs as MOS memories and imaging devices[1] have been made with high packing density. In these devices, the resistivity of the P-type well layer needs to be lowered in order to suppress voltage fluctuation in the P-type well layer and to realize a high signal-to-noise ratio. The P-type well layer is normally fabricated by diffusion or ion implantation of Boron. In diffusion, P-type well layers with low resistivity(~40 ohm/□) can be fabricated. However, the resistivities of these well layers are not easily controlled. In ion implantation, P-type well layers with high resistivity(~1 kohm/□) can be fabricated without defects, and these resistivities can be controlled very easily.

Therefore, demands for a defect-free well layer having resistivity from 40 ohm/□ to 1 kohm/□ have been increasing. Conventionally, low resistivity in a P-type well layer is achieved by employing high-dose Boron ion implantation. This, however, causes many defects to arise due to physical damage. These defects result in sharp rises in localized leakage current, which severely reduces the yield. However, no fabrication technique that produce defect-free P-type well layers with low resistivities by the ion implantation method has been reported up to the present.

In this paper, the relationship of defects to ion dose is analyzed. New facts based on this analysis leads to a new process that realizes defect-free P-type well layers through high-dose Boron ion implantation.

2 Defects in P-type well layer due to ion implantation

2.1 Defects due to Boron ion implantation

Samples for analysis of defects in P-type well layers due to Boron ion implantation were prepared utilizing the process steps shown in Fig. 1. Boron ions were implanted into the Si substrate after intrinsic gettering. After that, samples were annealed in N_2 gas atmosphere. During the wet oxidation step, such defects as oxidation-induced stacking faults were induced. These defects were observed after Secco etching[3].

Defects due to Boron ion implantation[2] were as shown in curve A of Fig. 2. Curve A indicates that there are 3 types of defects. The first type(a) is defects that do not depend on Boron ion dosage. This type appear especially in the lower ion dosage region. The second type(b) strongly depends on Boron ion dosage. The third type includes such defects as dislocation networks. In this figure, curve A represents defects in samples without intrinsic gettering, while curve B is the same for samples with intrinsic gettering.

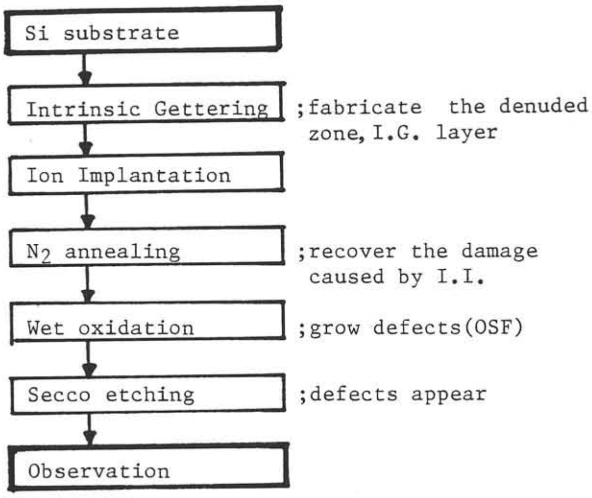

Fig. 1 Sample preparation flow.

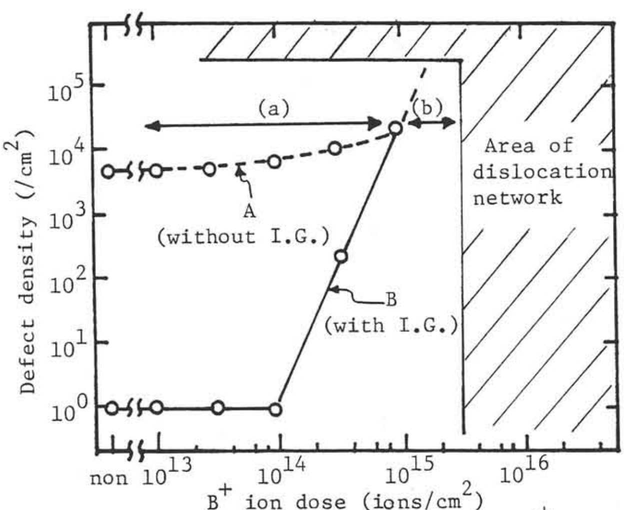

Fig. 2 Relationship between defects and B^+ ion dose. Line A:non I.G. ;line B:I.G.

2.2 Defects independent of dosage; type(a)

The type(a) defects, which are independent of dosage, were caused mainly by Oxigen impurities inherently present in the Si substrate. It was found that these defects could be suppressed by a new Intrinsic Gettering(I.G.) process. This process includes N_2 annealing[4] at high temperature after conventional 3-step I.G.[5],[6]. Surface defect density was less than 1 $/cm^2$ and a denuded zone about 60 μm thick was formed at the surface of the Si substrate. A layer with a high defect density, which acts as the gettering source, was formed in the bulk, as shown in Fig. 3. With this I.G. process, defects of type(a) are suppressed, as shown by the curve B in Fig. 2.

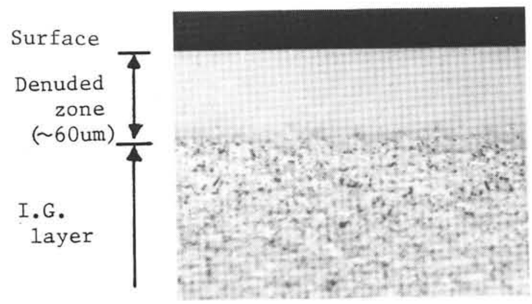

Fig. 3 Section of Si substrate after I.G. processing.

2.3 Defects that depend on dosage; type(b)

Fig. 2 shows that certain defects, type(b), depend on Boron ion dosage. It also indicates that these defects are related to physical damage caused by ion implantation. In order to reduce these defects by recovering the damage, N_2 annealing was utilized.

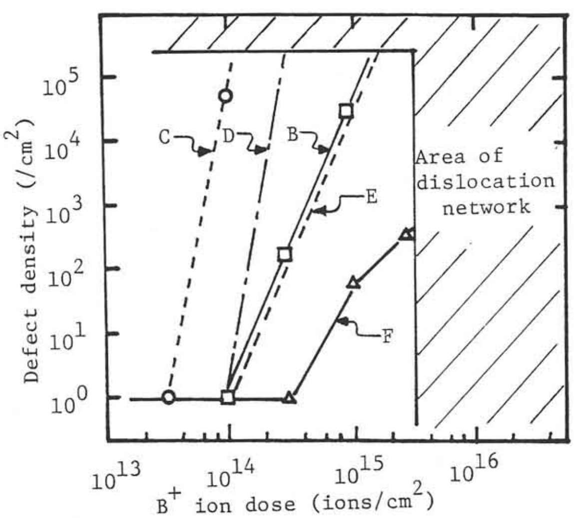

Fig. 4 Relationship between defects and Boron ion doses. Curve C:without N_2 annealing; curve D:N_2 annealing(1000 C,60min.); curve B:N_2 annealing(1100 C,60min.); curve E:N_2 annealing(1150 C,60min.) and curve F:by Plural Ion Implantation method.

The effects of N_2 annealing conditions and temperature on defects are illustrated as curves B,C,D and E in Fig. 4. Curve C shows the characteristic without N_2 annealing. Curves B,D and E were obtained as parameters of annealing temperature. Curves C and D show that defects are eliminated for dosages up to 10^{14} /cm^2 by utilizing N_2 annealing. Curves B,D and E indicate that more damage is recovered and defect dependency on ion dosage becomes smaller as the N_2 annealing temperature is increased. The most important indication is that there is a specific threshold dose, Ndt (10^{14} ions/cm^2), and that defects grow sharply above this Ndt. This , in turn, means that damages due to ion implantation can be completely annealed out and that no defects should appear for ion dosages of less than this Ndt.

These results lead to a new method that realizes a defect-free P-type well layer with a low resistivity.

3 New Plural Ion Implantation Method

Based on the new facts concerning threshold dose, Ndt, a Plural Ion Implantation Method(PIM) that involves many pairs of ion implantation and annealing steps has been developed, and is shown in Fig. 5.

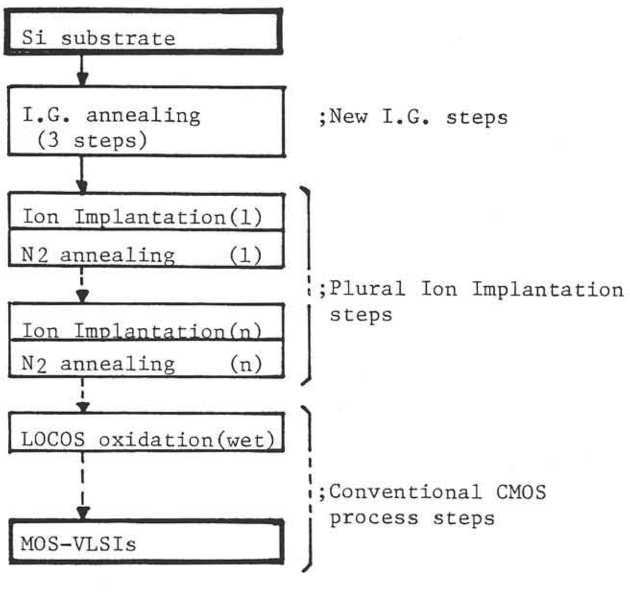

Fig. 5 CMOS process flow included I.G. steps and PIM steps.

In this method, n pairs of implantation-annealing steps with doses of less than the threshold dose, can produce a total dose that is n times the original threshold dose, Ndt, without any defects. As a result, a defect-free P-type well layer with low resistivity can be realized.

Curve F in Fig. 4 shows the relationship between defects and ion dosage in the case where 3 pairs of steps were applied with PIM. The enlarged threshold doses were measured and found to be 3 times larger than the original Ndt(10^{14} ions/cm^2), that is, 3×10^{14} ions/cm^2.

4 Discussion

4.1 Leakage Current

Leakage current in a P-N$^+$ junction[7] within a P-type well layer made by PIM steps were measured, as shown in Fig. 6.

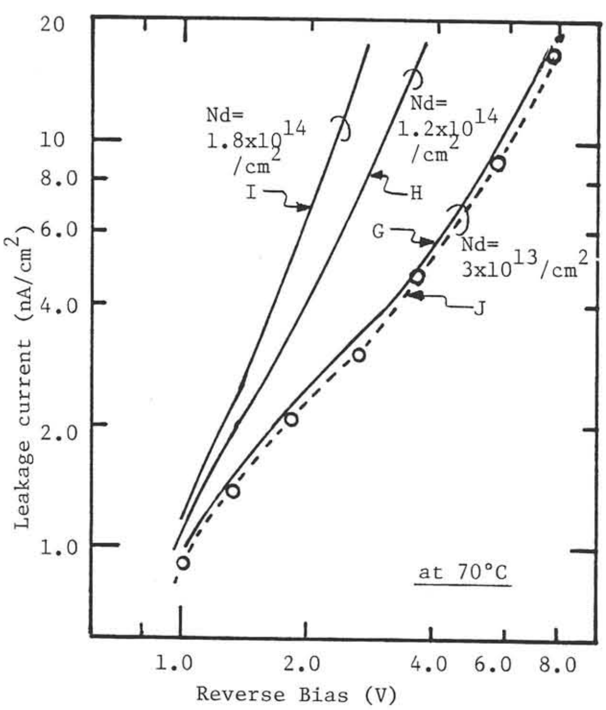

Fig. 6 Leakage current characteristics; curves G,H and I for the 3 pairs of steps, curve J for a conventional process with one pair of steps.

In this figure, curves G,H and I show leakage current characteristics for the PIM steps and curve J shows that for a conventional process with one pair of steps. Curve G shows the same characteristics as curve J. Curves G,H and I show the leakage current characteristics with depletion width and break down phenomenon held constant. Activation energy, Ea, was also measured and found to be 0.6 eV. This value is almost same to that for the conventional process.

4.2 Resistivity

With the PIM, low-resistance P-type well layers without defects were fabricated, as shown in Fig. 7. This figure shows that the resistivity decreases as the Boron dose increses.

Although 1 kohm/□ could only be obtained by the I.G. method, 500 ohm/□ was realized by adding the N_2 annealing step.

Thus, the PIM produces low-resistance P-type well layers, of from 40 ohm/□ to 1 kohm/□ that have not been realized by either conventional ion implantation or diffusion.

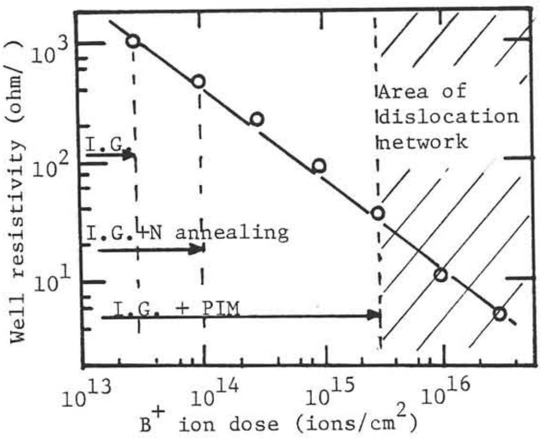

Fig. 7 Relationship between well resistivity and Boron ion dosage.

5 Conclusions

A defect-free P-type well layer with low resistivity has been realized. Defects in the P-type well layer arising from damage due to ion implantation have been analyzed with the following results: (1) Defects that are independent of ion dosage are clealy reduced to less than 1 /cm^2 by the process adding N_2 annealing after a 3-step intrinsic gettering. (2) Defects that depend on ion dosage have specific threshold dosages, Ndt, and grow sharply above this Ndt under any N_2 annealing conditions.

These results have led to a new "Plural Ion Implantation Method" that realizes defect-free P-type well layers with high-dose Boron ion implantation. It has been proven that the PIM is an applicable process for producing CMOS-VLSIs with low-resistance P-type well layers.

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