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Reduction of Thickness Secondary Defects in MeV Ion Implanted Silicon by Intrinsic Gettering

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Effects of Intrinsic Gettering (IG) treatments on secondary defects in MeV boron implanted silicon were investigated. IG treatment was carried out by controlling oxygen concentration. Etch pit density decreased to 1/5 and defect lengths shrunk from 3.8μm to 1.5μm in Denuded Zone (DZ) formed samples. The relation between defect density reduction and DZ forming conditions were also studied. Precipitated oxides in the bulk were found ineffective in reducing implantation induced defects. It was concluded that defect density strongly depended on oxygen concentration in the silicon substrates.

1. Introduction

Recently, MeV ion implantation technology has been studied because of its attractive properties. There are some proposals for device applications, such as buried collector in bipolar devices[1] and retrograde well in CMOS devices to improve the latch-up immunity[2-4]. For applying MeV ion implantation to device fabrication, ion implantation induced secondary defects must be controlled. Some studies in secondary defect properties have been reported[5]. However, few works have been published about secondary defect reduction; implantation into FZ Si substrates[6] and two step annealing[7].

In this paper, we report on the reduction of secondary defects induced by boron implantation by using Intrinsic Gettering (IG). The effect of gettering sites formed by precipitated oxides and oxygen concentration in boron implanted layer are investigated.

2.Experiments

1.5 MeV boron ions were implanted at room temperature into silicon substrates at a dose of $2\sim5\times10^{14}$cm^{-2}. Oxygen concentration of p-type (100) Czochralski (CZ) silicon substrates was in the range of 9.6×10^{17} $\sim1.7\times10^{18}$cm^{-3}. Substrates underwent IG treatment process prior to the implantation. During the IG treatment, Denuded Zone (DZ) was formed in silicon substrates. DZ formation conditions are shown in Table 1. Three step annealing was performed in each preparation. Oxygen concentration of the substrates at initial state and after DZ formation was measured by FT-IR. [ΔOi] is the difference of oxygen concentration before and after DZ formation. DZ thickness was estimated from etch pit distributions observed in the cross section of the substrates by

Table 1 Conditions of DZ formation

No.	Annealing Condition	[Oi] ($\times10^{17}$cm^{-3})	[ΔOi] ($\times10^{17}$cm^{-3})	DZ Thickness (μm)
1	1100°C,2hr (dry O_2) 700°C,16hr (N_2) 1000°C,2hr (N_2)	15.6	1.0	18
2	800°C,2hr (N_2) 1100°C,5hr (dry O_2) 1000°C,9hr (dry O_2)	8.7	7.9	12

Initial [Oi] 16.6×10^{17}cm^{-3} (ASTM-79)
Oi measurement method (FT-IR)

optical microscope.50nm thick oxide was formed on the substrate before boron implantation. After boron implantation, all of the substrates were annealed at 1050°C for 2h in N_2 ambient.

Implantation induced defects were observed by secondary electron microscopy (SEM) after Wright etching, and also by transmission electron microscopy (TEM). SIMS measurements were also carried out for estimating oxygen concentration in the substrates.

3. Results and Discussion

3.1 Etch pits in IG treated samples

Typical cross sectional SEM micrographs of etch pits in 1.5 MeV, $2\times10^{14}cm^{-2}$ boron implanted substrates are shown in Fig. 1. Without IG treatment [Fig. 1(a)], many etch pits are observed. While there are few etch pits in the IG treated sample made by condition No.1 [Fig. 1(b)]. Initial oxygen concentration in the substrates was $1.6\times10^{18}cm^{-3}$. These etch pits are located at a mean depth of 2.4 μm from the substrate surface. As the Rp of 1.5 MeV boron ions is 2.3 μm, etch pits are strongly localized near Rp. Etch pit density for the samples .with and without IG treatment are $3.5\times10^{8}cm^{-2}$ and $6.7\times10^{7}cm^{-2}$, respectively. Defects associated with precipitated oxide in IG treated substrates are formed at a deeper position, more than 10 μm, so these defects are not shown in this micrograph

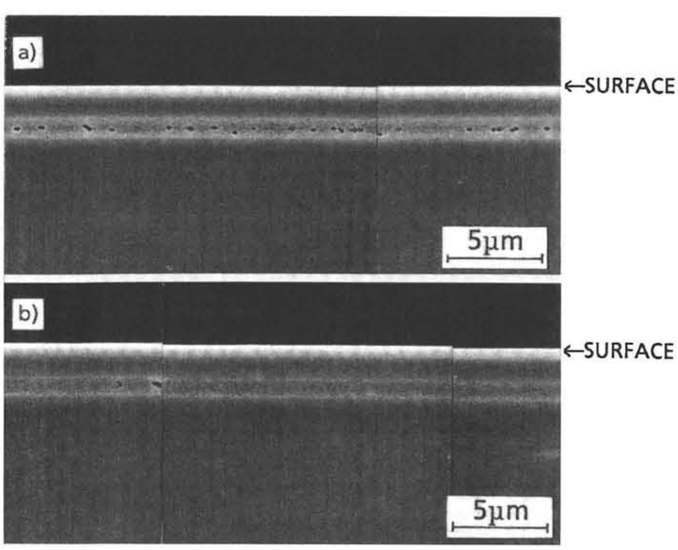

Fig.1 Cross sectional SEM micrographs of etch pits formed in boron implanted samples of without DZ (a), and with DZ (b). The implant energy is 1.5 MeV and the dose is 2×10^{14} cm^{-2}.

3.2 Dependence of IG treatment conditions

The relation between defect density in the implanted regions and DZ formation conditions were studied. Etch pit density in the implanted region versus boron implanted dose is shown in Fig. 2. Defect density depends on DZ formation conditions. At a dose of $2\times10^{14}cm^{-2}$, etch pit density decreased to 1/3 and 1/5 for samples of treatment conditions No.1 and No.2, respectively.

Condition No.2 of shallow DZ and low [Oi] is desirable. Large [ΔOi] under the No.2 condition corresponds to the fact that precipitated oxide becomes large in size and high in density. This indicates that the gettering is more effective in the case of condition No.2.

There may be two factors for secondary

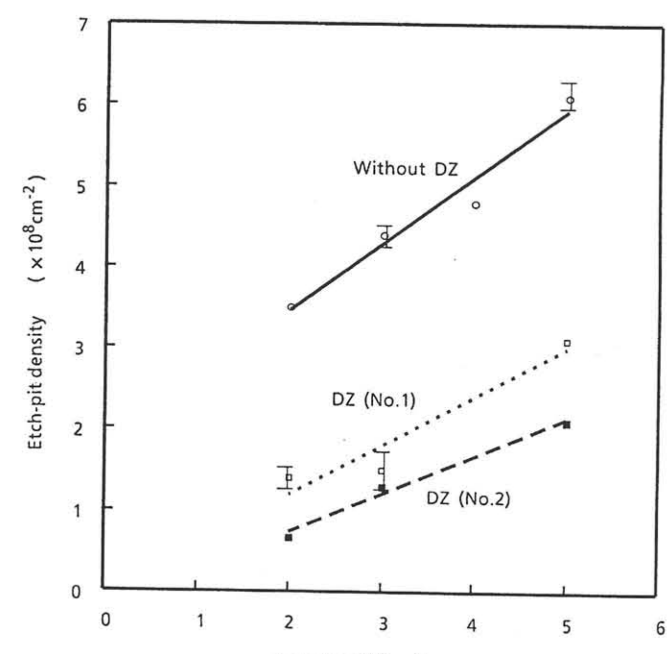

Fig.2 Dependence of etch pits density on dose as a parameter of IG treatment conditions in case of 1.5 MeV boron implantation.

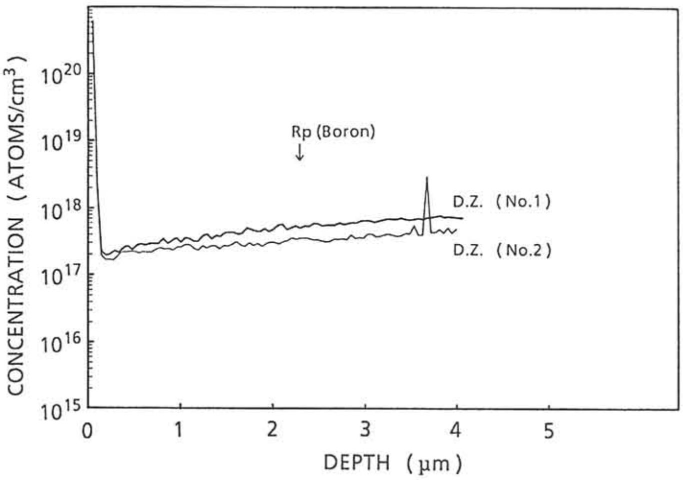

Fig.3 Depth profiles of oxygen measured in IG treated samples of (a) No.1 condition and (b) No.2 condition. The samples are annealed at 1050°C for 2h in N_2 ambient.

defect reduction. One is the gettering effect due to precipitated oxides, and another is the lowering of oxygen concentration in boron implanted layer formed in DZ.

Oxygen concentration near Rp of boron was studied by SIMS. Fig. 3 shows the SIMS profiles measured in the DZ treated samples. SIMS measurements were carried out after annealing at 1050°C , 2h in N_2 ambient. Oxygen concentration in DZ formed under No.2 condition is about half that formed under No.1.

3.3 Gettering ability

The effects of precipitated oxide on implantation induced secondary defects are discussed. Density of precipitated oxide increases in the substrates with high initial oxygen concentration. Therefore gettering effect becomes effective in high initial oxygen concentration substrates. The IG treatment process was carried out for high and low oxygen concentration substrates. In these experiments, No.2 condition was employed. Initial oxygen concentrations in the substrates were 9.6 and $16.6\times10^{17}cm^{-2}$. The density of etch pits caused by precipitated oxides in the bulk were $2.5\times10^3cm^{-3}$ and $4.5\times10^5cm^{-3}$ in low and high oxygen concentration substrates, respectively. Fig. 4 shows the dependence of the etch pit density

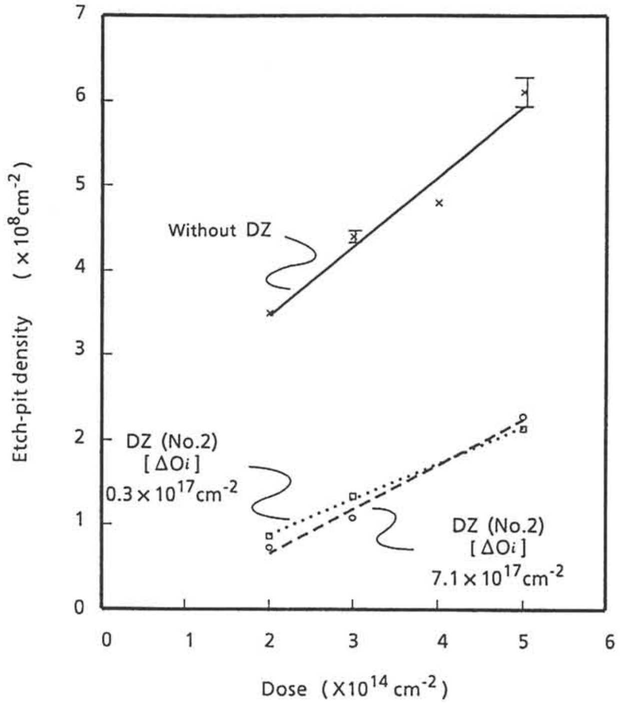

Fig.4 Etch pit density versus dose as a function of substrates oxygen concentration. The implant energy is 1.5 MeV.

in the boron implanted layer on initial oxygen concentrations. In this figure, the etch pit density in the boron implanted layer is not related to precipitated oxide density in the substrates.

Etch pit density in the boron implanted layer depends on IG preparation conditions as shown in Fig. 2. While etch pit density in the boron implanted layer does not depend on precipitated oxides, as shown Fig. 4.

Precipitated oxides in the bulk have little effect on the reduction of implantation induced secondary defect density. Oxygen concentration in boron implanted layer is very effective for secondary defects reduction.

3.4 TEM micrograph analysis

TEM micrographs of the samples implanted with boron dose of $2\times10^{14}cm^{-2}$ are shown in Fig. 5. Defects at the depth of about 2.5 μm from the substrate surface are observed. All of the defects were identified as dislocation loops. Defects in the untreated substrates grew larger in size and higher in

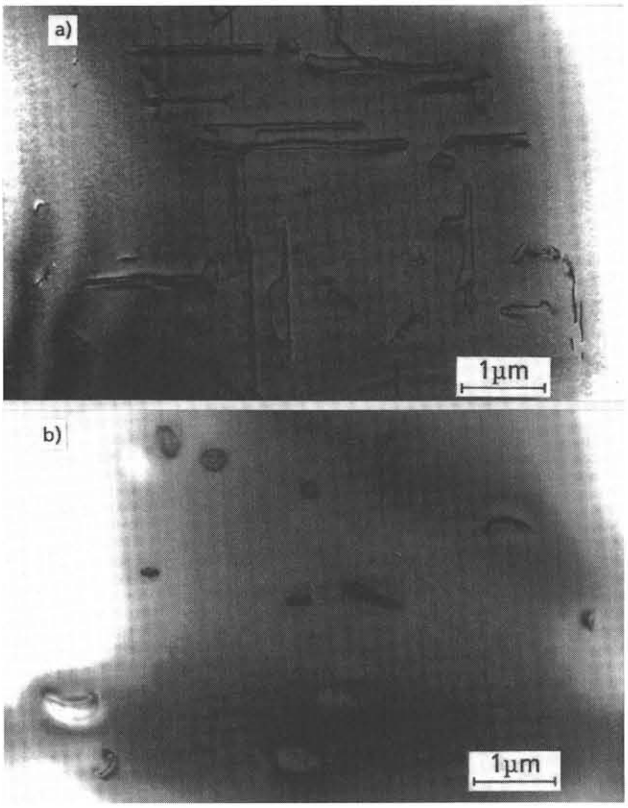

Fig.5 Plane view TEM micrographs of boron implanted samples at a depth of 2.5µm from the surface. Implantation conditions are 1.5 MeV and a dose of $2x10^{14}cm^{-2}$. (a) and (b) show samples implanted into the untreated and the DZ samples, respectively.

density. TEM micrograph of the substrate prepared under No.1 condition is not shown, but defects are nearly the same as those of No.2

These photographs are plane view TEM micrographs, so it shows defects of two dimensional distribution. Defect density is $9.7x10^{7}cm^{-2}$ in the untreated substrate, $6.0x10^{7}cm^{-2}$ in the sample formed under No.1 condition and $3.4x10^{7}cm^{-2}$ in the sample formed under No.2 condition. The maximum dislocation length is 3.8 µm in the untreated sample, 1.5 µm in No.1 and 2.3 µm in No.2. An IG treatment is very effective to decrease not only defect density but also defect size.

These results suggest that growth mechanism of the defects differ among DZ preparation methods.

3. Conclusion

MeV boron ion implantation induced secondary defect can be reduce by using silicon substrates prepared by IG, in the dose range of $2\sim5x10^{14}cm^{-2}$. Reduction of secondary defect density is attributed to low oxygen concentration in boron implanted layer.

Acknowledgments

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