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Modeling of Mechanism of Leakage in Shallow p^+/n Junction Formed by Pre-amorphization

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A model of the leakage induced by pre-amorphization is developed, assuming that the depth profile of excess interstitials making up dislocation loops is equal to the profile before being annealed to condense into dislocation loop. It is confirmed that this model well reproduces experimental data. Also Ge^+ pre-amorphization was compared with Si^+ in detail. An advantage of Ge^+ pre-amorphization over Si^+ is confirmed in a wider range of conditions than the previous report. 0.08-μm-deep p^+/n junction whose leakage current is less than $1x10^{-8}$ A/cm^{-2} is fabricated with 40-nm-thick amorphous layer formed by Ge^+ implantation.

1. INTRODUCTION

The pre-amorphization method, which eliminates ion channeling with an pre-amorphized layer formed by ion implantation of heavy ions such as Si^+, is very attractive for forming shallow p^+/n junction in Si[1]. The major problem of this method is the presence of residual defects (dislocation loop) formed below the original amorphous/crystal interface (a/c interface), which drastically increase junction leakage current when contained within depletion layer[2]. In order to form a shallow junction with low leakage current, influence of pre-amorphization on this leakage has been investigated in detail and it has been confirmed that the leakage is a function of pre-amorphization conditions such as the thickness of pre-amorphized layer and the kind of ions implanted for pre-amorphization[2,3]. Recently, we have also reported that leakage current due to Ge^+ pre-amorphization dose not increase so drastically compared with Si^+ [4]. However there has been no model for leakage mechanism, which quantitatively explains these dependences of leakage current on pre-amorphization conditions.

In this study, we have proposed a model for the leakage mechanism and compared it with experimental data. We have also carried out Ge^+ pre-amorphization experiment to compare Ge^+ pre-amorphization with Si^+ more exactly.

2. EXPERIMENTAL

In this study, n-type (100) Si wafers with doped phosphorus concentration of $1x10^{17}cm^{-3}$ were used. p^+/n diode regions were defined with the standard LOCOS process. For pre-amorphization, $^{74}Ge^+$ was implanted at 30 or 220keV and at the dose of $5x10^{14}cm^{-2}$. BF_2^+ implantation was performed at 10 or 85keV at the $2x10^{15}cm^{-2}$. The pre-amorphized layer was recrystallized by solid phase epitaxy at 600°C for 1h in a furnace. Rapid thermal annealing for dopant activation was carried out at the temperature of 950°C or 1000°C for the period ranging from 10 to 105sec. Boron profiles were measured by secondary ion mass spectrometry (SIMS). Junction depth is defined at the background concentration of $1x10^{17}cm^{-3}$. The thickness of the pre-amorphized layer was determined from the drastic redistribution of fluorine contained within the amorphous layer[3,5]. Residual defect layers were observed by transmission electron microscope (TEM). Leakage currents were measured on three kinds of rectangular diodes. We measured about thirty chips for each kind of diode at reverse bias voltages of -5V and obtained the average leakage current. Area leakage current density was determined from three leakage currents with a least squares method assuming that measured leakage current is composed of area and

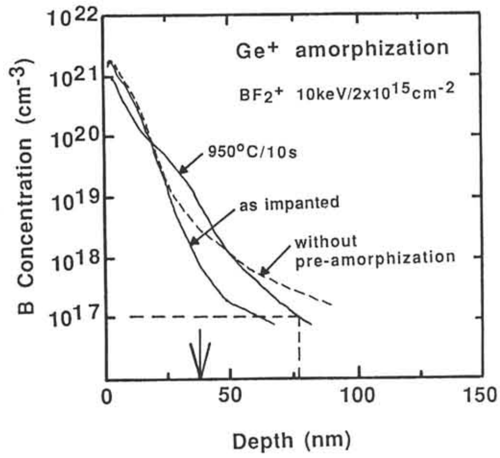

Fig.1 B profiles for pre-amorphized and crystal samples. The arrow indicates the a/c interface position.

perimeter parts.

3. RESULTS AND DISCUSSION

(1) Comparison of Ge^+ pre-amorphization with Si^+

Figure 1 shows Boron profile for pre-amorphized layer thickness xa=40nm case. As shown, channeling of B from BF_2^+ implanted at 10keV is eliminated and 0.08-µm-deep junction is formed after 950°C/10sec annealing. Figure 2 shows a variation of leakage current density Jl with junction depth, xj, together with data from the previous study[4]. Leakage current for xa=40nm case dose not increase so drastically compared with xa=220nm. As can be seen, 0.08-µm-deep p^+/n junction whose leakage current is less than $1x10^{-8}$ A/cm^2 is fabricated with 40-nm-thick amorphous layer formed by Ge^+ implantation.

To be compared for various pre-amorphization conditions, Jl are replotted as a function of a distance between amorphous/crystal interface (a/c interface) and junction, xj-xa, in fig. 3[4,6]. Si^+ data from the previous study[3] are also shown. There is an apparent difference in xj-xa dependence of Jl for different thickness of pre-amorphized layer, xa, in these Ge^+ cases as well as in the previous Si^+ cases[3]. The distance xj-xa, where leakage current is equal to $1x10^{-8}$ A/cm^2 (refereed as xj-xa(Jl=$1x10^{-8}$ A/cm^2) in the following), is less than 40nm for Ge^+(xa=40nm) case and 70nm for Si^+(xa=50nm), that is, Ge^+ pre-amorphization can form p^+/n junction shallower than Si^+ by 30nm (=70-40). An advantage of Ge^+ pre-amorphization over Si^+ for forming a shallow junction is confirmed in this xa=40nm case as well as in the previous xa=90nm case[4].

These difference in xj-xa dependence for various pre-amorphization condition can be explained by differences of defect layer and depletion layer thicknesses. Figure 4 shows cross-sectional TEM images for Si^+(xa=50nm) and Ge^+(xa=220nm) samples after 1000°C/15sec annealing. The defect spreads from a/c interface in the range of 50nm for Si^+ case and 80nm for Ge^+ case. On the other hand, the thickness of depletion layer on the side of p^+, which is determined from B profile, is 30nm for the Si^+ case and 50nm for the Ge^+ case. These results explain that xj-xa(Jl=$1x10^{-8}$ A/cm^2) is 70nm for the Si^+ case and 120nm for the Ge^+ case shown in fig. 3.

(2) Modeling of leakage mechanism

We will propose a model for leakage mechanism which quantitatively explains the above-mentioned dependences of leakage current on pre-amorphization conditions. The mechanism of leakage induced by pre-

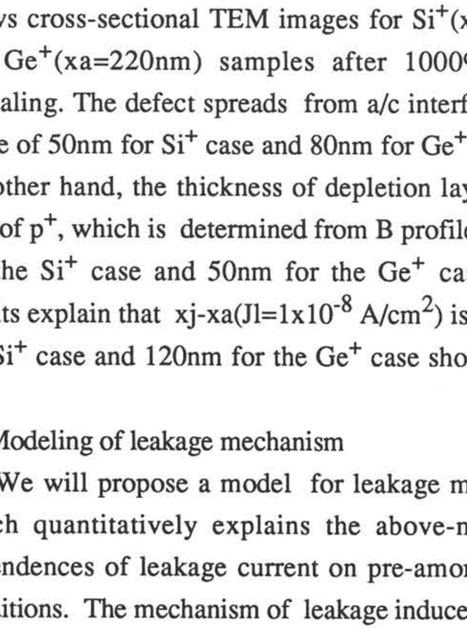

Fig.2 Variation of leakage current density for Ge^+ pre-amorphized samples. Closed squares and open squares indicate the present and previous data, respectively. Solid lines indicate $Jl^{model}=C/m\int Nint(x)dx$ for $C/m=2x10^{-19}$.

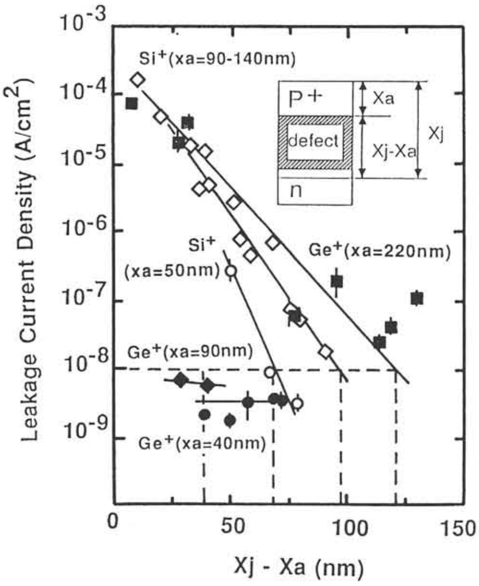

Fig.3 The dependence of leakage current density on the xj-xa for several pre-amorphized layer thickness xa formed by Si^+ and Ge^+ implantations. For Si^+ pre-amorphized samples, xa=50nm (open circles), xa is in the range from 90 to 140nm (open diamonds). For Ge^+ pre-amorphized samples, xa=40nm (closed circles), xa=90nm (closed diamonds) and 220nm (closed squares).

amorphization have been explained as follows: implantation for pre-amorphization induce excess interstitials below a/c interface. During annealing, they redistribute and condense into dislocation loops located underneath a/c interface[7,8]. The dislocation loops have generation centers and increase leakage current[9], when contained in depletion layer. Therefore, to model the leakage mechanism the following assumptions are made:

(i) averaging over a large number of dislocation loops, the depth profile of excess interstitials making up dislocation loops is equal to the profile before being annealed to condense into dislocation loops, $N_{int}(x)$, although interstitials redistribute during annealing. A dislocation loop consists of m interstitials and the average number of dislocation loops contained within a depletion layer, N_{dis}^{depl}, is given by

$N_{dis}^{depl}=1/m \int N_{int}(x)\,dx$.

(ii) a dislocation loop contained in depletion layer induces leakage current of C (A/loop). Using the above-mentioned N_{dis}^{depl}, leakage current is given by

$J_l^{model}=C \times N_{dis}^{depl} = C/m \int N_{int}(x)\,dx$.

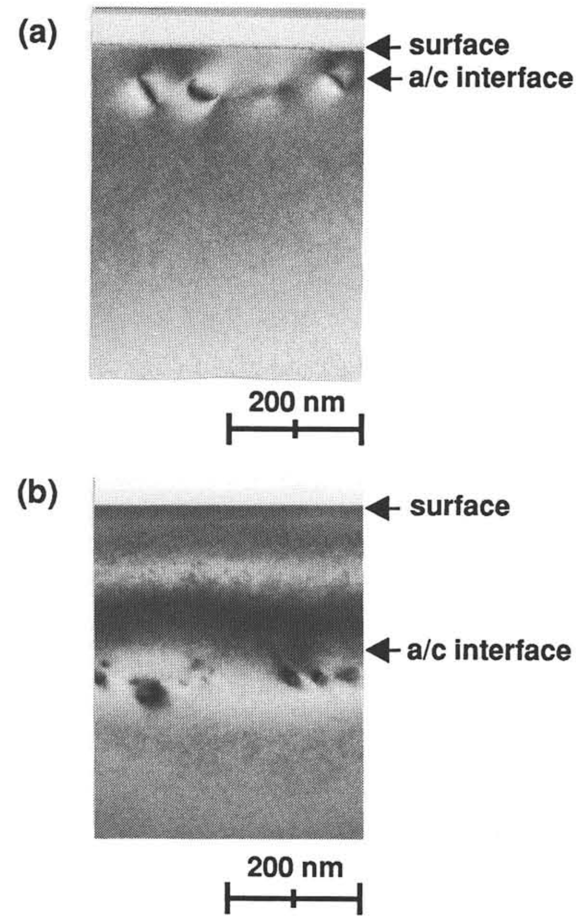

Fig.4 Cross-sectional TEM images for Si^+(xa=50nm) (a) and Ge^+(xa=220nm) (b) samples after 1000°C/15sec annealing.

Here C/m is regarded as a fitting parameter, and N_{int} is approximated by a concentration of Ge or Si implanted for pre-amorphization. These concentrations can well approximate $N_{int}(x)$ within the present experimental accuracy[8]. Solid lines in fig. 2, 5, and 6 indicate J_l^{model} for $C/m=2\times10^{-19}$. As shown, J_l^{model} reproduces all the data, regardless of the thickness of pre-amorphized layer and the kind of ions implanted for pre-amorphization, Ge^+ or Si^+. This good reproduction suggests that the model is reasonable. We have firstly proposed a model for the leakage mechanism which quantitatively explains dependences of leakage current on pre-amorphization conditions. Using this simple model, we can simulate leakage current to optimize pre-amorphization conditions for forming shallow junction with low leakage current.

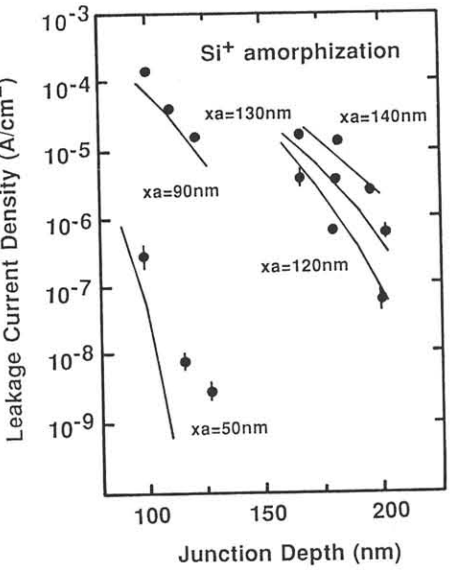

Fig.5 Variation of leakage current density for Si^+ pre-amorphized samples. Solid lines indicate $Jl^{model}=C/m\int Nint(x)dx$ for $C/m=2x10^{-19}$.

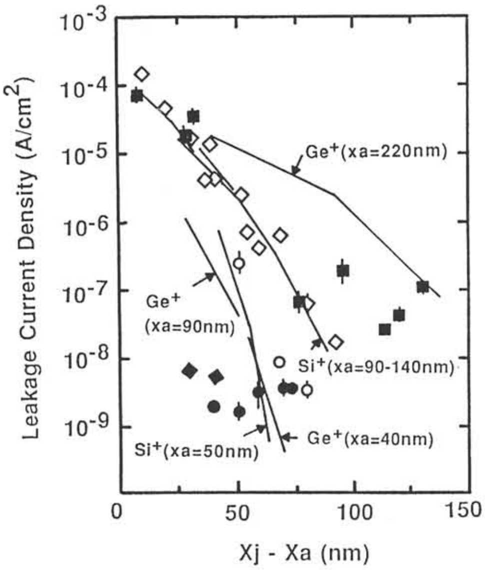

Fig.6 The dependence of leakage current density on the xj-xa for several pre-amorphized layer thickness xa formed by Si^+ and Ge^+ implantations. Solid lines indicate $Jl^{model}=C/m\int Nint(x)dx$ for $C/m=2x10^{-19}$.

4. CONCLUSION

We have developed a model of the leakage induced by pre-amorphization, assuming that the depth profile of excess interstitials making up dislocation loops is equal to the profile before being annealed to condense into dislocation loop. This model well reproduces experimental data. Also We have compared Ge^+ pre-amorphization with Si^+ in detail. An advantage of Ge^+ pre-amorphization over Si^+ is also confirmed in a wider range of conditions than the previous one. 0.08-µm-deep p^+/n junction whose leakage current is less than $1x10^{-8}$ A/cm^2 is fabricated with 40-nm-thick amorphous layer formed by Ge^+ implantation.

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