Optimization of the Amorphous Layer Thickness and the Junction Depth on the Preamorphization Method for Shallow-Junction Formation

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0.1-µm-deep p⁺/n junction was formed by Si⁺ pre-amorphization method. Thickness of pre-amorphized layer and junction depth were optimized systematically. It is found that channeling of 15keV, $2x10^{15}$ cm⁻² dose BF₂⁺ implantation is eliminated by 40-nm-thick pre-amorphized layer, and that junction must be formed 70-90nm deeper than amorphous/crystal (a/c) interface to reduce leakage current density J₁ less than $1x10^{-8}$ A/cm⁻². Furthermore the dependence of J₁ on the distance between junction and a/c interface (x_j - x_a) was investigated in detail. It is confirmed that the pre-amorphized layer thickness influences the behavior of J₁ on x_j - x_a and that thinner pre-amorphized layer forms thinner or lower-defect-density residual defect layer.

1. INTRODUCTION

Pre-amorphization method, which eliminates ion channeling with pre-amorphous layer formed by implantation of heavy ion such as Si⁺, is one of attractive methods for forming shallow p^+/n junction. The major problem of this method is the presence of residual defects formed below original amorphous/crystal interface (a/c interface), which drastically increases junction leakage current when the defects are contained within a depletion layer. Therefore, for forming low leakage shallow junction, pre-amorphous layer thickness x_a must be minimized, thus making defect layer shallow, and junction must be formed at some distance ($x_1 - x_a$) from the a/c interface. However, no systematic optimization of Xa and x_i-x_a has been reported.

In this work, we investigated the dependence of junction leakage current on x_j - x_a in detail and systematically optimized x_a and x_j - x_a for forming 0.1-µm-deep p⁺/n junction. The differences in this x_j - x_a dependence of J₁ for several pre-amorphized layer thicknesses were also investigated.

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 preamorphization, 28 Si⁺ was implanted at the energy ranging from 15 to 66 keV and at the dose of $2x10^{15}$ cm⁻². BF₂⁺ implantation was performed at the energy of 15 or 33 keV and at the dose of $2x10^{15}$ cm⁻². The pre-amorphized layer was recrystallized by solid phase epitaxy at 600° C for 1h in furnace. Rapid



Fig.1 (a)XTEM image before recrystallization (b) F profile before annealing (dotted line) and after annealing (solid line).



Fig.2 The dependence of amorphized layer thickness on Si⁺ implant energy.

thermal annealing for dopant activation was carried out at the temperatures of 950 and 1000° C for the period ranging from 10 to 120sec.

Boron profiles were measured by secondary ion mass spectrometry (SIMS). Junction depth is defined at the background concentration of $1 \times 10^{17} \text{ cm}^{-2}$. The thickness of pre-amorphized layer was measured using the drastic redistribution of fluorine contained within amorphous layer¹⁾. Fig.1 shows an example, where the dotted line represents profile of F implanted at 110keV. $5 \times 10^{13} \text{cm}^{-2}$ dose after pre-amorphization performed by 60, 120 and 180 keV, $1 \times 10^{15} \text{ cm}^{-2}$ dose Si⁺ implantation and the solid line represents F profile after 600°C/1h recrystallization annealing. The crosssectional transmission electron microscopy (XTEM) image before recrystallization is also shown. As shown, F is redistributed drastically during annealing. The redistribution is due to not diffusion but accumulation of F at the a/c interface. because F doesn't almost diffuse at 600°C. Accumulated F moves as the a/c interface moves from the original a/c interface to surface and only F contained within preamorphized layer is swept out¹⁾. As revealed by comparison between the F profiles and the XTEM image, the original a/c interface is correspond to the point indicated by the arrow in Fig.1 and the pre-amorphized layer thickness is defined as the distance between the surface and the a/c interface indicated by the arrow. The accuracy of this method is about 10nm corresponding to SIMS measurement errors. Thicknesses obtained by this method and Rutherford backscattering spectroscopy (RBS)² are shown in Fig.2, which are identical within the accuracy of measurement. All the thicknesses in this work were measured by this method. Leakage current was measured at reverse bias voltages of -5 and -2 V.

3. RESULTS AND DISCUSSION

3.1 FORMATION OF 0.1-µm-DEEP p*/n JUNCTION

Fig.3 shows as-implanted B profiles for four samples having different Si-implant preamorphized layer thicknesses($x_a = 40, 50, 70$ and 90 nm). Channeling of B for BF₂⁺



Fig.3 As implanted B profile for preamorphized and crystal samples. The arrow indicates the positon of the a/c interface.



Fig.4 Annealed B profiles for pre-amorphized samples. The solid and dotted lines represent measuered and calculated profile, respectively.

implanted at 15keV, $2x10^{15}$ cm⁻² dose is eliminated to the same extent for all the pre-amorphized samples. In previous studies by other investigators³⁾, Si⁺ was implanted 40keV, $2x10^{15}$ cm⁻² dose in order to at eliminate the channeling for the ${\rm BF_2}^+$ implantation mentioned above. However, our data reveals that 15keV, 2x10¹⁵cm⁻² dose Si⁺ completely eliminates the implantation channeling. In Fig.4, B profiles after 1000⁰C/10s annealing are shown by solid lines for four pre-amorphized layer thicknesses. They are identical within the accuracy of SIMS measurement. The junction depth, defined at the background concentration of 1×10^{17} cm⁻ 2 , is approximately 0.1 μ m. The present data agrees with that of the normal diffusion model calculations shown in Fig.4 by the dotted line and little enhanced diffusion is observed. Enhanced diffusion in preamorphized Si has been reported in a number of studies $^{4,5)}$, which occurs in a region beyond residual defect layer. In this study, the defect layer is, as mentioned below, formed in the range of 70-90 nm below 40 to 90-nm-deep a/c interface, so that such a enhanced diffusion region is expected to be located more than 0.1µm deep from the surface even in the xa=40nm case. It is consistent with the result in Fig.4



Fig.5 The dependence of leakage current density on the junction depth for several pre-amorphized layer thicknesses.

Fig.5 shows the dependence of the leakage current density J_1 on the junction depth x_j for several pre-amorphized layer thicknesses. J_1 greatly depends on both the junction depth and amorphous layer thickness. As can be seen, 0.1-µm-deep p⁺/n junction whose leakage current is less than $1x10^{-8}$ A/cm² (Vb=-5V) is formed with 40 or 50nm amorphous layer.

3.2 DEPENDENCE OF J1 ON X1 - Xa

We investigated how deeper the junction must be formed than the a/c interface in order to reduce junction leakage current. J1 in Fig.5 is replotted with respect to the junction - a/c interface distance ($x_i - x_a$) in Fig.6, where closed circles are data for x_{a} =40-50nm and closed squares are data for $x_a = 70-90$ nm. Data for $x_a = 120-140$ nm are also shown by open circles(For x_a=120-140nm, Si⁺ implantations were performed through 20nm-thick-oxide film. no influence of oxide film on the x_i-x_a dependence is seen in Fig.7). The reverse bias voltage is -5V. For all the cases J1 decreases exponentially with increasing $x_j - x_a$, and the rate of decrease of J₁ is similar within the accuracy

of measurement. $x_j - x_a$, where leakage current is equal to $1x10^{-8}$ A/cm⁻², is about 70nm for the x_a =40-50nm case and about 90nm for the x_a =70-90nm and x_a =120-140nm cases. Junction must be formed 70-90nm deeper than the a/c



Fig.6 The dependence of leakage current density on the xj-xa for several preamorphized layer thicknesses.



Fig.7 The influence of 20-nm-thick oxide film on the xj-xa dependence.

interface in order to reduce J_1 less than 1×10^{-8} A/cm². The result indicates that residual defects distribute in the range of about 70-90nm below the a/c interface, which is consistent with the XTEM observation in which defect layer thickness ranges from several tens to a hundred of nanometers⁶.

Finally we will discuss the apparent difference between the x_a =40-50nm case and the x_a =120-140nm case. A difference in the $x_1 - x_a$ dependence of J_1 reflect a difference in quality of a defect layer. The present difference indicates that the defect layer for the x_{A} =40-50nm case is thinner or lower in defect density than one for the $x_a=120$ -140nm case. Ajmara et al.⁷⁾ reported similar phenomena for Ge⁺ pre-amorphization. They could not reduce the residual defects formed by 150keV, $9x10^{14}$ cm⁻² dose Ge⁺ preamorphization but could reduce the residual defects which are formed near the surface by 40keV, $2x10^{14}$ cm⁻² dose Ge⁺ preamorphization. They proposed the model that if the pre-amorphized layer were thin and the location of the residual defects were positioned near the surface, where the concentration of interstitials is reduced below the equilibrium value, then the dislocation loops composed of interstitials would be removed. We have not taken any XTEM photograph to confirm the reduction of

defects, therefore it is not certain that defects induced by Si⁺ pre-amorphization are reduced in the same way observed in Ge⁺ preamorphization. However, it is certain that thinner amorphous layer gives lower leakage current and that this phenomenon is concerned with some reduction of defects inducing leakage current.

4. CONCLUSION

We have shown that $0.1-\mu m$ -deep p⁺/n junction with low leakage current is formed with 40-nm-thick pre-amorphized layer. Detailed studies on the dependence of J_1 on the x_j-x_a have shown that junction must be formed 70-90nm deeper than a/c interface. Difference in the x_j-x_a dependence for different pre-amorphized layer thicknesses is observed, which indicates that thinner pre-amorphized layer leaves thinner or lowerdefect-density residual defect layer.

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REFERENCE

- 1) M.Y.Tsai et al.; J.Appl.Phys.<u>50</u>(1979)188.
- 2) S.D.Brotherton et al.; J.Appl.Phys.<u>60</u> (1986)3567.
- 3) M.Miyake et al.; Proc.of VLSI Symp(1987)91.
- S.Solmi et al.; Appl.Phys.Lett.<u>51</u> (1987)331.
- T.O.Sedgwick at al.; J.Appl.Phys.<u>63</u> (1988)1452.
- 6) K.S.Jones et al.; Appl. Phys. <u>A45</u>(1988)1.
- 7) A.C.Ajmera et al.; Appl.Phys.Lett.<u>49</u> (1986)1269.