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Resistance Increase in $CoSi_2$ Layer by Irradiation Induced Damage

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Abstract: Damage induced by ion irradiation in $CoSi_2$ layers on SiO_2 films has been investigated. $CoSi_2$ layers with 25 nm thickness were irradiation with 25 keV Ar^+ ions to a dose of $2\times10^{14}\,cm^{-2}$ with various dose rate. Pulsed irradiation with various duty ratios was also employed. After the irradiation, the change in sheet resistance of the layers was evaluated. The increase in the resistance increased with increasing the dose rate for samples irradiated with dose rates above the critical value of $7.5\times10^{11}\,cm^{-2}\,s^{-1}$ at room temperature. The increase has been discussed on the basis of our proposed model and attributed to the overlapping of cascade zones induced by irradiation with dose rates above the critical value. The result of the pulsed irradiation showed that the incremental sheet resistance decreases with increasing the irradiation temperature, and the relaxation time was estimated at shorter than 200 μs at room temperature. Higher irradiation temperature and lower dose rate than the critical value result in the lower resistivity $CoSi_2$ layers.

Keywords: $CoSi_2$, Irradiation, Relaxation time, Cascade zone, Damage

1. Introduction

The importance of the transition metal silicides in VLSI application is increasing. Especially, cobalt silicide is one of the most attractive silicides due to the chemical and thermal stability and the low resistivity, and thus suitable for the conduction materials in Si based devices. In conventional processing technology, $CoSi_2$ is usually formed by heat treatment at a temperature above 700 °C.$^{1)}$ However, it is difficult to etch $CoSi_2$ by conventional dry processing.$^{1)}$ One candidate for the direct formation method of $CoSi_2$ patterned structures is silicidation induced by ion irradiation of Co/Si stacked layers. Co and Si layers in unirradiated regions can be removed by an appropriate wet etching technique without removing silicide regions formed by irradiation. Using focused ion beams (FIB), $CoSi_2$ structures with deep sub-micron feature sizes can be easily formed without any mask process.$^{2)}$

We have investigated the formation of $CoSi_2$ layers on SiO_2 films by irradiation to the Co/Si stacked layers on SiO_2 films. From the experimental results, it has been found that the resistance of $CoSi_2$ layers increases after the ion irradiation.$^{3)}$ It is speculated that the damage induced by the irradiation increases the resistance of the $CoSi_2$ layers. Although cobalt silicidation has been investigated by many researchers,$^{4),5),6),7),8),9),10)}$ there are few reports on the damages in $CoSi_2$ layers induced by the irradiation.

In the present study, the changes in sheet resistance for $CoSi_2$ layers irradiated with 25 keV Ar^+ ions was investigated. The experimental results are discussed on the basis of the defect relaxation model, and the irradiation conditions to obtain the low resistance $CoSi_2$ layers will be proposed.

2. Experimental Procedure

In the present study, P-doped n-type CZ-Si(100) wafers with 8-12 Ω cm were used. The wafers were cut into the chips about 5×10 mm. These chips were chemically cleaned by the standard RCA procedure. Immediately after the cleaning, the chips were loaded into the oxidation furnace. Dry oxidation was performed at 900 °C for 75 min with O_2 flow rate of 500 sccm. SiO_2 films with 20 nm thickness were formed on the substrates. After the oxidation, the chips were transferred into the molecular beam evaporation chamber equipped with the K-cells. Si and Co were sequentially deposited on SiO_2 films at room temperature in a vacuum below 5×10^{-8} Torr. The Co/Si layer thickness was 7/25 nm, and the deposited Si films were amorphous. The ratio of the layer thickness corresponded to the atomic ratio of Co:Si=1:2.$^{11)}$ The Co/Si samples were heat treated at 700 °C for 20 min to induce the silicidation of Co/Si layers. The heat treatment was performed in the deposition chamber in a vacuum below 5×10^{-7} Torr. This heat treatment converted the deposited Co/Si layers into the $CoSi_2$ phase.$^{2)}$ The samples were irradiated with 25 keV Ar^+ ions

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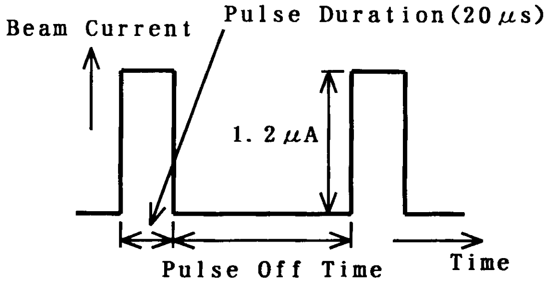

Fig.1 Wave form of pulsed ion beam current.

to a dose of $2\times10^{14}\,\mathrm{cm}^{-2}$ with dose rates between 7.5×10^{10} and $7.5\times10^{12}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ at 24 and 35°C. The pulsed beam irradiation was also carried out by applying the pulsed bias to the blanking electrodes of the ion gun. The wave form of the beam current is depicted in **Fig. 1**. The pulsed irradiation was performed with the pulse duration 20 μs and the off time varing between 0 and 500 μs.

The sheet resistance of the $\mathrm{CoSi_2}$ layers was measured using the Van der Pauw technique.

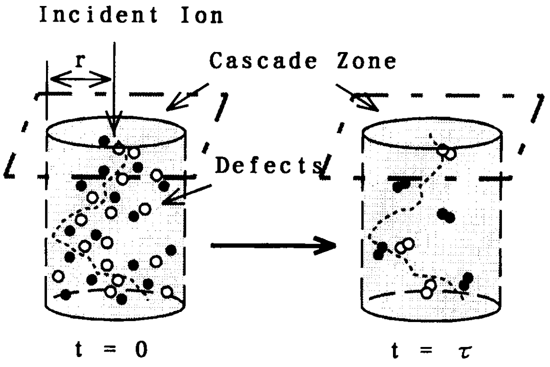

Fig.2 Schematic of relaxation of defects induced by a single ion.

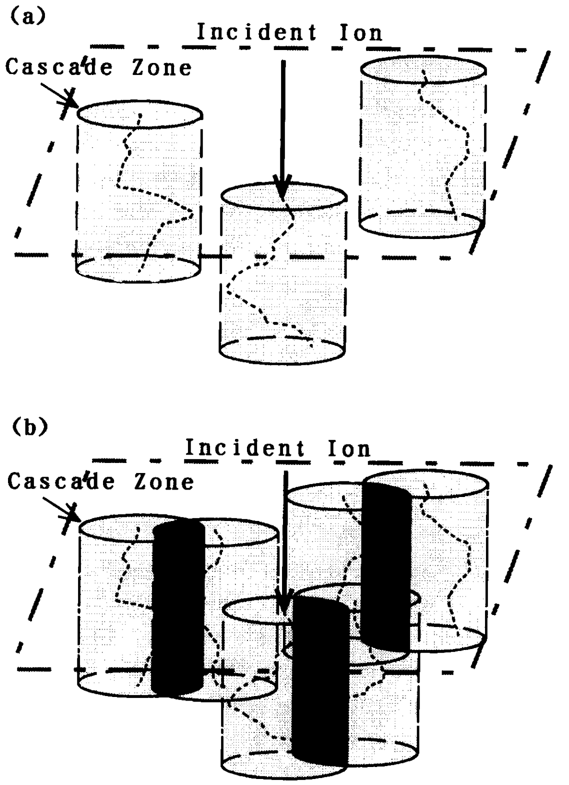

Fig.3 Schematic for dose rate dependence of the defect relaxation.

3. Model of Defect Relaxation

We discuss the model for defect relaxation. **Figure 2** is schematic of the relaxation of defects induced by a single ion. The irradiated ion creates the damaged region with high-density point defects such as vacancies and interstitials around the trajectory. If the point defects are created at a temperature, at which the defects can migrate, they migrate and annihilate or associate to form complex defects such as divacancies and clusters of two or more interstitials. The regions where the annihilation and association proceed can be approximated to cylindrical regions with radius r existing for a period τ. The region and the period are referred as the cascade zone and the relaxation time, respectively, in the present study. After the relaxation time, associated defects remain and form the damaged regions.

The dose rate dependence of the damage can be explained using the defect relaxation model. In the case of the low dose rate irradiation, the cascade zones do not overlap, as shown in **Fig. 3(a)**. The remaining damage corresponds to the sum of the complex defects formed by each irradiated ion. As the dose rate increases, the cascade zones start to overlap, and high-density defect regions are formed by the overlapping, as shown in **Fig. 3(b)**. It can be assumed that the higher defect density results in the formation of the more defects that are stable after the relaxation. Thus, the remaining damage after the relaxation depends on the dose rate.

The remaining stable complex defects act as scattering centers for carriers in the $\mathrm{CoSi_2}$ layers. Thus, the increment value of resistance after the irradiation correlates to the amount of the stable defects formed by the irradiation.

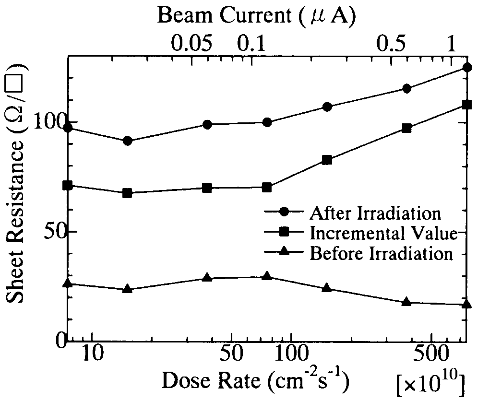

Fig.4 Dose rate dependence of the sheet resistance.

4. Results and Discussion

Figure 4 shows the dose rate dependence of the incremental value of sheet resistance. The resistances before and after the irradiation are also shown. The irradiation was performed at 24°C. Although the resistance for the starting materials slightly varies with samples, the incremental values show a clear trend. Thus, it is expected that the behavior of the cascade zones can be discussed on the basis of the incremental values. The incremental resistance starts to increase at a dose rate of 7.5×10^{11} cm^{-2} s^{-1}, and increases with dose rate above the critical dose rate.

The pulsed irradiation was also performed at 24 and 35 °C in order to estimate the relaxation time τ. **Figure 5** shows the dependence of the incremental sheet resistance on the off time of the pulse. For both samples, the incremental sheet resistance becomes constant at the off time longer than 200 μs. This constant incremental value corresponds to the situation where the cascade zones induced by the pulse irradiation do not overlap with the regions induced by the previous pulse. From these results, it is found that the relaxation time for both temperatures is shorter than 200 μs.

The incremental sheet resistance for the samples irradiated at 35°C is smaller compared with that at 24 °C, and it is suggested that the defects induced by a single pulse decrease more rapidly at a higher temperature. This is due to that the recombination rate of Frenkel-pairs increases, and the stable damages remaining after irradiation decrease with the temperature. Thus, the higher irradiation temperature results in the lower resistivity CoSi$_2$ layers.

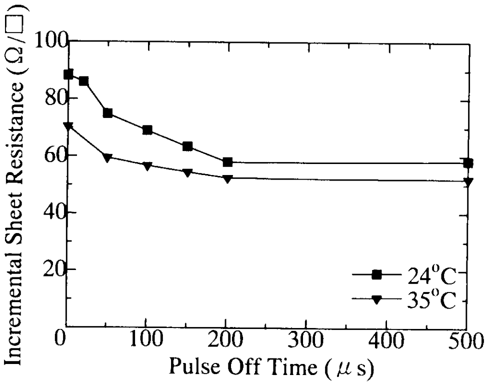

Fig.5 Pulse off time dependence of the incremental value extracted from the increment of sheet resistance.

5. Conclusion

The damage induced by 25 keV Ar$^+$ ion irradiation to a dose of 2×10^{14} cm^{-2} in CoSi$_2$ layers on SiO$_2$ films has been investigated. The result was discussed on the basis of the defect relaxation model.

The incremental value of the sheet resistance increased with the dose rates above the critical dose rate of 7.5×10^{11} cm^{-2} s^{-1}. The result of the pulsed irradiation showed the relaxation time was shorter than 200 μs at room temperature. Higher irradiation temperature and lower dose rate than the critical value result in the lower resistivity CoSi$_2$ layers.

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