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Anomalous Junction Leakage Behavior of Ti-SALICIDE Contacts on Ultra-Shallow Junctions

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An anomalous junction leakage of Ti-SALICIDE contacts were observed on ultra-shallow junctions below 0.1 μm. The leakage current behavior show a large increase for n+/p junctions and a slight decrease for p+/n junctions after annealing at around 460°C. A generation-recombination process cannot explain such an anomalous behavior. From SIMS, TEM, and EDX analyses, the leakage current was attributed to a large amount of Ti diffusion into Si in the early stage of Ti-silicidation.

1. INTRODUCTION

A titanium-self-aligned silicide (Ti-SALICIDE) process has been extensively studied for application to CMOS devices. 1-4) One of the serious problems with the Ti-SALICIDE process is the increase of junction leakage current with decreasing junction depth. 5-8) There are some reports on the leakage mechanism on silicided junctions. Yoshida et al. reported that Ti diffusion induced by a high electric field on α-Ti-Si contact degraded junction characteristics. 9) Kojima et al. reported that Ti-related electron traps were detected in Si after silicidation by DLTS measurements. 10) In this paper, we report the anomalous junction leakage behavior of Ti-SALICIDE contacts on ultra-shallow junctions below 0.1 μm. We found that the leakage current for n+/p junctions increased after annealing at around 460°C. On the other hand, it slightly decreased for p+/n junctions under the same conditions. From further investigations by SIMS, TEM, and EDX analyses, we confirmed that such anomalous behavior was attributed to a large amount of Ti diffusion into Si in the early stage of Ti-silicidation. The peak concentration of Ti in Si was approximately 1×10^{19} cm^{-3}. These phenomena have significant influence on the reliability of high-performance devices.

2. EXPERIMENTAL

On n- and p-type Si(100) wafers, As^+ ($1\times10^{14}cm^{-2}$ at 15-45 keV) and BF_2^+ (1×10^{14} cm^{-2} at 10-45 keV) were implanted to form an n^+ and a p^+ diffusion layers, respectively. The wafers were followed by rapid thermal annealing in N_2 atmosphere at 900°C for 30 sec. The junction depth was 0.05-0.15 μm for n^+-Si and 0.05-0.2 μm for p^+-Si. Prior to Ti deposition, the Si wafers were dipped into a dilute HF solution (H_2O:HF=200:1), and rinsed using DI water with an O_2 concentration below 10 ppb. The wafers were dried in an N_2 atmosphere, and no native oxide was detected on the Si surface by XPS analysis. Ti layer was deposited by DC magnetron sputtering to a thickness of 10-100 nm. These samples were annealed at 300-600°C in an Ar atmosphere for 30-180 min. The distribution of Ti diffused into the Si substrate was measured by SIMS and TEM. Prior to the SIMS analysis, the Ti layer and its chemical compounds were chemically removed, and no Ti residue was detected by XPS.

3. RESULTS AND DISCUSSION

Figures 1 (a) and (b) show the annealing temperature dependence of junction leakage current for an n^+/p junction and a p^+/n junction, respectively. These samples were annealed at 300-600°C for 30 min. Applied reverse bias (Vr) for the leakage current measurement was 1V. For the n^+/p junction, shown in figure 1 (a), the leakage current increased rapidly above 300°C and showed a clear peak at around 460°C. The maximum level of the leakage current is sixth-order higher than that of as-deposited sample. On the other hand, for the p^+/n junction, shown in figure 1 (b), the leakage current slightly decreased above 300°C and reached to a bottom at around 460°C. The minimum level the leakage current is second-order lower than that of as-deposited sample.

Figure 2 shows the annealing temperature dependence of Ti diffusion in the Si substrate obtained by SIMS. The amount of Ti also showed a clear peak at around 460°C. The peak concentration of Ti was estimated to be approximately 1×10^{19} cm^{-3}. Although Si is reported to be a dominant moving species during silicidation, 11) these data indicate that a large amount of Ti diffused into Si in the early stage of the Ti/Si reaction, especially at around 460°C, which induced an n^+/p junction degradation.

To investigate the leakage mechanism, temperature dependence of the leakage current was obtained. Figures 3 (a) and (b) show the arrhenius plots of the leakage current at Vr = 1 V as a function of annealing temperature for an n$^+$/p junction and a p$^+$/n junction, respectively.

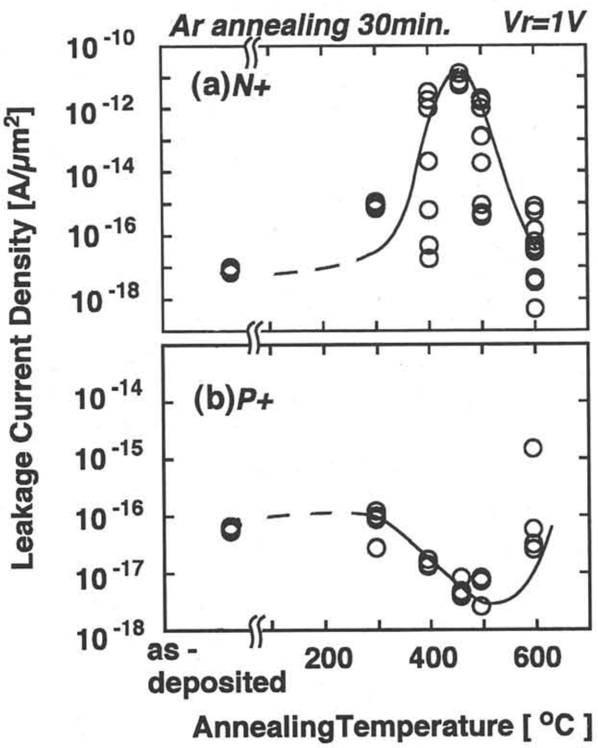

Fig. 1. Temperature dependence of leakage current density (a) for an n$^+$/p junction, (b) for a p$^+$/n junction.

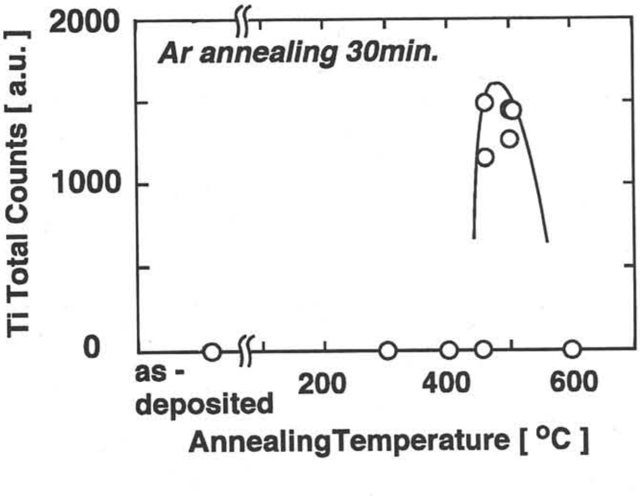

Fig. 2. Temperature dependence of Ti diffusion into Si analyzed by SIMS.

For the n$^+$/p junction, shown in figure 3 (a), the activation energy for the as-deposited sample and the annealed sample at 600°C were 0.92 eV, and 0.77 eV respectively. Compared to these results, the leakage current for the sample annealed at 460°C slightly depended on the temperature, and the activation energy was only 0.16 eV.

For the p$^+$/ n junction, shown in figure 3 (b), all samples had almost the same activation energy ranged from 0.86 eV to 0.97eV.

Above results indicate that the leakage mechanism for n$^+$/p junctions is different from that for p$^+$/n junctions. And an anomalous behavior at around 460°C cannot be explained by the generation-recombination process. [12] To explain these behavior consistently, we considered that an additional region with highly concentrated acceptors was formed near the n$^+$/p-Si and the p$^+$/n-Si interface by 460°C annealing.

Such a region might behave like a p$^+$-Si region, and form a n$^+$/ p$^+$/p-Si structure in the n$^+$/p junction. Current flow is dominated by a tunneling process through this additional p$^+$-region, showing a small activation energy. On the other hand, the additional region would form a p$^+$/ p$^+$/n-Si structure in the p$^+$/n junction, and the current flow is dominated by the generation-recombination and diffusion processes.

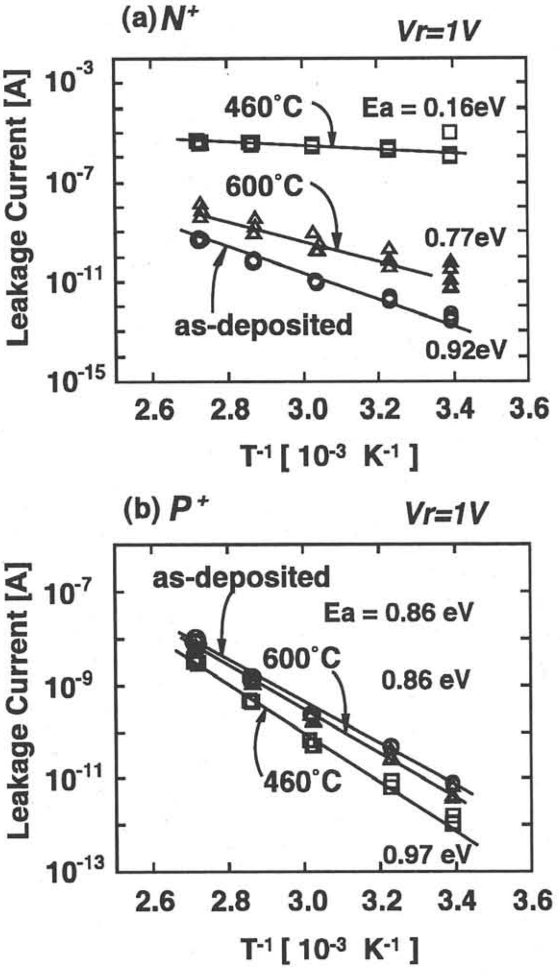

Fig. 3. Arrhenius plots of junction leakage current at Vr = 1 V (a) for an n+/ p junction, (b) for a p+/ n junction for the samples without annealing (as-deposited) (○) and annealed at 460°C (□),and 600°C (△).

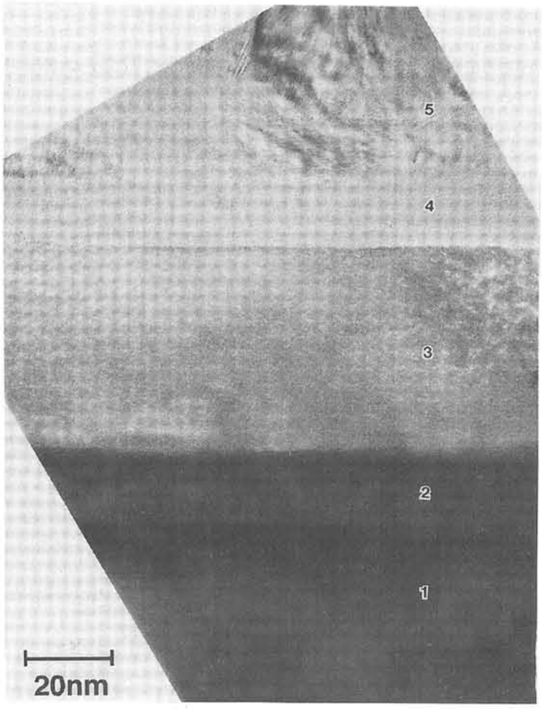

Fig. 4. Cross-sectional HRTEM photograph around the Ti/Si interface annealed at 460°C for 30 min.

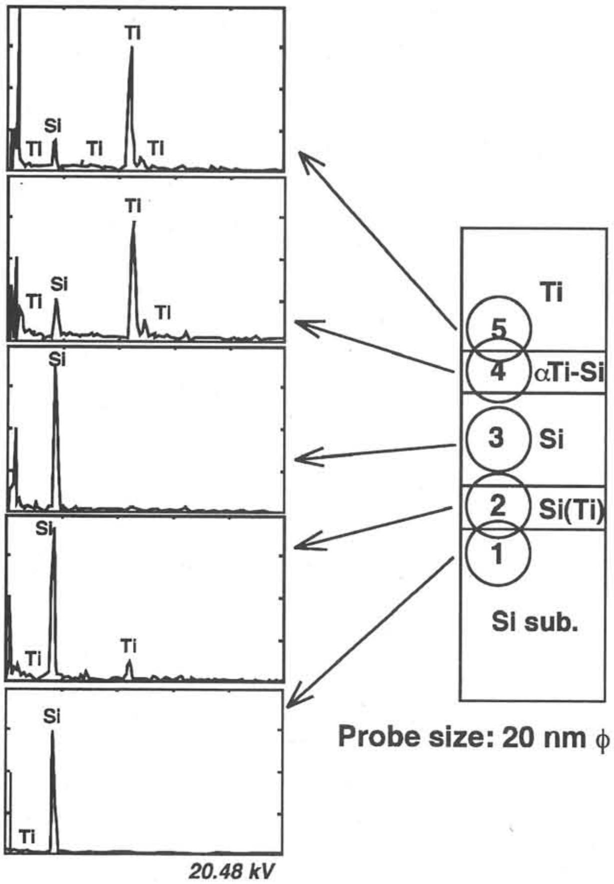

Fig. 5. EDX spectra around the Ti/Si interface for the sample annealed at 460°C for 30 min.

Figure 4 shows a cross-sectional HRTEM photograph near the Ti/Si interface for the sample annealed at 460°C. The numbers in the figure indicate the points analyzed by EDX. Points 5 and 4 are located in a Ti layer and in an α-Ti-Si layer, respectively. From the EDX spectra, shown in Figure 5, highly concentrated Ti was detected in the Si substrate at point 2. The lattice continuity of Si from region 1 to region 3 was confirmed. The Ti concentration was estimated to be approximately above 1×10^{19} cm^{-3}. We consider that such a Ti concentrated region in Si will form the additional p^{+}-region.

4. CONCLUSIONS

We found an anomalous junction leakage of Ti-SALICIDE contacts on ultra-shallow n^{+}/p and p^{+}/n junctions. The leakage behavior cannot be explained by a simple generation-recombination process. From TEM and SIMS analyses, these leakage were attributed to the Ti diffusion at low temperatures before silicidation. The Ti diffusion is highly depended on the annealing temperature. These phenomena will degrade the junction reliability of high-performance devices.

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