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Selective CVD-Al Contact Plug on Rapid Thermal Processed $TiSi_2$ in NH_3 for High Speed CMOS Using Salicide Process

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Selective CVD-Al contact plug formation on titanium silicided diffusion region is successfully demonstrated for the first time. In order to realize thermally stable contact with shallow junction, a direct nitridation of $TiSi_2$ layer by rapid thermal annealing in NH_3 ambient is carried out to be self-aliged to the contact region.The formation of the N-rich layer and it's thickness are confirmed by AES analysis. Diffusion of aluminum through the $TiSi_2$ layer into the Si substrate is found to be completely prevented by the nitridation of the $TiSi_2$ layer, resulting in low leakage current of reverse biased p-n junction. In addition to this, selectivity is also improved by the rapid thermal annealing in NH_3 ambient. Therefore, this new technique is very attractive for contact plug formation of high performance CMOS using salicide process.

1.Introduction

In multilevel interconnection technologies for ULSI, contact /via filling technique using chemical vapor deposition (CVD) becomes essential. For a contact hole filling, blanket CVD-W/etchback process is widely used. However, it become difficult to form blanket CVD-W plug in the contact hole with sputter deposited TiN/Ti adhesion layer whose coverage of the sidewalls of contact holes limits the aspect ratio of holes that can be filled. Therefore, selective CVD-W and CVD-Al formation on Si substrate have been investigated as promising contact filling processes(1,2). Serious problems of these techniques are thought to be a erosion of Si substrate and selective loss(1). Especially in a case of direct Al-Si contacts, electrical problems like junction leakage and high contact resistance limit its application. On the other hand, selective W or Al growth on silicide, required for high speed CMOS using salicide process, seems to be more possible due to the barrier property of $TiSi_2$ layer(3). However, in sputter deposited Al/$TiSi_2$/Si and CVD-W/$TiSi_2$/Si contact system with very shallow junction , $TiSi_2$ is reported to be insufficient as a barrier film(4,5). Considering the selective contact plug formation, self-alined formation of barrier metal at contact region is required. Recently selective CVD-W plug formation on a self-aligned nitridation of $TiSi_2$ was demonstrated(6).

This paper describes selective CVD-Al contact plug formation on $TiSi_2$ layer. In order to realize thermally stable contact structure with shallow junction, a direct nitridation of $TiSi_2$ by rapid thermal annealing in NH_3 ambient was performed to be self-aligned to the contact region. The diffusion barrier integrity of the $TiSi_2$ /TiN bilayer and its thermal stability were evaluated.

2.Experimental

Figures 1 (a)-1(d) show the key process flow for fabricating this novel self-aligned $TiSi_2$/TiN contact with selective CVD-Al contact plug. The $TiSi_2$ layer was formed on N+/P+ islands by conventional salicide process. Then dielectric layer was deposited. After contact patterning, contact holes were dry etched through to the $TiSi_2$ layer (a). Diameter of contact hole were varied from 0.4 to 1.0 μm. Then, thin surface layer of $TiSi_2$ was then converted to a $TiSi_2$/TiN bilayer by rapid thermal annealing in NH_3 ambient at 50 torr (RTN) (b).

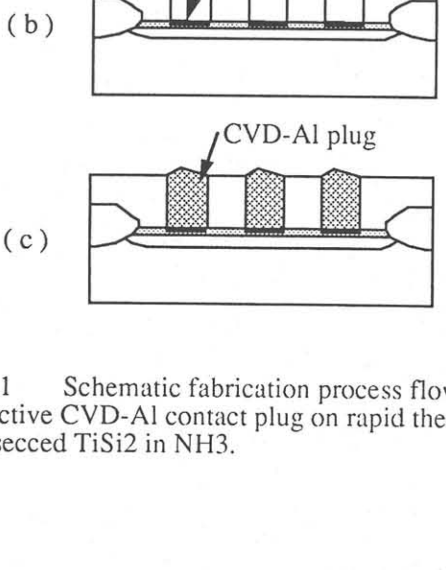

Fig.1 Schematic fabrication process flow of selective CVD-Al contact plug on rapid thermal prosecced $TiSi_2$ in NH_3.

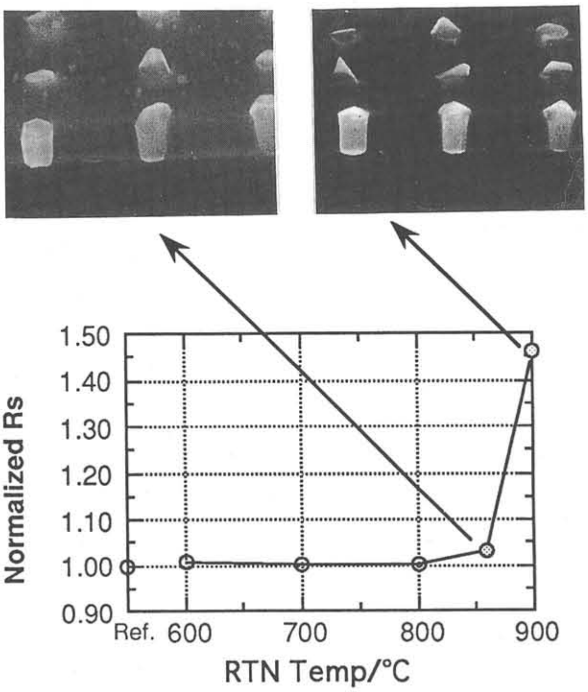

Fig.2 Normalized sheet resistance of TiSi2 film as a function of RTN temperature in NH3 for 20 sec and cross sectional SEM micrographs for a fabricated Al contact on the TiSi2 layer rapid thermal processed in NH3 at 865 °C and 900°C for 20 sec.

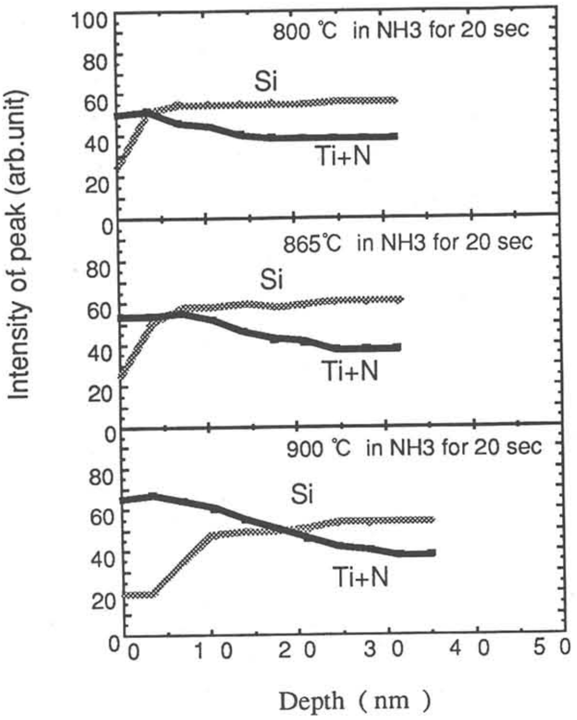

Fig.3 Dependence of AES in-depth profiles for Ti+N and Si on process temperature of rapid thermal nitridation in NH3.

Annealing temperature, annealing time were varied between 600 and 900°C and between 20 to 60 s respectively. After that, CVD-Al contact plug was formed selectively on the TiSi2/TiN bilayer (c). The deposition condition is as follow. The substrate temperature were varied from 210 to 260°C. The deposition pressure was kept at 2.0 torr. DMAH (Dimethyl Aluminum Hydride) was vaporized at room temperature and transported to the CVD reactor with H_2 gas of 100 sccm. Then the upper Al-Cu layer was sputter deposited and patterned.

Filling characteristics and selective loss was estimated by SEM observations. Elemental depth profiling of TiSix layer pretreated by the RTN process was analyzed using AES for identification of the TiN phase and it's thickness. Diffusion barrier integrity against Al diffusion was evaluated by SIMS depth profile of Ti, Si and Al in the TiSi2/Si layer and junction leakage current of p+n and n+p junctions after alloying. The junctions have an area of 200 μm x 200 μm and contain 2500 parallel contacts of 0.6 μm size. Junction depth of n+p and p+n junction was 0.2 and 0.25 μm respectively.

3.Results and Discussion

Figure 2 shows the change of sheet resistance (Rs) of TiSi2 layer as a function of the nitridation temperature and duration. The Rs remains constant at nitridation temperature up to 800°C. The increase of Rs at the nitridation temperature higher than 865°C is corresponding to the nitridation of the TiSi2 because the resistivity of the TiN is higher than that of the TiSi2. The thickness of TiN layer was estimated to be more than 10 nm (at 900°C for 20 sec) by the change of Rs. Nitraidation of the TiSi2 layer at 900°C for 20 sec on N+/P+ diffused region was achieved without causing agglomeration of the TiSi2 layer. Cross sectional SEM photographs of CVD-Al contact plugs selectively formed on the self-alined TiSi2/TiN bilayer in contact holes of 0.5 μm diameter. Favorable selective growth from the bottom of contact hole was obtained. It is noted that the rapid thermal annealing in NH3 ambient can prevent any CVD-Al nucleation on the surface of dielectric layer and undesirable growth from the inner side of contact hole. Figure 3 shows Auger in-depth profiles for the TiSi2 layer treated by the RTN for 30 sec at 800, 865 and 900 °C respectively. As can be seen from these profiles, the thickness of N-rich phase increases as temperature increases, which is approximately 4 nm ,7 nm and 17 nm for the samples processed at 800, 865 and 900°C for 30 sec respectively. The diffusion barrier integrity of CVD-Al/TiSi2/Si structure (sample (a)) and CVD-Al/TiN/TiSi2/Si structure (sample (b)) were evaluated SIMS depth analysis. The TiN layer was formed by nitridation of TiSi2 layer at 900 °C for 30 sec were investigated Figure 4 shows the SIMS depth profiles for sample (a) and (b) after annealing for 60 min at 450°C in forming gas. The Al layer and the TiN layer were removed in each sample before the measurements. In the sample (a), pilling up of aluminum was observed at the interface between the TiSi2 and Si substrate and a little amount of aluminum over detection limit was detected in the Si substrate. However, in the sample (b), an amount of aluminum in the Si substrate was below detection limit. Therefore, these results suggests that the aluminum easily diffuse through grain boundaries of TiSi2 layer, pile up at the interface between TiSi2 and Si substrate and then diffuse into Si substrate gradually from the TiSi2/Si interface. However, nitridation of the TiSi2 surface prevent the diffusion of aluminum through the grain boundaries of the TiSi2 layer. Figure 5 shows the leakage current of the reverse biased n+/p, p+/n junction at 7 V for Al/TiSi2/Si and Al/TiN/TiSi2/Si contact system after annealing at 400 °C for 30 min in hydrogen ambient. Nitridation of the TiSi2 was carried out at 865 °C and 900 °C for 30 sec. As shown in fig.6, leakage current in the Al/TiN/TiSi2/Si contact system was sufficient low. However, large leakage current was observed in the Al/TiSi2/Si contact system. From these results, thin TiN layer of which thickness is approximately 7 nm is found to act as a an effective diffusion barrier between CVD-Al and Si even after annealing. These results suggest that the nitridation of the surface of grain boundary is effective for suppressing diffusion of aluminum through the TiSi2 layer into the Si substrate.

4.Conclusion

Selective CVD-Al contact plug formation on titanium silicided diffusion region is successfully demonstrated for the first time. The key process is a nitraidation of the surface of TiSi2 layer by rapid thermal processing in NH3 ambient before CVD-Al plug formation. Selectivity and the barrier property were remarkably improved by the rapid thermal nitridation in NH3. Thus, this process is very promising for contact plug formation of high performance CMOS using salicide process.

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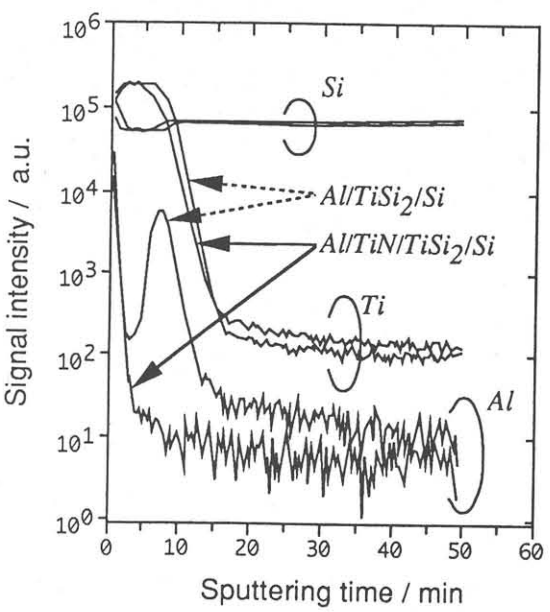

Fig.4 SIMS depth profiles for Si, Ti, and Al of Al/TiSi2/Si and Al/TiN/TiSi2/Si structures after annealing (450 °C, 60 min) and removing the Al and the TiN layers.

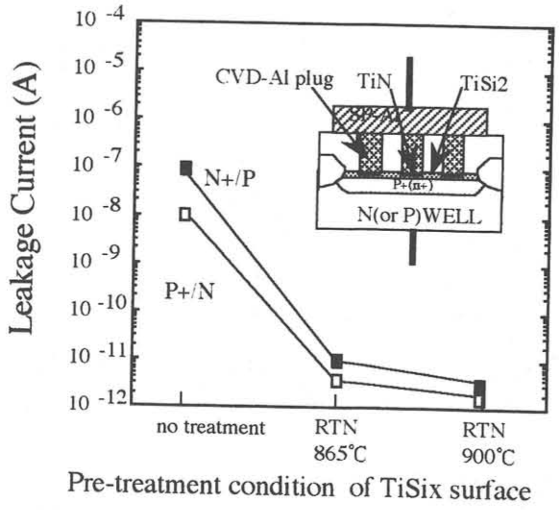

Fig.5 Junction leakage current for 2.5x10^3 parallel contacts of 0.6 μm contact size at 7V of P+/N and N+/P diode as a function of pre-treatment condition.