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A Highly Reliable Interconnection with Collimated Sputtering of Barrier Layer and High Temperature Sputtering of Al Alloy on Silicide Junction

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A highly reliable interconnection with collimated sputtering of Ti and TiN layers, and high temperature sputtering of Al-Si-Cu on silicide junction ($TiSi_2$) has been developed. Complete filling of 0.3μm diameter contacts with no alloy spike, drastically lower contact resistances and small variations in contact resistance compared with conventional case have been achieved. The average contact resistances of 0.35μm diameter contact for n^+ and p^+ were 32 and 17Ω, respectively. High EM resistance on this conductor has been realized.

1. INTRODUCTION

For increasing the packing density in ULSIs, both fine pattern technologies and three-dimensional approaches, such as stacked capacitor and multilevel interconnection technologies, are being pursued. In addition, highly reliable interconnection and contact filling technologies are becoming increasingly important for ULSI, since conventional sputtering processes have serious problems related to their reliability such as electromigration (EM), stressmigration and contact-migration attributed to their film property and poor step coverage. Recently, a high temperature Al sputter deposition has been proposed as a contact filling technology (1)-(2). This is the most simple and replacable technology in terms of material reliability. However, there are some problems such as alloy spikes and incomplete filling on subhalf-micron diameter contact holes in this technology. In order to improve the Al alloy filling characteristics and contact resistance, we employed collimated-sputtered Ti and TiN(3) that improved the step and bottom coverage for the barrier layers. Collimated sputtering and high temperature sputtering realized extremely low contact resistance and the complete filling of contact holes with 0.3μm diameter in Al alloy/Ti/TiN/Ti contact structure on silicide junction ($TiSi_2$). Highly reliable interconnections were achieved by these technologies.

2. EXPERIMENT

In this experiment, Al-Si-Cu and Ti were deposited by a multi-chamber type DC magnetron sputtering system with Al-1%Si-0.5%Cu and pure Ti targets. Ar pressure in Al-Si-Cu and Ti deposition were 2.0mTorr and 1.3mTorr, respectively. The TiN layer was formed by reactive sputtering using N_2 / Ar (60% N_2) mixed gases, and a 50nm $TiSi_2$ layer was formed by the AAS (n^+) and BAS (p^+) ($^{75}\underline{A}s^+$ or $^{11}\underline{B}^+$ doped into the silicide layer after silicidation)(4) processes using the Ti layer with 50nm thickness and two step rapid thermal annealing (RTA) in a N_2 atmosphere. The deposition of Ti and TiN were then preformed at a substrate temperature of 200°C employing a collimator with an aspect ratio of 1:1.

After contact hole definition in the dielectric with a 0.6μm thickness, an Ar back sputter etch and metallization were performed. Ti(20nm)/TiN(100nm)/Ti(50nm) barrier layers and 0.6μm Al-Si-Cu layer were sequentially sputter-deposited without exposing in air. The Al-Si-Cu deposition for high temperature sputtering was performed at the temperature range from 450°C to 550°C. After photolithography, these conductor patterns were delineated by ECR plasma etching, and then annealed at 420°C.

Contacts filling characteristics and grain structures of films were observed by scanning electron microscopy (SEM) and transmission electron microscopy (TEM). The contact resistances were measured using the Kelvin method. The EM life tests were carried out with 2000μm length at constant current density and temperature.

3. RESULTS and DISCUSSION

Figure 1 shows the cross-sectional SEM images of contact holes, giving Al-Si-Cu filling characteristics on collimated-sputtered (Colli.)Ti/TiN/Ti and conventional sputtered (Conv.) Ti/TiN/Ti. For the Colli.-Ti/TiN/Ti, the contact holes with 0.3μm diameter were completely filled with Al-Si-Cu. On the other hand, voids were observed in the holes for the Conv.-Ti/TiN/Ti. Collimated sputtering thus improved Al-Si-Cu filling characteristics because of the good step coverage of Ti and TiN, which has good wetting characteristics with Al alloy(5). However, alloy spikes were observed in the bottoms of the contact holes. It is considered that diffusion of Al to Si junction through Ti/TiN/Ti layers generated these spikes during high temperature sputtering. Figure 2 shows the cross-sectional SEM images of contact holes with collimated sputtering of Ti/TiN/Ti and high temperature sputtering of Al-Si-Cu at 500°C on silicide junction ($TiSi_2$), showing good filling characteristics and no alloy spike. In this contact structure, $TiSi_2$ film thicknesses are always uniform regardless of the contact hole diameter. In addition the $TiSi_2$ film plays two important roles to protect the diffusion of Al and Si and to lower contact resistance.

Figure 3 show the histograms of contact resistances in high-temperature-sputtered (H.T.) Al-Si-Cu/Colli.-Ti/TiN/Ti structure on silicide junction ($TiSi_2$) and the Conv.-Al-Si-Cu/TiN/Ti structure. It was confirmed that the variations in contact resistance are significantly reduced by H.T.-Al-Si-Cu/Colli.-Ti/TiN/Ti/$TiSi_2$. It can be considered that these variations are negligibly small compared with the total resistance of a MOS device. Table 1 shows the contact property of holes with 0.35μm diameter in H.T.-Al-Si-Cu/Colli.-Ti/TiN/Ti structure on silicide junction ($TiSi_2$) and the Conv.-Al-Si-Cu/TiN/Ti structure. In the former, contact resistances drastically lower than the conventional case by one order of magnitude were achieved for both n^+ and p^+. The average contact resistances of 0.35μm diameter contact for n^+ and p^+ were 32 and 17Ω, respectively. The leakage current with these contacts for n^+/p and p^+/n silicide junction were the same level as the conventional Si junction with conventional contacts. These contact characteristics indicate the thermal stability of this structure.

The Weibulle plots of the time-to-failure results on the EM life test for conductors are shown in Figure 4. These data were gathered by stressing EM test stripes at 1.5×10^7 A/cm^2 (in the Al-alloy layer) at 300 °C. The median time-to-failure (MTF) of H.T.-Al-Si-Cu/Colli.-Ti/TiN/Ti conductors were the same level as the Conv.-Al-Si-Cu/TiN/Ti conductors and the variations of time-to-failure of H.T.-Al-Si-Cu/Colli.-Ti/TiN/Ti conductors were smaller than the Conv.-Al-Si-Cu/TiN/Ti conductors. Figure 5 show SEM surface images of Al-Si-Cu films on SiO_2. It was clear that H.T.-Al-Si-Cu films have large grains. Figure 6 shows the dependence of average grain size of Al-Si-Cu on the sputtering temperature for under-layer of SiO_2, TiN and Ti/TiN. Grains of Al-Si-Cu on TiN were much smaller than a mono-layer Al-Si-Cu and those of Al-Si-Cu on Ti/TiN/Ti were the smallest. Grains of H.T.-Al-Si-Cu on Ti/TiN/Ti layers were larger than the Conv.-Al-Si-Cu on TiN/Ti layers. Because of the complete bamboo structure, the time-to-10% failure of the H.T.-Al-Si-Cu/Colli.-Ti/TiN/Ti conductors was longer than the Conv.-Al-Si-Cu/TiN/Ti conductors.

4. CONCLUSION

We have demonstrated a thermally stable and low resistance subhalf-micron contact with collimated sputtering of TiN/Ti barrier layers and high temperature sputtering of Al-Si-Cu on silicide junction.

We found that collimated sputtering of Ti and TiN layer improved Al-Si-Cu filling characteristics because of the good step coverage. H.T.-Al-Si-Cu/Colli.-Ti/TiN/Ti structure on silicide junction achieved complete filling of 0.3μm diameter contacts with no alloy spike, drastically lower contact resistances and small variations in contact resistance compared with the conventional case. The average contact resistances of 0.35μm diameter contact for n^+ and p^+ were 32 and 17Ω, respectively. The leakage current with these contacts for n^+/p and p^+/n silicide junctions were the same level as the conventional Si junctions with conventional contacts. Grains of H.T.-Al-Si-Cu on Ti/TiN/Ti layers were larger than the Conv.-Al-Si-Cu on TiN/Ti layers and high EM resistances on this conductor have been realized.

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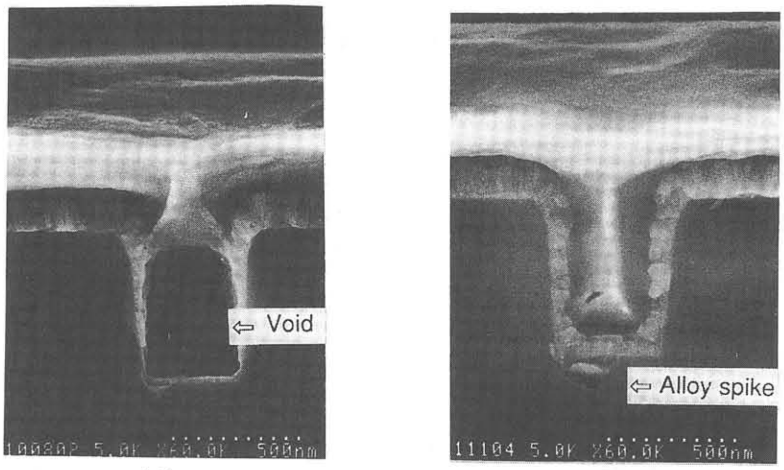


(a) (b)

Fig.1 SEM cross-sectional images of contact holes filled with Al-Si-Cu
(a) on conventional sputtered Ti/TiN/Ti
(b) on collimated sputtered Ti/TiN/Ti

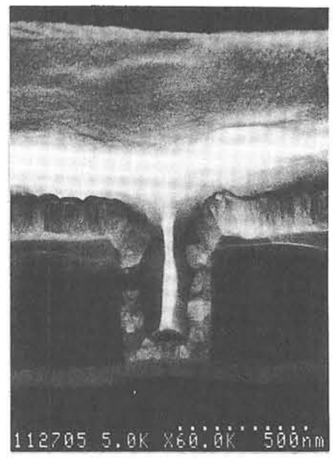


Fig.2 SEM cross-sectional image of contact hole on $TiSi_2$

Table1 The contact characteristics on $n^+$and p^+layers

		Contact Resistance (Ω)	Leakage Current (pA)@5V
n^+/p	High Temp.Al/Ti/TiN/Ti/$TiSi_2$	32	16
	Conv.Al/TiN/Ti/Si	160	15
p^+/n	High Temp.Al/Ti/TiN/Ti/$TiSi_2$	17	3
	Conv.Al/TiN/Ti/Si	251	3

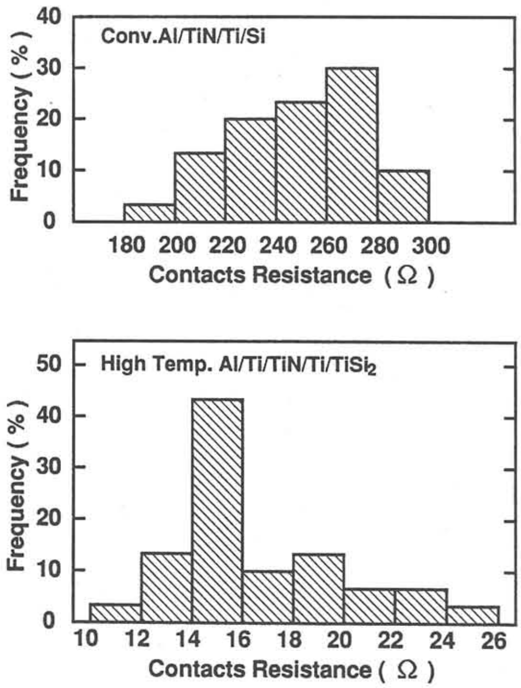


Fig.3 Histograms for the contact resistance of 0.35μm contacts

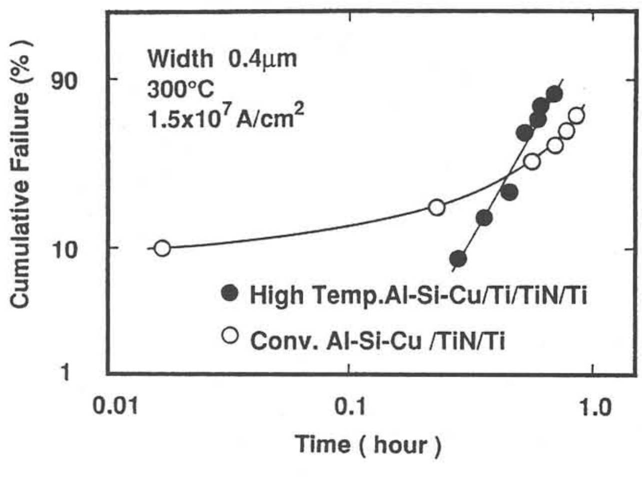
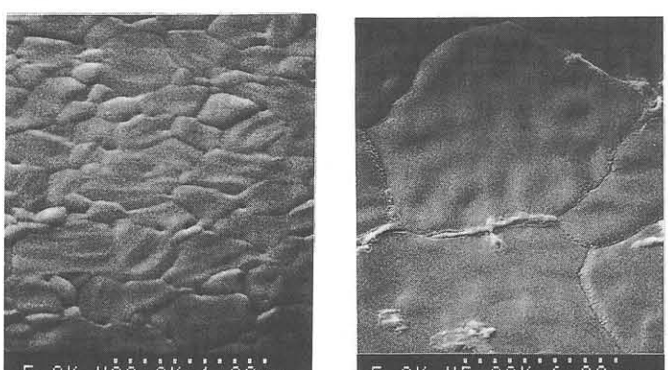


Fig.4 Weibull plots of the time-to-failure results on EM life test



(a)150°C (b) 500°C

Fig.5 SEM images of Al-Si-Cu grain structure on SiO_2

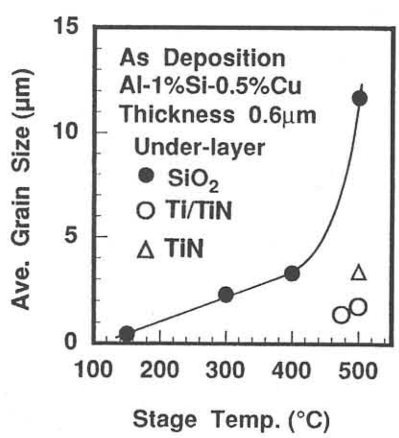


Fig.6 Effect of stage temperature on average Al grain size