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In-situ Rapid Thermal Processing for Collimated PVD Titanium as a Barrier Layer for Blanket CVD Tungsten

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A very thin bi-layered titanium nitride (TiN) / titanium (Ti) barrier were obtained from in-situ rapid thermal nitridation (RTN) for collimated-Ti by physical vapor deposition (PVD) as contact and barrier layers for blanket tungsten (W) plug by chemical vapor deposition (CVD). Even the initial deposited thickness of 600Å Ti provides the fine barrier properties by *in-situ* RTN rather than those by RTN with atmospheric exposure after Ti deposition. Furthermore a complete contact plug at a 0.25μm diameter with the aspect ratio of 4 was accomplished as a result of preventing the re-entrant profile of barrier layers at the contact shoulder. This is one of the contact filling technologies applicable to quarter micron devices.

INTRODUCTION

With increasing the aspect ratio of contact as a result of continuous scaling down of the devices, contact plug fabrication has become one of important techniques for a high reliable interconnection technology. Blanket CVD-W is widely used for a high reliable contact plug formation with its reliable stability and reproducibility. However, it is very difficult to form W plug with PVD barrier metal such as Ti and TiN in the contact with the aspect ratio of more than 3. For not only the bottom step coverage is poor, but the re-entrant profile of PVD metal at the shoulder of contact obstructs the complete contact filling of W with void in the plug. To reduce this re-entrant width, the deposited film thickness must be decreased less than 1000Å. A CVD barrier metal is desirable for its good step coverage in blanket CVD-W process. We had proposed that CVD-tungsten silicide (WSi_x) was applicable to the contact with the aspect ratio of 3.5 as a barrier layer [1,2]. TiN is one of attractive materials as a barrier layer because of its simplicity for PVD and the probability for CVD. Recently several TiN deposition techniques by CVD [3-9] and collimated PVD [10,11] were reported. The step coverages of TiN with plasma CVD degrades to the same level with that of collimated sputtering at the aspect ratio of more than 4. Another deposition technique by the organic metal CVD has a problem of a little higher impurity contents [9].

On the other hand, RTP was utilized to form the titanium silicide ($TiSi_x$) [12] and to improve the barrier properties of PVD-TiN film as a conventional barrier layer [13]. The conventional RTP was performed for atmospheric exposed Ti, therefore it is very difficult to obtain the high quality TiN film without the effect of oxidation at the Ti surface.

In this study, the contact technology is realized applicable to the contact with the aspect ratio of 4 by combining the collimation sputtering and *in-situ* RTN of Ti as a diffusion barrier layer.

EXPERIMENTAL

Both n^+ and p^+ Si contacts were prepared by conventional procedures summarized in Table 1.

RTP was performed at the temperature from 600 to 700°C in only nitrogen (N_2) and sequential flow of argon (Ar) / N_2 gases with and without atmospheric exposure after collimated Ti deposition. Transmission electron microscopy (TEM) and Auger electron spectroscopy (AES) were utilized for TiN / titanium silicide ($TiSi_x$) formation with 200-500Å of collimated PVD-Ti on an ion-implanted and magnetron enhancement reactive ion etched (MERIE) [14] Si substrate.

Contact plug was fabricated by the following process. After quarter micron contact definition, Ti was deposited by DC magnetron sputtering with 1:1 collimator. Immediately after Ti sputtering, RTP in N_2 was performed with and without atmospheric exposure. Contact holes were filled with blanket CVD-W and subsequent etch-back. Electrical characteristics were evaluated with Kelvin resistors and junction leakage.

Table 1 Sample Preparation for RTP.

	n^+ Si Contact	p^+ Si Contact
Ion Implantation	$^{75}As^+$, 50keV, 3E15cm^{-2}	$^{28}Si^+$, 30keV, 3E15cm^{-2} $^{49}BF_2^+$, 40keV, 3E15cm^{-2}
Activation Anneal	900°C, 10min.	
MERIE	Corresponding to 30% over etching for 1.2μm BPSG	
Ti Deposition	600Å	
Rapid Thermal Processing	at 600°C or 700°C	in Ar-N_2 for 30+30sec. or N_2 for 30sec.

RESULTS AND DISCUSSION

Figure 1 shows the bottom step coverage as a function of aspect ratio for various barrier layers. The collimated PVD-Ti provides not only about more than four times larger in the bottom step coverage but also as same as CVD-WSi_x.

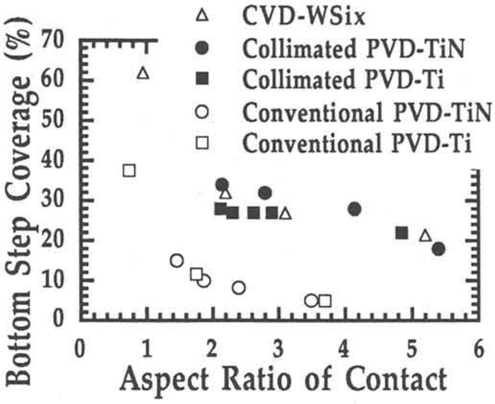

Figure 1 Step coverage of CVD-WSi_x, Ti and TiN between collimated and conventional PVD as a function of contact aspect ratio.

Regarding TEM observation after RTP for 200Å Ti on n^+ Si substrate as shown in Fig.2, there are obvious differences of silicided and nitrided layers between the various RTP conditions. The temperature is an effective factor for generating the $TiSi_x$ layer. At 600°C *in-situ* annealing, three different layers are observed. The upper and two lower layers are TiN and $TiSi_x$, respectively. The atomic ratio between Ti and Si was about 1:2 from electron probe micro analysis (EPMA). The existence of intermediate layer, transient region for $TiSi_x$ with the ratio of 3:2 from EPMA, are observed between them. At 700°C *in-situ* annealing, complete silicided and nitrided layers are observed. In the case of sequential RTP in Ar and N_2, complete silicided layer and no nitrided layer were observed. In the case of atmospheric exposed Ti, the obvious difference couldn't be observed between *in-situ* RTP and atmospheric exposed one. It seems that the formation of TiN hasn't drastically changed with and without atmospheric exposure from TEM observation.

Figure 3 shows the Auger spectra of the film surfaces with and without atmospheric exposed collimated Ti before RTN. The stronger oxygen peek and weaker nitride one are observed with atmospheric exposed Ti compared with *in-situ* RTN-Ti. This demonstrated that the oxidation of Ti occurred and suppressed the nitridation of Ti with atmospheric exposure on the surface.

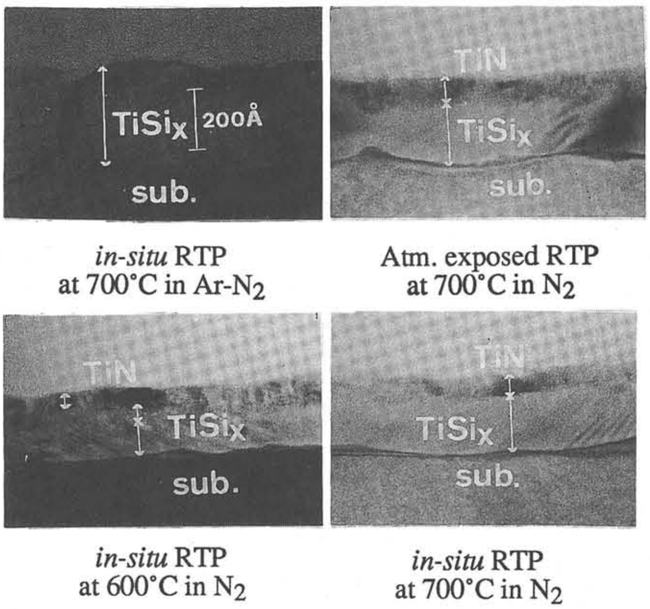

Figure 2 TEM cross-sectional photographs under various RTPs for Ti on n^+ Si substrate.

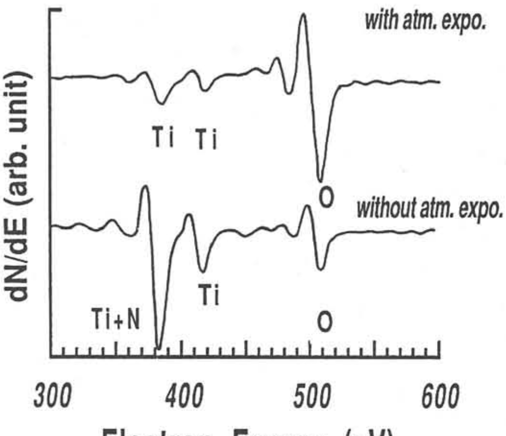

Figure 3 AES spectra of Ti deposited film surface with and without atmospheric exposure before RTN at 700°C.

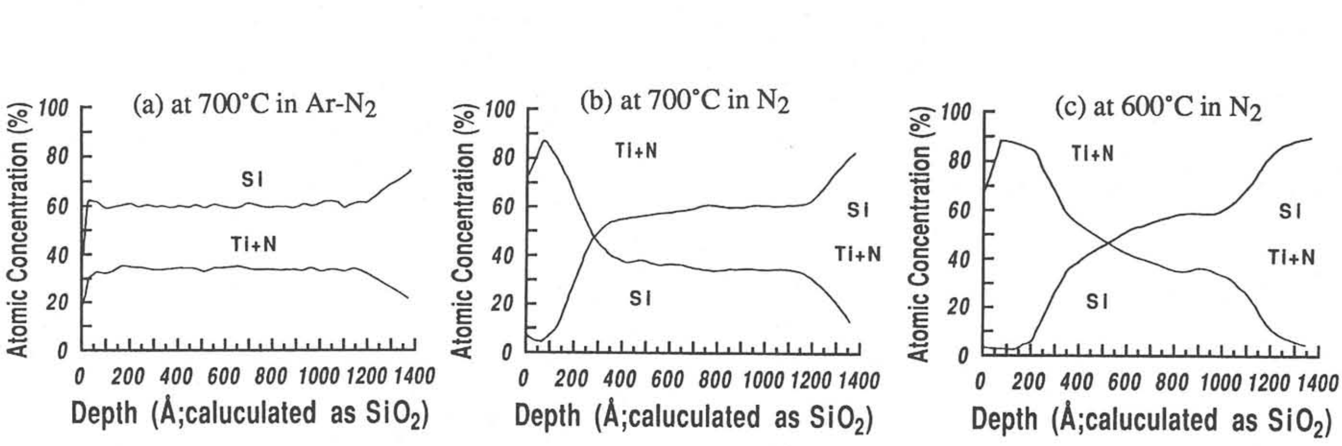

Figure 4 AES in-depth profiles for Ti and Si under various in-situ RTPs.

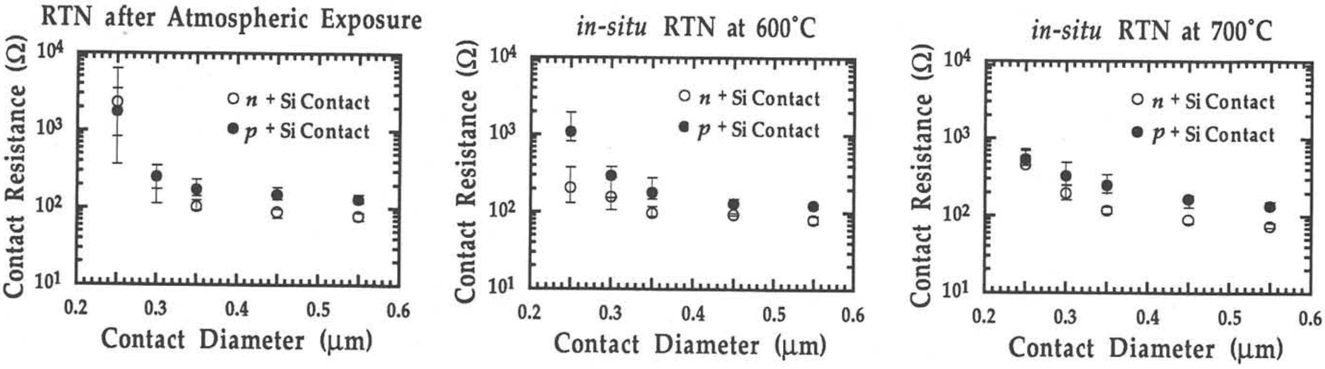

Figure 5 Comparison of contact resistance under various RTPs.

Figure 4 shows the AES in-depth profiles after RTP for 500Å Ti. The Si spectrum is observed at the same level toward the substrate with the about 1:2 of atomic ratio between Ti and Si in the sequential Ar and N_2 annealing as shown in Fig.4 (a). This indicates that there is no nitrided layer of Ti but only silicided layer because all of Ti layer has been consumed to form the silicide during the former annealing in Ar. On the other hand, little Si spectrum toward the substrate with the depth about 200Å only in N_2 atmosphere, as shown in Fig.4 (b), suggests that TiN is generated near the surface. This behavior becomes remarkable at reducing annealed temperature as shown in Fig.4 (c). These results indicate that it is essential to anneal in N_2 atmosphere for nitridation of Ti.

At a 0.25μm diameter plug of the blanket CVD-W / atmospheric exposed RTP-TiN / Ti / Si contact structure, the specific resistivities for both n^+ and p^+ Si were about $1\times10^{-6}\Omega cm^2$ and the resistances varied widely. By using *in-situ* TiN/Ti barrier, however, the resistivities of $2.2\times10^{-7}\ \Omega cm^2$ and $2.7\times10^{-7}\Omega cm^2$ were obtained for n^+ and p^+ Si, respectively, as shown in Fig.5. Though little difference of the average values of various RTP procedures were demonstrated, this is caused by no large difference at their interfaces between $TiSi_x$ and Si, which determine the contact resistance. However, the variations of the resistivities were very small by using *in-situ* TiN/Ti barrier.

Figure 6 shows the junction leakage current histograms of 0.25μm contact with 4M cell arrays across the p^+/n and n^+/p junction at a reverse bias voltage of 5 volts for various RTP procedures. In spite of no large difference between TiN / $TiSi_x$ formation with and without atmospheric exposed RTA from TEM observation, the junction leakage current in both p^+/n and n^+/p contacts degrades drastically in atmospheric exposed RTA. This indicates that the oxide or the existence of oxygen generated the porous TiN. In the case of *in-situ* RTP, the stable state of silicide at 700°C rather than that at 600°C reduces the junction degradation for the n^+/p contact, more sensitive for the leakage than p^+/n junction for its shallower junction depth.

CONCLUSION

A high reliable contact plug technology combining the collimated PVD of Ti and subsequent *in-situ* rapid thermal processing due to the bi-layered TiN/Ti. This is one of the promising technologies as a newly barrier formation.

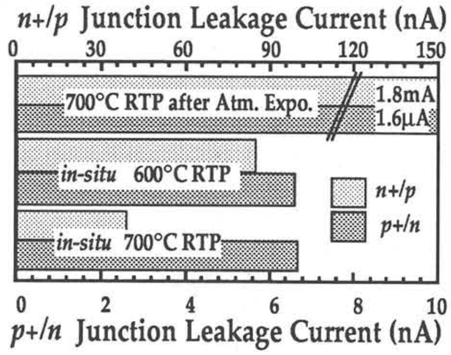

Figure 6 Leakage current histograms across the p^+/n and n^+/p junction at a reverse bias voltage of 5 volts for various RTP procedures.

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