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Resistance Anomaly of Al/CVD-W Interconnects in Deep Sub-Micron Width

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We have firstly found that anomalous sheet resistance increase depending on the line width in sub-half-μm AlSiCu/CVD-W lines after 450°C annealing. It is presumably due to preferable WAl_{12} formation near the edge of line. Using a TiN interlayer to eliminate WAl_{12} formation, 0.3μm wide lines of a new AlSiCu/TiN/CVD-W structure have demonstrated sufficiently low line resistance even after 450°C annealing for 300 minutes and 6 times longer electromigration (EM) life time compared with the previous AlSiCu/CVD-W structure.

1. INTRODUCTION

The Al/W bilayer interconnects(1-4) is one of the promising candidates for marginless contacts in future quarter-micron ULSIs, because a use of *blanket CVD-W without etchback* provides good step coverage without a recess in vicinity of contacts, which is in remarkable contrast to the popular *blanket CVD-W with etchback*(5,6) as shown in Fig.1. The Al/W structure, however, has disadvantages. One is increase of sheet resistance due to WAl_{12} formation even after 450°C annealing(1). The other is the poor EM endurance due to the smaller grain size of Al predominated by the roughness of CVD-W surfaces(2).

In this paper, undesirable sheet resistance anomaly of Al/W interconnects, which we have firstly found in sub-half-μm regime after low temperature annealing, is reported. The sheet resistance increase depends on the line width in sub-half-μm Al/W lines after 450°C annealing. This is a severe problem in designing future sub-half-μm ULSI's, since the interconnects has various high resistance depending its width. A practical new Al/TiN/W structure is proposed as a solution of this problem. This new structure also improves EM endurance that has been poor(2) in the conventional Al/W structure.

2. EXPERIMENTAL

The detailed structures of Al/W and Al/TiN/W lines are shown in Fig.2. In both structures, following sputter-deposition of a TiN/Ti adhesion layer of 30/10nm thickness on BPSG deposited Si wafers, a W layer of 130nm thickness was formed by the blanket CVD method. Prior to sputter-deposition of Al of 200nm and Al/TiN of 200/50nm thickness, native oxides on the W surfaces were removed by Ar-sputtering for the Al/W and Al/TiN/W structures, respectively. Al layer was sputter deposited Al-1%Si-0.5%Cu. As an anti-reflective layer for fine patterning in lithography, TiN layer of 40nm thickness was deposited on the Al layer. All TiN layers were deposited by a reactive sputtering from Ti target using Ar and N_2 gas mixture. Fine lines of various width (0.3-0.7μm wide) were patterned by KrF excimer laser lithography. Finally, these lines were passivated with plasma enhanced CVD silicon oxide of 500nm thickness.

The sheet resistance was measured as a function of the line width for different annealing conditions: temperature T=450°C/time t=30-300min. X-ray diffraction (XRD) analysis was done for both Al/W and Al/TiN/W plain structure after anneal: T=450°C/t= 30min. The EM test was performed at an ambient temperature of 200°C with a current density of $5E6A/cm^2$ for 0.3μm wide lines annealed: T=450°C /t=30min. As the line resistance of Al-alloy/CVD-W lines generally show gradual increase before open failure(2), the EM life time was defined as a time when the line resistance showed 20% rise from the initial value during the EM test.

3. RESULTS AND DISCUSSIONS

As shown in Fig.3(a), anomalous increase of sheet resistance has been found in Al/W interconnects with sub-μm width after low temperature (450°C) annealing. Especially the increase ratio is more remarkable in the narrower (0.29μm) line at earlier annealing time (0-100min.). Although the sheet resistance increase due to WAl_{12} formation in Al/W plain structure has been reported so far(1), its line width dependency has not been known yet. Figure 4(a) shows above fact more clearly. Sheet resistance of the Al/W lines becomes larger for the narrower line width.

XRD analysis of Al/W structure showed the existence of WAl_{12}(7) formed by a reaction of Al and W during the annealing (Fig.5(a)). Figure 6(a) shows W surfaces after AlSiCu layer removal by H_2PO_4 solution. Some grains with brighter contrast is observed in the edge of Al/W lines. The density of these grains seems to be almost the same between 0.3μm and 0.7μm wide lines. Presumably they are coincided with the WAl_{12} grains formed by a reaction of Al and W during the 450°C annealing. From these results, higher resistance increase in narrower Al/W lines is explained as follows: High resistive WAl_{12} grain formation occurs preferably in the edge of lines during 450°C annealing. As the line width becomes narrower, ratio of the area occupied by the high resistive part near edge becomes larger. Thus the line resistance increases as a whole.

To avoid the anomalous resistance increase by WAl_{12} formation, an interlayer between Al and W is required. We introduce TiN interlayer between Al and W layers, because TiN is an excellent diffusion barrier having high reaction temperature (550°C) with Al(8). As shown in Fig.3(b), the sheet resistance of Al/TiN/W did not vary during the most of annealing time except the slight increase in initial 50min. and did not depend on its line width, keeping much lower values than that of the Al/W lines (Fig.4(b)). A reactive-sputtered TiN film commonly tends to be Ti-rich(9). Presumably the initial increase of sheet resistance in Al/TiN/W lines is explained by Ti diffusion from the Ti-rich TiN interlayer into Al layer. According to XRD analysis (Fig.5(b)), spectrums indicating WAl_{12} formation was not detected in Al/TiN/W structure. Furthermore, SEM showed that the existence of high resistive grains as in the case of Al/W was not clear at TiN interlayer in both 0.3μm and 0.7μm lines (Fig.6(b)), which was consistent with XRD result and constant low resistance in Fig.3(b) and 4(b). Thus, the TiN interlayer prevents WAl_{12} formation by inhibiting interdiffusion between the Al and W layers.

Al/TiN/W structure has another advantage, i.e., EM life of 0.3μm wide Al/TiN/W line is 6 times longer than that of the Al/W line as shown in Fig.7. Al grain size was almost identical in both structures by SEM observation. Since resistance of 0.3μm Al/W line annealed: T=450°C/t=30min. is 1.7 times higher than that of the Al/TiN/W line as shown in Fig.3 and Fig.4, it is pointed out that local joule heating at WAl_{12} grains plays more important role in the EM life time of this sub-half-μm regime than Al grain size. Al/TiN/W lines include no WAl_{12} grains which makes current paths narrow by blocking the current to cause local joule heating. Otherwise the enhanced local joule heating would result in the open failure. After all, the longer EM life time of the Al/TiN/W line is also attributed to the elimination of the WAl_{12} formation.

4. CONCLUSIONS

We have firstly found that anomalous sheet resistance increase depending on the line width in sub-half-μm AlSiCu/CVD-W lines after 450°C annealing. It is presumably due to preferable WAl_{12} formation near the edge of line. A practical new AlSiCu/TiN/CVD-W structure have demonstrated sufficiently low line resistance even after 450°C annealing for 300 minutes and 6 times longer electromigration life time than the previous AlSiCu/CVD-W structure. This structure will be indispensable to realize sub-half-μm interconnects for marginless contacts in future ULSIs.

5. ACKNOWLEDGMENTS

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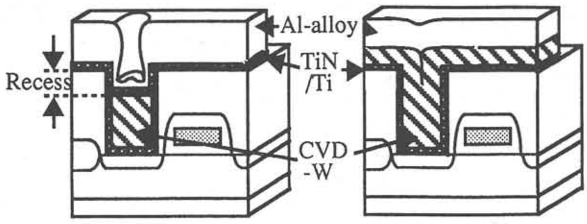
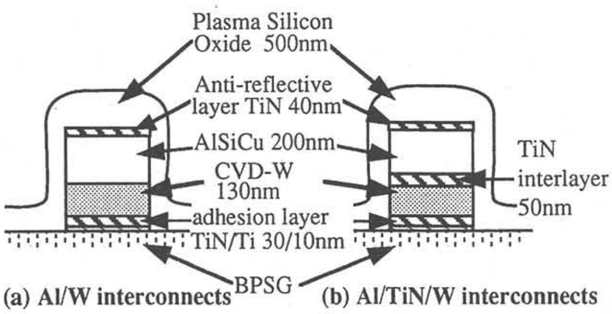


(a) Blanket-W with etchback

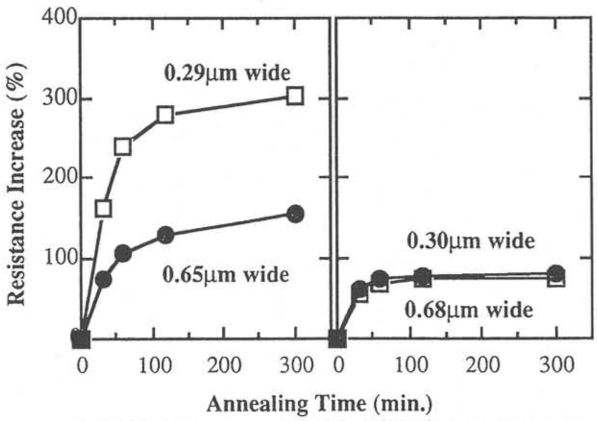
(b) Al-alloy/CVD-W interconnects

Fig.1 The step coverage of interconnects by two process of contact filling



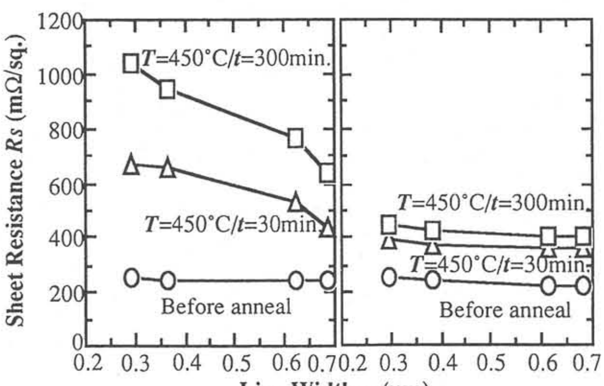
(a) Al/W interconnects (b) Al/TiN/W interconnects

Fig.2 Cross-sectional view of two interconnect structures



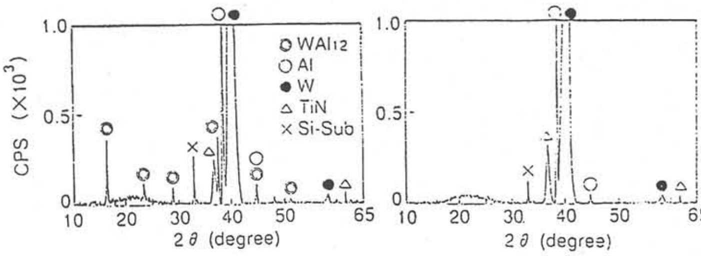
(a) Al/W interconnects (b) Al/TiN/W interconnects

Fig.3 Dependence of resistance increase on annealing (T= 450°C) time



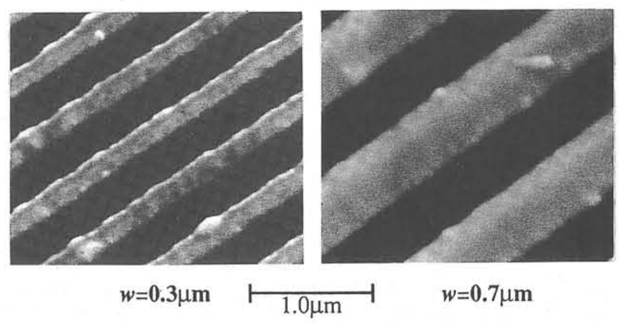
(a) Al/W interconnects (b) Al/TiN/W interconnects

Fig.4 Dependence of the sheet resistance on line width after anneal:T= 450°C

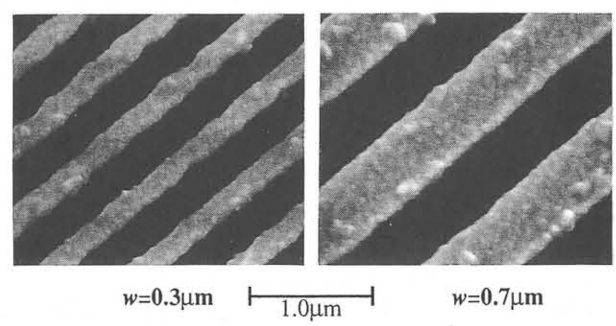


(a) Al/W structure (b) Al/TiN/W structure

Fig.5 The θ-2θ XRD spectra of two plain structures after anneal:T=450°C/t=30min.



(a) Surface of W layer in Al/W interconnects



(b) Surface of TiN layer in Al/TiN/W interconnects

Fig.6 The SEM Micrographs of the surface of two interconnects after Al removal by H_2PO_4 solution. Specimens were annealed: T=450°C/t=300min.

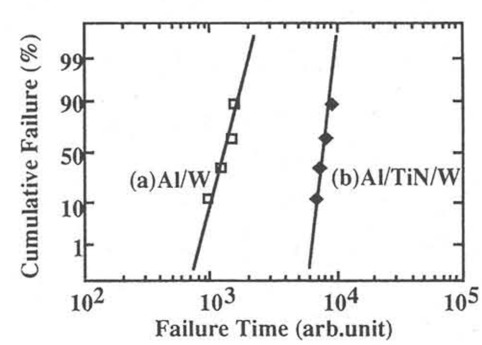


Fig.7 EM life time of w=0.3μm lines of the two structures. Specimens were annealed: T=450°C/t=30min. Test Condition: Ta=200°C, J=5E6A/cm²