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Interface Reactions in Al-Alloy/Ti Layered Structures

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Al-alloy/Ti interface reactions have been studied. When Al-alloy/Ti layered structures are annealed at high temperature, the reactions occur at the interface between Al and Ti. In the case of Al-Cu, the interactions proceed to form thick and uniform compound layer. The compound was confirmed to be Al_3Ti by XRD analysis. Si additions to Al-alloy makes a great change in the reaction products. A few compounds were observed locally at the interface, and the composition of the compounds were identified to be Al_3Ti and/or $Al_{23}Ti_9$ containing Si. The interface reactions were almost inhibited with Si addition to Al-alloy. In the case of Al-alloy with addition of Si (Al-0.8%Si-Cu), the interface reactions between Al-alloy and Ti would be locally composed of ternary phase (Al-Ti-Si) in which Al_3Ti is not stable with Si compounds. Therefore, the absence of Al-Ti compound can be seen at the interface locally.

1. INTRODUCTION

The multilayered interconnections composed of Al-alloy and refractory metals have become popular structures to avoid the metal line reliability problems[1]. TiN is frequently used as a barrier layer due to its thermal stability[2]. On the other hand, Ti layer have been used in combination with TiN layer to reduce the contact resistance to Si[3]. Recently, in the case of via-filling techniques by using Al high temperature sputtering and reflow, a good step coverage can be obtain with Ti adhesion layer[4]. In Al-alloy/Ti structures, it is well known that the reactions occur at interface between Al and Ti during high temperature treatment to form mainly binary compound Al_3Ti[5)6]. It is demonstrated that the reaction products improve the electromigration (EM) resistance acting as a current bypass in the previous papers[7]. It is reported in previous papers that interactions were substantially suppressed by addition of Si to Al-alloys[8-10] (the similar effect of Cu additions that were less than that of Si, were also reported[9]) . However, the behavior of Si in Al-Ti interactions is still not clear. In this report, we have investigated the influence of Si in Al-alloy on interface reactions in Al-alloy/Ti layered structures in detail by using analyzing tools, Rutherford backscattering spectrometry (RBS) , transmission electron microscopy (TEM) , x-ray diffraction (XRD) , and energy dispersive x-ray spectroscopy (EDX) .

2. EXPERIMENTAL

Samples were prepared in the following way. 50 nm thick Ti films were deposited on BPSG/Si substrates by using DC magnetron sputtering system. Then, 500nm thick Al-alloy films were successively deposited at 250°C. Two types of Al-alloys (Al-0.8%Si-Cu and Al-Cu), were used for comparison of interactions. Finally, Al-0.8%Si-Cu/Ti and Al-Cu/Ti layered structures were annealed in the temperature range from 410 to 500 °C for 30 min in N_2 ambient. Interfacial reactions were investigated using RBS, four points probe measurements, cross sectional TEM and micro EDX.

3. RESULTS AND DISCUSSION

Figure 1 shows RBS spectrums of Al-0.8%Si-Cu/Ti and Al-Cu/Ti structures after 450°C and 500°C annealing. In the case of the Al-Cu/Ti structures, the interdiffusion between Al and Ti completes after 500°C annealing. On the other hand, when Al-0.8%Si-Cu/Ti structures are annealed, the interdiffusion does not complete and the amount of diffusion is less than that of Al-Cu. Figure 2 shows sheet resistance changes of Al-0.8%Si-Cu/Ti and Al-Cu/Ti structures as a function of annealing temperature. In the case of Al-Cu/Ti structure, the sheet resistance increases 10 percent after annealing at 410°C. Furthermore, that increases 60 percent after 500°C annealing. On the other hand, in the case of Al-0.8%Si-Cu, the sheet resistance increases only 20 percent even after 500°C annealing. These results suggest that two Al-alloys are different in forming compounds after annealing.

Figure 3 shows cross sectional TEM images of Al-0.8%Si-Cu/Ti and Al-Cu/Ti structures after 30 min annealing at 500°C. In the case of Al-0.8%Si-Cu/Ti structure, as shown in Fig.3 (a), the reaction products were formed locally at the Al side of interface. On the other hand, the case of Al-Cu/Ti structure was found to be different, as shown in Fig.3 (b), the compounds were formed uniformly about 300 nm thick. Additionally, Ti layer was almost consumed to form reaction products. From these results, it was revealed that interface reaction was restricted when Si was added to Al-alloy as demonstrated in Ref.[8]_[10]. In order to investigate the composition of the reaction products, micro EDX analysis was performed on the same samples (Analysis points are shown in Fig.3 by numbers). The results are shown in table I. Only Al was detected in Al grains at both samples (point (1) and (6)). In the case of Al-0.8%Si-Cu/Ti structure, Al and Ti were detected in a reaction product grain (point(2)) and at a reaction product grain boundary (point(3)). Therefore, the reaction product turned out to be an Al-Ti binary compound, which was confirmed to be Al_3Ti and/or $Al_{23}Ti_9$ by XRD analysis. Moreover, in the unreacted Ti layer (point (4) and (5)), the presence of Si was identified in addition to Al. It is speculated from these results that dissolution of Si in Al-0.8%Si-Cu alloy into the Ti layer as well as reaction of Ti with Al were occurring competitively during heat treatment. Therefore, interfacial reactions between Al and Ti were restricted, resulting in the local formation of Al-Ti binary compounds. On the other hand, in the case of Al-Cu/Ti structure, a little amount of Si in addition to Al and Ti was detected at the upper part (point (7)) and the lower part (point (8)) of the compound layer. The compound layer has been confirmed to be Al_3Ti by XRD analysis. Si must have been supplied from BPSG film because Si is not contained in the Al-Cu alloy film (< 10 ppm). The roughness of the interface between the compound layer and the BPSG film as well as more incorporation of Si into lower part of the compound layer will support this inference. In the Al-Cu/Ti/BPSG system, Si-O bond must be dissociated before Si diffuses into the Ti layer and less Si will be contained in the Ti layer compared with the Al-0.8%Si-Cu/Ti/BPSG system. Accordingly, the interfacial reaction between the Ti film and the Al-alloy film can not be suppressed sufficiently, leading to the formation of the thick and uniform Al_3Ti layer including a little amount of Si.

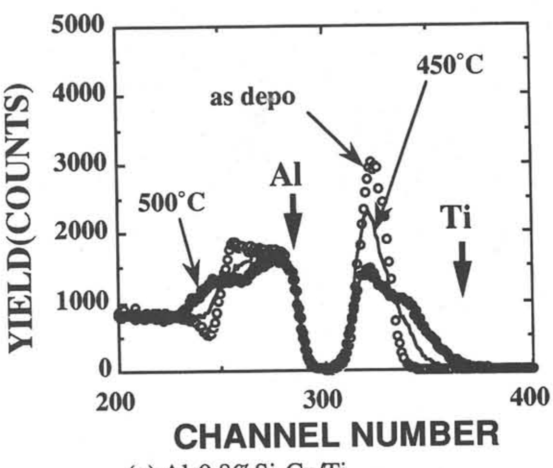
In the case of Al-Cu/Ti structures, the interface reaction between Al-alloy film and Ti film is simple binary phase system. On the other hand, in the case of Al-0.8%Si-Cu/Ti, reaction between Al-alloy film and Ti film is more complex because of the existence of a large amount of Si in Al-alloy compared with Al-Cu. However, it is expected that Si agglomeration occur locally by the heating up of Al-alloy deposition (250°C). Then, Si concentration is rather different with the location at the interface between Al-alloy and Ti films. At the part of the interface containing a large amount of Si, the interactions would be composed with Al-Ti-Si ternary phase. In ternary phase, Al_3Ti forms unstable system with Si compounds[11] (TiSi, $Al_5Ti_7Si_{12}$, etc.) resulting in the inhibition of Al_3Ti formation.

4. CONCLUSION

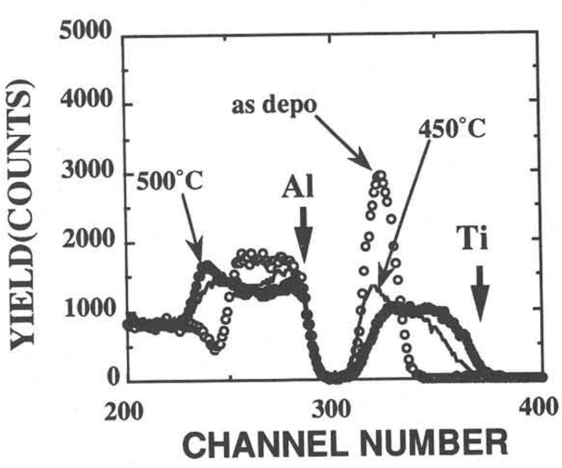
The influence of Si in Al-alloy on interface reactions in Al-alloy/Ti layered structures were examined by comparing Al-0.8%Si-Cu and Al-Cu. The difference in interface reactions between Al-0.8%Si-Cu and Al-Cu were characterized by using cross-sectional TEM micrograph, micro EDX and XRD analysis. When Al-0.8%Si-Cu/Ti structure was annealed, Al-Ti interface reactions were restricted to form Al-Ti binary compounds locally, because Ti layer absorbed Si from Al-alloy. In the case of Al-Cu/Ti structure, interface reactions would proceed to form Al-Ti binary compounds uniformly, because only a little Si was supplied from BPSG.

REFERENCE

1) M.Wittmer, J. Vac. Sci. Technol, A2(2)p.237,1984
2)S.Kanamori, Thin Solid Films, 136(1986)p.195
3)C.Y.Ting, and B.Crowder, J. Electrochem. Soc., 129, p.2590(1982)
4)K.Koyama, M.Taguchi, and Y.Sugano, SDM, p.19(1991)
5)R.W.Bower, Appl. Phys. Lett., Vol.23,No2,15, P.99(1973)
6)M.Ben-Tzur,M.Eizenberg, and J.Greenblatt, J. Appl. Phys., 69(7),p.3907(1991)
7)K.Hashimoto, K.Touchi, and H.Onoda, IEEE/IRPS p.185 (1994)
8)D.S.Gardner,T.L.Michalka,K.C.Saraswat,T.W.Barbee,JR., J.P.Mcvittie,and J.D.Meindl,IEEE Journal of Solid-State Circuits, Vol. sc-20,No.1,p.94(1985)
9)G.J.Slusser,J.G.Ryan,S.E.Shore,M.A.Lavoie,and T.D.Sullivan, J. Vac. Sci. Technol.A7(3)p.1568(1989)
10)M.Ben-Tzur,R.Fastow,M.Eizenberg, J.Rosenberg, and M.Frenkel, J. Vac. Sci. Technol. A8(6)p.4069(1990)
11)A.S.Bhansali, R.Sinclair, and A.E.Morgan, J. Appl. Phys., 68(3)p.1043(1990)



(a) Al-0.8%Si-Cu/Ti



(b) Al-Cu/Ti

Fig.1 RBS spectrums of Al-alloy/Ti after 450 and 500°C annealing. (Al-alloy is 500nm thick)

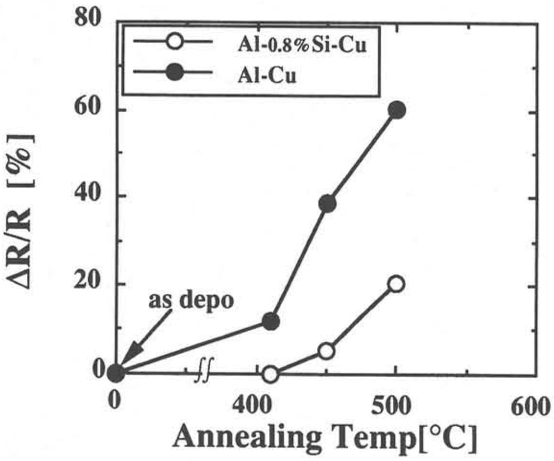
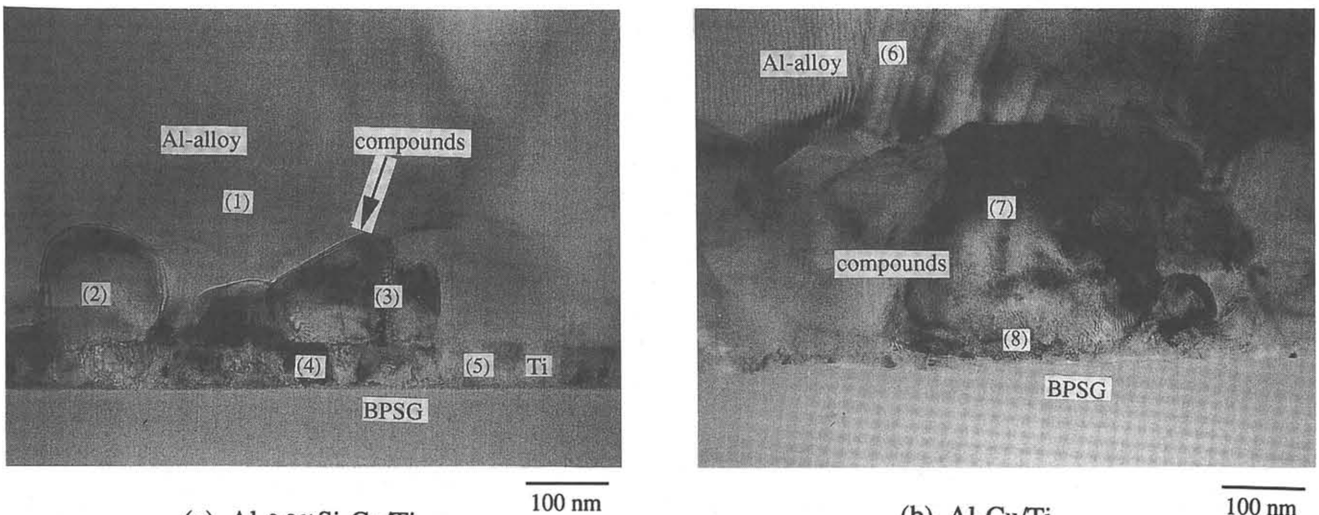


Fig. 2 Sheet resistance changes of Al-0.8%Si-Cu/Ti and Al-Cu/Ti structuresas a function of annealing temperature.



(a) Al-0.8%Si-Cu/Ti (b) Al-Cu/Ti

Fig.3 TEM cross sectional micrographs of Al-alloy/Ti after annealing at 500°C for 30 min.

Table. I Atomic compositions of the points analyzed by Micro EDX from the samples shown in Fig.3.

Point	Atomic Percent[%]	Point	Atomic Percent[%]
(1)	Al; 100.00 Ti; 0.00 Si; 0.00	(6)	Al; 100.00 Ti; 0.00 Si; 0.00
(2)	Al; 70.53 Ti; 29.47 Si; 0.00	(7)	Al; 70.29 Ti; 28.09 Si; 0.65
(3)	Al; 75.79 Ti; 24.21 Si; 0.00	(8)	Al; 71.08 Ti; 27.52 Si; 1.40
(4)	Al; 49.37 Ti; 47.25 Si; 3.38		
(5)	Al; 11.17 Ti; 80.35 Si; 8.48		