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The Effect of Film Texture and Zirconium Diffusion on Reliability Against Electromigration for CVD Copper

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1. Introduction

Cu CVD has been intensively studied as a promising copper metallization technology because of its high capability for via and trench filling. It, however, has not achieved sufficient reliability against electromigration compared to sputtered Cu film [1,2]. It is known that improving film texture and forming precipitation-hardening alloys, such as Cu-Zr or Cu-Sn, are effective ways to extend electromigration lifetime[3,4]. This paper examines the CVD Cu film texture and the diffusion properties of Zr in Cu and shows their effects on the electromigration resistance.

2. Film characteristics of CVD Cu film

The characteristics of CVD Cu are summarized in Table 1. Sample 1 is as-deposited Cu film on TiN liner. The deposition temperature was 180 C. This film comprises weakly (111) oriented small size grains. Oxygen and fluorine are the dominant impurities. As for the Sample 2, a thin sputtered Cu film was deposited as a seed layer before CVD, and a post-annealing in hydrogen at 400 C was performed after Cu CVD. With the sputtered Cu seed, the X ray diffraction peak ratio of (111) to (200) increased to 80. After the hydrogen annealing, both oxygen and fluorine concentration decreased and the grain size of the CVD Cu also increased. The grain size, however, is still relatively small compared to the grain size of the reference sputtered Cu film presumably due to the residual impurities.

3. Zirconium diffusion into CVD copper

Cu-Zr alloy was formed by thermal diffusion between Zr and Cu. Zr was deposited on Sample 1 by sputtering and was diffused at 400 C. SIMS profiles of the sample are shown in Fig. 1. These profiles suggest inter-diffusion between Zr and Cu during annealing. The Cu concentration profiles in Cu were flat and the value remained constant during the annealing. This indicates that stable CuZr compound was formed at the zirconium Cu interface. On the other hand, the Zr concentration in Cu increased to about 1% at the first stage of diffusion. It's profiles were nearly flat in the Cu layer. Then the profile became an error function like with increasing annealing time. These indicate that Zr incorporated Cu alloy were formed at 400 C annealing. Figures 2 shows the TEM image of the sample after 60-min annealing at 400 C. The sample was separated into three areas with different atomic compositions. From the diffraction data and the EDS spectra, the top, the intermediate, and the bottom area were identified to be Zr, $CuZr_2$ and Cu, respectively. After dilute HF dipping, the top layer was removed, whereas the Cu Zr_2 layer remained on the surface. The remaining surface intermetallic compound is expected to prevent surface migration. The electrical resistivity of the Zr diffused copper is shown in Fig. 3. The film resistivities depend on the Zr thickness and annealing time.

4. Electromigration resistance

Electromigration resistance was evaluated as follows. Cu wire 0.5 um width was fabricated by the damascene process. The fabrication process for Cu-Zr alloy wire is nearly the same as the previously reported self-aligned process for Cu-Al alloy wire [5]. Zr was deposited on the Cu wire and annealed at 400 C for 2 hours. Pure Zr on SiO_2 was removed by diluted HF and $CuZr_2$ remained on the Cu wire. The resistivity of the Cu-Zr wire is 2.2 micro-ohm-cm. Plasma silicon nitride was deposited as a passivation layer. The electromigration test was carried out with 8 MA/cm^2 at 200 C, and the results are shown in Fig. 4. The life time of the Sample1 is about the same as in other CVD studies. It was much longer than conventional multi-layered Al-Cu with a Ti base liner, but still shorter than highly (111) oriented multi-layered Al-Cu[6]. The lifetime extension of Sample 2 is not so large because the grain growth by hydrogen annealing is insufficient for forming a bamboo structure for 0.5-um wide wire.Å@ The relation between the grain size and the residual impurity (oxygen and fluorine) concentration indicates that further purification of Cu is required. The effect of the Zr diffusion is more evident. The lifetime is about five times longer than that of Sample 1. This value is comparable to some previously reported sputtered Cu data [2,3]. It is presumed that Cu atom transport is prevented by Cu-Zr intermetallic compound at the grain boundary and the surface of Cu wire.

5. Conclusion

Cu-Zr alloy formation is a very effective way to improve the reliability of CVD Cu. Zr incorporated Cu wires with surface CuZr2 compound were formed by a self-aligned process. Electromigration lifetime of CVD Cu wire was significantly increased by this process with a small increase of electrical resistivity. A reduction of the oxygen and fluorine concentration is required for further improvement of CVD Cu reliability.

References

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Table 1 Film texture and Impurities concentration of CVD copper

	Film Texture		Impurity Concentration (ppm)			
	(111)/(200)	Grain Size (nm)	O	H	F	C
Sample1	4	50-100	1000-2000	200-400	100-50	-
Sample2	89	200-500	100-300	100-300	<50	-
Sputter Copper	167	500-1000	<100	<100	-	-

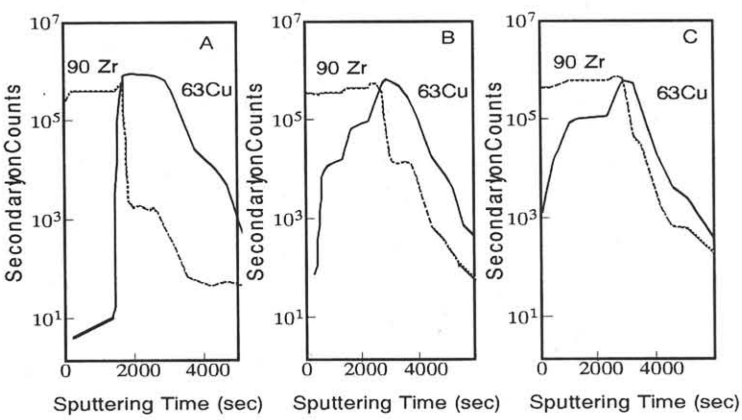

Fig.1 SIMS profiles of Zr diffused CVD Cu
A : as deposited, B : After 60min annealing at 400 C,
C : After 150 min annealing at 400 C

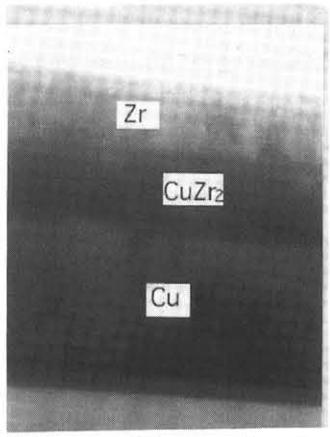

Fig.2 TEM image of the sample after 60-min annealing at 400 C

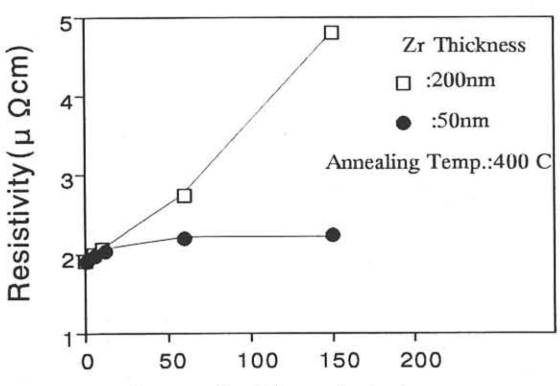

Fig.3 Electrical resistivity of the Zr diffused Cu

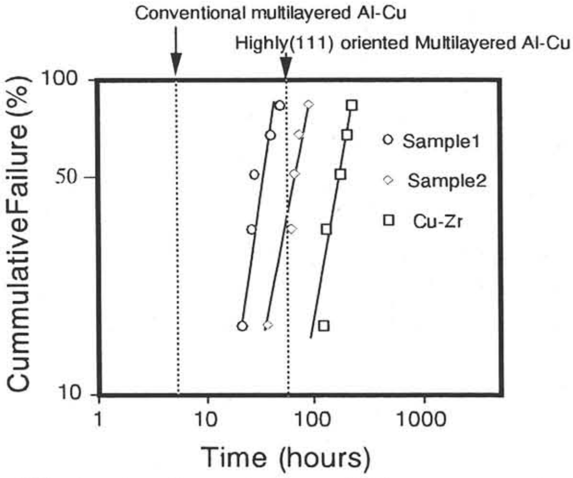

Fig.4 Electromigration resistance of 0.5 um copper wire with 8 MA/cm^2 at 200 C