The Mechanical Property of Electroplated Cu Film

Chul-Ho Cho[1], Seung-Mo Ha[1], Yoomin, Ahn[2], Daekun Kim[3], Jaeho Lee[4]

[1]*Graduate School of Precision Mechanical Engineering, Hanyang University*
[2]*Department of Mechanical Engineering, Hanyang University*
Sal-Dong, Ansan, Kyoung-Ki-Do 425-791, KOREA
[3]*Graduate School of Advanced Materials Engineering, Hongik University*
[4]*Department of Advanced Materials Engineering, Hongik University*
72-1 Sangsoo-Dong, Mapo-Ku, Seoul121-791, KOREA

This paper discusses the effect of plating condition on the mechanical property of electroplated Cu film. Current density, the amount of the organic additives was found to affect the residual stress of electroplated copper film. The result show that, in the case of residual stress, the copper film deposited at higher additive result in lower residual stress and a plating current by 15mA/㎠ induced a better result than any other ones.

Keywords: Electroplating, Copper film, Residual stress, Elastic Modulus, Hardness

1. INTRODUCTION

Although Al based alloy is still widely used, copper has emerged as the metal of choice for next generation semiconductor interconnects. Its higher electromigration resistance and significantly lower electrical resistance (Resistivity of bulk copper is around 1.7μΩcm) are particularly promising due to the rapid increase in current density. This increase is much anticipated due to the reduction of line cross-sectional area as the dimension shrink. Copper interconnects are created using electroplating. Electroplating offers economical benefits over the current PVD and CVD processes used for creating aluminum interconnects. In addition, high electromigration resistance is often obtained on the electrochemically deposited copper film.

Copper electroplating starts by immersing a wafer in an acid copper bath. A current is passed through the wafer creating a negative charge on the wafer surface. The negative charge attracts the positively charged ions in the acid copper bath. The copper ions create a film on the surface of the wafer filling all of the exposed features of the wafer. Three organic additives, accelerator, suppressor, and leveler, are used to control the physical properties of the deposited copper.

In order to achieve a highly reliable electroplated copper delineation, it is necessary to understand the property of a electroplated copper film. In this paper, we especially focus on the mechanical property of electroplated copper film. The value of hardness and elastic modulus were measured by nanoindenter and residual stress by Stoney formula

2. EXPERIMENTAL PROCEDURES

Silicon partial wafers (2 x 2 ㎠) were used throughout all experiments. A copper seed layer was deposited by PVD (Physical Vapor Deposition). Three plating solutions were used to deposit the films and the electrolytes consisted mainly of sulfuric acid, copper sulfate and hydrochloric acid with proprietary organic additive systems. The composition of plating solutions is shown in Table. 1 and current density is varied from 10mA/㎠ to 20mA/㎠. A measured nominal thickness of electrochemically deposited copper film iss around 5 ㎛. Thickness was measured by Alphastep 500.

Solution I	Solution II	Solution III
$CuSO_4 \cdot 5H_2O$ 200g/L	**$CuSO_4 \cdot 5H_2O$** 200g/L	**$CuSO_4 \cdot 5H_2O$** 200g/L
H_2SO_4 40g/L	**H_2SO_4** 40g/L	**H_2SO_4** 40g/L
	Gelatin 0.05g/l	**Gelatin** 0.1g/l

Table. 1 The composition of plating solutions

2.1 Residual Stress

To observe the residual stress of a copper film, we used a Stoney formula shown in equation (1). Stoney formula is the equation that can find out the residual stress from measuring the deflection due to residual stress.

$$\sigma_m = \frac{F_f}{d_f w} = \frac{1}{6}\left(\frac{1}{r} - \frac{1}{r_0}\right)\frac{E_s d_s^2}{d_f} \quad (1)$$

Where, r_0 is a curvature before deposition, r is a curvature after deposition, E_s is the elastic modulus of a substrate, d_s is the thickness of a substrate, d_f is the thickness of a film. To obtain a curvature, all specimens were measured before and after deposition at 8 measuring line using Talysurf.

2.2 Elastic Modulus and Hardness

A Nanoindentation (or depth sensing indentation) is useful method to measure the mechanical property of a material film with the thickness a few millimeters or below. Elastic modulus and hardness were measured by nanoindenter from 5 measuring point at 50 ㎛ interval

3. RESULT AND DISCUSSION

3.1 Residual Stress

Fig.1 compares the effect of organic additive, like Gelatin, and current density. From the measured curvature of the

sample and Stoney formula, the stress on the copper films turned out to be compressive stress. It is found that, in the case of solution II and III, residual stress are minimum value at 15mA/㎠ and a more organic additive result in a lower residual stress.

3.2 Elastic Modulus and Hardness

One sample is deposited by PVD(sputtering) for using to compare with electroplated copper film. The others were electrochemically copper deposited using plating solution II and current density by 15mA/㎠. Table. 2 shows that the elastic modulus of an electroplated copper films does not differ from that of bulk copper (110~120GPa), but a sample deposited by PVD has a higher value than that of the bulk copper. In the case of hardness, a film deposited by PVD has higher value than that of a film deposited electrochemically. It is thought that there may be a different deposition mechanism when a film is deposited on a substrate. In plated wafer, a deviation of data results from the rough surface of a plated copper film.

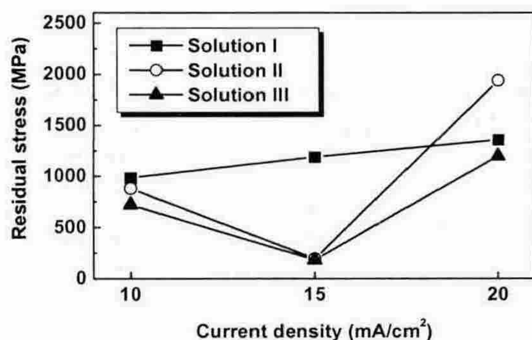

Fig. 1 Residual Stress with the variation of plating conditions

PVD	E(GPa)	H(GPa)	Thickness(㎛)
1	206.52	3.35	1
2	211.01	3.320	
3	199.05	3.37	
4	189.78	3.43	
5	178.37	3.53	
Mean	**198.45**	**3.39**	
ECP 1.			
1	127.63	1.52	5.186
2	129.76	0.73	
3	68.06	0.71	
4	125.12	1.87	
5	-	-	
Mean	**127.50**	**1.21**	
ECP II.			
1	64.90	0.66	5.412
2	137.0	0.76	
3	124.63	1.46	
4	79.14	0.36	
5	181.48	1.21	
Mean	**113.61**	**0.88**	

Table. 2 Elastic modulus and hardness of electrochemically plated film and physical vapor deposited film

4. CONCLUSION

The mechanical property of electroplated copper film was observed. The result show that, in the case of residual stress, the copper film deposited at higher additive result in lower residual stress and a current density by 15mA/㎠ induced a better result than any other ones. But, there were not enough data to determine reliable results. It is needed to be more experimental process to find out an optimal plating condition (current density, composition of plating solution) for reliable copper film. And another important property of copper film, like sheet resistance, should be observed with plating condition.

5. ACKNOWLEDGEMENT

This work was supported by grant No. R01-20002-00228 from the Korea Science & Engineering Foundation.

6. REFERENCES

[1] W.H. Teh, L.T. Koh, S.M. Chen, J. Xie, C.Y. Li, P.D. Foo, "Study of microstructure and resistivity evolution for electroplated copper films at near-room temperature", Microelectronics Journal, 32, pp.579-585, 2001.

[2] J. M. E. Harper, C. Cabral, Jr., P. C. Andricacos, L. Gignac, I.C. Noyan, K. P. Rodbell, and C. K. Hu. "Mechanisms for microstructure evolution in electroplated copper thin films near room temperature", J. of Applied Physics, Vol. 86, No. 5. pp.2516-2525, 1999

[3] T. Ritzdorf, L. Chen, D Fulton, C. Dundas, "Comparative investigation of Plating Conditions on Self-Annealing of Electrochemically Deposited Copper Films", int. Interconnect Technol. Conf., 1999, pp.287-289

[4] S Lagrange, S.H. Brongersma, M. Judelewicz, A. Saerens, I. Vervoort, E. Richard, R. Palmans, K. Maex, "Self-annealing characterization of electroplated copper film," Microelectronic Engineering, 50, pp. 449-457, 2000.

[5] C. H. Seah, S. Mridha, L. H. Chan, "Annealing of copper electrodeposits", J. Vac. Sci. Technol., A 17(4), pp.1963-1967, 1999