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Influence of Ti Liner on Resistivity of Copper Interconnects

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1. Introduction

The requirements for electric current density tolerance in copper interconnects continue to increase with scaling down of CMOS LSI circuits. The copper alloy technique has been studied to meet the demand of reliability. There are several methods of adding an element to copper lines [1-6] but they always cause an increase in the resistance. Therefore, the control of the balance between line resistance and the concentration of an additional element is very important. In this work, we performed a precise analysis on the grain size and the distribution of an additional element with the Ti liner. Then, the influence of Ti liner on the resistivity of copper lines was clarified using the resistivity model.

2. Experimental Details

In this study we used damascene lines fabricated using 45 nm technology Tantalum (Ta) or Ti liner was used for the liner film of the copper lines. We used the electron back scattering deflection (EBSD) method to evaluate the grain size and crystal structure of copper. For the distribution measurement of Ti atoms, micro auger electron spectroscopy (μ-AES) was applied to the sample annealed at 400℃ for 1 hour in vacuum ($<3\times10^{-4}$ Pa) at 400℃after chemical mechanical polishing. The copper grain size was measured from the EBSD patterns method. The resistivity of copper lines was obtained by the resistance ratio method [7].

3. Results and Discussion

Accurate evaluation of the grain size is important in discussing line resistivity based on the resistivity model [8,9]. Figure 1 shows the line width dependence of the copper grain size with Ta and Ti liners measured by EBSD. Grain size was defined as the average distance parallel to the longitudinal direction of a line between the grain boundaries. It was found that the grain size with the Ti liner was about 0.7 times small as that with Ta liner in the 1μm wide line. However, the grain sizes were almost the same at about 100 nm wide lines.

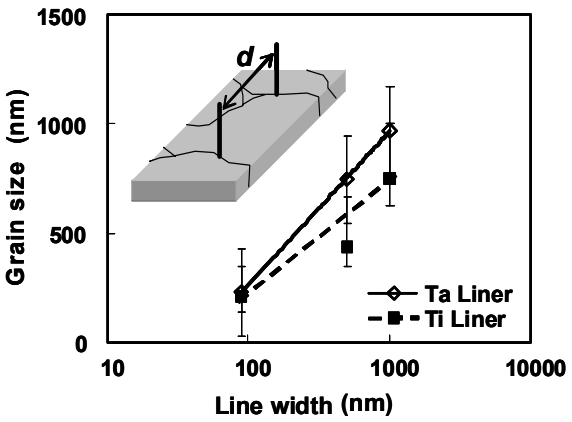

Fig. 1. Line width dependence of the grain size. Grain size is defined as an average distance parallel to the longitudinal direction of a line between the grain boundaries. The copper grain size with the Ti liner line is smaller than that with the Ta liner in the wider line.

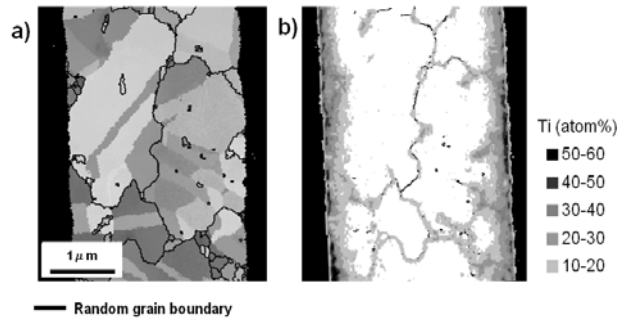

Fig. 2. EBSD top view image (a), and μ-AES image of Ti atoms (b) at the same position in 3μm wide copper line.

Figure 2 shows an EBSD grain boundary image of a 3μm wide line (a), and a μ-AES image (b) of the same region. Figure 2(a) illustrates the Σ3 twin boundaries with red lines and the random grain boundaries with black lines. It was found that Ti atoms diffuse through random grain boundaries and that twin boundaries are not the main diffusion path.

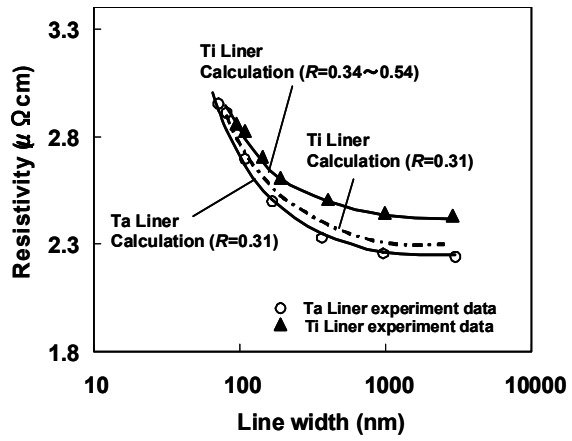

Fig. 3. A comparison of the experimental and the calculation results of the copper lines with Ta and Ti liner. In case of Ti liner, the fitting results with assumption that grain boundary scatter coefficient (*R*) changed from 0.34(narrow line) to 0.54(wide line) shows good agreement to the experimental results.

Table 1. Fitting parameters for resistivity model

	Ta Liner	Ti Liner
R	0.31	0.34～0.53
p	0.0	0.0
λ (nm)	39.0	39.0
c	1.2	1.2
ρ_0 (μΩcm)	1.963	1.963

We analyzed the influence of copper grain sizes on line resistivity using Fuchs-Sondheimer (FS) and Mayadas-Shatzkes (MS) models [10,11]. Figure 3 shows a comparison of the experimental and calculated results of the copper line resistivity. It was found that the resistance in copper lines with Ti liner is higher than that with Ta liner. The difference of the resistance between the two liners is particularly large for wider lines. The fitting parameters of the resistivity model are listed in Table 1. Here, p is a surface scattering coefficient, R is a grain boundary scattering coefficient, and λ is the average mean free path of the electron.

In the case of the Ta liner, the calculation result shows good agreement with the experiments as shown in Fig. 3. However, when the grain boundary scattering coefficient R is kept constant (R=0.31), the calculation of the Ti liner is much different from the experimental result although the smaller grain size is consistent. The analysis of Ti in the copper surfaces by μ-AES showed that the Ti atoms diffuse easily through random grain boundaries and accumulate at the grain boundary. Therefore, it is thought that Ti influences electron scattering at grain boundaries in the copper line. Assuming the grain boundary scattering coefficient (R) is changed from 0.34 (narrow line) to 0.54 (wide line), we can obtain a good fit to the experimental result as shown in Fig. 3.

Figure 4 shows the line width dependence of grain boundary scattering coefficient (R) used for the fitting of the resistivity. Moreover, this figure shows the Ti liner thickness at the trench bottom. Figure 4 exhibits that the line width dependence of the grain boundary scattering coefficient is almost the same as that of the Ti thickness at the trench bottom. Then, we can suppose

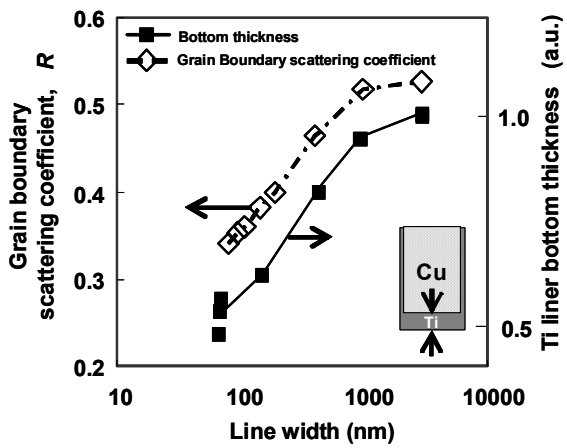

Fig. 4. Line width dependence of bottom thickness of Ti liner, t and grain boundary scattering coefficient, R

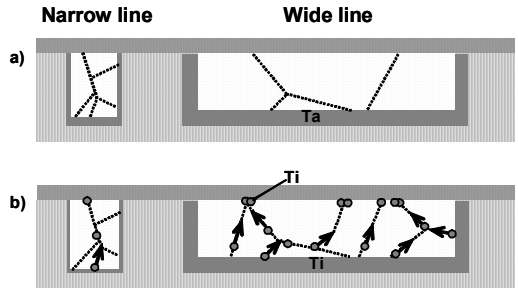

Fig. 5. Model of Ti diffusion and copper recrystallization in the case of Ta liner (a) and Ti liner (b).

that more Ti atoms are supplied to the copper in the wider line by diffusion from the bottom through the grain boundary. In addition, the smaller grain size relative to Ta liner may cause the enhanced diffusion path in Ti liner lines. Thus, it can be assumed that the accumulation of Ti at the grain boundary causes the large grain boundary scattering coefficient in wide lines as illustrated in Fig. 5.

4. Conclusions

The grain size and Ti distribution in the copper interconnects using the Ti liner were investigated by EBSD and μ-AES methods. It was found that the grain size with the Ti liner is smaller than that with Ta liner in wide lines. The μ-AES observation revealed that Ti atoms diffuse through random grain boundaries, but that twin boundaries are not the main diffusion path. The phenomenon of resistivity increase in copper lines with Ti liner was analyzed using the line resistivity model. The result showed that the resistance increase can be explained by combining the decrease in the grain size with the increase in the grain boundary scattering coefficient. This work clearly demonstrated that the influence of dopant atoms upon grain boundary scattering coefficient is the key issue for modeling the resistivity of copper alloy interconnects.

References

[1] S. Yokogawa, *et al*. *Proc. of* IRPS (2006) p667-668.
[2] M. Abe, *et al*. *Technical digest of* IEDM (2005) p77-80.
[3] S. Yokogawa, *et al*. *Technical digest of* IEDM S4P1 (2006) p1-4.
[4] Y. Igarashi, *et al*. J. Vac. Sci. Technol. B16(2006) 2745.
[5] M. Ueki, *et al*. *Technical digest of* IEDM (2002) p749 - 752.
[6] K. Ito, Jpn. J. Appl. Phys. Vol. 46, 4B (2007), 1942–1946.
[7] K. Hinode, *et al.* Jpn. J. Appl. Phys. Vol. 40 (2001), L1097.
[8] H. Kitada, *et al*. MRS Symp. *Proc.* 990 (2007)0990-B09-08.
[9] H. Kitada, *et al*. *Proc. of* IITC (2007) p10-12.
[10] A. F. Mayadas and M. Shatzkes, Phys. Rev. B1 (1970) 1384.
[11] E. H. Sondheimer, Phys. Rev.80 (1950) 401.