Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 1022-1023

G-8-2 (Invited)

Defects in Electroplated Cu and their Impact on Stress Migration Reliability

A. Uedono[1], T. Suzuki[2], T. Nakamura[2], T. Ohdaira[3] and R. Suzuki[3]

[1]Institute of Applied Physics, University of Tsukuba, Tsukuba, Ibaraki 305-8573, Japan
[2]Semiconductor Technology Academic Research Center (STARC),
17-2, Shin Yokohama 3-chome, Kohoku, Yokohama, 222-0033 Japan
[3]National Institute of Advanced Industrial Science and Technology (AIST)
1-1-1 Umezono, Tsukuba, Ibaraki 305-8568, Japan

1. Introduction

Copper interconnects are replacing aluminum-based wiring in the fabrication of deep sub-micron integrated circuits because of copper's low resistivity and better electromigration properties [1]. The microstructure and texture evolution of electroplated Cu have been extensively studied, because they are critical factors affecting the ability to fill damascene architectures without voids and obtain good electrical characteristics and high reliability. The interaction between impurities or their by-products, however, is expected to lead to microstrains or dislocations in the films, which may drive or retard the recrystallization process. Point defects, such as monovacancies or small vacancy clusters, are also expected to play an important role, but their behavior is not fully understood. Positron annihilation is one established technique for investigating defects in metals [2]. Point defects in electroplated Cu have been investigated using this method [3,4], and the results show that positrons are a useful probe for studying vacancy-type defects in Cu films. In the present study, we used a monoenergetic positron beam to probe vacancy-type defects in electroplated Cu films.

When a positron is implanted into condensed matter, it annihilates with an electron and emits two 511-keV γ rays [2]. Those annihilation γ rays are broadened because of the momentum component of the annihilating electron-positron pair. A freely diffusing positron may be localized in a vacancy-type defect because of the Coulomb repulsion from ion cores. Because the momentum distribution of electrons in such defects differs from that in bulk materials, one can detect these defects by measuring the Doppler broadening spectra of annihilation radiation. The resultant change in the Doppler broadening spectra is characterized by the *S* parameter, which mainly reflects the change due to the annihilation of positron-electron pairs with a low-momentum distribution [2].

2. Experiment

The sample structure used in the present experiments was Cu/Ta(20nm)/SiO_2(100nm)/Si. Cu films were electroplated at room temperature with three different types of electrolytes [5]. In this article; the electrolytes were referred as "chemistry1", "chemistry2", and "chemistry3", respectively. The impurities in the Cu films were measured by SIMS (Fig. 1). For SIV tests, a two-level via chain structure was fabricated. A dual damascene process was used to fabricate lines and vias; where the width of M1 and M2 lines were 10 μm and 0.8 μm, respectively. The samples were kept in the furnace at 150°C and 200°C. The failure criterion was set to 10% relative resistance increase from the initial value. The results are also shown in Fig. 1.

We used a monoenergetic positron beam to measure the Doppler broadening spectra of the annihilation radiation as a function of the incident positron energy *E* [2,3]. The measured spectra were characterized by the *S* parameter.

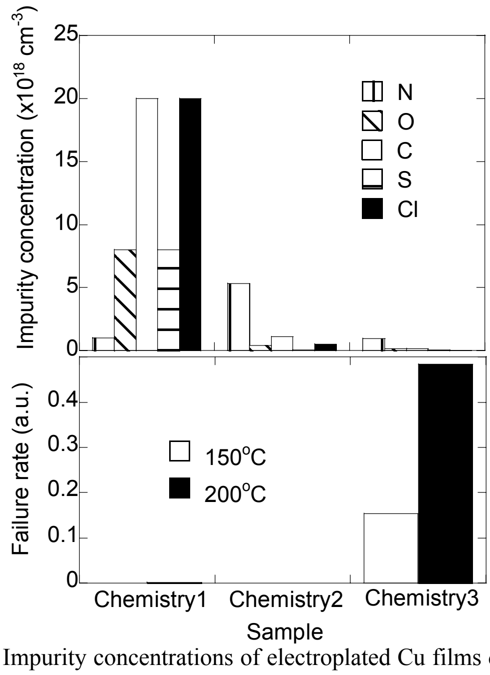

Fig. 1 Impurity concentrations of electroplated Cu films deposited by different chemicals (E1, E2, and E3) and their failure rates of SIV tests.

3. Results and Discussion

Figure 2 shows the time dependence of both *S* and conductivity for the 1- and 2-μm Cu films deposited using E1 (time zero corresponds to the deposition time). The behavior of *S* was similar to that of the conductivity. The *S* values of the two samples were almost identical just after the deposition, suggesting that the annihilation characteristics of positrons in the two Cu films were the same before grain growth. The increase in the *S* value can be attributed to the increase in the fraction of positrons annihilating in vacancy clusters in grains [3,4]. The saturated *S* value for the 1-μm Cu film was larger than that for 2-μm Cu film, suggesting the increase in the size of the vacancy clusters. Figure 2 summarizes the relationship between the *S* value and the thickness of Cu films. Since the 0.5-μm Cu films were not fully crystallized after self-annealing, positron annihilation in the non-crystalline region affected the *S* values. For thicker samples, the *S* value and the conductivity decreases with increasing the film thickness. An impact of grain boundaries on the electrical properties is expected to be larger than that of defects in the grains. Thus, the increase in the size of vacancy cluster is considered to decrease the scattering probability of electrons at the grain boundaries.

In order to know the interaction between vacancy clusters and impurities, the annealing experiments of the Cu films deposited using different chemicals were performed (Fig. 4). The results for the annealed and deformed pure Cu samples are also shown. For the sample deposited using E1, the largest *S* value was obtained after annealing at 200°C. The *S* value started to decrease with annealing above 300°C, and it appears to saturate at 600-700°C. It is known that the annealing behavior of defects in Cu irradiated with light particles (electrons, neutrons, and protons) can be divided into five stages [6]. Stage V (~300°C) is the final annealing stage of defects introduced by the irradiation. Thus, the decrease in *S* was observed at stage V, which can be attributed to the dissociation of vacancy clusters. For the Cu films deposited using E2 and E3, however, the *S* value was smaller than that for the sample deposited using E1, and no clear decrease in the *S* value at stage V was observed. Thus, it can be concluded that the increase in the impurity concentration causes the increase in the mean size of vacancy clusters. This can be attributed to the pining of vacancies in the grains, and a resultant agglomeration of such defects. As shown in Fig. 1, the failure rate was small for the sample fabricated using E1. Thus, the suppression of the diffusion of vacancies towards the grain boundaries by impurities is considered to be a key parameter to decrease the resistivity and reliability of interconnects. In Fig. 3, the resistivity also decreases with increasing the size of defects. The slow grain growth could increase the interaction probability between vacancies and impurities. As a result, the impurity concentration at the grain boundaries could decrease, and could be an origin of the obtained low resistivity. The information about the defects in grains obtained here will be useful in developing device processes for the fabrication of Cu interconnections.

References

[1] J. Reid, Jpn. J. Appl. Phys. **40**, 2650 (2001).

[2] P. Hautojärvi, *Positron in Solids*, Topics in Current Physics **12** (Springer-Verlag, Berlin, 1979).

[3] A. Uedono, T. Suzuki, and T. Nakamura, J. Appl. Phys. **95**, 913 (2004).

[4] A. Uedono, T. Suzuki, T. Nakamura, T. Ohdaira, and R. Suzuki, J. Appl. Phys. **98**, 043504 (2004).

[5] A. Hobbs, S. Murakami, T. Hosoda, S. Ohtsuka, M. Miyajima, S. Sugatani, and T. Nakamura, Mater. Trans. **43**, 1629 (2002).

[6] S. Mantl and W. Triftshäuser, Phys. Rev. B 17, 1645 (1978).

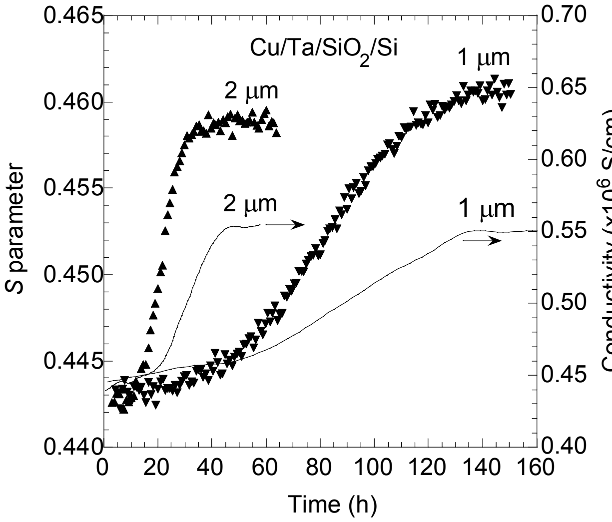

Fig. 2 Time dependence of *S* and the conductivity for 1- and 2-μm Cu films (deposited using E1) measured during self annealing.

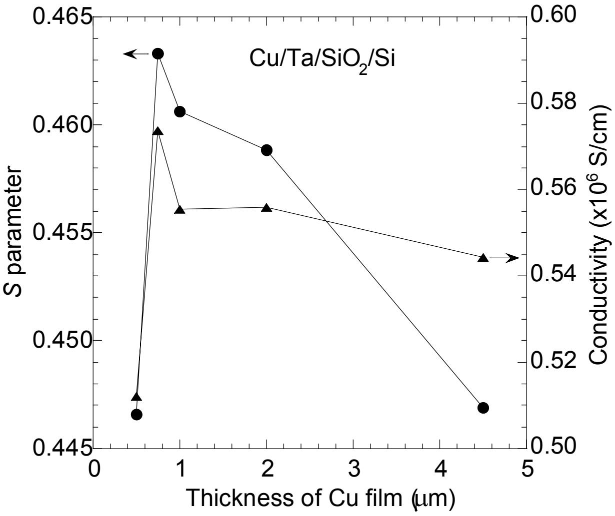

Fig. 3 *S* and the conductivity for Cu films deposited using E1.

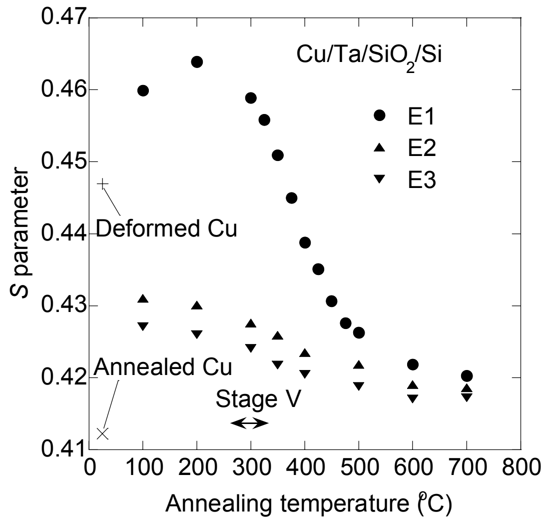

Fig. 4 Annealing behavior of the *S* value for 2-μm Cu films. The temperature range corresponding to the recovery stage V for pure Cu is indicated in the figure.