Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp447-448

Temperature and Humidity Accelerations to Establish Lifetime Prediction Model for Cu-based Metallization

Ploybussara Gomasang[1], Satoru Ogiue[1], Shinji Yokogawa[2], and Kazuyoshi Ueno[1, 3]

[1] Graduate School of Engineering and Science, Shibaura Institute of Technology (SIT), Koto, Tokyo, 135-8548, Japan
[2] Info-Powered Energy System Research Center, The University of Electro-Communication, Chofu, 182-8585, Tokyo, Japan
[3] SIT Research Center for Green Innovation, Koto, Tokyo, 135-8548, Japan
Phone : +81-3-5859-8330 E-mail: ueno@shibaura-it.ac.jp

Abstract

To establish the lifetime prediction model for Cu-based metallization against moisture, temperature humidity storage (THS) tests under various acceleration conditions are performed to measure the Cu sheet resistance change with the Cu oxidation by four-point probe method. The activation energy and the humidity acceleration factor for Cu-based metallization has been derived by the statistical analysis for the first time. It is found that the Cu metallization is more sensitive to the temperature than the humidity in moisture.

1. Introduction

Long lifetime of Cu-based metallization used in LSIs, especially storage class memories (SCMs) [1], is essential for long-term storage of digital data in an environment. To test the long-term reliability, temperature humidity storage (THS) test under the acceleration condition has been adopted for LSIs.

The lifetime of THS reliability has been predicted based on the Peck's model [2] mostly for LSIs with Al-based metallization, however, the prediction model for Cu-based metallization is lacking. We found that the accelerated humidity conditions of the THS test over 85% relative humidity (RH) at 85°C which is used for Al-based metallization were not appropriate for Cu-based metallization because of the nonlinear humidity dependence of Cu sheet resistance change due to the rapid change of Cu oxide structure during THS test [3].

This work proposes to establish the practical model for lifetime prediction of Cu-based metallization with testing at lower acceleration conditions than 85°C/85% RH corresponded to the real usage of passivated Cu.

2. Experimental Methodology

100-nm-thick Cu film was deposited on 2×2-cm-size SiO_2/Si substrate using DC magnetron sputtering at 200°C to complete the Cu grain growth for stabilizing the initial sheet resistance. To measure the change of Cu sheet resistance in various accelerated conditions, a couple of Cu film samples were kept in a THS chamber for testing the temperature dependence (85, 75, and 65°C) at fixed 75% RH and the humidity dependence (75, 65, and 55% RH) at fixed 85°C. During the THS test, the sheet resistance of each Cu film sample was measured by four-point probe method after 25, 50, 100, and 200 h and normalized by its initial sheet resistance.

Moreover, after 200 h of the THS test, each Cu sample was analyzed by X-ray photoelectron spectroscopy (XPS) to obtain the depth profiles of Cu and oxygen (O) [4] to investigate the reason for the difference in sheet resistance. The Cu LMM Auger peak was also observed to determine the interface between the metallic Cu and the Cu oxide layer [5].

The Cu lifetime prediction model was acquired by the correlated statistical models for lifetime acceleration. The important parameters of the derived model for Cu lifetime prediction were compared with reported values for LSIs with Al-based metallization.

3. Results and Discussion

3.1. Sheet Resistance Measurements

Fig. 1 shows the time evolution of normalized sheet resistance (R) for each Cu film sample under the THS test. In the temperature dependence, the resistance increase rate clearly increased with increasing the temperature. On the other hand, only tiny difference in R was observed in the humidity dependence. The results indicate that the increase of Cu sheet resistance is more sensitive to the temperature than the humidity.

3.2. XPS Analysis

Fig. 2(a) shows the XPS depth profiles of Cu and O for the different acceleration temperatures after 200 h of THS tests. In Fig. 2(a), the interface of Cu/Cu_2O, which was determined by the Cu LMM Auger region (Fig.2(b)), is also indicated. From Fig. 2(a), the thickness of Cu oxide increased as the test temperature increased as schematically shown in Fig. 3. The results accord with the temperature dependence of R. Therefore, oxidation of Cu is considered as the reason for the resistance increase.

3.3 Lifetime Prediction Model

We propose the lifetime prediction model based on the Peck's model which is composed of the following dependencies on the time, temperature, and humidity [6], as in eqs. (1) to (3), respectively. Total model is shown in eq. (4).

Time (Power law): $$R \propto t^{n} \tag{1}$$

Temperature (Arrhenius law): $$R \propto \exp\left(\frac{E_a}{kT}\right) \tag{2}$$

Humidity (Power law): $$R \propto RH^{m} \tag{3}$$

$$R \propto \exp\left[n\ln(t) - \frac{E_a}{kT} + m\ln(RH)\right] \tag{4}$$

Here, t and n in eq. (1) are time and law's exponent, respectively. E_a , k, and T in eq. (2) are the activation energy, Boltzmann's constant, and temperature, respectively. In eq. (3), m is law's exponent.

With the statistical analysis by fitting the measured resistance increase with the time, temperature, and humidity, the following model was obtained as eq. (5).

$$R = \exp\left[1.708 + 0.039\ln(t) - \frac{0.062}{kT} + 0.056\ln(RH)\right] \quad (5)$$

Fig. 4 shows the relationship between observed R and predicted R. This prediction model seems to be reasonable by the coefficient of determination (R2) that is closed to 1 (~0.984).

To compare the necessary parameters of this Cu lifetime prediction model with those of Al-based metallization (Peck's model; Eyring model) [2], eq. (5) is then modified to Peck's model about the fixed R, as shown in eq. (6).

$$TTF = A_0(RH)^{-1.436}\exp\left(\frac{1.59}{kT}\right) \quad (6)$$

TTF and A_0 are time to failure and arbitrary scale factor, respectively. The modified Peck's model for Cu film (E_a = 1.59 eV and m = 1.436) is larger in the activation energy and smaller in the humidity acceleration factor than the reported parameters for LSIs using Al-based metallization (E_a = 0.79 eV and m = 2.66) [7]. Although further studies are required, the results suggest that different model parameters will be necessary for the lifetime prediction of LSIs using Cu-based metallization.

4. Conclusions

Based on the temperature and humidity dependence of Cu resistance increase during the THS tests, the lifetime prediction model for Cu film against moisture has been proposed. The increase of Cu oxide thickness measured by XPS depth analysis corresponds to the increasing of sheet resistance. It is also found that the increase of Cu sheet resistance by oxidation is more sensitive to the temperature than the humidity. Our results suggest that different parameters of Peck's model will be required for the lifetime prediction of LSIs with Cu-based metallization in the THS reliability tests.

Acknowledgements

This work was supported by CREST, JST. Grant Number JPMJCR1532. A part of this work was supported by JSPS KAKENHI Grant Number JP17H06293 and JP15H01786. This presentation was supported by SIT Res. Ctr. for Green Innov.

References

[1] I. F. Adams *et al.*, Tech. Report UCSC–SSRC–11–07 (2011).
[2] O. Hallberg and D. S. Peck, Qual. Reliab. Eng. Int. **7** (1991) 169.
[3] P. Gomasang *et al.*, *IEEE International Interconnect Technology Conference* (2018).
[4] H. Bubert *et al*., Fresenius J. Anal. Chem. **353** (1995) 456.
[5] M. C. Biesinger, Surf. Interface Anal. **49** (2017) 1325.
[6] J. W. McPherson, *Reliability Physics and Engineering* (Springer, New York, 2010) p.5.
[7] D. S. Peck, *IEEE International Reliability Physics Symposium* (1986) 44.

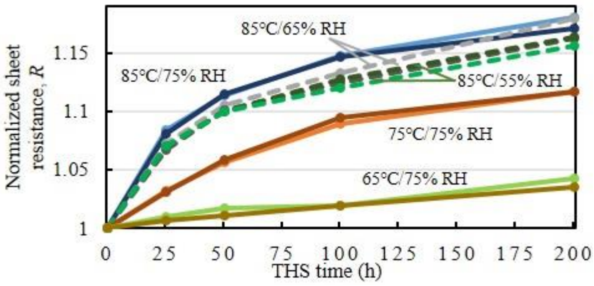

Fig. 1. Time evolution of the normalized sheet resistance (R) during THS test.

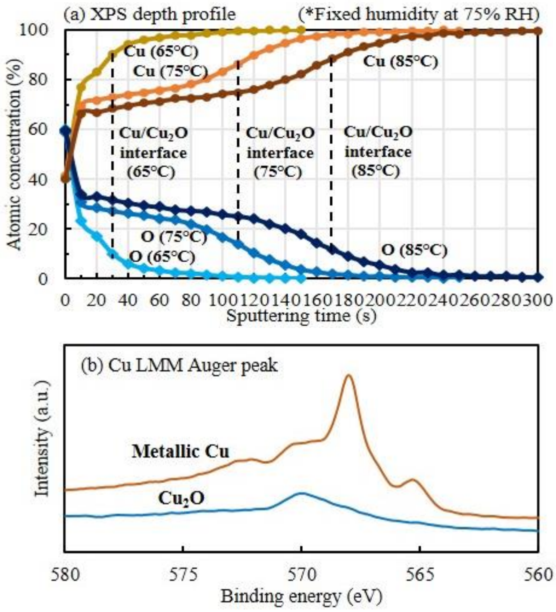

Fig. 2. (a) XPS depth profiles and (b) Cu LMM Auger peaks of Cu and Cu_2O.

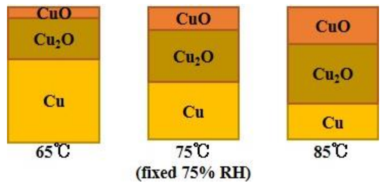

Fig. 3. Schematic model to explain the difference of Cu thickness in the temperature dependency.

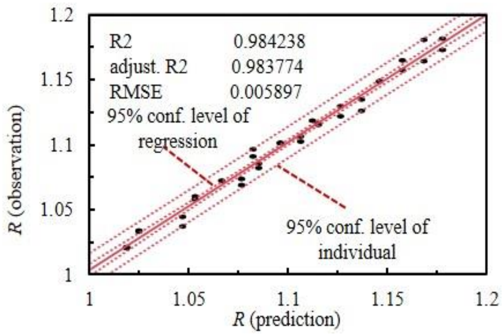

Fig. 4. Correlation accuracy between observed normalized sheet resistance and prediction, indicating very good accuracy of the model.