Extended Abstracts of the 2005 International Conference on Solid State Devices and Materials, Kobe, 2005, pp.56-57

C-1-4

A Novel Short-time Characterization Method of SIV Properties by Using the Empirical Equation

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Introduction

Stress Induced Voiding (SIV) has been recognized as one of the controversial reliability issues for Cu interconnects integration. Kinetic phenomenon regarding SIV in Cu interconnect has been extensively studied in the past two decades, and SIV failure is regarded as a failure mode of resistance increase depending on geometrical features and microscopic properties, e.g. metal line width, via location, grain structure, diffusivity and atomic transportation [1]. In recent years, advanced studies for quantification of SIV properties have been conducted by quantitative evaluation supported by experimental and computational works for controlling SIV failures [2, 3]. From a viewpoint of reliability, however, the engineering notation of SIV property has not been completely established yet.

Also, ULSI's development has been recently engaged with application of low-k material for interconnects dielectric layer (ILD), aiming at decrease of RC delay. Because of higher thermal expansion coefficient with lower Young's modulus, however, evaluations under thermal stress had technical difficulties in deciding stress temperatures, and which would result in essential issues on SIV evaluation at lower temperature and long time analysis. Therefore, the establishment of SIV characterization method achieving short turn around time evaluation is eagerly required for further experimental works for efficient improvements in Cu interconnect development.

Experiments

In this work, time evolutional SIV (TE-SIV) testing [2, 3], resistance shift caused by stress storage time, was characterized from 175 to 400 ℃ thermal stress. Resistance measurement was performed at the same stress temperature. SIV failure was evaluated by more than 5% increase of resistance shifting in this work. A two-layer Cu dual damascene structure was fabricated by 0.13um process for this work: TEOS/FSG for ILD layer, SiN for trench-stopper layer and Ta/TaN for barrier metal layer. A test structure of via chains was intentionally used, e.g. via landing upon wide lower metal, connected onto narrow upper metal, illustrated in Fig.1. Impacts on SIV failure were quantitatively analyzed in the function of size of lower metal W (from 0.5 to 10um) and of via size ϕ (from 0.18 to 0.24um).

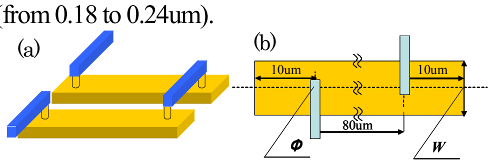

Fig.1 Schematic image of test structure of this work: (a)three dimensional view and (b) plain view.
Lower wide large metal has dimension of the value: W multiplied by 100 um. Two vias were separated by 80um for avoidance of resonance of void growth. Upper narrow metal has width as 0.2 um and length as 15 um. Also, via size Φ is 0.2 um as default value.

Results and Discussion

Acceleration on temperature :

Dependency of SIV property on the thermal stress was shown in Fig.2. At each temperature, from 175 to 400 ℃, the test samples were failed according to lognormal distribution. Mean Time-to Failure (MTF) had a tendency of inverse proportion to stress temperatures, as seen from Fig.2. Also, failure scattering trend had no correlation with stress temperature. According to reports [1, 6], SIV dependence on stress temperature was observed as a two-mode characterization, e.g. Cu migration regime and tensile stress regime. However, a report [4] concludes that SIV property on stress temperature was based on linear trend. Our experimental results showed that property of SIV failure was ruled by general failure on lognormal distribution but did not depend on stress temperatures.

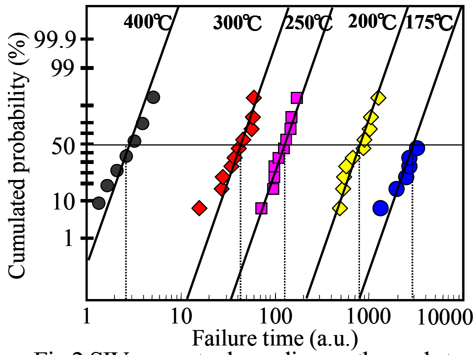

Fig.2 SIV property depending on thermal stress.

Besides, the results mentioned above suggested that the activation energy Ea by MTF can be precisely evaluated, and the activation energy of Cu atoms was experimentally derived as 0.8eV. The activation energy was equivalent to activation energy of the diffusion at Cu-SiN interface [5], and the failure caused by void growth was observed at via bottom as shown in Fig.3. Hence, it was numerically clarified that the diffusion path of Cu atoms inducing SIV was dominant at the diffusivity of Cu-SiN interface. Accordingly, it was verified that our fundamental SIV testing evaluated SIV failure quantitatively.

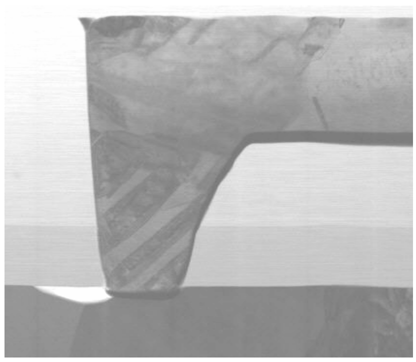

Fig3. Cross-sectional view of SIV failure at 250 ℃. The failure is observed at MTF.

SIV properties induced by design dimension：

MTF according to a lower metal width W was evaluated by TE-SIV to different process A and B. In case of process A, the conformality of barrier metal layer is sufficient. However, in case of process B, it is insufficient, especially at the bottom of vias. MTF had a tendency of inverse proportion to the impact of width W as shown in Fig.4.

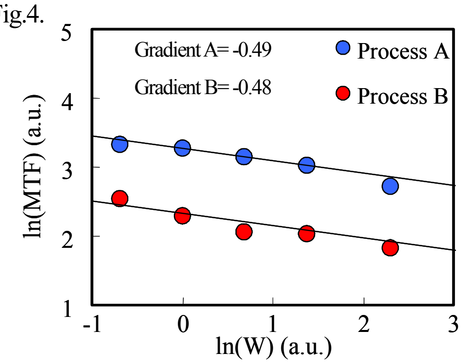

Fig.4 Dependence of SIV degradation on lower metal width W. The grandniece was no correlation with process.

However, the overall trend was shifted lower in process B, compared to the result of process A.

From a point of view of functional approximation, it was found out that the degradation property was based on the following function, not depending on process A neither B.

$$MTF = A \cdot \frac{1}{\sqrt{W}} \qquad \text{Eq.(1).}$$

Here, A and W denote constant value and width of wide lower metal, respectively. Hence, fundamental property depicted by Eq.(1) was formulated, and the property also did not depend on the process in which only MTF value was different. Therefore, it was clarified that the impact on lower metal width to SIV failure could be formulated as an eigen-function according to MTF: SIV degradation function.

As for via size, the SIV function could be experimentally derived as Eq.(2).

$$MTF = A' \cdot \phi^2 \qquad \text{Eq.(2).}$$

Here A' and ϕ denote constant value and via size, respectively. The trend of SIV degradation has been explained [1], due to the definition of via size for open failure. The tendency was identified with our experimental results. Accordingly, by using Eq.(1), Eq.(2) and the Ea from Fig.2 under an assumption of independent factor between W and ϕ, SIV degradation function was expressed by Eq.(3).

$$MTF = B \cdot \frac{\phi^2}{\sqrt{W}} \cdot \exp\left(\frac{Ea}{kT}\right) \qquad \text{Eq.(3).}$$

SIV general degradation function of design impacts could be experimentally resolved by our schematic derivation.

Characterization of SIV by empirical equation:

From the former equations derived by experimental works, Geometric Acceleration Factor (GAF) was contrived by characterization of SIV, and which would be applied for MTF calculations to specific test structure.

$$G(X_{cal}) = \frac{g(X_{cal})}{g(X_{emp})} \qquad \text{Eq.(4).}$$

Here, function g, X_{cal} and X_{emp} denote SIV eigen-function, design parameter to be calculated, such as W in Eq.(1), and the parameter to be experimentally evaluated, respectively. Conventional studies were only evaluated by SIV failure rate. However, the GAF could work as a resolution to estimate SIV tolerance of test structure characterized by parameter X_{cal}, by means of simple functional analogy.

$$MTF_{cal} = MTF_{emp} \cdot G(X_{cal}) \qquad \text{Eq.(5).}$$

Furthermore, Eq.(5) played a quite important role in SIV testing in short turn around time. Fig.5 showed acceleration ratio by test pattern of lower wide metal width W. SIV testing even at 175 ℃ could be improved by seven times acceleration efficiency, and which would be expected as a novel characterization method attained by Eq.(5) for SIV degradation.

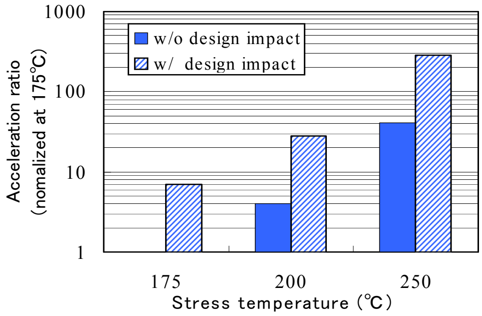

Fig.5 Effect of acceleration ratio applied by design dimensional factor: width of lower large metal W, and stress temperature. The effect of W was conventionally expressed by Eq.(1), for the impact of W=10um toward W=0.2um.

These results and empirical function are one methodology based upon time evolutional analysis of SIV degradation quantitatively. For further experimental works targeting on low-k electronic devices in which SIV cannot be evaluated at high temperature, intentional use of test structure inducing design impact would provide one possibility to test rapidly even at low temperature, and of course, in short turn around time. And for further scaling-down devices, our method would evaluate higher impacts on SIV tolerance to specific design dimension by empirical calculation. Therefore, it is concluded that our SIV characterization method based on TE-SIV and empirical equation, has been pretty promising for further SIV analysis.

Conclusions

We have studied a novel characterization method of SIV failure in short turn around time by using empirical equation. A methodology has been contrived, based on the intentional evaluation of an accelerating pattern characterized by SIV's induction in short time. And SIV degradation function has been successfully derived by our experimental works. It is clarified that the function, which depends on geometric feature, can be applied for estimating SIV tolerance in short turn around time compared with conventional works and is a promising analysis of SIV properties for further Cu-interconnect reliability.

References

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