Extended Abstracts of the 1998 International Conference on Solid State Devices and Materials, Hiroshima, 1998, pp. 268-269

Thermal and Bias-Temperature Stress Induced Leakage Current Failure of Cu/BCB Single Damascene Integration

Sang U. Kim* , Taiheui Cho+, and Paul Ho+
Advanced Technology, SEMATECH, 2706 Montopolis, Austin, Texas 78741-6499, USA
Phone: (512) 356-7468, Fax: (512) 356-7668, E-mail: sang.kim@sematech.org
* on assignment from Intel Corporation, +U of Texas, Material Science and Eng

1. Introduction

In recent study[1], the thermal stability of BCB (benzocyclobutene) was improved at 400C for a potential application to advanced interconnect technology. However, the thermal stability of a Cu/BCB integration has not been reported. The thermal stability behavior of Cu/BCB was quite different from BCB film. In this study, it was found that Cu/BCB is stable only up to 250-300C under thermal stress. The leakage current failure occurred at $T \geq 250$-300C. The Cu/BCB also failed very rapidly under B-T stress. Electrical and physical analysis was performed to identify the nature and cause of the thermal and B-T stress induced leakage current failures. These include EBIC (electron beam induced current) and FIB (focused ion beam) X-section through the EBIC emission site. From these results, a model for thermal and B-T stress induced leakage current failure mechanism was proposed.

2. Stress Results

The leakage current was measured using a large area ($1.2 cm^2$) comb test structure with 7 meters long comb lines. The Cu line to line spacing is ~ .35 um and Cu line width is .4 um. Cu thickness is .7 um. Ta barrier with 20 nm is used. The test structure was capped with a 10 nm thick nitride layer. Cu/BCB single damascene process was used. The Cu line to line leakage current, I_L was very low, less than 10 nA at room temperature, but it failed under thermal stress. The bake temperature was raised from 200C to 450C in 50C increments. I_L-1/T is shown in Fig.1. Devices fails at $T_L \geq 250$-300C. The curve can be divided into two regions. 250-300C is a transition temperature of the leakage current, dubbed T_L. I_L surges abruptly at $T \geq T_L$ or it fails.

The following B-T stress conditions were used: a constant electric field equal to .5MV/cm and four temperatures; 150C, 190C, 230C and 270C. The B-T stress was continuously on until device became breakdown. The breakdown current was defined as $I_L \geq 100$ua at V_L=1V. Breakdown characteristics are shown in Fig. 2. Breakdowns occur at 34 hr for 150C, at 4 hr for 190C, 36 min for 230C, and 11 min for 270C. The breakdown occurs rather rapidly. From Arrhenius plot, thermal activation energy equal to .91ev, associated with the B-T stress induced leakage current failure for Cu/BCB, was obtained.

3. EBIC Analysis and FIB X-section

One of the B-T stress induced broken down devices was EBIC analyzed. A high magnification of EBIC emission site is shown in Fig. 3. It is clearly seen that the hottest emission site occurs between the two Cu lines. FIB X-section was performed across the brightest emission site. This is shown in Fig. 4. The thin nitride layer between the affected two Cu lines is partly melted away due to excessive Joule heating caused by the high current flow as a result of B-T stress induced breakdown. Enormous current flows at the breakdown of the very small, localized defect site. The BCB film between the two Cu lines, however, appears to be intact. It means that the damage seen is caused by the surface leakage current flowing along the nitride-BCB interface, not by the bulk leakage current inside the BCB film. The Ta barrier at the top surface edge of the Cu line at the top right hand corner as pointed by an arrow looks partly missing or damaged. Such damages in Ta barrier may have occurred during the Cu/BCB damascene process.

4. A proposed Failure Mechanism

A proposed leakage mechanism model for B-T stress induced leakage current failure is schematically shown in Fig.5. Cu ions are initially injected from the positive Cu electrode through a localized surface defect as shown by EBIC, and drift towards the ground electrode under the bias field and temperature, and accumulate near the electrode. This results in an internal field, E_i to develop. As a result, two field regions, R1 and R2 are being developed. In R2, the external and internal fields enforce each other, resulting in a stronger field, while in R1, they oppose each other, resulting in a weaker field. Cu ions initially drift very rapidly and then slow down because of build-up of the retarding field. The leakage current results from electrons injected from the ground electrode because of the high field in region R_2. The electron injection mechanism is most likely due to trap assisted tunneling through grain boundaries of Ta barrier layer. As electrons drift towards the positive electrode, the retarding field in region R_1 is reduced through charge neutralization. This causes an enhanced Cu^+ injection to occur, which in turn leads to more electron injection in R_2. The regenerative process continues until the breakdown occurs. The model is similarly applicable to the case of thermal stress except that the process is much slower.

5. Conclusion

The transition temperature of leakage current failure, T_L equal to 250-300C for Cu/BCB under thermal stress is too low to be compatible with advanced CMOS technology. The rapid degradation of B-T stress induced breakdown failure poses a potential reliability exposure. In order to alleviate the leakage current failure, the localized surface defects must be under control. Thermal stability of Cu/other low K material warrants further study to validate the similar T_L behavior.

References

[1] G. Passemard, F. Pires, et al., 1998DUMIC Conference, P31-37.

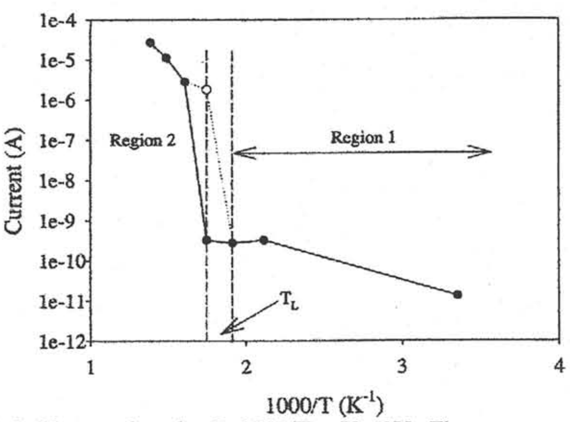

Fig. 1; I_L-V_L was plotted as I_L-1000/T at V_L=3V. The curve can be divided into two regions: region 1 (low temperature, 25-250C) and region 2 (high temperature, 300-450C). 250-300C is a transition temperature of the leakage current, T_L. The leakage current surges above T_L or it fails.

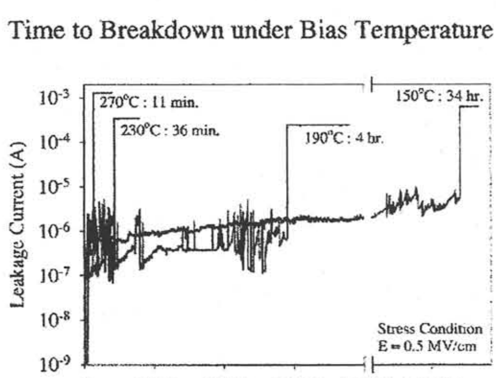

Fig. 2; B-T stress induced breakdown characteristics. Breakdown occurs from 34 hr for 150C to 11 min for 270C.

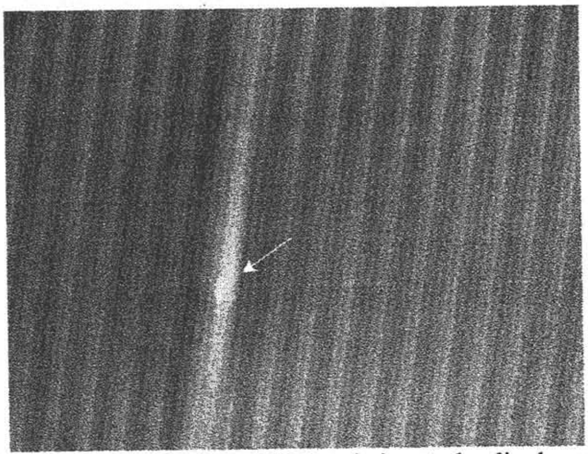

Fig. 3; A high magnification of EBIC emission at a localized, small defect site. The hottest emission occurs between two Cu lines.

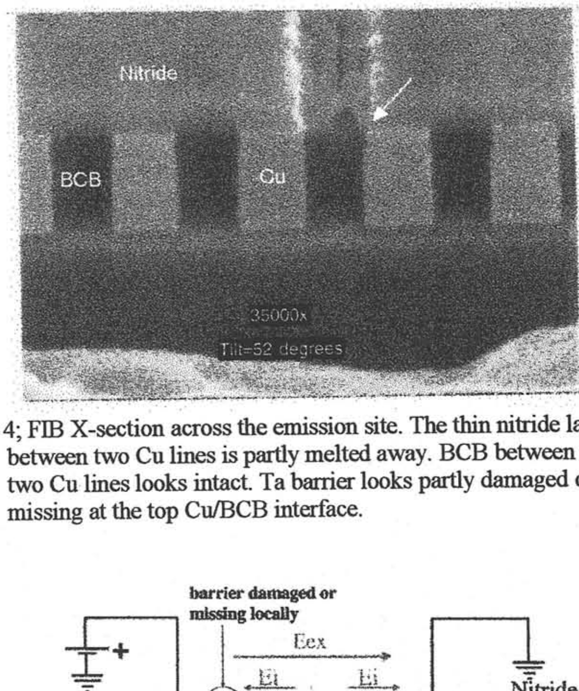

Fig. 4; FIB X-section across the emission site. The thin nitride layer between two Cu lines is partly melted away. BCB between the two Cu lines looks intact. Ta barrier looks partly damaged or missing at the top Cu/BCB interface.

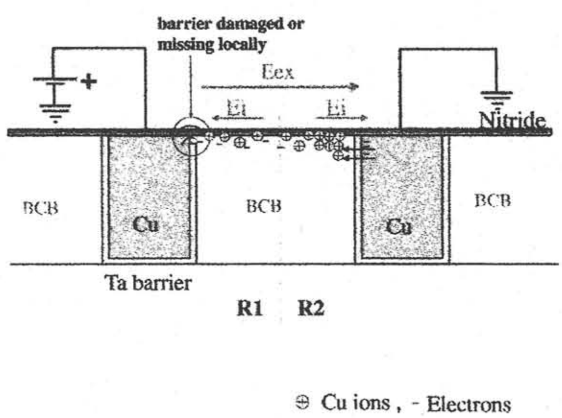

Fig. 5; A proposed model for B-T stress induced leakage failure mechanism.