Time-Zero Failure Current Measurement for Early Monitoring of Defective Cu Lines at Wafer Level

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With increase in density, interconnect dimensions are decreased and the number of metal level is raised. This will led to an increase of interconnect parasitics. Particularly the RC delay of the metal lines will become a limitation for the running of high-speed circuits. Thus the need for reduced resistance and capacitance interconnects has led to an evolution from Al-based to Cu based interconnect processes. However, the conventional electromigration test, which employs a constant current, requires too much measuring time for reliability monitoring especially Cu line. Therefore, it is necessary to have an in-line monitoring tool for metal line reliability to quickly feed back the results.

In our study, the measurement of time-zero failure current with a constant current ramping rate was proposed from the first-order Joule heating model as a new method of monitoring failures in Cu lines. This time-zero metal failure (TZMF) method was found to be in good agreement with experimental results.

The Cu line samples were prepared in the following sequence. A 600 nm-thick SiO_2 was deposited on a silicon wafer and a etch-stopping layer, SiON (50 nm) by a PE-CVD (plasma enhanced chemical vapor deposition) method was deposited. After a 400nm-thick SiO_2 with containing fluorine for low dielectric constant, so-called SiOF, was deposited by a HDP-CVD (high density plasma CVD) method, the damascened lines were then patterned. A TaN (25nm) for Cu barrier metal and Cu (100nm) for seeding layer were sequentially deposited by the IMP(ion metal plasma) sputtering methods. A Cu layer (70nm) by a electroplating method was additionally deposited and then Cu CMP(chemical mechanical polishing) process was performed after annealing (350 °C, 30 min, N_2). The TaN layer could be a good solution to obtain simultaneously a high selectivity during the Cu CMP. After depositing a SiON (50 nm) layer and opening pad contact area, the failure current (I_f) in the metal lines was measured using the TZMF method with a default ramping rate of 1 mA/s and a maximum ramping rate of 10 mA/s. The substrate temperature (T_{sub}) during the measurement ranged from room temperature to 220°C. In each TZMF experiment, 15 samples were tested and the median value of failure currents (median I_f) was obtained. The damascened Cu lines of 0.2 to 2.0-μm-wide and 500-μm-long were designed.

Fig. 1 shows the failure current as a function of substrate temperature for different line-widths. The TZMF test was performed with a 1 mA/sec ramping rate. The I_f^2 decreases linearly with increasing T_{sub}. The extrapolated values (T_m) for the axis of T_{sub} approach 720 °C. Because electroplating Cu could be contained impurities such as various additives for improving the surface morphology of electroplating Cu film, this value would be very lower than the melting point of pure Cu (1083 °C).

Fig. 2 shows the breakdown current as a function of ramping rate for Cu lines. The measurements were performed at room temperature. The I_f increases as the ramping rate increases. It is expected that a higher current ramping rate will not supply enough Joule heating and a lower current ramping rate will significantly occur the electromigration damage. Fig. 2 also shows two mode mechanisms of the breakdown current. Since we have to measure the breakdown current under a steady-state without electromigration damage, the current ramping which was chosen in the range from 0.5 to 1 mA/s will provide more reliable results.

Fig. 3 shows the measured failure currents and simulated fittings with our model as a function of metal-line width for the damascened Cu line. The TZMF test was performed with a 1 mA/sec ramping rate at 112 °C. The median I_f almost linearly increases as the line width increases when the metal width is larger than the metal thickness.

The failure current measurement by TZMF method has been found to be a good method for the in-situ monitoring and screening the early failure by the defective aluminum and copper lines.

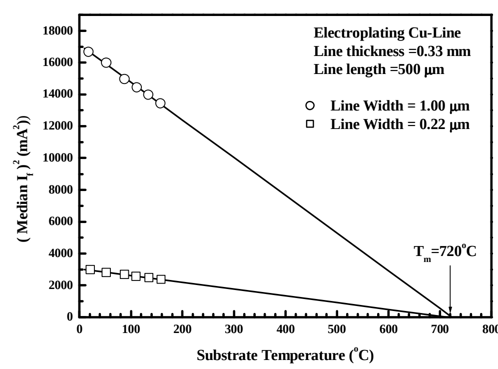

Fig. 1 Median failure current as a function of substrate temperature with two line-widths (0.22, 1.0 μm)

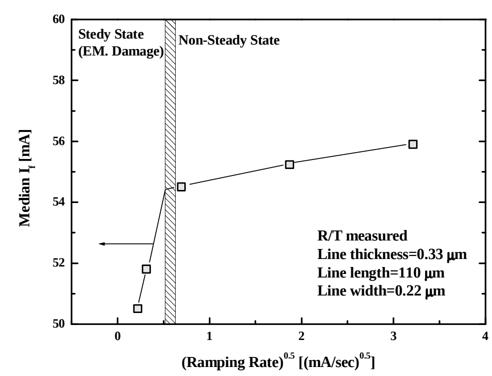

Fig. 2 Median failure current as a function of ramping rate.

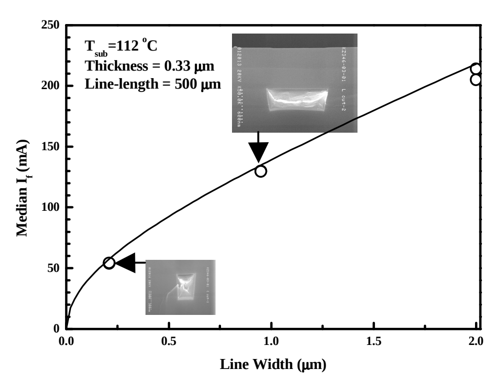

Fig. 3 Median failure current of metal lines with various Cu line widths The solid line is simulated failure current