INSIGHT INTO USING THE ELECTROMIGRATION BLACK EQUATION FOR MTTF ESTIMATES

MTTF Predictions Using The Black Equation

The Black equation[1,2] is widely use for making MTTF predictions in the literature. The time acceleration factor due the Black equation for current density and temperature between a stress and use condition is

$$AF = \left(\frac{J_{Stress}}{J_{Use}} \right)^N Exp\left\{ -\frac{E_a}{K_B} \left(\frac{1}{T_{Stress}} - \frac{1}{T_{Use}} \right) \right\} \qquad \text{(Eq. 1)}$$

Where

AF is the Acceleration factor between Stress and Use conditions
J is the current density
E_a is the thermal activation energy
K_B is Boltzmann's constant
T is the absolute temperature
N is the Current density exponent

If the $MTTF_{stress}$ at a stress condition is known, then the $MTTF_{use}$ at use is

$$MTTF_{use} = AF \times MTTF_{stress} \qquad \text{(Eq. 2)}$$

Numerous values for the Black equation parameters N and E_a have been reported in the literature. The lower the value, the more conservative is the estimate. N is found to range between 2 and 3.3 while E_a ranges between 0.5 to 1.1 eV. Numerous experiments have been performed under stress conditions in the literature. There is a great deal of variation in the literature. From the numerous experiment performed on electromigration in the literture, the following number are overly conservative for Al metallization:

E_a=0.5 eV
N=2.0
MTTF= 2000 Hours at J_{stress}= $3x10^5$ A/cm^2 and T_{stress}=185°C

Using these numbers, and the following use conditions

T_{use}=100°C and J_{use}=$2x10^5$ A/cm^2

the MTTF is estimated to be at about 8 years. What if the same conductor is replaced with gold? All thing being equal, we note that the ratio of the gold to Al conductivity squared is about 1.3 and may be entered into the electromigration equation [3,4] (i.e. conductivity will have same power dependency as current density). This yields a MTTF of about 11 years. Furthermore, if we use this value and a conservative estimate for sigma of 0.33 in a lognormal estimate, the anticipated 5 year lognormal cumulative percent failure is about 0.8%.

Reference 4 reported for a Mo-Au structure (about 1 micron line width), an MTTF of about 80 hours at 300C and $3x10^6$ A/cm^{2}current density. Using the above Tuse and Juse and the conservative Black parameters, this yields a Use MTTF of about 450 years. Note this illustrates the difficulty of estimating a proper value without careful experimentation on the particular process of interest.

References

1. Black, "Metallization Failures in Integrated Circuits,' Technical Report, RADC-TR-68-43 (Oct. 1968).
2. Nelson, *Applied Life Data Analysis*, p.206, (1982) John Wiley & Sons.
3. B. Oliver and D.E. Bower, "Theory of the Failure of Semiconductor Contacts by Electromigration," 8th Annual Proc. Reliability Physics, (1970), pp116-120.
4. Agarwala, "Electromigration Failure in Au Thin-Film Conductors," IEEE Reliability Physics, pp107-112 (1975).