Via Electronmigration

(classified from Dr. Tim's notes)

Via Electronmigration Failure:

The failure mechanism of the metal to metal contacts, or vias, in multi-level metal system is similar to that of contact migration, expect it is only the metal that is being transported either away from via or toward the via. The difference in via migration is that the voiding can occur in both directions of electron flow. Via failures are strongly affected by the tendency for current crowding due to either oxygen residuals or silicon nodules in the via. The most common cause of via failure is a contaminated via. The contamination in this case is most commonly either SiO_2 or Al_2O_3.

Via EM test:

Via strings can be tested in much the same way as metal lines using the SWEAT test. The theory is the same except that the design of the structure is different.

The test structure is a via string where the cross-sectional area of the two different metal layers is the same, and the cross-sectional area of the via is as close as possible to that of the lines. This insures a uniform flow of vacancies and voids without material differences. The metal lines connecting between vias are at least 40 microns long to minimize stress gradients, and to insure that there are sufficient vacancies in any line segment to allow the generation of a void large enough to open the via. Different combinations of topography around or under the vias may also be included. A heater resistor with a simple minimum width metal line for a thermometer is included for processes including stud vias.

Turner test structure for the via electromigration test is a long, via chain. The chain should be as long as possible within the limitations of the available space and the power supply available for the test. (Dr. Tim notes)

For traditional vias, the test is conducted by forcing a high current density in the via string. The current level is adjusted to provide a constant acceleration factor using the procedure described as the SWEAT test, or one that provides a constant line temperature (isothermal test). The combination of high current density in the line and the high temperature caused by joule heating causes a rapid rate of electromigration. Following is the SWEAT test description.

Test procedure: (SWEAT test)

The test uses a feedback control loop to adjust the stress current applied to the test line. The stress current is adjusted such that the temperature and current density of structure maintain the estimated time to failure, derived from Black's equation, at the selected target value. A brief account of the test method is given as follows:

- The test begins with a measurement of the resistance of the metal line and the determination of its TCR at room temperature.
- This resistance and TCR measurement will be used as references throughout the test.
- A high current density typically at $10MA/cm^2$ is applied and a change in resistance is then calculated.

- Based on this change and the TCR of the metal used, a line temperature is measured, using the following equation.

  $$T = \frac{R(T)xR(T_{ref})}{R(T_{ref})xTCR(T_{ref})} + T_{ref}$$

  Where T_{ref} is the reference temperature at which the experiment started.
- Knowing the line temperature and the forced current, a "Stress Level" is calculated.
- The calculated stress level is then compared to the desired stress level.
- Based on the difference between the desired stress level and the measured stress level, a second guess as to the stress level is made and forced through the line.
- This cycle of guess and correction is performed until the intended stress condition is obtained.
- Once obtained, the current is continually adjusted until the test line reaches thermal equilibrium and is fixed for the rest of the test.
- Measurement will be continued till the targeted DUT resistance change is reached.

Definition:

(1) The estimated time to failure is from Black equation:

$$t_{FE} = \frac{A}{jn}\exp\left[\frac{E_a}{kT}\right]$$

Where A is a constant dependent on metal film material and structure,

n is the current density factor depend on various fabrication and test parameters, (usually 2.0)

E_a is the activation energy, K is Boltzmann’s constant and T is temperature.

(2) Error band B_E
a boundary for the estimated t_{FE} around the target time to failure.

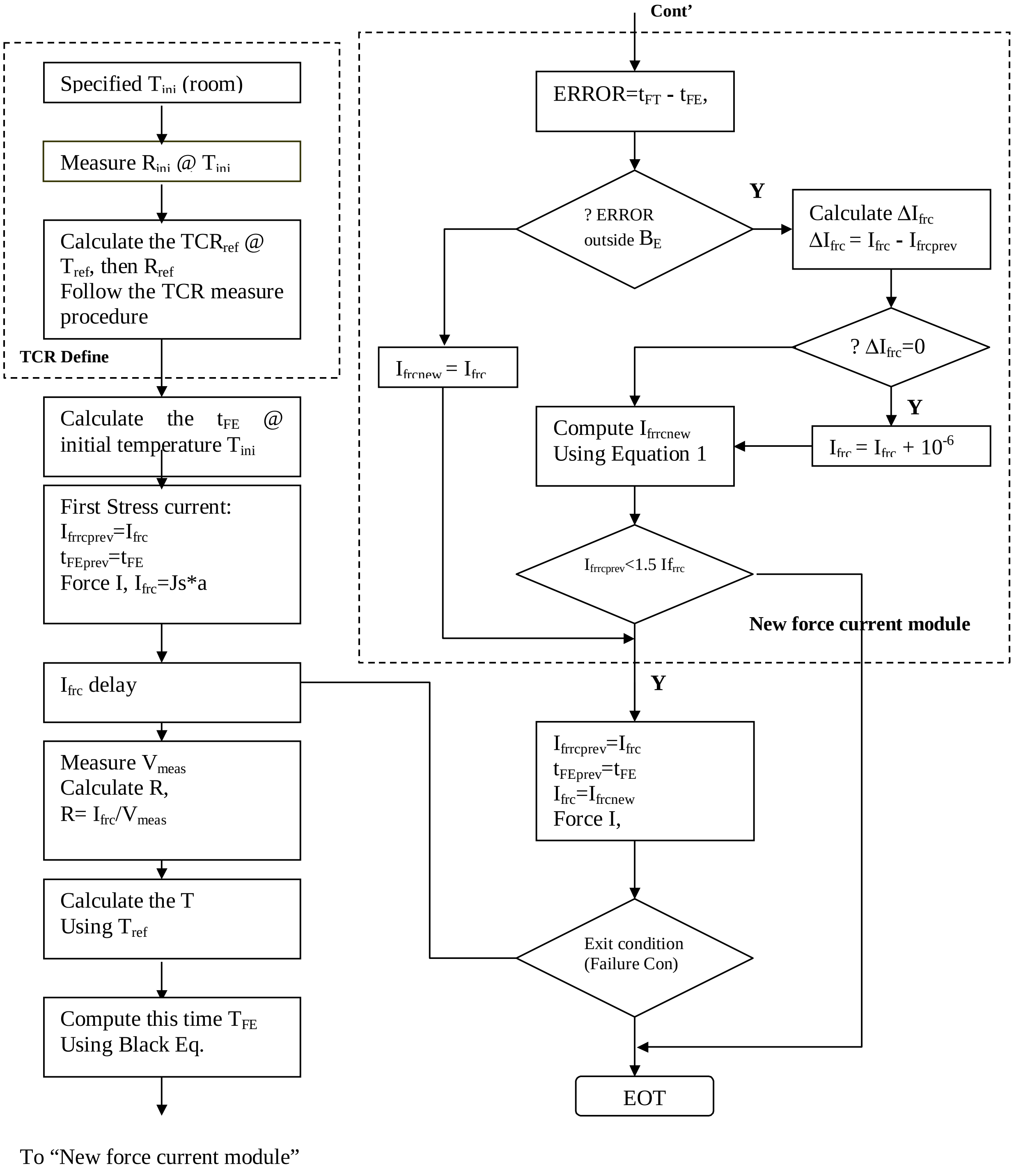
(3) new force current can be calculated from:

$$I_{frcnew} = I_{frc} + (t_{FT} - t_{FE})\left(\frac{I_{frc} - I_{frcprev}}{t_{FE} - t_{FEprev}}\right) \qquad (1)$$

Input parameter:

t_{FT}, (target times to failure), B_E , T_{ini}, T_{ref}, Js, a, T_{delay}, Failure condition,

Output parameter:
t_{FE} , t_f , R_f , J_f , T_f ,


Cont'
Specified T_{ini} (room)
Measure R_{ini} @ T_{ini}
Calculate the TCR_{ref} @ T_{ref}, then R_{ref}
Follow the TCR measure procedure
TCR Define
Calculate the t_{FE} @ initial temperature T_{ini}
First Stress current:
$I_{frrcprev}=I_{frc}$
$t_{FEprev}=t_{FE}$
Force I, $I_{frc}=Js*a$
I_{frc} delay
Measure V_{meas}
Calculate R,
R= I_{frc}/V_{meas}
Calculate the T
Using T_{ref}
Compute this time T_{FE}
Using Black Eq.
To "New force current module"
ERROR=t_{FT} - t_{FE},
? ERROR outside B_E
Y
Calculate ΔI_{frc}
$\Delta I_{frc} = I_{frc} - I_{frcprev}$
? ΔI_{frc}=0
Y
$I_{frc} = I_{frc} + 10^{-6}$
Compute $I_{frrcnew}$
Using Equation 1
$I_{frcnew} = I_{frc}$
$I_{frrcprev}$<1.5 If_{rrc}
New force current module
Y
$I_{frrcprev}=I_{frc}$
$t_{FEprev}=t_{FE}$
$I_{frc}=I_{frcnew}$
Force I,
Exit condition
(Failure Con)
EOT