
Evaluation of Electromigration Using the SWEAT Procedure

Application Note 4156-7

**HP 4155A/4156A
Semiconductor Parameter
Analyzer**



Introduction

With the size of metal interconnects shrinking along with device geometries, electromigration has become an important issue affecting circuit reliability.

Electromigration is the phenomenon in which the metal atoms in the metal interconnect move by current flow, leading ultimately to metal voids and circuit failure.

SWEAT (Standardized Wafer-level Electromigration Accelerated Test) is an accelerated electromigration test performed on microelectronic metalization on the wafer. SWEAT is getting much attention by semiconductor manufacturers, because it can quickly provide data for monitoring metal reliability and process consistency.

This application note describes a SWEAT application for the HP 4155A/4156A semiconductor parameter analyzer, based on the proposed JEDEC 4-June-92 standard.

What is SWEAT?

SWEAT procedure

SWEAT evaluates sensitivity of metal lines to failure caused by electromigration. An initial current is forced through the electromigration test structure. Then theoretical time-to-failure ($CTTF^{*1}$) is computed from Black's equation. Current is adjusted so that $CTTF$ stays close to the pre-defined target time-to-failure ($TTTF$). Gradually, the resistance of the test structure increases due to electromigration voids ($CTTF$ deviates from $TTTF$). By continuously adjusting the current, $CTTF$ is forced to track $TTTF$. Finally, the test structure ruptures open (failure). Here, 1) Time to Fail (TTF), 2) Resistance at Fail (Rf), 3) Current Density at Fail (Jf), 4) Temperature at Fail (Tf), and 5) Test Status are obtained as output parameters. These parameters give useful insight about failure characteristics. Figure 1 shows the flow of the SWEAT procedure.

Problems with SWEAT measurements

Since test structures fail suddenly, monitoring the structure voltage, calculating the structure temperature and $CTTF$, and adjusting the forcing current must be done quickly to obtain accurate measurement results. Therefore, computer control is mandatory. There is also a need to draw a graph and to extract resultant parameters.

The HP 4145B semiconductor parameter analyzer, provides automatic measurement with its ASP (Auto Sequence Program) function. But the SWEAT procedure requires feedback control too complicated for ASP to handle. The HP 4142B DC source/monitor requires an external computer and sophisticated programming to cope with the SWEAT procedure.

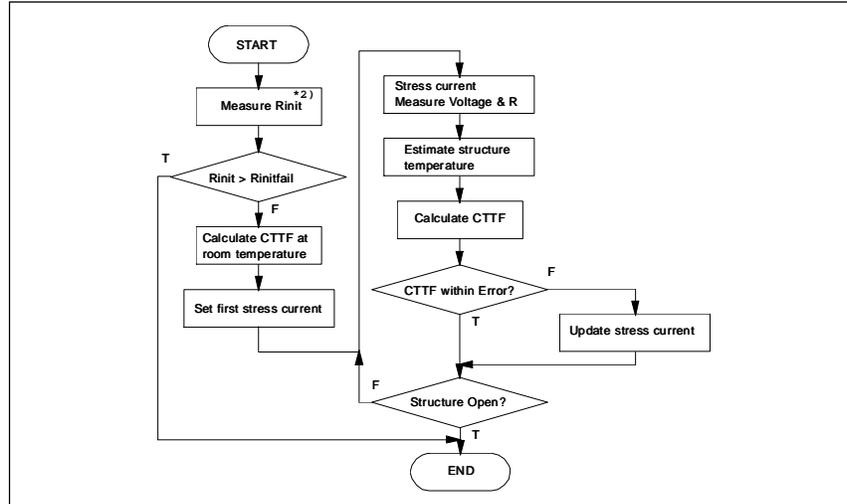


Figure 1. Flowchart of SWEAT

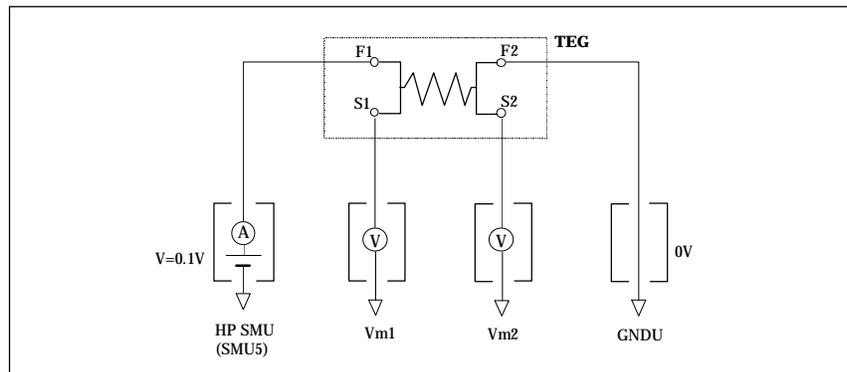


Figure 2. Measurement Circuit of Rinit

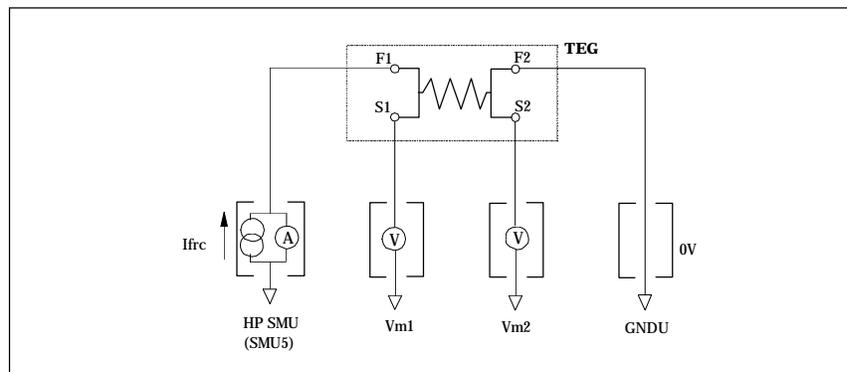


Figure 3. Structure Resistance Measurement Circuit

Besides the necessity of automation, SWEAT requires high current, more than 100mA in most cases, to force electromigration to a timely failure. Precise voltage measurement capability (μV levels) is necessary to detect small deviations in the metal resistance caused by electromigration.

HP 4155A/4156A Solution

The HP 4155A/4156A features built-in HP Instrument BASIC. HP Instrument BASIC is tailored especially for instrument control and scientific calculations, such as the SWEAT procedure. Thus, an external computer is no longer necessary.

CHANNELS: CHANNEL DEFINITION 94 JUL03 07:27 AM

* MEASUREMENT MODE
SAMPLING

* CHANNELS

UNIT	VNAME	I NAME	MODE	FCTN	STBY	SERIES RESISTANCE
SMU1: HR						0 ohm
SMU2: HR						
SMU3: HR						
SMU4: HR						
SMU5: HP	Vfrc	Ifrc	I	CONST	ON	0 ohm
VSU1		-----				
VSU2		-----				
VMU1	Vm1	-----	V	-----	----	
VMU2	Vm2	-----	V	-----	----	
PGU1		-----				
PGU2		-----				
GNDU	Vgnd	-----	COMMON	CONST	----	

Figure 4. CHANNEL DEFINITION Page

MEASURE: SAMPLING SETUP 94 JUL03 07:29 AM

* SAMPLING PARAMETER

MODE	LINEAR
INITIAL INTERVAL	2.00ms
NO. OF SAMPLES	1
TOTAL SAMP. TIME	AUTO

* STOP CONDITION

ENABLE/DISABLE	DISABLE
ENABLE DELAY	0.000000 s
NAME	
THRESHOLD	0.0000000
EVENT	Val > Th
EVENT NO.	1

HOLD TIME 0.000000 s

FILTER OFF

* CONSTANT

UNIT	SMU5: HP			
NAME	Ifrc			
MODE	I			
SOURCE	1.0000 mA			
COMPLIANCE	20.000 V			

Figure 5. SAMPLING SETUP Page

```
OUTPUT @Hp4156; " :PAGE:MEAS:SAMP:CONS:SMU5
"&VAL$(Iforce(I))
```

Figure 6. Example Code to Update the Current Value

```
OUTPUT @Hp4156;"TRAC:DEF
'Time',"&VAL$(No_points)! Array size
OUTPUT @Hp4156;"TRAC:DEF
'CTTF',"&VAL$(No_points)
OUTPUT @Hp4156;"TRAC:DATA
'Time'," ;Time_d(*) ! Data transfr
OUTPUT @Hp4156;"TRAC:DATA
'CTTF'," ;Cttf_d(*)
```

Figure 8. Example Code to Transfer Data to Internal Data Array of the HP 4155A/4156A

CHANNELS: USER VARIABLE DEFINITION 94 JUL03 07:30 AM

* USER VARIABLE

NAME	UNIT	SIZE
Time	sec	1
CTTF	sec	1

Figure 7. USER VARIABLE DEFINITION Page

The stress and measurement conditions are defined by loading pre-saved stress/measurement setup files. These setup files are easily created, in fill-in-the-blank manner, from the front panel. One of the hardest parts of programming, instrument control, can be skipped by this method. The HP 4155A/4156A can draw graphs of the data arrays very easily on its GRAPHICS page. You can make use of its analysis function to extract the required SWEAT parameters. Complicated programming to graph the results and analyze the data is eliminated. Use the optional High Power SMU (HPSMU), to force enough current (up to 1A) for rapid electromigration. The VMU, with 1 μ V resolution, is ideal for detecting small deviations in resistance of metal test structures.

SWEAT procedure.

The entire procedure described below is fully automated by the HP Instrument BASIC controller built-in to HP 4155A/4156A.

First Rinit, initial resistance, is measured using the circuit shown in Figure 2. A small voltage, which will not cause Joule heating, is applied to the test structure and voltage drop across the test structure is measured.

Then, the stress current (Ifrc) is applied to the test structure. Ifrc is controlled and adjusted until the CTTF, computed by the measured results, has settled close enough to the TTF. The HP 4156A is set to sampling mode to make a single spot measurement. The current output port is set to standby mode to keep the current continuously applied while measurements and calculations are performed. The

measurement circuit of this current update routine is shown in Figure 3. Figure 4 and Figure 5 show an example CHANNEL DEFINITION and SAMPLING SETUP page for this measurement.

This setup is stored as a measurement setup file on the floppy disk and called at the beginning of the measurement. After every measurement, only the value of current to be forced, indicated in Figure 5, is updated programmatically. The example code to update the current is shown in Figure 6.

The test ends when sufficient electromigration has occurred to change the structure resistance as specified.

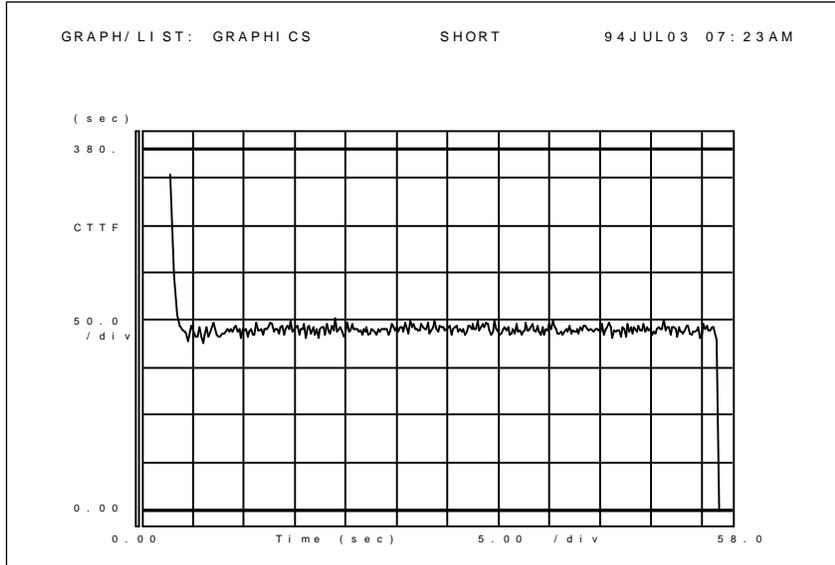


Figure 9. CTF vs. Time

The calculated measurement results from HP Instrument BASIC as well as results measured directly by the HP 4155A/4156A can easily be transferred to the GRAPHICS page. Figure 7 shows an example USER VARIABLE setting to draw the graph CTF vs. Time. Array sizes are defined for the CTF and Time data which will be transferred from HP Instrument BASIC into the HP 4156A GRAPHICS page. The example code to transfer the data is shown in Figure 8. Figure 9 is an example of CTF vs. Time measured by the HP 4156A.

Conclusion

The HP 4155A/4156A provides you with many features which greatly simplify SWEAT evaluation. Pre-saved setup files and graphical display and analysis drastically reduce the programming effort. The built-in HP Instrument BASIC controller eliminates the need for an external computer.

- *1 CTF is the Calculated Time to Failure of the structure based on the following Black's Equation:

$$CTF = Acc \times J^{-n} e^{Ea/kT}$$

Acc: Acceleration factor
J: Current density
Ea: Activation energy
k: Boltzman constant

- *2 Rinit is the structure resistance at room temperature and low current density, where Joule heating is negligible.

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Printed in USA 7/94
5963-1110E