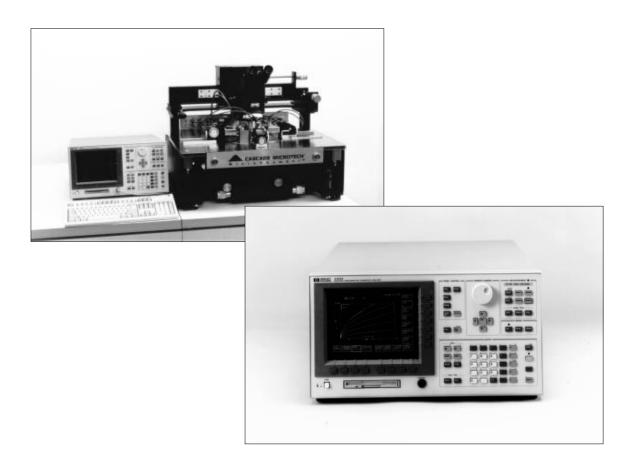# Evaluation of Oxide Reliability Using V-Ramp / J-Ramp Test

Application Note 4156-8

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

Introduction

With the size of gate area and the thickness of the oxide shrinking along with device geometries, creating a reliable thin oxide has become an important issue. The integrity of the thin oxide in a MOS device is a dominant factor determining overall reliability of a micro-circuit.

This application note describes V-Ramp and J-Ramp tests using the HP 4155A/4156A semiconductor parameter analyzer, based on the JEDEC Standard No. 35.

They can promptly give useful feedback to the manufacturing process about oxide reliability.

What are V-Ramp and J-Ramp?

Both Voltage Ramp (V-Ramp) and Current Ramp (J-Ramp) are one of so called Wefer Level Reliablity (WLR) tests. They force a constantly increasing charge through an oxide capacitor until failure occurs. They both record total charge (Qbd) and breakdown voltage (Vbd). These parameters are extracted from a large amount of test structures and usually plotted as cumulative breakdown/ breakdown charge distribution on probability chart. The manufacturing process should be driven so that this distribution becomes closer to the ideal shape. V-Ramp is more sensitive at detecting breakdown at lower voltages (i.e. logic, micrprocessors). J-Ramp which is more sensitive at higher voltages (i.e. EPROM, flash). V-Ramp test is more commonly applied to test structures which may have large oxide areas equal to that of an entire semiconductor integrated circuit, or larger. On the other hand, J-Ramp test is more often applied to small scribe-line test structures.
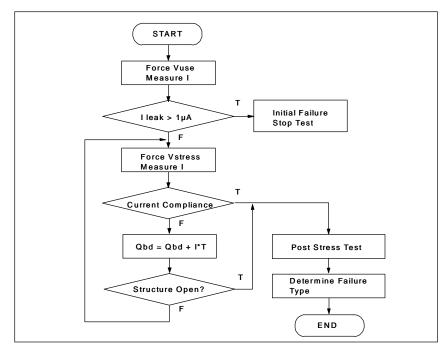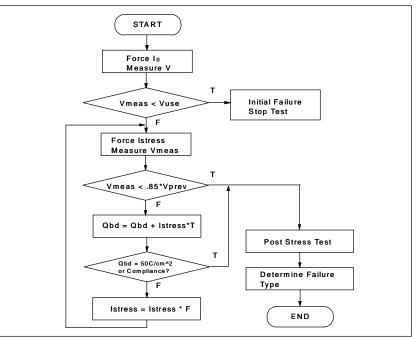

Figure 1. Flowchart of V-Ramp

Figure 2. Flowchart of J-Ramp

V-Ramp Procedure

First, the test structure is checked for integrity by measuring the leakage current after applying a constant voltage (Vuse).

Second, voltage is applied to the test structure in steps until the oxide ruptures, compliance occurs, or voltage exceeds specified limit. This ramped test should be performed in accumulation mode.

Finally, a post stress analysis is performed to record the failure category. Figure 1 shows the flow of the V-Ramp Test.
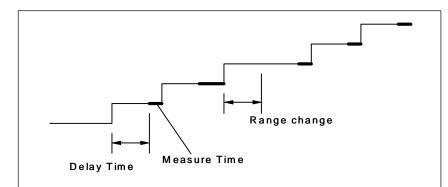
Figure 3. Duration Varies Due to Range Change and Inconsistent Measurement Time
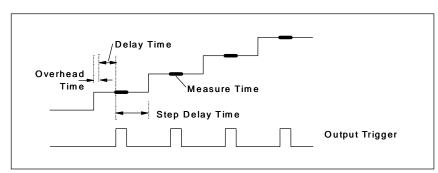

Figure 4. Constant Duration by Using Output Trigger Function

J-Ramp Procedure

First, an initial test is made to determine the quality of the oxide capacitor by monitoring the voltage after applying a current (typically 1µA). If the voltage does not reach the use condition voltage within specified time, it fails the initial procedure.

Then, current is applied to the test structure in steps until oxide ruptures, or total charge exceeds the specified value. The current is increased by multiplying a certain factor (F) by the previous stress current. JEDEC No.35 specifies that F should be less than square root of 10. Breakdown is defined by a 15% drop in voltage. This ramped test should be performed in accumulation mode.

Finally, post stress test is performed to determine the failure category. Figure 2 shows the flow of the J-Ramp Test.

Problems with V-Ramp and J-Ramp

Since oxides can rupture suddenly, changing the step, monitoring the voltage, and judgement of the exit condition must be done very quickly to insure reliable measurement results. Automation using a computer is mandatory for both of these tests. Several JEDEC requirements make creating the test program difficult.

It is desirable to keep the step time as uniform as possible to measure Qbd precisely and consistently. During the ramped test, maintaining a constant step time may be difficult. Using the clock in the external computer, with its resolution and accuracy limitations, you cannot set small and consistent step durations. Even if you use the sweep function of the instrument and set the delay time, any range changing that occurs during sweep will add unpredictable step variation as shown in Figure 3.

HP 4155A/4156A Solution

The HP 4155A/4156A has built-in HP Instrument BASIC. The whole V-Ramp or J-Ramp tests can be automated using HP Instrument BASIC which is suitable for instrument control and scientific calculation. Thus, an external computer is no longer necessary.

Initial stress measurement, ramped test, and post stress test are done by loading the pre-saved measurement setup files. These setup files can easily be created by fill-in-the-blank manner from the front panel. This eliminates one of the most difficult parts of a program, instrument control.

Of course, each setting parameter can be changed from the program later. So, any setting parameter which is determined by complicated calculation or by measured results can be updated later.

You can make use of the HP 4155A/4156A's analysis function to extract the resultant parameters. Extraction of Vbd and calculation of Qbd is possible by setting the USER FUNCTION and moving the marker to the breakdown point. Complicated programming to analyze the data is eliminated.

The requirement of maintaining a precise and constant time step throughout the ramp test, is accomplished by using a fixed range, and by using the output trigger function (see Figure 4). The output trigger function gets its name from the ability of the HP 4156A to synchronize with external instruments. Step delay time for external instruments is required to provide consistent settling time for reliable measurements. You can make use of this function to keep the step duration constant during the ramped test. Precise Qbd values can be obtained by using this function by setting time steps to 100µs resolution.
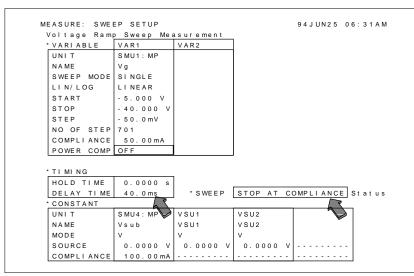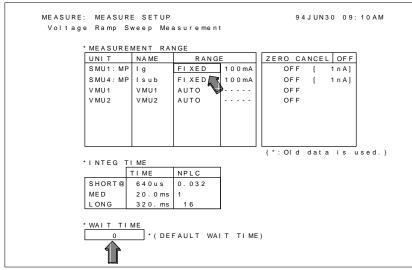
```
MEASURE:  SWEEP  SETUP                        94JUN25  06:31AM
Voltage  Ramp  Sweep  Measurement
* VARIABLE       VAR1              VAR2
  UNIT           SMU1:MP
  NAME           Vg
  SWEEP MODE     SINGLE
  LIN/LOG        LINEAR
  START          - 5.000  V
  STOP           - 40.000  V
  STEP           - 50.0mV
  NO OF STEP     701
  COMPLIANCE     50.00mA
  POWER COMP     OFF

* TIMING
  HOLD TIME      0.0000  s
  DELAY TIME     40.0ms       * SWEEP   STOP AT COMPLIANCE  Status
* CONSTANT
  UNIT           SMU4:MP    VSU1         VSU2
  NAME           Vsub       VSU1         VSU2
  MODE           V          V            V
  SOURCE         0.0000  V  0.0000  V    0.0000  V    - - - - - - - - -
  COMPLIANCE     100.00mA   - - - - - -  - - - - - -   - - - - - - - - -
```

Figure 5. SWEEP SETUP Page

```
MEASURE:  MEASURE  SETUP                       94JUN30  09:10AM
Voltage  Ramp  Sweep  Measurement

* MEASUREMENT RANGE
  UNIT        NAME       RANGE              ZERO CANCEL    OFF
  SMU1:MP     Ig         FIXED    100mA     OFF    [  1nA]
  SMU4:MP     Isub       FIXED    100mA     OFF    [  1nA]
  VMU1        VMU1       AUTO     - - - - -  OFF
  VMU2        VMU2       AUTO     - - - - -  OFF

                                            ( *: Old data is used. )

* INTEG TIME
              TIME     NPLC
  SHORT@      640us    0.032
  MED         20.0ms   1
  LONG        320.ms   16

* WAIT TIME
      0             *( DEFAULT  WAIT  TIME )
```

Figure 6. MEASURE SETUP Page

```
MEASURE:  OUTPUT  SEQUENCE                     94JUN30  09:13AM
Voltage  Ramp  Sweep  Measurement

* OUTPUT SEQUENCE                      * TRIGGER SETUP
      UNIT       NAME     MODE         ENABLE/DISABLE    ENABLE
  1   SMU4:MP    Vsub     V            FUNCTION          TRIG OUT
  2   SMU1:MP    Vg       V            STEP DELAY        21.4ms
  3   SMU2:MP                          POLARITY          POSITIVE
  4   SMU3:MP
  5   VSU1       VSU1     V
  6   VSU2       VSU2     V
  7   SMU5:MP
  8   SMU6:MP
  9   PGU1
  10  PGU2
```
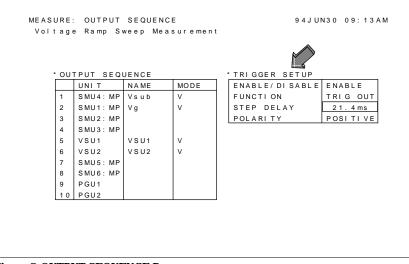
Figure 7. OUTPUT SEQUENCE Page

V-Ramp with the HP 4155A/ 4156A

V-Ramp test

The entire procedure described below is fully automated by the HP Instrument BASIC.

First, an initial test checks leakage current when Vuse is applied to the test structure. To make a single spot test, the HP 4155A/4156A is set to sampling mode and the number of steps is set to "1". The post stress test, which is made at the end of entire test, is identical to the initial test. Both measurements are performed by loading presaved measurement setup files. The setup file can easily be created or modified from the front panel.

Then the ramped test is performed using the sweep measurement function. Figure 5 and 6 show the SWEEP SETUP and MEASURE SETUP pages.

Constant duration through out the ramped test is desirable. The following setup procedure maintains a constant step time interval during the ramped test.

1. Set output trigger function in OUTPUT SEQUENCE page.
2. Set DELAY TIME in SWEEP SETUP page.
3. Set STEP DELAY time in OUTPUT SEQUENCE page.
4. Set measurement time to fixed range in MEASURE SETUP page.
5. Set WAIT TIME to zero in MEASURE SETUP page.

JEDEC No.35 specifies that the ramp rate should be from 0.1 to $1.0 MV/cm^2$. If you define step voltage (Vstep), the duration of each step is calculated as follows.

$$Duration = Vstep / (Ramp\ rate \times Tox)$$
$$[sec]$$

Tox: Oxide thickness

The delay time and step delay time should be chosen so that they satisfys the following equations.

- In case of V-Ramp:
  Duration = 1.2ms + (DELAY TIME)
  +(STEP DELAY - 100μs)

- In case of J-Ramp:
  Duration = 1.5ms + (DELAY TIME)
  +(STEP DELAY - 100μs)

where: 1.2ms and 1.5ms are
measurement overhead.

DELAY TIME should be set large and according to the above formula so that the measurement is performed close to the end of each step. STEP DELAY time must be larger than sum of setting INTEG TIME and measurement overhead. When keeping constant step duration, you can't use USER FUNCTIONs. Analysis with USER FUNCTIONs can be done after the ramped test procedure is completed. The calculation and update of these parameters is done by Instrument BASIC. Select SWEEP STOP AT COMPLIANCE Status in the SWEEP SETUP page so that sweep aborts immediately if compliance occurs.

The calculation of Qbd in equation below, is automatically performed by a HP 4156A USER FUNCTION. The set up of USER FUNCTION should be made after the ramped measurement to keep the duration constant. Time is defined as multiplication of measurement data (@INDEX) and step duration. When the marker is moved to the breakdown point, Qbd appears on the GRAPHIC page.

$$Qbd = \int i(t)\,dt$$

The search for breakdown voltage is made in the HP Instrument BASIC program. JEDEC defines breakdwon voltage as the voltage when current becomes ten times larger than the expected current. Expected current is decided by either a pre-measured curve or theoretical curve.
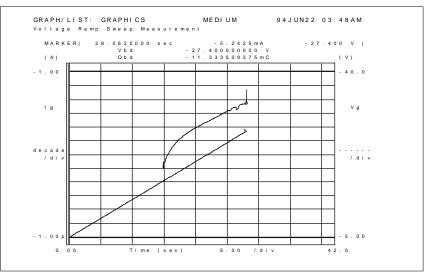

Figure 8. USER FUNC SETUP Page

Figure 9. GRAPH Page

Theoretical current is called the Fowler-Nordheim current, which is given as follows.

$$J = A \times E^2 \times e^{(-B/E)}$$

where: A and B are constants in terms of effective mass and barrier height.

E: Electric field

Or, since current starts flowing right after oxide rupture, it will be OK to detect the breakdown voltage one step before the Ig compliance as a simplified alternative.

Another V-ramp test for studying ultra thin oxide leakages

The main purpose of WLR V-ramp tests is to monitor the qualitative tendency of the process. Parameters such as Qbd give prompt process control feedback by quickly stepping the stress voltage to breakdown, in uniform time increments.

For thin oxides (less than 100 angstroms thick), low voltage "direct tunneling" leakage must be accurately studied. The HP 4156A is ideally suited for this purpose due to its ability to measure currents down to fA levels at high speeds.
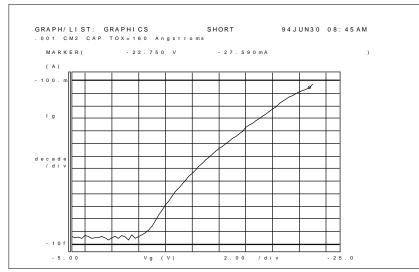
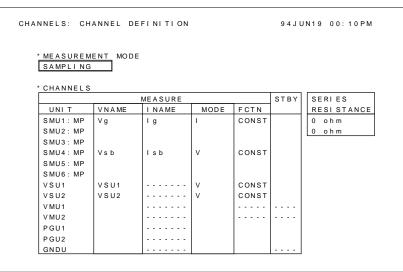**Figure 10. Low Level Ig-Vg Characteristics Using Auto Ranging**

Figure 11. CHANNEL DEFINITION Page (Initial Test)

Figure 12. SAMPLING SETUP Page (Initial Test)

Use auto ranging in the MEASURE SETUP page to increase accuracy. Add a hold time only if you sweep from a non-zero start point. Add delay time only for large voltage step size or if probes are not fully guarded. Leakage sweeps, such as shown in Figure 10 can be made in less than one minute using the HP 4156A with a well guarded probe station such as the Cascade Microtech 9500.

J-Ramp with the HP 4155A/4156A

The entire procedure described below is fully automated by the HP Instrument BASIC.

The initial test is performed using the sampling mode function. Specified current is forced and voltage is repeatedly measured with constant time interval. The measurement stops when the voltage reaches the specified threshold value, in this case 2V. Figure 11 and Figure 12 show CHANNEL DEFINITION and SAMPLING SETUP page respectively.

After the initial test, the ramped test is performed using the sweep measurement function. Figure 13 and Figure 14 show SWEEP SETUP and MEASURE SETUP page respectively.

Also with the J-Ramp test, constant step time duration throughout the ramped test is desirable. The duration is fixed constant by setting the output trigger function, delay time, step delay time, and zero wait time as explained in the V-Ramp test.

The current is increased as $I \times F^n$ (n is integer). To increase the current while satisfying this equation, use the LOG sweep function of the HP 4155A/4156A. Three kinds of F values can be chosen, which are $10^{(1/10)}$, $10^{(1/25)}$, and $10^{(1/50)}$.

The stop current is calculated by solving the following equation.

$$\int_0^n I \times F^n \geq MaxQ \times Area \qquad ----- (4)$$

MaxQ: Maximum charge density given by user (50C/cm^2 in JEDEC No.35)

Area: Oxide area.

In case of the HP 4155A/4156A, the sweep measurement won't stop right after the breakdown occurs. After the specified sweep is over, it can quickly search for the breakdown point. Figure 15 is an example of J-Ramp ramped test.

Conclusion

The HP 4155A/4156A provides you with features that greatly simplify V-Ramp / J-Ramp tests. Pre-saved setup files and auto analysis drastically reduce the programming effort. The built in HP Instrument BASIC controller eliminates the need for an external computer. Precise Qbd value is acquired by maintaining a constant step time duration through out the ramped test.
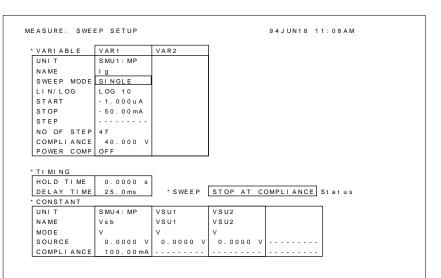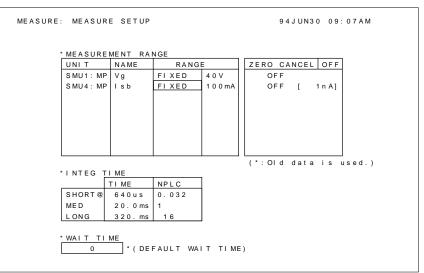
```
MEASURE:  SWEEP  SETUP                          94JUN18  11:08AM

  * VARIABLE      VAR1          VAR2
    UNIT          SMU1: MP
    NAME          I g
    SWEEP MODE    SINGLE
    LIN/LOG       LOG 10
    START         - 1.000uA
    STOP          - 50.00mA
    STEP          - - - - - - - -
    NO OF STEP    47
    COMPLIANCE    40.000  V
    POWER COMP    OFF

  * TIMING
    HOLD TIME     0.0000 s
    DELAY TIME    25.0ms        * SWEEP   STOP AT COMPLIANCE  Status
  * CONSTANT
    UNIT          SMU4: MP      VSU1          VSU2
    NAME          Vsb           VSU1          VSU2
    MODE          V             V             V
    SOURCE        0.0000  V     0.0000  V     0.0000  V  - - - - - - - -
    COMPLIANCE    100.00mA    - - - - - - - -  - - - - - - - -  - - - - - - - -
```

Figure 13. SWEEP SETUP Page

```
MEASURE:  MEASURE  SETUP                         94JUN30  09:07AM

    * MEASUREMENT  RANGE
      UNIT        NAME      RANGE               ZERO CANCEL  OFF
      SMU1: MP    Vg        FIXED     40V          OFF
      SMU4: MP    Isb       FIXED     100mA        OFF    [    1nA]


                                                ( *: Old data is used.)

    * INTEG TIME
                  TIME      NPLC
      SHORT@      640us     0.032
      MED         20.0ms    1
      LONG        320.ms    16

    * WAIT TIME
            0           * (DEFAULT WAIT TIME)
```

Figure 14. MEASURE SETUP Page

```
GRAPH/LIST:  GRAPHICS            SHORT        94JUN18  11:12AM

  CURSOR(  0.00000000  sec   16.666688667GA  -100.87083175  V )
  MARKER(  2.20000000  sec      - 24.69mA        - 8.0686  V )
                      Qbd    - 5.2717947500mC
  ( A )               Vbd    - 8.0686000000  V                  ( V )
```
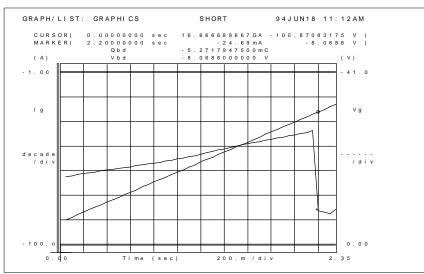

Figure 15. Example Measurement Results

H

For more information, call your local HP sales office listed in your telephone directory or an HP regional office listed below for the location of your nearest sales office.

United States:
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4 Choke Cherry Road
Rockville, MD 20850
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5201 Tollview Drive
Rolling Meadows, IL 60008
(708) 255 9800

Hewlett-Packard Company
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Fullerton, CA 92631
(714) 999-6700

Hewlett-Packard Company
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Atlanta, GA 30339
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