



Voltage Ramp WLR

Thin dielectrics used in semiconductor devices for the gate oxide can be exposed to very high electric fields. These fields can cause a breakdown of the dielectric material. This breakdown is called Time Dependent Dielectric Breakdown (TDDB). This mechanism causes the dielectric to breakdown and becomes electrically shorted after some duration of operation. The thin oxide integrity is an important reliability concern. In general the intrinsic oxide lifetime is much longer than the use requirements. However, defects in the oxide shorten this lifetime by many orders of magnitude. Thus, the random defect density is the parameter that primarily determines the reliability of the oxide.

There are two WLT techniques used to monitor oxide integrity: Voltage Ramp (V-Ramp) and Current Ramp (J-Ramp). Both techniques provide fast feedback for oxide evaluation. The most common test is a voltage ramp test. This test is described in a JEDEC standard test method for thin oxides used in semiconductor products.

V-Ramp Test:

The test is performed by applying a voltage across an oxide at room temperature. The V-Ramp test starts at the use condition voltage or lower and ramps linearly from this value at constant rate until the failure criteria are met (oxide breakdown) or until the maximum voltage limit is reached. Test record total charge (Qbd) and breakdown voltage (Vbd).

V-Ramp test is more sensitive when it detects breakdown at low voltage.

Input variables:

Parameters	Default value
use_voltage - pre and post-stress applied test voltage (V)	
check_current - pre and post-stress check current (A)	
use_voltage_delay - pre and post-stress measurement and first voltage step delay (ms)	
start_voltage - starting ramp voltage (V)	
final_voltage - maximum ramp voltage (V)	
step_voltage - voltage ramp step size (V)	
step_delay - duration of each step in the voltage ramp (typ. value: 40-100)(ms)	100ms
sample_rate - measurement sampling rate (< step delay) (ms)	10ms
fail_current - fail Current (mA)	100mA
exit_curr_mult - exit current multiplier. See Note2. (typ. value: 10-100)	10
max_time - time limit on ramp (s)	20s
charge_limit - charge limit (C/cm ²)	
area - area of oxide structure (cm ²)	
display_mode - display mode	1
0: no display of test results	
1: displays test results	

Note: The exit_mode allows the user to specify two different criteria for oxide failure. Exit_mode values are described below:

- exit_mode: 0 Specifies that oxide failure is determined by a measured current that exceeds the user specified failure current (fail_current).
- exit_mode: 1 The second criteria is a current measurement that is a factor (exit_curr_mult) times the expected value at the voltage. See JEDEC document JESD-35 and Addendums.



Output variables:

Q_{bd} Charge breakdown, V_{bd} voltage breakdown, I_{bd} current breakdown, TTF time to breakdown,

test_status - test status: 2: no test errors (exit due to measured current calculated AND fail_current), 1: no test errors (exit due to measured current calculated failure current ONLY) 0: no test errors (exit due to measured current fail_current ONLY)

- 1: failed pre-stress test
- 2: cum charge limit reached
- 3: voltage limit reached
- 4: maximum time limit reached
- 6: masked Catastrophic Failure
- 7: non-Catastrophic Failure
- 8: Invalid specified step_delay or sample_rate
- 9: file open error

Test Descriptions:

There are three steps in whole voltage ramp testing.

1) Pre-Ramp oxide current test

The test begins with a leakage test by forcing use_voltage and measuring the current, if the current exceeds the check_current (“bad device”), then the test termination. This is to determine initial oxide integrity.

2) Ramp voltage stress.

If the initial leakage test is passed, the test begins to ramp the voltage starting at start_voltage. A linear or stepped voltage ramp is applied in this test. The voltage ramps at a predefined ramp rate (typically is 1MV/cm*s). At each voltage step the measured current should be compared to the oxide breakdown criterion. If breakdown has not occurred, the Q_{bd} (accumulated oxide charge) should be recalculated. During the test, the failure criteria can be: 1) The measured current exceeds the user specified failure_current (exit_mode0). Or 2) current is a factor (exit_curr_mult) times the expected value at the voltage (exit mode 1). Also, 3) a significant change in V-I slope (after the initial tunneling current begins) should be considered a failure. *

The voltage is ramped until the failure criteria is met. At the completion of this step, the program should record the Q_{bd} up to the point of failure. Additionally, the voltage at failure V_{bd} , current just prior to failure I_{bd} , failure category should be recorded.

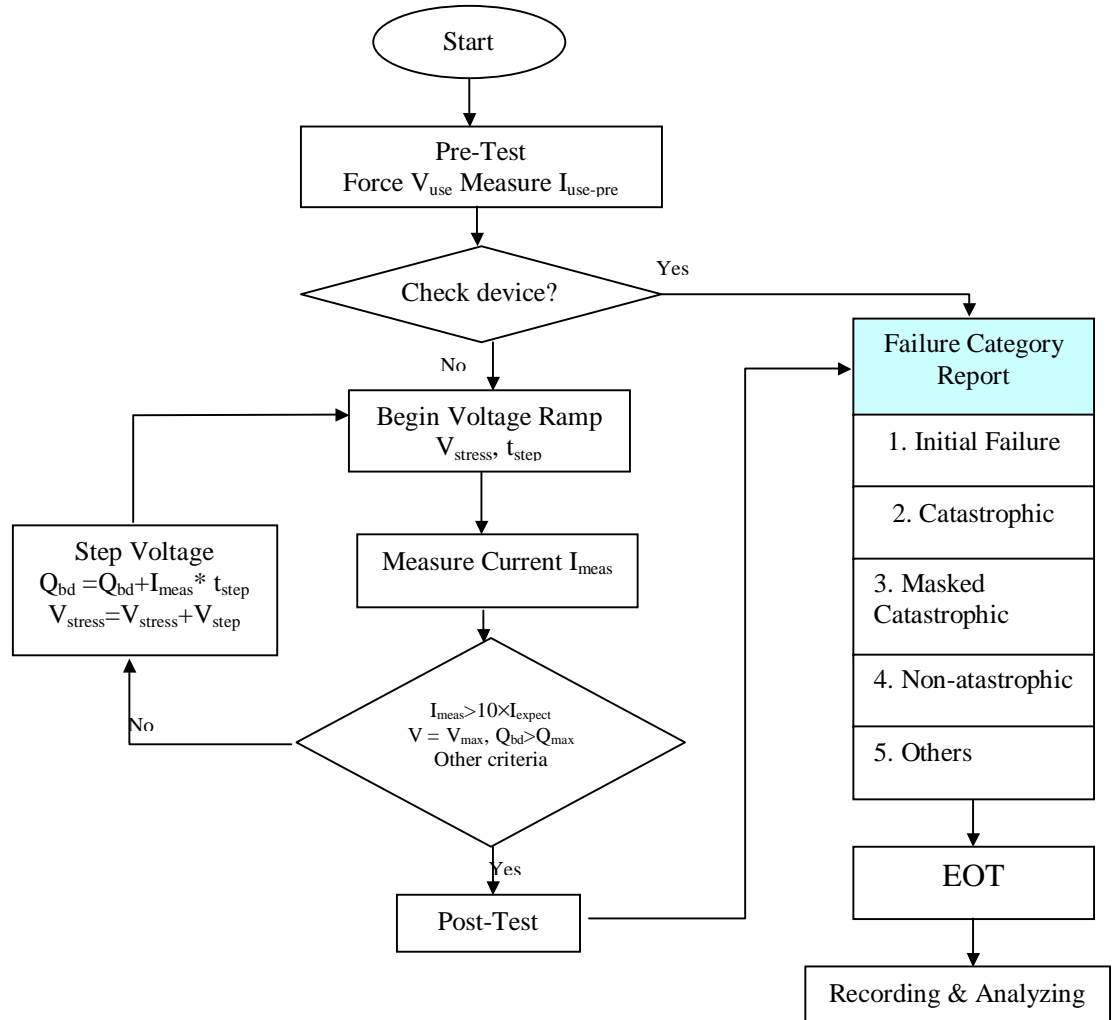
3) Post-ramp oxide current test.

Once the test has indicated failure, or one of the final_voltage; max_time, chage_limit is reached before a failure is detected, the test then forces the use_voltage again and measures the leakage current. This test is performed to determine the final state of the test device. Based on these test results, the oxide failure category is then determined.

Two types of data are provided. The entire current Vs. voltage plot is stored in a data file for presentation. And the current is measured as a function of time.



Basic voltage-ramp test flow diagram:



Oxide failure categories:

Stress Failure Type	Pre-Test	Ramp Test	Post Test
1. Initial	F	-	-
2. Catastrophic	P	F	F
3. Masked Catastrophic	P	P	F
4. Non- Catastrophic	P	F	P
5. Others	P	P	P

1. Initial: - initial oxide current exceeds failure criteria. Typical value is $10\mu\text{A}/\text{cm}^2$, when biased at V_{use} . Device is shorted.
2. Catastrophic Failure: - Breakdown is detected both during the voltage ramp and during the post-ramp test. This is the desired outperform.

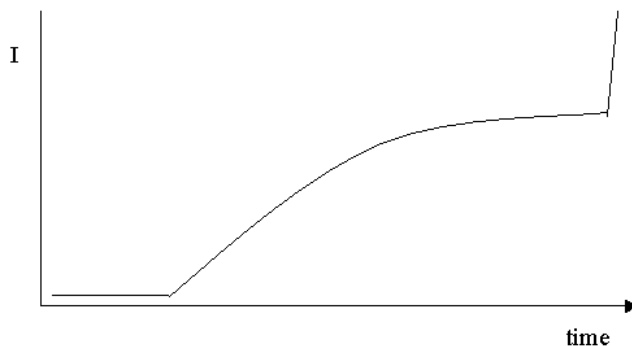


3. Masked Catastrophic Failure: - Oxide breakdown is only detected during post-ramp leakage test.
4. Non- Catastrophic Failure: - Oxide breakdown is detected during V-ramp, but not during post-ramp test.
5. Other Failure: - Oxide breakdown is detected both during V-ramp and post-ramp leakage test.

Oxide Breakdown Criteria:

Oxide breakdown criteria may be specified in different ways.

- (1). Absolute current level: The breakdown occurs when the magnitude of the oxide current exceeds the breakdown current level I_{bd} . I_{bd} is normally defined as 10 times the expected oxide current based on I-V curves. (~20-30 A/cm²)
- (2). Change in slope of oxide current Vs. voltage:
The breakdown occurs when the logarithmic slope of I_{meas} vs V_{stress} curve increases by a factor great than the previously calculated slope. (typically is 3, or 2.5~5 times)



A typical I-t curve in Vramp testing.

Voltage Ramp Algorithm (VRAMP)

This test starts by forcing the use voltage and measuring the resultant current. If the current is greater than the check current, the test aborts. If the structure passes the initial test, a linear ramp voltage is applied to the device until dielectric failure occurs. The formula for the applied stress voltage is given by:

$$\text{Stress Voltage} = \text{start_voltage} + (n - 1) * \text{step_voltage} \quad (n \text{ is the voltage step number})$$

The voltage ramp is applied to the device until device failure as determined by a measured current exceeding the fail current and/or the measured current exceeding a calculated fail current value. After completion of the test the use voltage is again applied to the device. If the measured current exceeds the check current the device is said to experience catastrophic failure, while if the measured current is less than the check current a non-catastrophic failure test status is returned. If the device does not fail during the stress but fails final test, a masked catastrophic failure test status is returned.



Two possible exit criteria can be specified to denote oxide failure. These modes are specified by setting the value of the `exit_mode` parameter to 0 or 1. An `exit_mode` value of 0 specifies that oxide failure be determined ONLY by the failure current (*fail_current*). An `exit_mode` of 1 specifies that TWO criteria should be used to determine oxide failure: the *fail_current* and a measured current that is a factor (*exit_curr_mult*) times the expected value at the applied voltage. In the case of an *exit_mode* of 1 a failure in either criteria will terminate the test.

Features of VRAMP include measuring breakdown voltages to $\pm 200V$, the use of test delays *use_voltage_delay* and *start_delay* that can be separately specified to optimize measurement speed, and a display mode that allows the printing of test and debug results to the screen and a file during testing.

C Calling Prototype:

```
void vramp( int high_pin, int low_pin1, int low_pin2, int low_pin3, float use_voltage, float
    check_current, int use_voltage_delay, int start_delay, float start_voltage, float
    final_voltage, float step_voltage, int step_delay, int sample_rate, float fail_current,
    float exit_curr_mult, float max_time, float charge_limit, float area, float noise_current,
    int exit_mode, int display_mode, float early_voltage, float *crit_voltage, float
    *box_voltage, float *fowler_slope1, float *fowler_slope2, float *charge_brkdwn, float
    *voltage_brkdwn, float *current_brkdwn, float *time_brkdwn, int *test_status )
```