Evaluation of Hot Carrier Induced Degradation of MOSFET Devices

Application Note E5250A-2

Agilent E5250A Low Leakage Switch Mainframe

Introduction
As device geometry scales down, reliability problems of semiconductor devices are increasing. The evaluation of hot carrier induced degradation becomes very important for developing reliable ULSI. This application note introduces you to Agilent's new solution for evaluation of hot carrier induced degradation of multiple MOSFET devices.

What is Hot Carrier Induced Degradation
Due to the short channel length of MOSFETs in today's ULSI, the electric field of the channel has become very high. The drain current easily ionizes electrons and holes around the drain (impact ionization), which cause hot electron and hot hole injection into the gate oxide (Drain Avalanche Hot Carrier; see Figure 1).

Some of the hot carriers are captured in the deep gate bias region, so the device's drain current (Id), threshold voltage (Vth), and transconductance (Gm) are shifted.

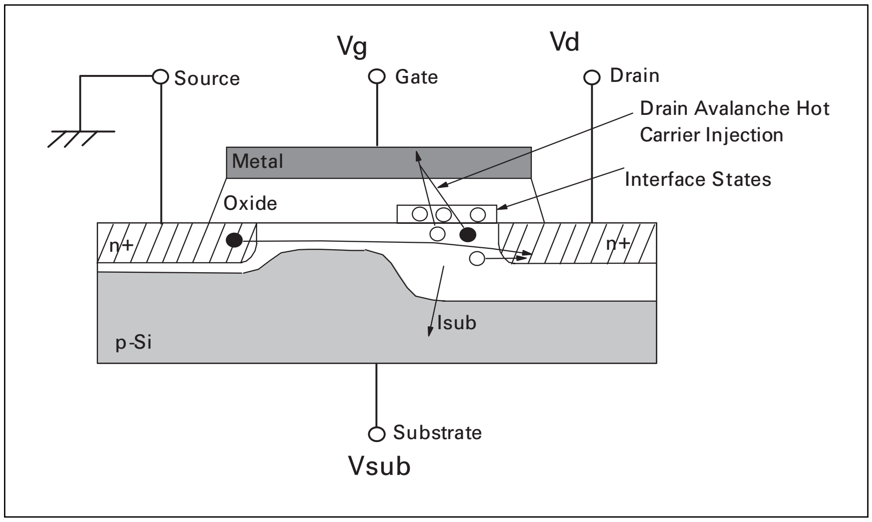

Figure 1. Drain avalanche hot carrier

Problems in Evaluation of Hot Carrier Induced Degradation
To efficiently evaluate hot carrier induced degradation of a MOSFET process, electrical stress should be applied to many devices for an extended period of time. Parameters such as Id, Vth, and Gm must be repeatedly measured during this time. The resulting hot carrier life is estimated from the measured parameter shift versus stress time graph. (The test flow is shown in Figure 2.) Therefore, there are the following requirements in the test:

- Due to the long total test times required, devices should be tested in parallel to improve efficiency.

- Several stress conditions must be applied to the test devices to evaluate the relationship between parameter shifts and stress conditions.
- High resolution and precision measurements in current and voltage are required for evaluating sensitive parameter shifts.
- If the parameter measurements are not performed right after stress ends, the test results may be incorrect.

Until now, there has not been a switch that can meet these requirements and that does not sacrifice the measurement performance of the parameter analyzer.

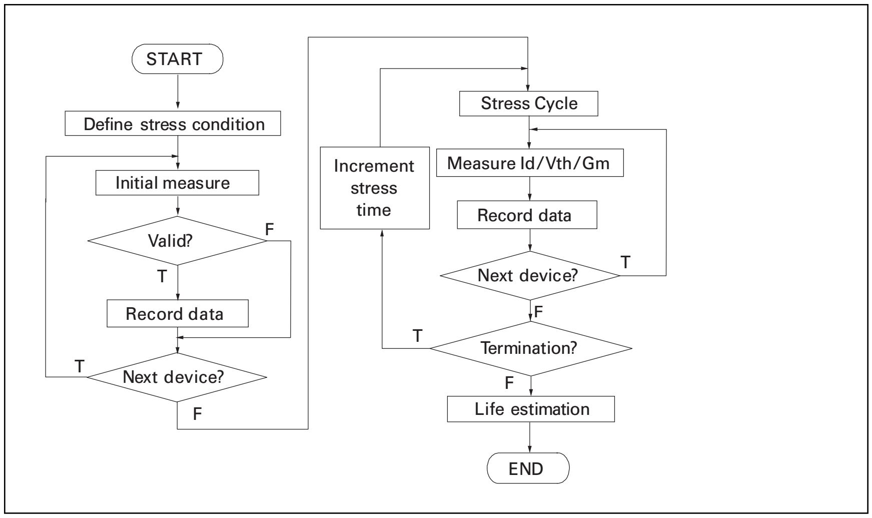

Figure 2. Flowchart of evaluating hot carrier induced degradation

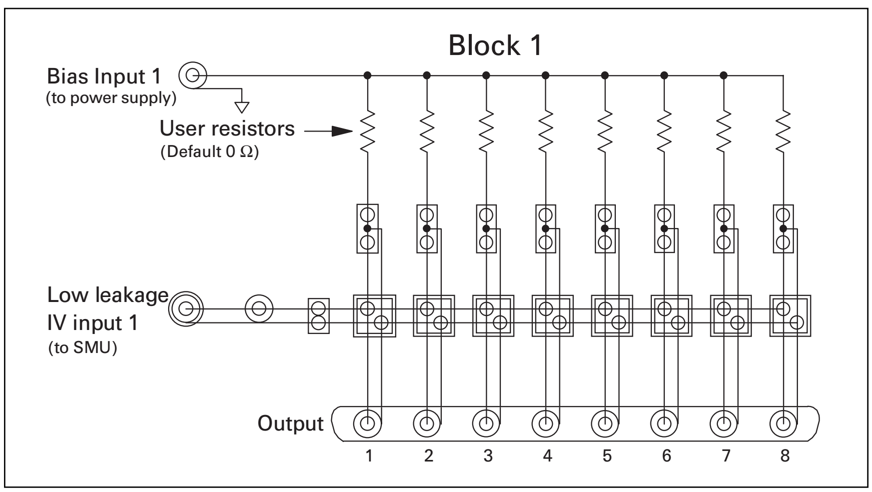

Figure 3. Block circuit diagram of multiplexer (one block).

New Solution using the Agilent E5250A
Combining the Agilent E5250A Option 501 24-channel multiplexer card and the Agilent 4155C/4156C parameter analyzer, you can configure a test system with up to 384 channels (using 4 Agilent E5250As including 4 multiplexer cards).

Each multiplexer card contains 3 individual 8-channel multiplexers as shown in Figure 3. Each block has a bias input port that you can connect to an external power supply for stressing multiple devices.

For accurate parameter measurements, the low leakage I-V input port is used to connect the Agilent 4155C/4156C to a device. This port has offset current of less than 100 fA. The example measurement result in Figure 4 shows that the subthreshold region of Id-Vg curve can be stably measured.

If the power supply is disconnected from all the devices, there will be a lag time as SMUs are connected to each device and measured one by one. By using the single route mode and bias mode of the Agilent E5250A, a selected output channel of one multiplexer can be connected to an SMU while the other channels are connected to power supply output. With this capability, you can obtain correct test results by measuring parameters right after the stress termination.

How to Measure using the Agilent E5250A, 4155C/4156C, and Agilent 6626A
Figure 5 shows an example connection diagram for evaluation of hot carrier induced degradation using the Agilent E5250A, 4155C/4156C, and Agilent 6626A Multi-Channel Power Supply. In this example, one 24-channel multiplexer card is installed into a slot of the Agilent E5250A for test of 8 MOSFETs, which have common substrates.

The SMUs of the Agilent 4155C/4156C are connected to the I-V input ports of the Agilent E5250A Low Leakage Switch Mainframe. The outputs of the Agilent 6626A for applying stress voltages to devices in parallel, are connected to the bias input ports on the multiplexer card.

These instruments are controlled directly from the Agilent 4155C/4156C by using its built-in Agilent Instrument BASIC (IBASIC) capabilities. You do not need an external controller. The parameter measurements are executed by calling the pre-saved setup file from the IBASIC program. The parameter values such as Vth, can be extracted by using the auto analysis function right after the sweep measurement is performed. This frees you from complicated programming for instrument control and data extraction.

Stress and measurements are alternately performed by IBASIC program. The stress time is incremented logarithmically with each stress-measure cycle. The cycles stop when a maximum stress time is reached or when one of the measurement parameters drifts past its target value.

At the end of the test, graphs of the measured parameter shift versus stress time are drawn on the Agilent 4155C/4156C display. Using the user variable function, it is very easy to transfer arrays of parameter values in IBASIC program to the Agilent 4155C/4156C's graphics data. The hot carrier life is estimated using the regression line function. In example test result of Figure 6, the hot carrier life is defined as the stress time at which Vth has shifted by 50 mV from its initial Vth. The hot carrier life is estimated as about 104.5 hours.

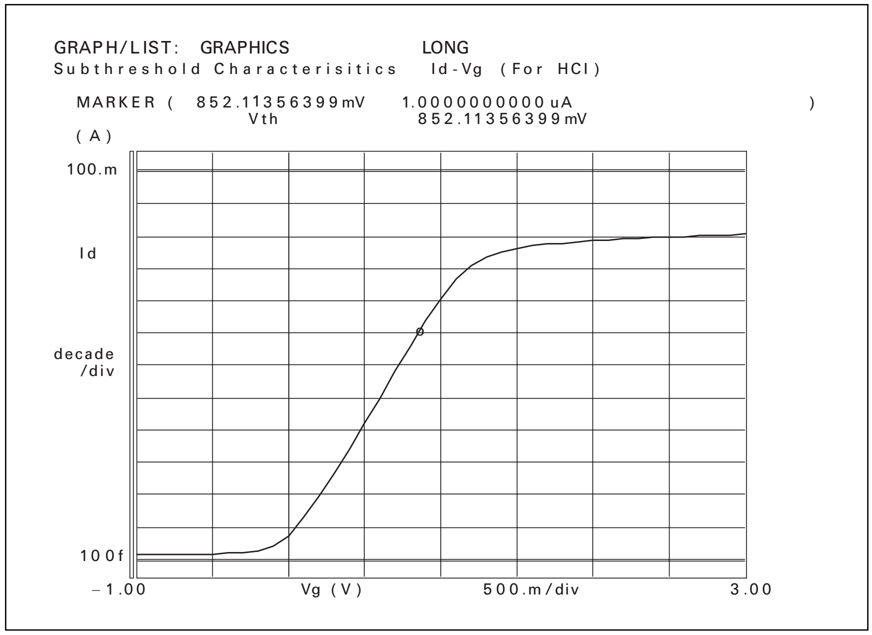

Figure 4. Id-Vg curve obtained using the Agilent 4156C with E5250A

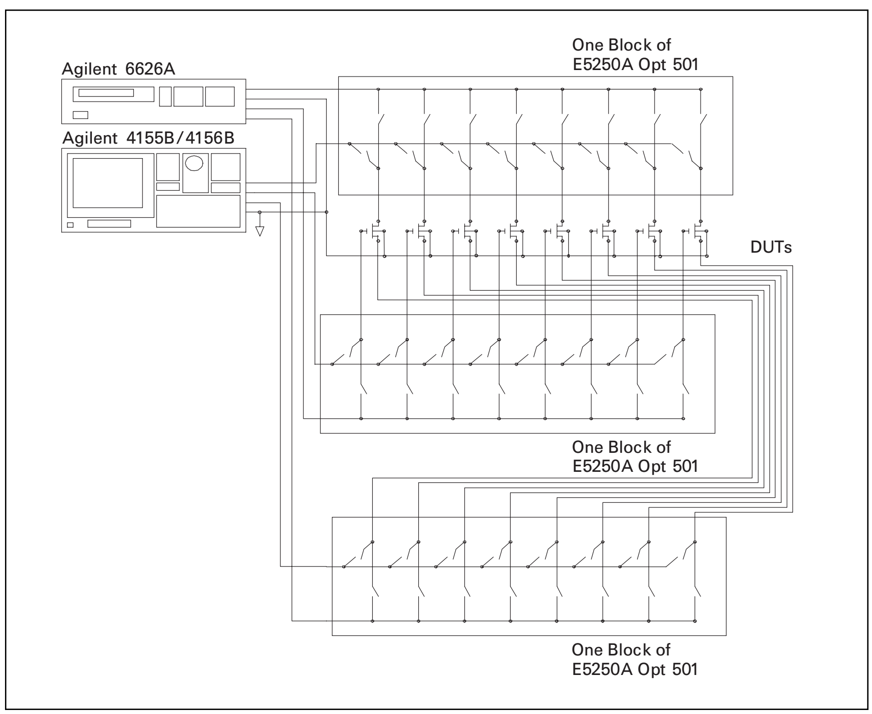

Figure 5. Connection diagram for evaluating hot carrier induced degradation of multiple devices

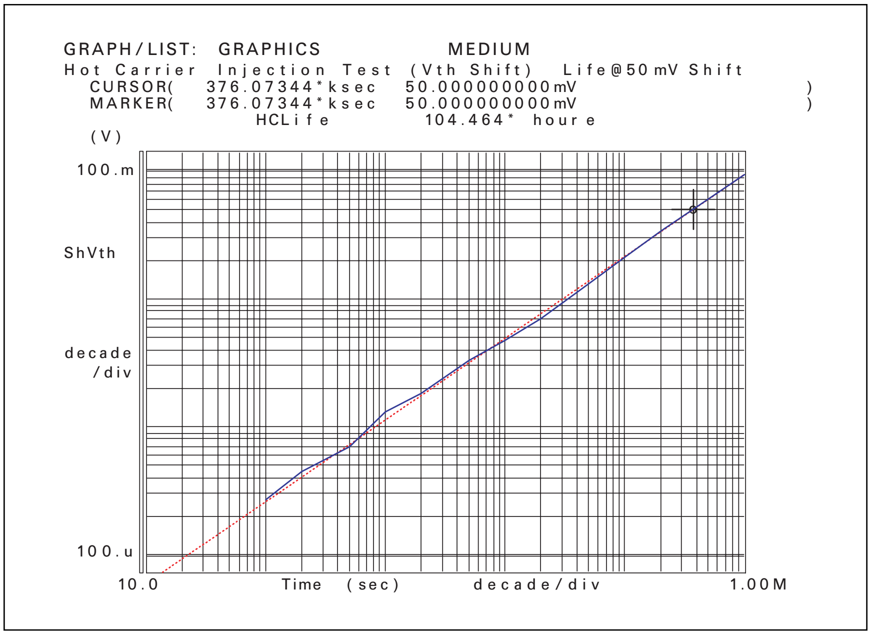

Figure 6. Estimation of hot carrier life

Conclusion

Using the Agilent E5250A and 4155C/4156C with a power supply, you can electrically stress many devices in parallel. You can monitor each device one at a time while maintaining stress on the other devices, thus eliminating error due to measurement lag time. You can configure up to 384-channel system for hot carrier induced degradation evaluation of a large number of devices. By using individual bias input ports, you can perform test under various stress conditions. The multiplexer cards can be used for other long term reliability tests, such as TDDB and temperature lifetime.

Note: The information in this application note referring to the Agilent 4155C/4156C also applies to the Agilent 4155A/4156A and 4155B/4156B.

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