Ultra Low Current dc Characterization of MOSFETs at the Wafer Level

Application Note 4156-1

Agilent 4156C Precision Semiconductor Parameter Analyzer

Introduction

Safe operation of next-generation sub-micron devices requires that power dissipation and signal levels be scaled accordingly. To successfully characterize these devices and semiconductor processes, more precise and noise free low current measurements are needed. The Agilent 4156C precision semiconductor parameter analyzer allows you to measure down to the fA level. This application note shows how to precisely evaluate subthreshold characteristics of a MOSFET device using the 4156C's ultra low current measurement capability.

Current Problems

Accurate low current measurements on a wafer are difficult because of the following reasons:

- Leakage and electric noise in the measurement cables, and interface between the measurement instrument and wafer prober
- Leakage and electric noise at the interconnect wires and probe needles due to insufficient guarding, and the effects of light due to incomplete shielding of the wafer

Due to these limitations, you have to design special parametric test elements. For example, in the measurement of oxide leakage current, you may have to design test elements that have larger areas to minimize the effect of leakage and noise.

But these "scaled-up" test elements waste valuable wafer layout area. There is also the question of how valid the data taken on large test elements is for your actual "scaled-down" process. With the 4156C, you can measure with confidence, the actual MOSFET devices without developing special higher current test elements.

Measurements using the Agilent 4156C

The 4156C and Cascade Microtech Summit series analytical wafer prober together provide you with a solution for fast measurement throughput at these very low current levels.

- The 4156C's A to D converter and guard design of the measurement system is newly designed, resulting in revolutionary improvements in resolution and accuracy. The 4156C has 1 fA resolution and 20 fA offset. Each of four SMUs has the same resolution and accuracy. You are free from worrying about cable connections according to the pin assignment of your devices.
- The measurement cables are also re-designed by reviewing the materials and forms. Kelvin Triaxial Cable (Patent) minimizes electric noise and leakage. Moreover, it reduces the effect of electromotive force (emf) in the cable.
- The Zero Offset function and Self Calibration function reduce the offset current and offset voltage in the measurement system including the measurement cables and probes. Now you can perform ultra low current test by eliminating errors caused by thermal and emf effects.
- The Summit series prober was designed to mate with the 4156C. All measurement paths are fully guarded and shielded, including the wafer chuck (substrate) connection. You can measure surface and bulk leakages to the full potential of the 4156C.

Measurement Instruments and Connection
The 4156C's kelvin-triaxial cables can be connected directly to the optional connector plate of the Summit prober.

You do not have to solder measurement wires to the connector plate, so there will be no flux and fingerprints that increase leakage (Figure 1).

It is recommended to use 1.5 m kelvin triaxial cables (option) to connect the 4156C and the prober. Shorter measurement cable has less leakage and noise.

Measurement of Threshold Characteristics of an n-channel MOSFET
The measurement block diagram and measurement setup for the measurement of the threshold characteristics of an n-channel MOSFET are shown in Figure 2 and Figure 3. The sweep step interval is kept small to reduce charging currents caused by any residual cable or probe capacitances.

To perform accurate ultra low current measurements, use the measurement conditions recommended in the MEASURE SETUP page shown in Figure 4.

In this page, the measurement range should be set to Auto range or Limited Auto 10 pA range. The 10 pA range is the minimum range and has 1 fA resolution. Also the measurement integration time is set to Medium or Long to prevent the effect of electric noise.

On SWEEP SETUP page, you will need to add a Hold Time at the beginning of non-zero voltage sweeps to allow for initial charging time constants. Increase the Delay Time between each point in the sweep as needed to account for the effects of dielectric absorption from residual ground or guard capacitances.

The measurement environment should be considered as well.

- Turn off any sources of mechanical vibration

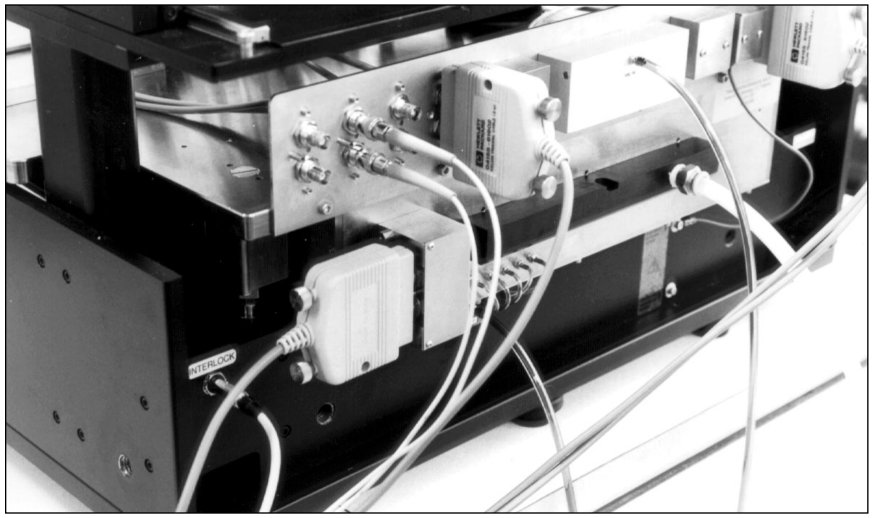

Figure 1. Connector plate at the rear of the Summit 10500

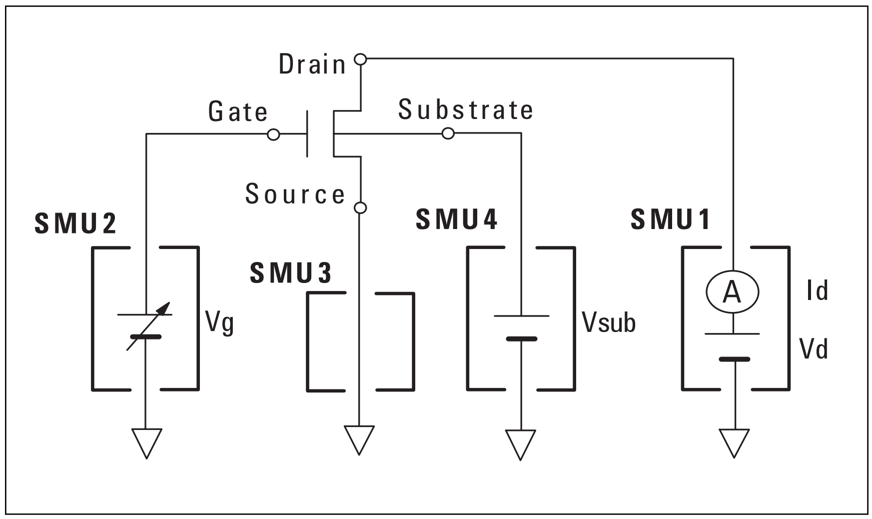

Figure 2. Measurement block diagram

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MEASURE: SWEEP SETUP
 Subthreshold Characteristics Id-Vg (Low Current Meas)
 *VARIABLE     VAR1          VAR2
  UNIT         SMU2:HR
  NAME         Vg
  SWEEP MODE   SINGLE
  LIN/LOG      LINEAR
  START        -1.0000 V
  STOP          4.000 V
  STEP          50.0mV
  NO OF STEP   101
  COMPLIANCE    100.00mA
  POWER COMP   OFF

 *TIMING
  HOLD TIME     5.00 s
  DELAY TIME    0.0000 s    *SWEEP  CONTINUE AT ANY    Status
 *CONSTANT
  UNIT         SMU1:HR      SMU3:HR      SMU4:HR
  NAME         Vd           Vs           Vsb
  MODE         V            V            V
  SOURCE        3.000 V      0.0000 V     0.0000 V   ---------
  COMPLIANCE    100.00mA     100.00mA     100.00mA   ---------
```

Figure 3. SWEEP SETUP page

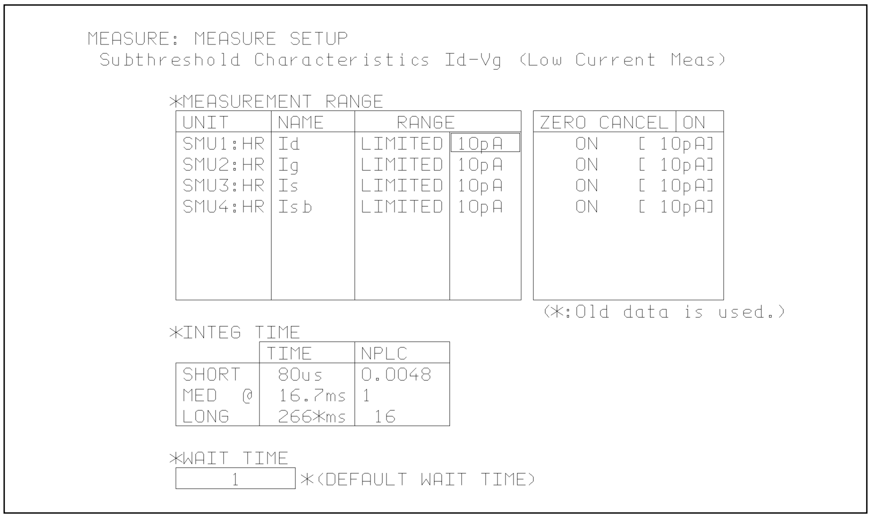

Figure 4. MEASURE SETUP page

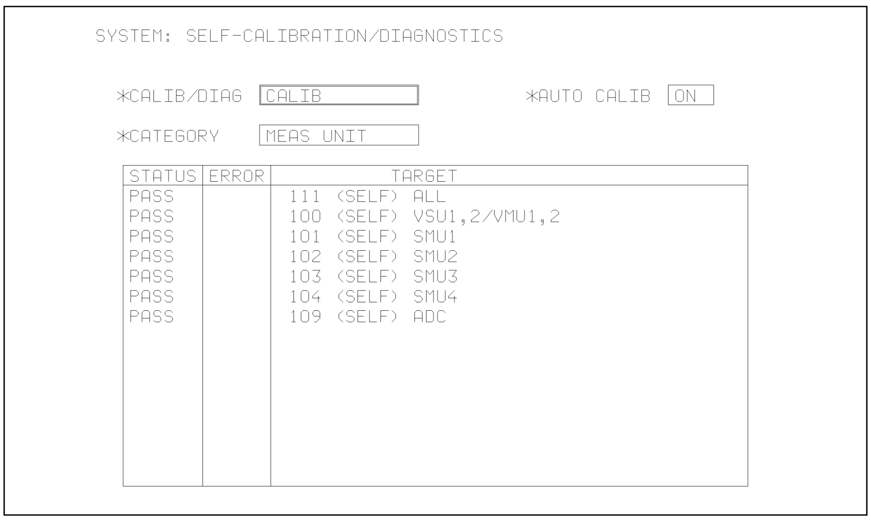

Figure 5. CALIBRATION/DIAGNOSTICS page

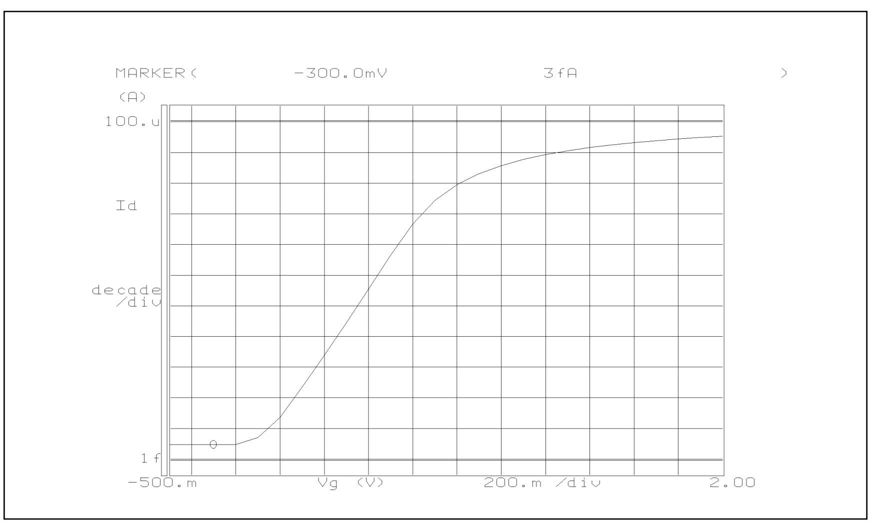

Figure 6. Subthreshold characteristics of a MOSFET

- Turn off all electric instruments except for the 4156C
- Keep room temperature and humidity stable

This minimizes external noise and thermal induced offset currents in the SMU circuitry.

Before making measurements, it is recommended that you perform the self calibration and Zero Cancel. Connect measurement cables to the probes. Be sure that all measurement conditions are set and that the probes are up and off the wafer. Perform the self calibration using the CALIBRATION/DIAGNOSTICS page shown in Figure 5.

Next, go to the GRAPHICS page, push the green key, then push the Stop key to perform the Zero Cancel.

This procedure should be done after the 4156C has been turned on for thirty minutes warming up and right before the measurements. If you change cables or probes, you need to wait for a few minutes until the offset current generated by emf or friction subsides to negligible values.

Measurement Result

Figure 6 shows measurement results of the subthreshold characteristics of a MOSFET to fA current levels.

Conclusion

The Agilent 4156C can perform ultra low current measurements that are critical to evaluating future semiconductor devices. Leakage current of oxides, substrate current of MOSFETs, reverse biased characteristics of diodes, and Gummel plot of bipolar transistors can be measured accurately. Each of four SMUs has the same resolution and accuracy. You can perform low current measurement without sacrificing flexibility. Moreover, you don't have to sacrifice device performance due to scaled-up test structures. You can now evaluate the devices of same geometry used in the final ULSI chip.

Note: The information contained in this application note is also applicable to the Agilent 4156A and Agilent 4156B.

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Printed in U.S.A. 10/00
5963-2014E

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