
Ultra Low Current DC Characterization of MOSFETs at the Wafer Level

Application Note 4156-1

**HP 4156A
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 HP 4156A 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 HP 4156A'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 HP 4156A, you can measure with confidence, the actual MOSFET devices without developing special higher current test elements.

Measurements using the HP 4156A

The HP 4156A and Cascade Microtech's Summit 9500/10500 analytical wafer prober together provide you with a solution for fast measurement throughput at these very low current levels.

- HP 4156A's A to D converter and guard design of the measurement system is newly designed resulting in revolutionary improvements in resolution and accuracy. The HP 4156A has 1 fA resolution and 20 fA offset. Each of 4 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. New 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 9500/10500 prober was designed to mate with the HP 4156A. 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 HP 4156A.

Measurement Instruments and Connection

The HP 4156A kelvin-triaxial low leakage cables can be connected directly to the optional connector plate of the Summit 9500/10500. You are not have to solder measurement wires to the connector plate, so there will be no flux and fingerprints that increase leakage (Figure 1).

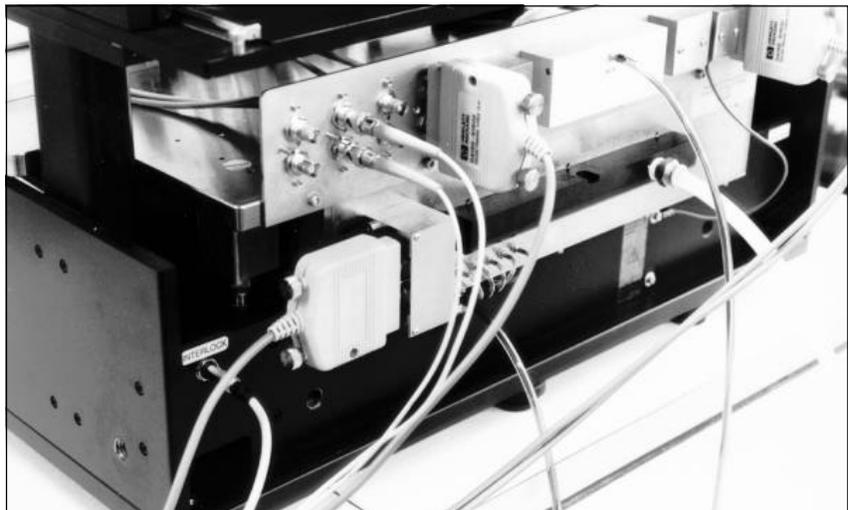


Figure 1. Connector Plate on the Rear Side of The Summit 10500

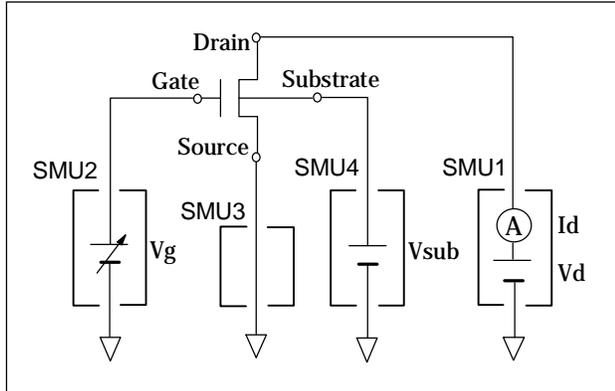


Figure 2. Measurement Block Diagram

MEASURE: SWEEP SETUP
CMI Summit 9500 Id-Vg Meas. IDVG4.DAT 94JUN06 06:50PM

* VARIABLE

UNIT	VAR1	VAR2
NAME	SMU2: HR	
	Vg	
SWEEP MODE	SINGLE	
LI N/ LOG	LINEAR	
START	-1.0000 V	
STOP	4.000 V	
STEP	50.0 mV	
NO OF STEP	101	
COMPLIANCE	100.00 mA	
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	Vsb	Vs	
MODE	V	V	V	
SOURCE	3.000 V	0.0000 V	0.0000 V
COMPLIANCE	100.00 mA	100.00 mA	100.00 mA

Figure 3. SWEEP SETUP Page

MEASURE: MEASURE SETUP
CMI Summit 9500 Id-Vg Meas. IDVG4.DAT 94JUN06 06:49PM

* MEASUREMENT RANGE

UNIT	NAME	RANGE	ZERO	CANCEL	ON
SMU1: HR	Id	LIMITED	10 pA	ON	[10 pA]
SMU2: HR	Ig	LIMITED	10 pA	ON	[10 pA]
SMU3: HR	Isub	LIMITED	10 pA	ON	[10 pA]
SMU4: HR	Is	LIMITED	10 pA	ON	[10 pA]

(*: Old data is used.)

* INTEGRATION TIME

	TIME	NPLC
SHORT	80 us	0.004
MED	20.0 ms	1
LONG @	320. ms	16

* WAIT TIME

1	*(DEFAULT WAIT TIME)
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Figure 4. MEASURE SETUP Page

SYSTEM: SELF-CALIBRATION/DIAGNOSTICS 94JUN06 06:53PM

* CALIB/DIAG * AUTO CALIB

* CATEGORY

STATUS	ERROR	TARGET
PASS		111 (SELF) ALL
PASS		100 (SELF) VSU1.2/VMU1.2
PASS		101 (SELF) SMU1
PASS		102 (SELF) SMU2
PASS		103 (SELF) SMU3
PASS		104 (SELF) SMU4
PASS		105 (SELF) SMU5
PASS		107 (SELF) PGU1.2
PASS		108 (SELF) GNDU
PASS		109 (SELF) ADC

Figure 5. CALIBRATION/DIAGNOSTICS Page

It is recommended to use 1.5 m kelvin triaxial cables(option) to connect the HP 4156A 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

- Turn off all electric instruments except for the HP 4156A

- 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.

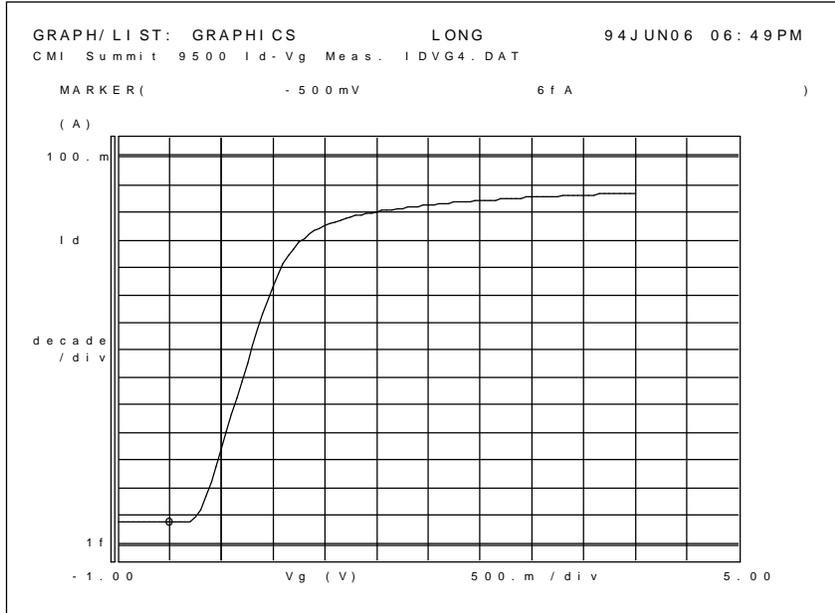


Figure 6. Subthreshold Characteristics of a MOSFET

This procedure should be done after the HP 4156A has been turned on for 30 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 HP 4156A 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 extra space on the wafer or device performance due to scaled-up test structures. You can now evaluate the devices of same geometry used in the final ULSI chip.

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