

Ultra Low Current DC MOSFET Characterization at the Wafer Level

Application Note B1500-15

Agilent B1500A Semiconductor Device Analyzer

Introduction

Nanoscale devices require both lower signal levels and lower power levels for proper operation. In order to characterize these devices and the semiconductor processes on which they are made, it is essential to be able to make accurate low-level current measurements. The Agilent B1500A Semiconductor Device Analyzer meets this need by supporting current measurements in the sub fA range. This application note will explain how to evaluate MOSFET subthreshold characteristics precisely using the B1500A's ultra low current measurement capabilities.

Low-current measurement challenges

Accurate low current on-wafer measurements face many challenges that can potentially degrade measurement quality including:

- Leakage currents and electrical noise created by the measurement cables and the interface between the measurement instrument and the wafer prober



- Leakage currents and electrical noise on the interconnect wires and probe needles in the prober caused by insufficient guarding
- Photoelectric effects arising from failure to completely shield the wafer from ambient light

These issues are not always correctable by improvements to the measurement equipment, but instead may require specially designed test structures. For example, the proper measurement of oxide leakage currents may necessitate the design of large area test elements to minimize the effects of leakage and noise.

However, using "scaled-up" test elements wastes valuable wafer real estate. Moreover, it is not clear how well data taken on oversized test elements correlates with the behavior of normal sized devices. Fortunately, the Agilent B1500A possesses the low current measurement capabilities necessary to enable you to measure your actual MOSFET devices without the need for special test structures.



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Key Agilent B1500A low current measurement features

The B1500A mainframe has ten slots available for modules and it supports a variety of source/monitor unit (SMU) module types, such as a high resolution SMU (HRSMU), a medium power SMU (MPSMU) and a high power SMU (HPSMU). You can easily customize your B1500A configuration to fit your exact device measurement requirements. The following features explain how the B1500A can provide you with low-current measurement solutions down into the sub fA range.

- The HRSMU has a 1 fA measurement resolution with 15 fA of measurement offset. In addition, the HRSMU accepts an optional Atto Sense and Switch Unit (ASU), which improves its low current measurement resolution to 100 attoamps (0.1 fA) and its measurement offset to 12 fA.
- Agilent makes Kelvin triaxial cables to connect the B1500A to semiautomatic wafer probers, and these cables produce less electrical noise and leakage than do standard triaxial cables. In addition, Kelvin triaxial cables exhibit less electromotive force (EMF) than do standard triaxial cables. Virtually all of the major analytical wafer prober manufacturers have connector plates that support Agilent's Kelvin triaxial cables, so no soldering or any other special connection technique is required.

This means that you do not need to worry about flux or fingerprint oil from poor soldering work causing sneak leakage paths.

Note: For optimal low-current measurements Agilent recommends using 1.5 m length Kelvin triaxial cables to connect the B1500A to a wafer prober, since shorter measurement cables innately produce less leakage and noise.

- The B1500A also has both Zero Offset and Self Calibration functions to reduce the inherent offset currents and voltages in the measurement cables and probes. By eliminating errors caused by thermal and EMF effects, these functions greatly facilitate ultra low current measurement.

Some probers are designed to interface with the B1500A. All measurement paths are fully guarded and shielded, including the wafer chuck (substrate) connection. This allows you to measure surface and bulk leakages and fully utilize the capabilities of the B1500A.

N-channel MOSFET subthreshold measurement

The measurement block diagram is shown in Figure 1.

The B1500A comes standard with EasyEXPERT software, which provides a convenient GUI-based solution for instrument control. EasyEXPERT has two main test modes for making measurements through its graphical user interface. The first is the application test mode, which simplifies the measurement process by providing you with a library of over 230 predefined and user modifiable application tests. The second is the classic test mode, which provides a user interface similar to that found on the Agilent 4155/56 semiconductor parameter analyzers. EasyEXPERT also has the capability to control semiautomatic wafer probers, and you can run both application mode tests and classic mode tests as you automatically step across the wafer. For more information please refer to the product brochure *Agilent B1500A: Making Every User a Parametric Test Expert* (5989-5440EN).

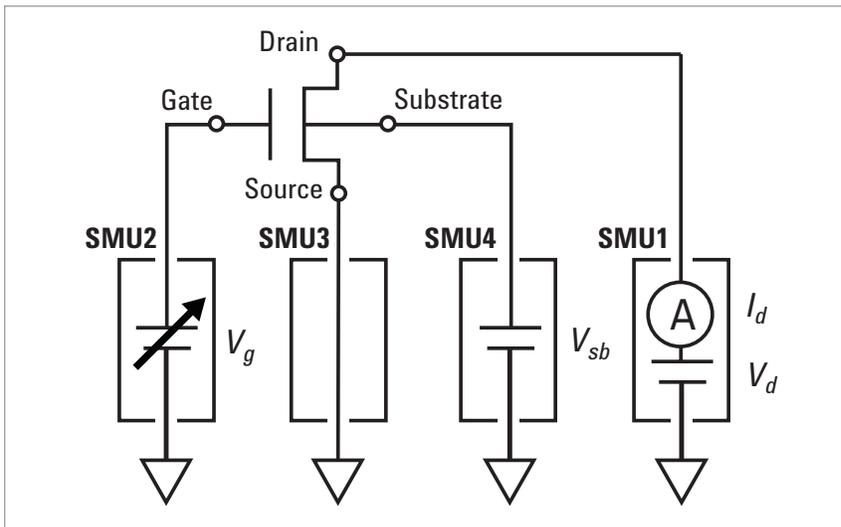


Figure 1. Measurement block diagram

Before attempting a low-current measurement, you should first execute the Self Calibration function and the Zero Cancel function. The procedure to do this using EasyEXPERT is as follows:

1. Connect the measurement cables to the probes.
2. Make sure that all measurement conditions are set and that the probes are up and off the wafer.
3. Perform the self calibration using the Module Self Calibration tab screen shown in Figure 2.
4. Go to the SMU Zero Cancel tab screen and perform a Zero Cancel.

This procedure should be done after the B1500A has had a warm up period of at least forty minutes and right before attempting a measurement. If you change the cables, probes, or any of their connections then you must wait for about three minutes until the offset currents generated by EMF and piezoelectric effects subside to the negligible values.

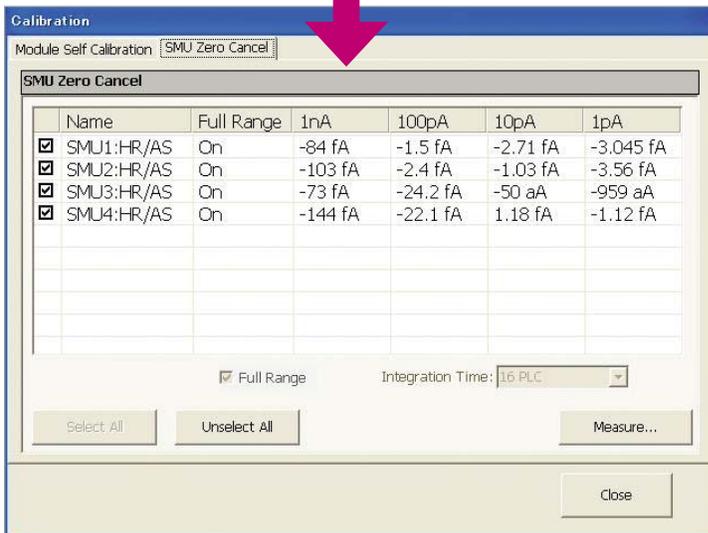
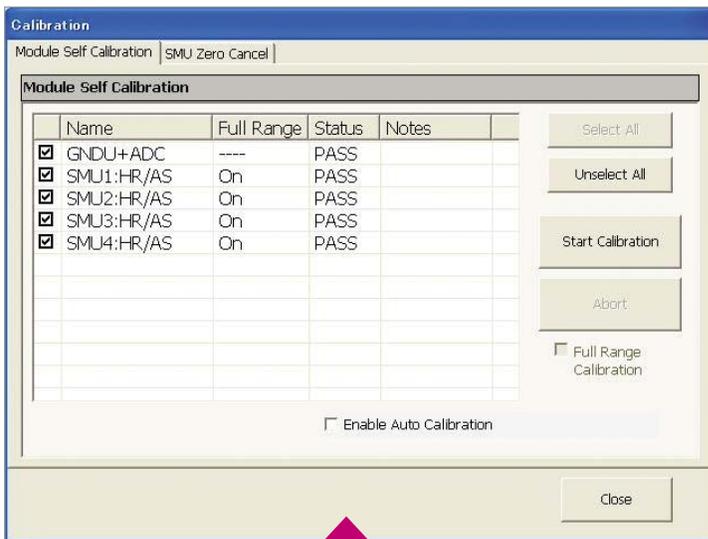


Figure 2. Calibration window

Figure 3 and Figure 4 show configurations for measuring the subthreshold characteristics of an n-channel MOSFET. The sweep step interval is kept small to reduce charging currents caused by the residual capacitance in the cables and probes.

Figure 3 shows the recommended measurement conditions to make an accurate low current measurement at the sub fA level. In the classic test mode, clicking the Range button or the ADC/Integ button on the Measurement Setup screen displays these windows. In the SMU Range Setup window, the measurement range should be set to either Auto range or Limited Auto 1 pA range. The 1 pA range is the minimum range of the HRSMU when used with an ASU, and in this range the HRSMU/ASU combination has a 0.1 fA resolution. In addition, in the A/D Converter & Integration Time Setup window the measurement integration time must be set to Medium or Long to prevent electrical noise from disturbing the measurement.

On the Measurement Setup screen, it is also necessary to add a Hold Time at the beginning of the sweep measurement, and a Delay Time between each measurement point in the sweep to provide enough time for transient voltages caused by dielectric absorption in the measurement path to decay.

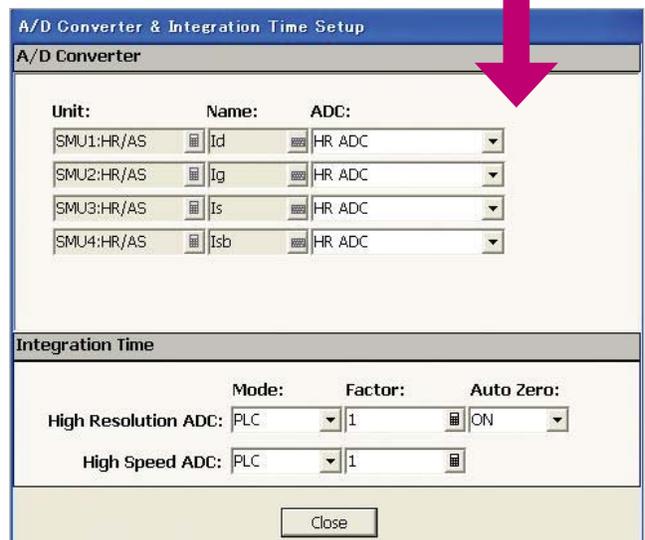
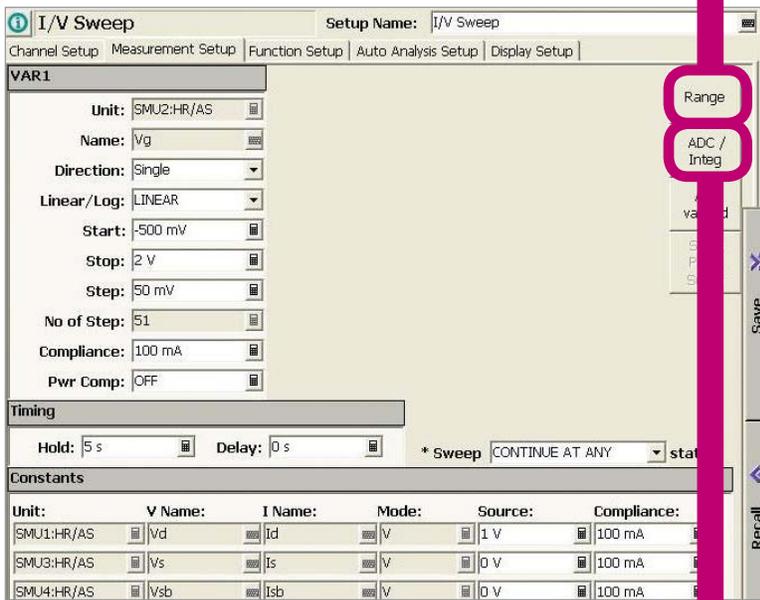
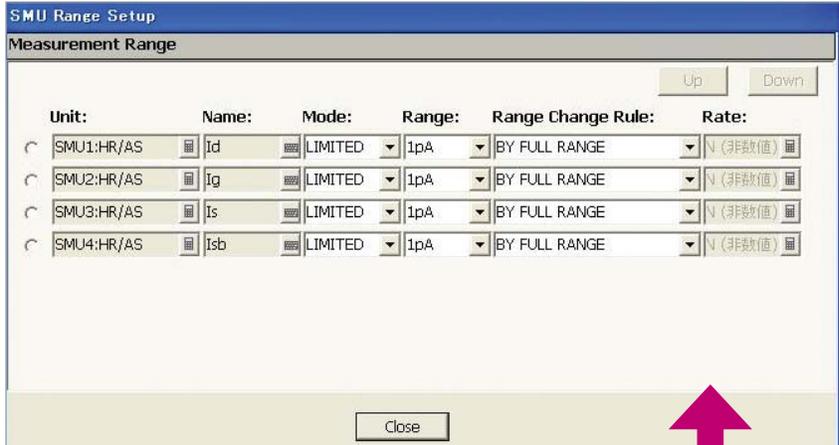


Figure 3. Measurement setup screen in classic test mode

Besides the instrument settings, factors impacting the measurement environment also need to be taken into account.

- Turn off any equipment that could cause mechanical vibration
- Turn off all electric instruments except for the B1500A
- Keep the ambient temperature and the humidity stable

Following these guidelines will minimize the external noise and the thermal induced offset currents in the SMU circuitry.

Measurement result

Figure 5 shows the results of a subthreshold MOSFET measurement using the B1500A HRSMU/ASU combination. The measurement shown was made using the instrument settings as described above. As this data demonstrates, the B1500A enables you to make an accurate and stable sub fA low current measurements.

Conclusion

The B1500A can perform ultra low current measurements critical to the evaluation of nanoscale semiconductor devices. The B1500A's HRSMU/ASU combination provides 0.1 fA resolution, which enables the accurate characterization of parameters such as gate insulator leakage, MOSFET substrate currents, diode reverse bias characteristics, and bipolar transistors Gummel plots. The B1500A eliminates the need to create special scaled-up test structures, thereby allowing you to measure devices the same size as you will use in your actual integrated circuit.

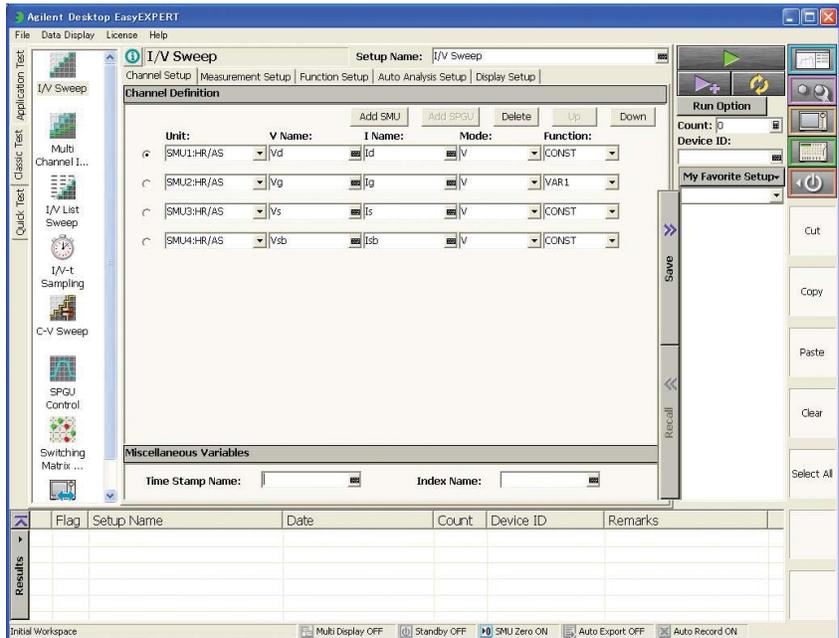


Figure 4. Channel setup screen in classic test mode

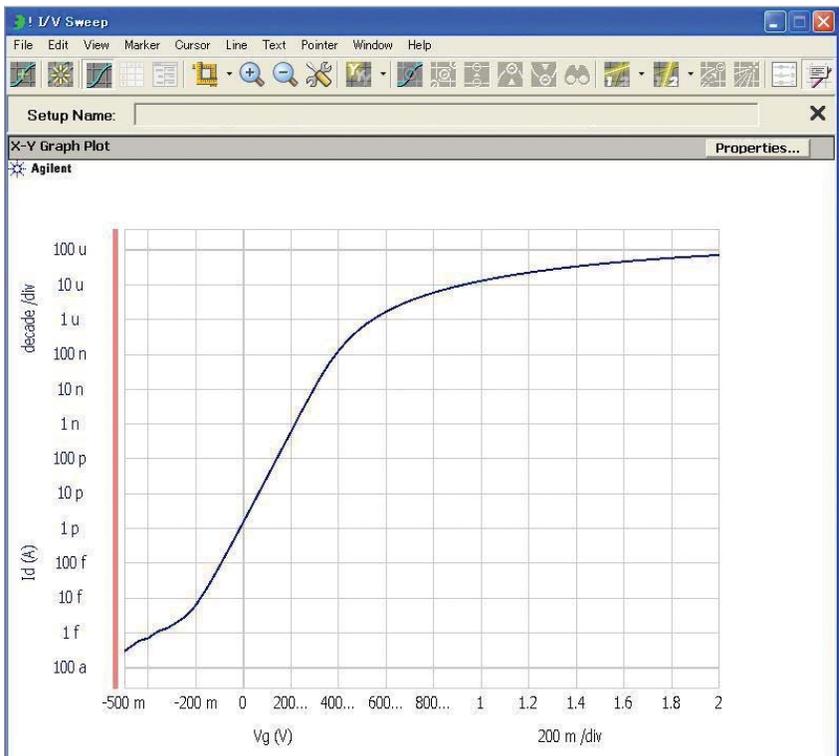


Figure 5. Subthreshold characteristics of a MOSFET

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