

Keysight Technologies

B1500A: A Complete Solution for CMOS
Device Electrical Characterization
Semiconductor Device Analyzer

Application Note





Introduction

Complementary Metal–Oxide–Semiconductor (CMOS) Field Effect Transistor (FET) technology continues to be the basis for large scaled integrated circuits such as microprocessors and memory devices. CMOS technology is now so pervasive that it is intimately interwoven into the fabric of people’s everyday lives in items such as cell phones, high definition TVs and computers.

The key challenges to improving CMOS device performance are the opposing goals of high speed operation and low power consumption. To achieve both simultaneously, researchers need to fully characterize MOSFET parameters. This includes not only static (DC) behavior but also the dynamic and time-dependent characteristics of the devices.

The Keysight Technologies, Inc. 4155 and 4156 semiconductor parameter analyzers have been the industry standard for almost twenty years. The Keysight B1500A Semiconductor Device Analyzer is the next-generation semiconductor parameter analyzer, and it possesses the measurement capabilities necessary to accurately characterize advanced CMOS devices.

EasyEXPERT, the B1500A’s resident control software, comes standard with ready-to-use measurement libraries. These libraries cover the evaluation of both basic and advanced CMOS device parameters, including reliability test.

This application note gives an overview of the B1500A’s key features and it goes on to show how the B1500A is a complete solution for CMOS device electrical characterization.

Comprehensive State-of-the-art Measurement Capabilities

Ten module slots and a wide selection of source/monitor units (SMUs) and other state-of-the-art module types enable the B1500A to be configured to meet the most exacting measurement requirements of advanced CMOS processes. Figure 1 summarizes the available B1500A modules.

Medium Power SMU (MPSMU)

The MPSMU is a general purpose SMU possessing moderate voltage and current sourcing capability and measurement resolution. The MPSMU's maximum output voltage is ± 100 V and its maximum output current is ± 100 mA. The MPSMU's minimum current measurement resolution is 10 fA and its minimum voltage measurement resolution is 0.5 μ V.

High Resolution SMU (HRSMU)

The HRSMU is designed for measurements requiring extreme precision such as gate leakage, off-state leakage and sub threshold current measurement. The HRSMU's minimum current measurement resolution is 1 fA (versus 10 fA for the MPSMU). In addition, when combined with the atto-sense and switch unit (ASU) the HRSMU can achieve a current measurement resolution of 100 aA (0.1 fA) while still maintaining the same voltage and current sourcing capabilities as the MPSMU.

High Power SMU (HPSMU)

As the name implies, the HPSMU has expanded voltage and current sourcing capabilities relative to the other SMUs. The HPSMU's maximum output voltage is ± 200 V and its maximum output current is ± 1 A. The 200 V output capability is useful for breakdown measurements and the 1 A output capability supports important reliability tests such as device interconnect electromigration testing.

All of the B1500A's SMUs are Kelvin, with separate force and sense inputs. In addition, all SMUs can perform Quasi-Static CV (capacitance versus voltage) measurement, and they possess a leakage current compensation feature to help with the measurement of thin gate dielectrics.

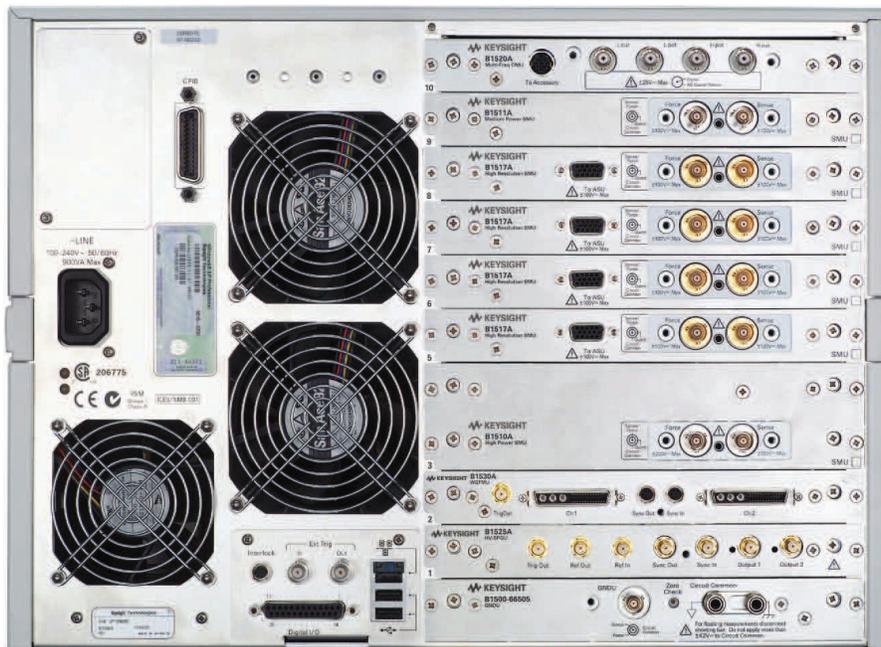


Figure 1. Wide choice of modules gives the B1500A great flexibility

Multi Frequency Capacitance Measurement Unit (MFCMU)

Capacitance measurements are necessary to evaluate certain CMOS device parameters such as gate dielectrics thickness, terminal overlap, and capacitance between the interlayer dielectrics. The B1500A's MFCMU module can perform these capacitance measurements, thereby eliminating the need for a separate external capacitance meter.

The MFCMU has a frequency range from 1 kHz to 5 MHz, and it can supply a DC bias of ± 25 V. An optional SMU CMU unify unit (SCUU) supports automated capacitance versus voltage (CV) and current versus voltage (IV) switching in positioner-based wafer probing environments, which eliminates the need to use a switching matrix to perform this function. Also, the SCUU expands the available capacitance measurement DC bias voltage to ± 100 V using either the MPSMUs or HRSMUs as a bias sources.

High Voltage Semiconductor Pulse Generator Unit (HV-SPGU)

The HV-SPGU is specifically designed to meet the challenges posed by advanced non-volatile memory (NVM) testing needs such as characterization of the write/erase behavior of multi-level-cell (MLC) Flash memory.

Each HV-SPGU module has two independent channels, and each channel has ± 40 V sourcing capability and a built-in tri-state feature. A maximum of five HV-SPGU modules can be installed into a single B1500A, with all module channel outputs synchronized so that it is possible to apply pulse stimuli to multiple device terminals simultaneously. The 16445A SMU/PGU Selector Connection Adapter allows the B1500A to control the 16440A SMU/Pulse Generator Selector unit, which supports effortless switching between the HV-SPGUs and SMUs. Due to all of these advanced features the HV-SPGU provides unmatched write/erase endurance testing performance, with the ability to complete 1,000,000 cycles within just a few hours.

In addition to supporting superb flash memory cell characterization capability, the HV-SPGU has an arbitrary linear waveform generation (ALWG) capability that enables it to output the complicated waveform sequences necessary to characterize new types of NVM such as phase-change (PRAM) and resistance random access memory (RRAM).

Waveform Generator / Fast Measurement Unit (WGFMU)

The WGFMU is a two-channel module that combines ALWG voltage pulsing capability with ultra-fast IV measurement. Voltage waveforms can be specified with a minimum sampling rate of 10 ns. The WGFMU module's voltage output has a 16 bit resolution and it covers the following voltage ranges: - 5 V to 5 V, -10 V to 0 V, or 0 V to +10 V. The module's minimum sampling interval for IV measurements is 5 ns and it supports measurement ranges of 1 μ A, 10 μ A, 100 μ A, 1 mA and 10 mA (14 bit resolution).

Applications covered by this module include pulsed IV measurement, advanced ultra-fast negative bias temperature instability (NBIT) / positive bias temperature instability (PBTI) measurement (both DC and AC stress), random telegraph noise (RTN) measurement, micro electro mechanical systems (MEMS) capacitor characterization, new types of non volatile memory characterization, as well as other types of transient or time-domain measurement.

Ultra Narrow Pulsed IV Measurement System

The B1542A Pulsed IV system provides 10 ns pulsed IV capability to measure intrinsic IV characteristics of MOSFETs fabricated on SOI wafers or using high-k gate dielectrics. The B1542A consists of a B1500A, application software, pulse generator, oscilloscope and specially designed accessories.

Easy and Intuitive Operation

EasyEXPERT

Keysight EasyEXPERT software, which is resident on the PC-based the B1500A, is a powerful Microsoft Windows application program for controlling the B1500A.

EasyEXPERT provides an easy and effective measurement and analysis environment combined with an intuitive graphical user interface (GUI). Interaction with EasyEXPERT can occur either through the B1500A's touch screen LCD panel or via an optional USB keyboard, and mouse. The familiar Windows environment reduces the learning curve and supports easy networking and data export into MS office-based tools.

Ready-to-use Measurement Library

EasyEXPERT employs a unique “top-down” approach to device characterization that allows users to immediately focus on making measurements without having to learn all the intricacies of the instrument hardware. EasyEXPERT comes with more than 230 measurement algorithms conveniently organized by device type, application, and technology.

Figure 2 shows an application test example of a MOSFET threshold voltage measurement. First, the user selects the “CMOS” technology category. Next, the user selects the “Vth gmMax” application test from the displayed list. The application test documentation feature describes how this application test extracts the threshold voltage by extrapolating from the linear region of the drain current. Finally,

the user fills in the measurement parameters and clicks on the start button. The measurement begins and Vth is automatically extracted using built-in analysis functions. After completion, measurement results are automatically stored into EasyEXPERT's built-in database.

If necessary, you can also easily modify and customize the furnished application tests to fit your specific needs. The furnished application tests make it easy to begin making productive parametric measurements immediately.

In addition, application tests for other devices like bipolar junction transistors (BJT), discrete devices, Flash memory cells, mixed signal devices, carbon or metal nanotubes, power FETs and thin film transistors are included in the application test library. This greatly expands the B1500A's usefulness for overall semiconductor devices characterization.⁴

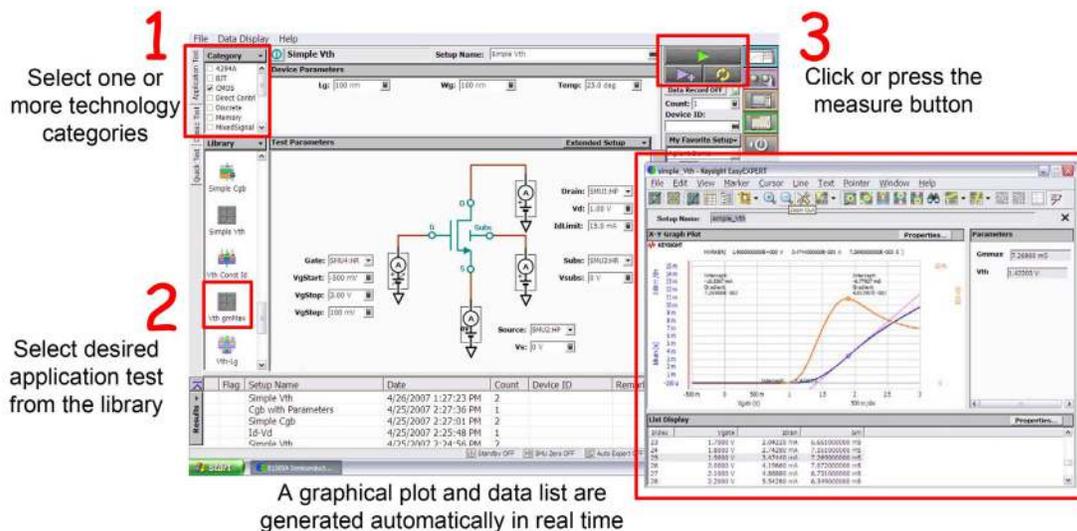


Figure 2. EasyEXPERT application tests make it easy to execute a complicated measurement

Table 1 through table 3 show the lists of application test libraries available for CMOS process and device electrical characterization.¹

Table 1. Material and components development

| Category | Measurement item | Application test |
|--------------|-----------------------------------|---|
| Structure | Gate dielectrics | BVgb, BVgb ThinOx, Cgb-Vg[2], Cgb-Freq[2] Log, Cgb-Vg 2Freq, QSCV[2], Ig-Vg lforce, Ig-Vg Vforce |
| | Junction | Junction DcParam, Junction IV Fwd, Junction IV Rev, Junction BV, Cj-Freq Log, Cj-V, Diode BVAndCj-V ASU, Diode BVAndCj-V SCUU |
| | Diffusion layer | VanDerPauw Square, R-I, R-I kelvin, R-I DVM, Rdiff-I, Rdiff-I kelvin, R-V, R-V kelvin, R-V DVM, Rdiff-V, Rdiff-V kelvin |
| | Interconnection | Interconnect CouplingCap, Interconnect OverlapCap |
| Generic test | Gate dielectrics, diffusion layer | Generic C-f, Generic C-t |

Table 2. For IV and CV characterization of MOS-FET

| Category | Measurement item | List of application test |
|----------|------------------|---|
| CMOS | IV | Id-Vd, Id-Vd pulse, Id-Vd[3], Id-Vd pulse[3], Id-Vg, Id-Vg pulse, Id_Vg[3], Id-Vg Vpulse[3], IonloffSlope, lsub-Vg, IdRdsGds |
| | Vth | Simple Vth, Vth Const Id, Vth gmMax and Id, Vth gmMax, VthAndCgg-Vg ASU, VthAndCgg-Vg SCUU, Vth-Lg, Vth-Wg |
| | CV | Simple Cgb, Cgb-AC Level, Cgb-Freq Log, Cgb-Vg High Voltage, Cgb-Vg, Cgc-Freq Log, Cgc-Vg, Cgg-Freq Linear, Cgg-Freq Log, Cgg-Vg 2Freq, Cgg-Vg, QSCV[4] |
| | Breakdown | BVdss, BVgso |

Table 3. Reliability test

| Category | Measurement item | List of application test |
|-------------|---------------------------------------|--|
| Reliability | Charge pumping | Charge Pumping, Charge Pumping2 |
| | HCI | HCI, HCI2, HCI 3devices |
| | BTI by SMU | BTI, BTI[3], BTI2, BTI2[3], BTI 3devices, BTI 3devices[3], Timing On-the-fly NBTI ² |
| | Ultra Fast BTI by WGF MU ³ | Fast BTI(AC stress Id-Sampling), Fast BTI(DC stress Id-Sampling), Fast BTI(AC stress Id-Vg), Fast BTI(DC stress Id-Vg) |
| | TDDB | TDDB lstress, TDDB lstress 3devices, TDDB lstress2, TDDB lstress2 3devices, TDDB Vstress, TDDB Vstress 3devices, TDDB Vstress2, TDDB Vstress2 3devices, TZDB |
| | V-Ramp/J-Ramp | V-Ramp, J-Ramp |
| | Electro migration | EM lstress, EM lstress2, EM lstress[2], EM lstress2[2], EM lstress[6], EM lstress2[6], EM Vstress, EM Vstress2, EM Vstress[2], EM Vstress2[2], EM Vstress[6], EM Vstress2[6] |

¹For more information on a particular application test, please refer to the "Keysight EasyEXPERT Application Library Reference" (P/N: B1500-90050).

²For more information on Timing On-the-fly NBTI, please refer to application note "AN B1500-6 Accurate NBTI Characterization using Timing-on-the-fly sampling Mode" (P/N: 5989-5711EN).

³For more information on ultra-fast NBTI, please refer the application note "AN B1500-10 Ultra-Fast 1μs NBTI Characterization using the Keysight B1500A's WGF MU Module" (P/N: 5989-9963EN).

⁴For more information on these application tests, please refer the "Keysight EasyEXPERT Application Library Reference" (P/N: B1500-90050).

Conclusion

CMOS is the most widely used transistor technology today, serving as the backbone of the modern electronics industry. Despite advances in alternative technologies, it is unlikely that CMOS will be supplanted anytime soon. The opposing goals of high speed operation and low power consumption require the precise evaluation of both the static and dynamic electrical properties of CMOS devices. The B1500A is a modular and self-contained instrument that allows you to configure solutions capable of performing even the most challenging CMOS device measurements. Keysight EasyEXPERT software provides easy and intuitive instrument control for the B1500A, and the furnished application test libraries reduce the learning curve and allow you to begin making productive CMOS device measurements immediately.



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