Agilent IC-CAP
Total Analysis Environment for Device Modeling/Characterization

IC-CAP Device Modeling Software
N5242A PNA-X Microwave Network Analyzer
N5250A Millimeter Wave PNA Series Network Analyzer
4294A Precision Impedance Analyzer
B1500A Semiconductor Device Analyzer

Application Note
June 2008

Introduction

The range of applications covered by silicon devices, particularly CMOS transistors, continues to increase, driven in part by continuous lithography scaling and the use of novel new materials. For example, power devices used in automotive systems and millimeter wave radar circuits have taken their place alongside more established memory, logic, analog, and RF devices. This increasing spectrum of uses requires devices to be optimized for a variety of different goals, such as speed, low power consumption or high-power capability. Device scaling is well-established and has many advantages, including higher device densities, speed improvement and lower power supply voltages; however, it also faces many new challenges such as leakage currents, circuit self-heating, frequency effects, noise dependencies (due to 1/f and RTS noise), non-linear scaling issues and device variations.

High-speed logic, RF and millimeter wave applications require the measurement of many different circuit elements, such as spiral inductors and varactor diodes, in addition to RF S-parameter measurements on more traditional MOS devices. To properly evaluate these components, not only capacitance and inductance but other parameters such as Q (quality factor), self resonant frequency, capacitance between the body and well and the resistance of the body must be measured. In addition, a characteristics analysis based on this measured data must be performed. Agilent's latest generation of measurement equipment and analysis techniques support these requirements. Agilent can also provide design simulators and model libraries that meet the needs of the fast-paced semiconductor industry.

Agilent IC-CAP Device Modeling Software

Agilent IC-CAP is flexible and high-performance software that is capable of accurate device characterization, analysis, and easy measurement, and these capabilities take on importance for today's semiconductor modeling.

Our IC-CAP delivers state-of-the-art features including measurement instrument control, data acquisition, graphical analysis, simulation, optimization, and statistical analysis, which meet diverse modeling needs. IC-CAP provides a convenient software umbrella that controls many different instruments and allows a variety of different types of measurement data from these instruments (such as DC, CV, and S-parameter measurements) to be analyzed and processed. Utilized with the IC-CAP features, the standard models and your original macro models assure an efficient and accurate extraction of model parameters for the active/passive device. Modeling packages with the ability to extract industry-standard device models, such as BSIM4 and HiSIM, are available as turnkey solutions. The modeling packages include a new, user-friendly graphical user interface that supports both the measurement setup and an intelligent parameter extraction process flow for improved efficiency.

Agilent Technologies

High Performance Modeling Hardware

Agilent can provide hardware configurations for modeling systems that meet a variety of different measurement needs. These high-performance modeling systems can perform device measurements from DC to RF, providing the capabilities necessary for modern semiconductor processes and devices. The RF subsystem uses a high-performance network analyzer (PNA series) possessing exceptionally high dynamic range, very low trace noise, and fast measurement Capability with improved usability. For each RF configuration you can select a PNA that covers a specific measurement frequency range. For example, the E8364C (10 MHz to 50 GHz) is part of the 50-GHz hardware configuration. The high-precision DC subsystem is configured around either the B1500A Semiconductor Device Analyzer or the E5270B 8-slot Precision Parametric Measurement Mainframe. For additional modeling hardware resources, visit our IC-CAP website at **www.agilent.com/find/eesof-iccap**

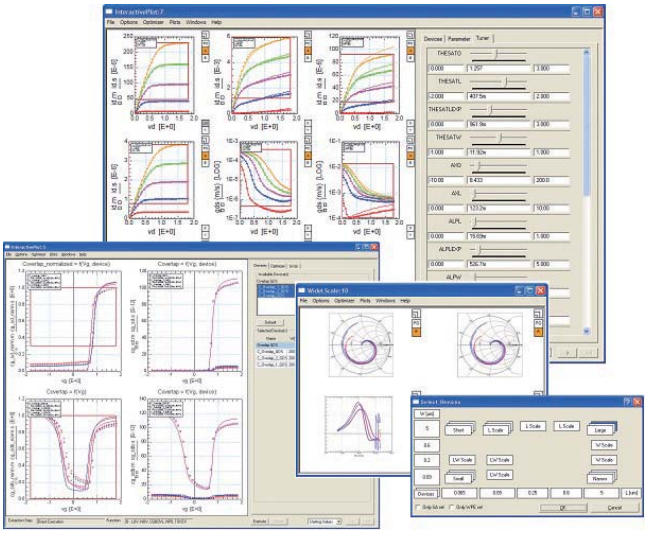

Figure 3: IC-CAP Analysis Screen

PNA-X (N5242A) 26.5-GHz Network Analyzer

Nonlinear device behavior has always been hard-to-measure and hard-to-analyze. The Agilent PNA-X is a network analyzer focused on the analysis of nonlinear phenomena. It possesses a number of measurement capabilities for non-linear analysis in addition to standard network analysis capabilities. These include:

- Gain compression - Speed up measurement times by employing a new algorithm to locate the 1 dB point.
- Intermodulation distortion - Assures an accurate measurement of the two signals delivered from the two built-in sources using a built-in ultra-low distortion receiving mixer, without any external equipment.
- Noise figure - Greatly improves measurement accuracy using a new calibration method that eliminates mismatches caused by the cables and probes.
- Harmonics measurement - Permits the measurement of signal harmonics including their phase. By performing an inverse Fourier transform of the measured signals, it also allows you to obtain waveform data with higher accuracy than would be obtained from using an oscilloscope.
- Pulse measurement - Supports the measurement of pulse signals, as short as 250 nsec, and permits measurements of fundamental waves and harmonic pulse profile (envelope measurement).
- X parameter - This is a new approach that behavior-models a device to include its nonlinear behavior and facilitate a measurement. Upon receiving measured values, the ADS simulator runs a nonlinear simulation and analysis.

N5250A 110-GHz Millimeter Wave Network Analyzer

In recent years CMOS devices have achieved cut-off frequencies of over 100 GHz, requiring millimeter wave measurements for accurate modeling and analysis. The conventional network analyzers are capable of measurements up to 50GHz and extrapolation is used for the frequencies above it. The PNA and PNA-X Series Network Analyzers, however, use a millimeter wave head to exercise its measurement capabilities, up to 500 GHz. Using a 67-GHz PNA in concert with a 110-GHz millimeter wave head, the N5250A can measure up to 110 GHz signals without the need to toggle any connections. With a dynamic range of 87 dB, the 110-GHz Network Analyzer is an excellent choice for accurate device analysis. Moreover, it can also compensate for the effects of cables, probes and wafer pads when performing on-wafer measurements.

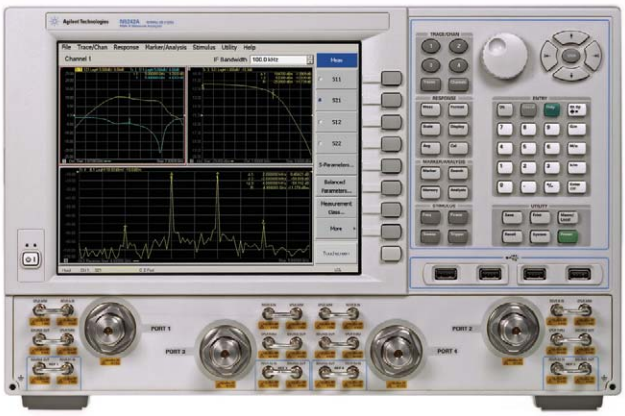

Figure 1: PNA-X 26.5 GHz Network Analyzer

Figure 2: N5250A 110 GHz mmWave Network Analyzer

4294A Precision Impedance Analyzer

Leakage current associated with thin films is a significant challenge as device lithographies shrink. For example, portable devices such as cell phones have expanded in functionality and the need to extend battery life by reducing standby power consumption makes reducing leakage currents in ICs a critical concern. However, thin gate dielectric film technology has continued to expand in use. The Agilent 4284A LCR meter can only measure CV up to 1 MHz. Thin film gate dielectrics (which can be less than 2 nm thick) require frequencies much higher than 1 MHz so as to decrease the impedance of the capacitor and increase the proportion of the measurement current passing through the capacitor (and reduce the dissipation factor D). In contrast, the Agilent 4294A Precision Impedance Analyzer, which uses the well-proven 4 terminal pair connection method and auto-balancing bridge technique (same as used in the 4284A and E4980A), can measure CV up to 110 MHz. The 4294A's frequency range enables it to accurately measure the capacitance of thin gate oxides.

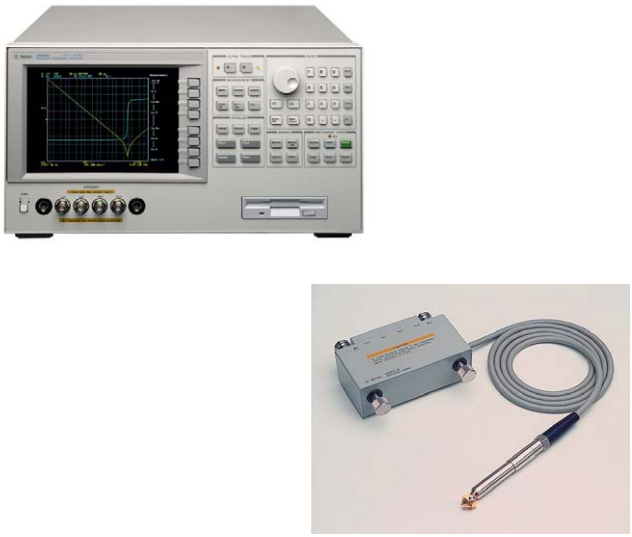

Figure 4: 4294A Precision Impedance Analyzer and 42941A Impedance Probe Kit

B1500A Semiconductor Device Analyzer

Characterization of advanced CMOS devices and the analysis of novel new materials such as high-k metal gates and low-k wiring require instrumentation with software and hardware that is modular, flexible, and easy-to-use. Building upon the technology of the industry-standard 4155C and 4156C semiconductor parametric analyzers and 4070/4080 Series parametric testers, the Agilent B1500A Semiconductor Device Analyzer combines an intuitive user interface with modular hardware that supports flexible configurations and allows for easy upgrading. Key features of the B1500A include:

- **Agilent's EasyEXPERT software**
  EasyEXPERT software installed on the B1500A provides a more interactive operating environment through the GUI (graphic user interface). Over 230 Application tests covering a wide range of device types and applications, are preinstalled in EasyEXPERT.
- **Large touch screen display**
  A large touch-screen display facilitates the intuitive operating environment for engineers. The screen is also capable of batch displays of multiple data.
- **Support for measurement of sub-femtoamp electric current**
  A combined use of the B1517A high-resolution SMU and the E5288A Atsense switch unit produces a current resolution of 100 aA at minimum.
- **Versatile data analysis and display**
  The B1500A supports a major analysis of parametric measurements including Vth, GmMax, and β as standard.

Figure 5: B1500A Semiconductor Device Analyzer

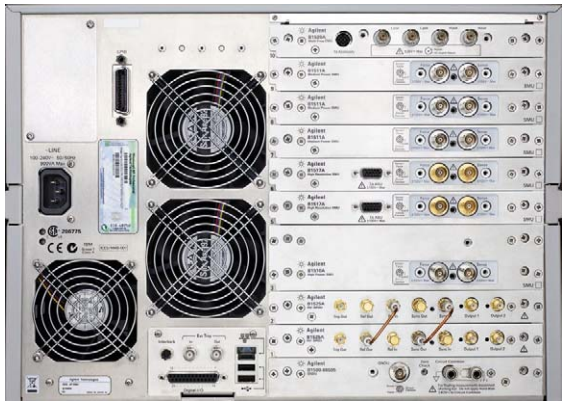

Figure 6: B1500A Back and Measurement Module

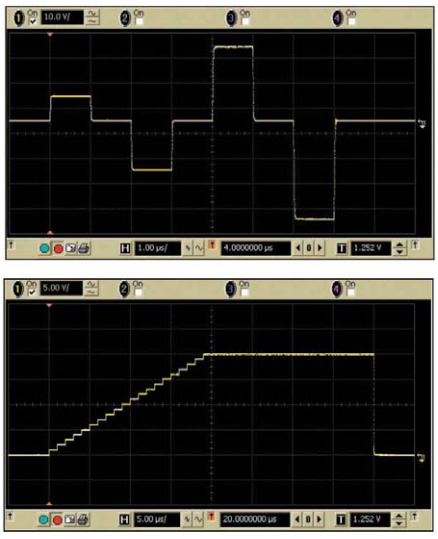

Figure 7: B1525A HV-SPGU Pulse Output

Semiconductor device analysis requires not only DC current and voltage measurement, but also other types of AC and pulsed measurement. The B1500A is a modular instrument with 10-slots that supports a variety of module types that span the range from DC to fast pulsed IV measurement. Modules that perform AC or pulsed sourcing/measurement include:

- 5 MHz-capable B1520A MFCMU
  The multi-frequency capacitance measurement unit can measure capacitance from 1 kHz to 5 MHz. In addition to built-in calibration features, the MFCMU supports an optional SMU/CMU unify unit (SCUU) that allows switching between the IV and CV measurements without having to change any cables.
- B1525A HV-SPGU
  The high-voltage semiconductor pulse generator unit can supply the high-voltage output (±40 V) required for state-of-the-art non-volatile memory cell characterization. EasyEXPERT supports a GUI for this module that includes an arbitrary linear waveform generator (ALWG) capability.
- B1530A WGFMU
  The waveform generator/fast measurement unit has both a 100 ns ALWG capability and a 5-nsec IV measurement sampling capability. These capabilities enable the WGFMU to be used for a variety of applications, including NBTI, SILC, and RTS noise measurement.

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