

Evolving Semiconductor Characterization and Parametric Test Solutions for the Evolving Semiconductor Industry

The range of applications for semiconductor ICs and components has broadened dramatically and now plays a role in almost every aspect of our lives. Once, semiconductor manufacturers focused mainly on the component needs of those building computers, industrial/scientific/medical (ISM) equipment, and military/aerospace hardware. Later, there came a huge proliferation of cell phones, PDAs, electronic games, and myriad other consumer electronic products, all with ever-higher levels of semiconductor content. In the new millennium, the applications for semiconductors continue to proliferate and include automotive electronics, TVs/displays, portable/wireless products, energy conversion/efficiency devices (photovoltaic cells and panels, power converters, high-brightness LEDs, etc.), as well as many others.

In order to support this growing array of applications, to improve product performance, and to differentiate their products, semiconductor companies must constantly innovate vis-à-vis new materials, device structures, fabrication processes, and IC designs. But what does this mean in terms of semiconductor companies' device test and analysis requirements and whether these requirements involve device characterization, reliability analysis, or production process monitoring?

Essentially, it means that measurement needs across the broad range of semiconductor companies and technologies must be matched by a broad set of measurement solutions; one-size test solutions can no longer fit all. Each of the various technology segments continually experiences new measurement

challenges, such as the challenge of testing transistors that incorporate high- κ materials in scaled CMOS, of coping with higher voltages/currents associated with wide bandgap devices such as compound semiconductors, of controlling doping/implantation in power CMOS, and of characterizing new photovoltaic materials, etc. Test vendors need to address these challenges in a way that makes economic sense for customers.

To understand where the semiconductor industry as a whole and the semiconductor test segment specifically is headed, it's important to keep a few other business dynamics in mind:

- **The semiconductor industry is becoming increasingly diverse, as are its test requirements.** Although consolidation is occurring among the industry's top 300mm high-output CMOS companies, many other semiconductor manufacturers are choosing not to get caught up in the "More Moore" chase (that is, the never-ending effort to build smaller devices). Instead, these companies are finding more profitable niches among the broad range of other technologies/applications. Because these niches are typically not high-volume businesses (such as DRAMs, CPUs, etc.), they are not driven by the same economies of scale as the highest-volume semiconductor manufacturers; instead, their businesses are built around the diversity and uniqueness of their end products. That means that their test needs are often very different than those of the highest-volume semiconductor manufacturers. The growing diversity of the semiconductor industry as a whole demands a more diverse set of test solutions. Costly single-purpose test solutions designed to run around the clock that make sense for the largest semiconductor manufacturers often represent overkill for those in the rest of the industry, many of whom need flexible, scalable system solutions that deliver the core measurement capabilities while allowing quick adaptation to rapid market changes.
- **All companies must do more with less and do it faster.** During the semiconductor industry's earliest days, many of the R&D test systems and much of the software that semiconductor companies used was developed and maintained in-house by the companies' own employees. In those days, semiconductor companies enjoyed the luxury of large technical staffs, long time-to-market cycles, and long product life cycles. Those business conditions are largely just a memory today, so semiconductor companies are forced to rely more extensively on their test equipment vendors to obtain the full range of test solutions they require, from R&D through production. They also need vendors who can help them control their cost of test, both at the time of initial test system purchase and over the long term.

The road ahead

In shaping our role within the semiconductor market in the coming years, Keithley is taking a number of emerging market forces into account:

- **The consumer products market's growing demand for non-volatile memory.** The explosion in demand for consumer electronics such as PDAs, sophisticated multifunction mobile phones, MP3 players, recording devices, cameras, personal game systems, and other handheld devices has produced a corresponding demand for many types of nonvolatile memory, including Multi-Level Cell (MLC) flash memory and Phase Change Memory (PCM). Increasingly, memory producers must be able to characterize new materials and designs quickly and flexibly to create higher-density memory devices that consume less battery power. The ability to perform pulsed I-V testing is and will continue to be a critical requirement for such characterization applications.
- **More testing, more data, more analysis.** The ongoing scaling of device technologies guarantees that the semiconductor industry's research and development labs will require lots more testing, producing lots more data. Processing smaller devices demands the ability to acquire ever-larger data sets to select appropriate materials, to characterize device designs, and to tweak production processes. Semiconductor manufacturers need tools that let them acquire this huge mass of data quickly and accurately and then turn it into the material, device, and process knowledge that they need to bring new devices to market faster.
- **Device reliability phenomena associated with continued CMOS scaling.** As transistor gate dielectrics get thinner and more susceptible to leakage, the ability to characterize their reliability rapidly and accurately grows more critical. Semiconductor manufacturers need ultra-high-speed source-measure testing solutions with the accuracy to handle device reliability tests such as HCI, NBTI, and PBTI; gate oxide integrity tests such as TDDB, V_{RAMP} , and J_{RAMP} ; and metal interconnect tests such as isothermal electromigration, poly heater, constant current, and ILD TDDB tests. In addition to precision DC I-V measurements, pulsed I-V measurements will become increasingly important for characterizing devices in the time domain.
- **The burgeoning demand for power conversion/efficiency devices (solar cells/panels, power converters, high-brightness LEDs, etc.).** The world is looking for more sustainable alternatives to fossil fuels and other mainstream energy sources, and the U.S. government is placing special focus on alternative energy. Testing technologies

such as solar cells and HB-LEDs typically require higher source-and-measure voltages and currents than they did in the past, as well as higher accuracy. However, the mere ability to make high integrity measurements at higher signal levels is not enough; these capabilities need to be packaged in systems that can be easily and cost-effectively scaled up and that can be rapidly reconfigured to address changing test requirements.

- **The differing test needs of new semiconductor materials.** Single-purpose, relatively inflexible test solutions that make sense in a high-volume 300mm CMOS fab simply aren't economically viable in fabs focused on new materials and technologies such as photovoltaic devices, compound semiconductors, nanoelectronic devices, etc. Rather, such fabs need flexible, scalable test solutions that are suitable for lower-volume materials research and characterization applications. For example, C-V measurements are becoming increasingly critical to the characterization of thin-film technologies used in photovoltaic devices such as solar cells.

Tomorrow's testing technologies

These emerging market drivers, which Keithley has been tracking for many years, demand a fundamentally new way of thinking about creating solutions for semiconductor characterization and parametric test. Rather than the "shrink-wrapped" approach some vendors have taken in the past, Keithley's approach is to provide a range of scalable, flexible solutions designed to adapt readily to the expanding range of semiconductor technologies, companies, and applications. The company is committed to producing products that keep pace with the rapidly evolving test environment.

Keithley's systems solutions are engineered from our market-leading measurement capabilities. The company combines its knowledge of high-accuracy, low-level measurement technology with its expertise in evolving test capabilities such as pulsed I-V testing, and its powerful software, which embodies decades of device characterization and parametric test applications expertise. The combination of these various strengths enables Keithley to produce high-performance turnkey systems that are designed to grow with customers' changing test requirements.

Keithley offers semiconductor companies of all sizes a growing continuum of semiconductor characterization and parametric test solutions, all of which offer configurations that are sufficiently scalable and flexible to suit them to a broad array of test environments and applications, including:

- Materials research and testing
- Device characterization
- Device modeling
- Device reliability analysis
- Nanotechnology research
- Failure analysis
- Production die sort
- Process integration
- Process control monitoring

Keithley has been an innovation leader in semiconductor device characterization and parametric test technology since the 1970s. Today, Keithley's solutions for semiconductor characterization and parametric test range from individual SourceMeter® instruments for testing individual devices or components in a benchtop fixture, to highly integrated semiconductor parametric analyzers, to multiple instruments linked by a high-integrity switch, to fully automated, fully integrated test systems for use with automated wafer probers. Whether someone needs raw test results or advanced analysis capabilities, interactive or automated operation, results on a single device or a full cassette of wafers, Keithley has the I-V, C-V, and pulsed test hardware and test management and analysis software solutions to meet the challenge. Just as important, the company's flexible solutions are backed by its global team of semiconductor test specialists, who have the expertise necessary to help customers obtain the optimal solution for their current needs with maximal scalability for potential future expansion. These test experts can even deliver full turnkey solutions, including test code development as new test requirements evolve. This enables Keithley's semiconductor characterization and parametric test customers to focus on their jobs and enhance their own profitability, rather than on time-consuming tasks such as test system building and maintenance or test code development and optimization.

Keithley's semiconductor characterization and parametric test solutions are configured from several of the highly adaptable, first-in-their-class products developed by the company over the last decade:

- **Windows-based parameter analyzer** – The Model 4200-SCS Semiconductor Characterization System makes it easy to keep pace with an organization's changing

test needs or to tailor a system to a lab's or test floor's specific applications by providing leading-edge options such as **capacitance-voltage testing** and **pulsed I-V testing**.

Today, the Model 4200-SCS is the instrument of choice for labs and test lines in areas as diverse as device characterization, materials research, nanotechnology and MEMs research, incoming inspection, failure analysis, flash memory testing, Hall Effect and van der Pauw testing, solar cell characterization, reliability testing, device modeling, and many other applications.

- **Modular source-measure units** – Because they cover the industry's widest voltage and current ranges, Keithley's SourceMeter® instruments are extensively used in both benchtop and system-level application. The Series 2600A System SourceMeter® line, the company's latest source-measure innovations, were designed especially for use in high-performance test systems. As such, they feature tightly synchronized operation, a unique embedded script engine, and a high-speed virtual backplane that allows seamless and cost-effective system scaling.
- **Automated Characterization Suite (ACS) systems** – This architecture makes it easier to build scalable, modular, flexible, and extremely fast test systems for applications ranging from single device testing to fully automatic wafer- or cassette-level testing. ACS systems can combine the individual strengths of Keithley's parameter analyzer, switching, and source-measure unit technologies into test solutions that offer high scalability and high performance.

ACS Integrated Test Systems are complete solutions for applications such as parametric die sort and Wafer Level Reliability testing. When paired with appropriate semi-automatic and fully automatic probe stations, their hardware configuration and test project development can be easily optimized for specific test tasks. ACS leverages the on-board Test Script Processors in Series 2600A System SourceMeter instruments into a multi-processor environment that's ideal for true parallel test in both single- and multi-site configurations.

- **Our other instruments for a variety of test and measurement applications.** Keithley's broad array of high performance measurement products—from switching to DMMs to sophisticated RF generators and analyzers—expands its applications among semiconductor customers far beyond the areas of device characterization and parametric test.

Adapting today's test solutions to tomorrow's test challenges

Although much has changed in the semiconductor industry over the last several years, some things have stayed the same: semiconductor companies still need test solutions that deliver accurate data and analysis quickly, simply, and cost-effectively. Keithley's ever-growing offering of scalable, flexible test hardware and software solutions enables its semiconductor and parametric test customers to meet this challenge. What's more, Keithley's test solutions are backed by a global team of support professionals who are dedicated to delivering solutions that work the way its customers work and that provide superior speed and simplicity.

In summary, Keithley is dedicated to providing its customers with the tools they need to keep pace in the evolving semiconductor industry, including

- A range of unique and precise measurement capabilities including I-V, C-V, pulse sourcing, pulsed source-measure (i.e., pulsed I-V), etc.
- Powerful and flexible software that embodies decades of semiconductor applications expertise
- Scalable and flexible solutions in a variety of form factors (from discrete System SourceMeter Instruments to integrated turnkey systems)
- Solutions that address the broad and diverging needs of the industry (CMOS scaling, non-volatile memory, power MOS, solar devices, nanoelectronics, etc.)
- Solutions and services that let customers focus on their day jobs and improve time to market, while minimizing their cost of test



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