Advanced Measurement for Advanced Technology

CN FAE

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Advanced Measurement for Advanced Technology

http://breakthroughinitiatives.org/
Advanced Measurement for Advanced Technology

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To achieve this, what’s the challenge there?
Nanoscale Materials & Devices

- Nanotechnology is science and engineering conducted at the nanoscale level
  - 1 to 100 nanometers
- Requires multiple disciplines:
  - Physics, material science, chemistry and measurement system design
- Nanoscale technologies have the potential to improve our quality of life
  - Medical delivery systems & detection
  - Faster electronics
  - Cheaper energy
  - Bio- and chemical detection systems
Nanoscale Materials & Devices

• Graphene:
  ◦ 100 X stronger than the strongest steel
  ◦ conducts heat and electricity efficiently
  ◦ nearly transparent
  ◦ And so on….

By Dexter Johnson
Posted 19 May 2016 | 20:00 GMT

Illustration: Moscow Institute of Physics and Technology

Researchers at the Moscow Institute of Physics and Technology (MIPT) new tunnel transistor based on bilayer graphene
• reduce its power consumption
• increase in processors’ clock speeds(two orders of magnitude)

Wideband Gap material: GaN, SiC

Wide bandgap materials are often utilized in applications in which high-temperature operation is important.

Bandgap > 2.3eV (or 3eV)
WBG material: GaN, SiC

- Greater emphasis on *commercialization* of devices made from wide bandgap materials, especially SiC and GaN
  - Benefits of SiC and GaN:
    - Faster switching speed than Si $\rightarrow$ smaller passive components $\rightarrow$ smaller size and lower weight $\rightarrow$ higher efficiency
      - Lower switching losses than Si (especially lower recovery losses in diodes)
    - Lower leakage currents $\rightarrow$ better switch
    - Higher power density
      - Pack more power into smaller areas $\rightarrow$ higher efficiency
      - Higher operating temperature (especially SiC) $\rightarrow$ able to handle higher power with fewer parametric changes and without requiring cooling systems as extensive as silicon-based electronics $\rightarrow$ smaller size and higher efficiency
What is a Source Measure Unit (SMU)?

- Simultaneously source and measure voltage and/or current
- Perform resistance measurements
Keithley SMU Family - Instruments

**2400 SourceMeter SMU Instruments**
- Family of single-channel models with I-V capability from 1100V to 100nV and 10.5A pulse to 1pA
- Smart alternative to separate Power Supplies and Digital Multimeters (DMMs)
- Convenient DMM-like user interface

**2450 & 2460 Touchscreen SourceMeter SMU Instruments**
Industry-first 5” color capacitive touchscreen GUI
Test up to 200V and 1A (2450) or up to 100 V and 7A (2460)
Sub pA and sub µV resolution

**2600B System SourceMeter SMU Instruments**
- Family of dual- or single-channel models with I-V capability from 10A pulse to 0.1fA and 200V to 100nV
- TSP® (Test Script Processor) technology for best-in-class throughput and lowest cost of test
- Browser-based GUI enables testing on any PC from anywhere in the world

**2650A Hi-Power System SourceMeter SMU Instruments**
- Source and measure up to 3kV or 50A pulse, with best-in-class low current resolution
- Up to 2000W pulse or 200W DC power
- Optimized for characterizing and testing high power semiconductors, electronics, and materials
Keithley SMU Family - Systems

**Parametric Curve Tracers**
- Power device characterization up to 3kV and 100A including high quality instruments, cables, test fixturing, and software
- ACS Basic Edition software features real-time curve tracing and full parametric characterization modes
- Easily re-configurable to meet changing test needs

**4200-SCS Semiconductor Parameter Analyzer**
- An integrated analyzer for complete and precise characterization: I-V, C-V, Ultra-Fast I-V, and Pulse measurements
- Characterize devices, materials, and semiconductor processes with sub-fA resolution
- Easy-to-use Windows® GUI, modular architecture, and over 450 user-modifiable test applications simplify complex measurement

**S530 Parametric Test Systems**
- High-speed semiconductor parametric testing with low cost of ownership
- Designed for production and lab environments managing a broad range of devices and product wafers
- Proven SMU instrumentation technology ensures high measurement accuracy and repeatability

**S500 Parametric Test Systems**
- Highly configurable and scalable SMU instrument-based system
- Semiconductor device testing along with Automated Characterization Suite (ACS) at the device, wafer, or cassette level
- Ideal for SMU-per-pin Wafer Level Reliability (WLR) testing, high speed parallel test, die sort, and Process Control Monitoring (PCM)
PART 1: New Material and Nano-technology

PART 2: Power semiconductor devices

PART 3: MEMS and Semiconductor Sensors

PART 4: Signal, Data storage/sorting

PART 5: Power management

PART 6: Opto-electronics
Power semiconductor device:

- A power semiconductor device is a semiconductor device used as a switch or rectifier in power electronics; a switch-mode power supply is an example. Such a device is also called a power device or, when used in an integrated circuit, a power IC.

- **Typical device**: GTO / GTR / power MOSFET / IGBT
Characterization of power semiconductor device:

<table>
<thead>
<tr>
<th>Characterization</th>
<th>Test Category</th>
<th>Devices and Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>IGBT</td>
</tr>
<tr>
<td>Static</td>
<td>ON-state</td>
<td>$V_{CE,I_C}$</td>
</tr>
<tr>
<td>Static</td>
<td></td>
<td>$V_{GE,I_C}$</td>
</tr>
<tr>
<td>Static</td>
<td>OFF-state</td>
<td>$I_{CEO}$</td>
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<tr>
<td>Static</td>
<td></td>
<td>$I_{CES}$</td>
</tr>
<tr>
<td>Static</td>
<td></td>
<td>$BV_{CES}$</td>
</tr>
<tr>
<td>Static</td>
<td></td>
<td>$BV_{CEO}$</td>
</tr>
<tr>
<td>Dynamic</td>
<td>Charge</td>
<td>$Q_G$</td>
</tr>
<tr>
<td>Dynamic</td>
<td>Capacitance</td>
<td>$C_{iss}$ (a.k.a. $C_{ies}$)</td>
</tr>
<tr>
<td>Dynamic</td>
<td></td>
<td>$C_{oss}$ (a.k.a. $C_{oes}$)</td>
</tr>
<tr>
<td>Dynamic</td>
<td></td>
<td>$C_{rss}$ (a.k.a. $C_{res}$)</td>
</tr>
<tr>
<td>Switching</td>
<td>Timing</td>
<td>$T_{d(on)}$</td>
</tr>
<tr>
<td>Switching</td>
<td></td>
<td>$T_f$</td>
</tr>
<tr>
<td>Switching</td>
<td></td>
<td>$T_{d(off)}$</td>
</tr>
<tr>
<td>Switching</td>
<td></td>
<td>$T_f$</td>
</tr>
</tbody>
</table>

Static Characterization directly describes DC performance and the quality of the devices, and the test is easy to perform.
Keithley Power Semi Test Solutions

MEET A WIDE RANGE OF CURRENT-VOLTAGE TESTING NEEDS

Up to 100A pulse for ON-State tests

Up to 3kV for OFF-State tests

Up to 10kV for breakdown voltage testing

Complete solution for ON-State, Off-State and C-V tests

NEW!! Up to 7A DC, 10A pulse for interactive ON-State testing
Keithley Power Semi Test Solutions

CONFIGURABLE SOLUTIONS
Single- or Dual-Channel SMU Instruments

COMPLETE SOLUTIONS
Parametric Curve Tracers

Options available:
• **Software**: ACS Basic Edition with built-in test libraries and real-time and parametric test modes
• **Accessories**: Test fixtures, protection modules, high voltage triaxial cables

A complete bench top system that includes a variety of SMU instruments, cables, test fixtures, and software for characterizing power devices
Power Semi Test Accessories

SUPPORT A VARIETY OF MEASUREMENT TYPES AND SIMPLIFY SYSTEM INTEGRATION

- Specialized Cabling
- High Power Test Fixtures
- High Voltage Bias Tee kits
- Overvoltage Protection Modules
Power Semi Test Software

ACS BASIC, ACS

• ACS Software is the “glue” that brings all of the instruments together to make a solution
  ◦ Supports Series 2400, 2600, and 4200 SMUs

• Includes hundreds of built-in device test libraries
For designers/researchers of lighting, power management, power conversion & control circuits and related devices

- Power transistor forward characteristics
- Battery Load Curves
- Charger simulation
- Dynamic load simulation
- 7A DC, 10A pulsed
- 2460/2461 SMU
Model 2461 SourceMeter SMU

KEITHLEY CONTINUES TO INVEST IN ITS LINE OF
GRAPHICAL SOURCE MEASURE UNITS

10A @ 100V 1000W Pulse version of the Model 2460
  ◦ 1000W Pulse Source/Sink, 100W DC Source/Sink
  ◦ Pulses as fast as 150μS. Dedicated pulse screen and commands

Dual 18-Bit 1MS/s Digitizers for simultaneous I&V. Store up to 5 million rdgs.

Contact Check
  • Succeeds the Model 2430, 2420-C, 2425-C, 2430-C, 2440-C SourceMeter SMUs. Opportunity to upsell to the 2461.
IVy Android/iOS App – Visualize, Interact, Share
For Series 2600B SourceMeter SMU Instruments

• Visualize Instant Responses
  ◦ Swipe to change the source value and instantly see your device’s response

• Interact for Better Understanding
  ◦ Pinch and zoom to gain deeper insight into your device’s performance

• Share Your Results
  ◦ Share screen shots and CSV files instantly using built-in Android tools
IVy Application Examples

- DUT comparison
- Diode Reverse Bias
- LED Vf vs. Time
- MOSFET Family of Curves
PART 1: New Material and Nano-technology

PART 2: Power semiconductor devices

PART 3: MEMS and Semiconductor Sensors

PART 4: Signal, Data storage/sorting

PART 5: Power management

PART 6: Opto-electronics
MEMS Background

MEMS (Micro-electro-mechanical Systems)

The technology of fabricating Micro mechanical structures/devices, Usually in Silicon wafers

Sensors: turn non-electro-signal into electrical signal

Actuator: Micro-motor moving or controlling a mechanism or system

Structures: delicate structures for special use (silicon pump, e.g.)

Widely Used

- Pressure/Force
- Light
- Vibration/ acoustic wave
- Fluidics
- Temperature

Stress induced R, C…value change

Stress

Measurable electrical signal

0.243 mv

- Classical application:
  - Accelerometers, MEMS gyroscopes (used in Wii, smart phone…)
  - Silicon pressure sensors (car tire, blood pressure)
  - Bio-MEMS (biosensor, chemosensor)
  - Optical switching (for data communication)

...
Keithley Solution for MEMS device test

- Customer application:
  - Test with sensor structure for its intrinsic characteristic without stress (pressure, vibration etc.)
  - To verify if fabricating process are within control.
  - **Micro-phone:**
    - Voice $\rightarrow$ airflow $\rightarrow$ Capacitance change in MEMS sensor $\rightarrow$ electrical signal ---C test
  - **Pressure sensor:**
    - Pressure $\rightarrow$ R change in MEMS sensor $\rightarrow$ electrical signal ---R test

- Test requirement:
  - **I-V:**
    - R test: Force V measure I
    - $V<10V$
    - $R\approx K\Omega$
  - **C-V:**
    - Capacitance test
    - $f=100KHz$ DCV<$30V$
    - $C\approx 10pF$ (0.1pF accu.)
  - wafer level with auto-prober
Keithley Test Solution:

- Configuration:
  - 4200-SCS/C x 1ea
  - 4210-CVU*1
  - 4200-SMU*2
  - 4200-PA*1
  - 707B x 1ea
  - 7174A x 1ea
PART 1: New Material and Nano-technology

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New Flash Memory, bigger and faster.

3D NAND Flash tech. makes the massive data store more easier and faster.

From How Samsung connects to the wordlines in the array (courtesy Techinsights)
Configuration of Solution2 for 3D Nand Flash reliability test in one of our customer.
Example of Flash Memory Cell Test Setup

- SMUs are used to accurately measure $V_t$ and $I_D$
- PMU and RPM are used to generate program/erase segments

All connections made via the probe station
PART 1: New Material and Nano-technology

PART 2: New power devices

PART 3: MEMS and Semiconductor Sensors

PART 4: Signal, Data storage/sorting

PART 5: Power management

PART 6: Optical energy and device
More power and wisely use them

- Increase the Capacity of battery
  - **Ultra capacitor**: Need of Public transportation
  - **Electrochemistry** research for new battery
- Decrease the power consumption.
  - More accurate Power measurement for different mode.

“The limitation to the number of sensors and amount of generated data is the battery life of the Wearable.”

**Credit Suisse**

*Power Management...is crucial in wearable technology because poor power management translates into battery drain...Battery life has a direct impact on a product’s real usefulness... Characterizing a usage profile is a non-trivial design activity.*

Mitch Maiman, president and co-founder of Intelligent Product Solutions
Using SMU for Ultra-capacitor test

- **Test Instrument:**
  - Keithley 2612/36B* for $C \leq 20F$
  - Keithley 2651A for $C \geq 350F$

- **Connection:**
  - 4-wires connection (remote sense)

- **Test Sample:**
  - KAMCAP 10F Urate=2.7V
  - Maxwell 350F/3000F Urate=2.7V

*The test instrument can be anyone of SMUs family as long as the current can fulfill the requirement.*
Experiment – Result

for \( 10F \) capacitor with \( 2636B \)

- Test result:
  - 2 cycles are tested

\[
C_{ch} = I_2 \times (t_2 - t_1) / (V_2 - V_1) = 10.93 \text{ F}
\]

\[
C_{dch} = I_5 \times (t_5 - t_4) / (V_5 - V_4) = 10.88 \text{ F}
\]

Test result chart by Keithley test software: ACS Basic

Programmable, sensitive, fast, accurate TEST.
Electrochemistry is the cornerstone for many new products such as: batteries, glucose sensors, solar cells, coatings, medical devices etc.

Involving Research, Design, Characterization, Performance Testing
Keithley’s Electrochemistry test solution

• 2450-EC: 1A, 200V, 20W Potentiostat/Galvanostat

• 2460-EC: 7A, 100V, 100W Potentiostat/Galvanostat

• Includes:
  ◦ Potentiostat (SMU)
  ◦ Cable for 2,3 or 4 electrodes
  ◦ Built-in software with test techniques
  ◦ Full documentation
Keithley SMU for Electrochemistry Applications

GROWING LIBRARY OF TECHNIQUES

• Cyclic Voltammetry
• Linear Sweep Voltammetry
• Open Circuit Potential
• Potential Pulse and Square Wave with Current Measure
• Current Pulse and Square Wave with Voltage Measure
• Chronoamperometry
• Chronopotentiometry
Distinctive differences

SIMPLICITY

- Configure test, run experiment, generate voltammogram plot, analyze results

Simplify learning and test set-up
Solution for low power consumption measurement: DMM7510 + 2280S
Example Application
More Detailed Power Consumption Info with DMM7510

Zoom In

Set Cursor

Zoom In

Zoom In
Optical energy: Solar cell

Keithley provides solution from single cell research test and mass production test.
Solar cell test solution:

Based on SMUs’ powerful capability of I-V characterization, solar cell test engineers are able to test the cell or cells more efficiently along with ACS Basic solar cell suit.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>SolarCell-24</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2450</td>
<td>±1.05A DC</td>
<td>±210V</td>
<td>10fA/10nV</td>
<td>ACS Basic</td>
</tr>
<tr>
<td>2460</td>
<td>±7A DC</td>
<td>±100V</td>
<td>10fA/10nV</td>
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</tr>
<tr>
<td>2601B</td>
<td>±3A DC/±10A Pulse</td>
<td>±40V</td>
<td>100fA/100nV</td>
<td>ACS Basic</td>
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<tr>
<td>2611B</td>
<td>±1.5A DC/±10A Pulse</td>
<td>±200V</td>
<td>100fA/100nV</td>
<td>ACS Basic</td>
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<td>2635B</td>
<td>±1.5A DC/±10A Pulse</td>
<td>±200V</td>
<td>10fA/10nV</td>
<td>ACS Basic</td>
</tr>
<tr>
<td>2651A</td>
<td>±20A DC/±50A Pulse</td>
<td>±40V</td>
<td>0.1fA/100nV</td>
<td></td>
</tr>
</tbody>
</table>

Standard Solar cell characterization test can be done in **ONE MINUTE!**
Optical Module Components in Optical Communication

• Optical communication (a.k.a. optical telecommunication) is communication at a distance using light to carry information.

• Electrical signal (message) $\rightarrow$ optical signal $\rightarrow$ Electrical signal (information)

• “sender” and “receiver”
  • Laser diode
  • Photo detector
Keithley solution for Optical Module Components test

- Final DC test, Process control DC test, Coc parallel test, FA test for TOSA/ROSA, Tuneable, Coherent etc., telecom, Datacom products

- 26** SMU:
  - 4-quadrant voltage/current source and measure instruments
  - 10A pulse to 0.1fA and 200V to 100nV
  - TSP (Test Script Processing) technology

- 6485/6487 Picoammeter/Source
  - 10fA (10x10-15A) sensitivity
  - <200µV voltage burden
  - Bipolar 500V floating source
  - Displays resistance
Display: wearable, touchable,

- **LCD**: Liquid crystal display
  - TFT: Thin film **Transistor**
  - liquid crystal molecular
  - Backlight (light source)

- **OLED**: Organic Light Emitting **Diode**
  - “Sandwich” structure: organic semiconductor between two electrodes
  - Each pixel is LED/LEDs

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**Diagram**

- **Display**
  - **ITO**
  - **LCD**
    - a-Si
    - LTPS
    - IGZO
    - CGS
  - **OLED**
    - AMOLED
    - PMOLED
Keithley solution for Display

S500/S530 system for TEG test in Display manufacture
Researchers use Our Sensitive Instruments to Make Great Scientific Discoveries

Dr. Klaus von Klitzing
1985 Nobel Prize in Physics
Quantized Hall effect

Dr. K. Alexander Muller and Dr. J. Georg Bednorz
1987 Nobel Prize in Physics
Superconductivity in ceramic materials

Dr. Konstantin Novoselov
2010 Nobel Prize in Physics
Graphene (two dimensional material)
And They Need All Our Equipment

Typical University/Research Lab

- SourceMeters
- Scopes
- Power Supplies
- DMMs
- Other Equipment

2014 Physics Nobel Laureate for the development of the Blue LED

Shuji Nakamura and his research group at UCSB.

Team that invented Violet Nonpolar Vertical-Cavity Laser Technology
Need More Sensitivity: The Most World’s Most Sensitive Meter

Sensitivity:

0.000000000000000001A (10^{-18}A, 1aA)

= 6.241 electrons/second

Note: Q of 1e^- = 1.6X10^{-19} C
1A = 6.2 x 10^{18} electron/second

Our Key Advantage:

- the world’s most sensitive current measurement instrument
Today, we commit to this next great leap into the cosmos.
Because we are human.
And our nature is to fly.