Precise Characterization of Power Semiconductor Devices Made Affordable

Power semiconductor devices are core components of power electronic systems. Knowing their characteristics well helps reducing costs and increasing reliability. When designing a system, it is important to consider the spread of parameters of the various components. But when it comes to the verification of the design, how can we know about the parameters of the samples we have actually built into the prototype?

By Burkhard Bock and Thorsten Masuch, Scienlab electronic systems GmbH

Characterizing power semiconductors

Without knowing, a decent portion of safety margin has to be added to the design which deteriorates performance and increases costs.

Being able to measure the characteristics of power semiconductor devices not only eliminates uncertainty in a design. It also facilitates the comparison of different semiconductor technologies and suppliers and helps identifying the device that fits best into the application. Further fields of application of systems for characterizing power semiconductor devices are incoming inspection and failure analysis as well as quality assurance.

Measuring equipment for precise characterization of high power semiconductors is hard to find on the market. So-called Curve Tracers that were available in the past feature current and voltage ranges that are not sufficient for high power modules. Moreover, these units are sold at a price that small companies or universities cannot afford. This is why Scienlab as a provider of power semiconductor characterization services and as a supplier of electronic test systems developed a Curve Tracer that satisfies the requirements of people dealing with high power semiconductor modules. Along with the technical specification, an affordable price was an important design goal right from the start.

Requirements

After talking to many people from the power electronics scene, we figured out that most people would be happy with a Curve Tracer with a maximum output current of 2500 A and a maximum voltage of 3000 V. We also saw that simply providing a high voltage is not enough: blocking current values up to 100 mA may appear at high voltages, especially at high temperature and in the presence of humidity.

From our own experience as a provider of test services we knew quite well that performing the measurements is only half of the whole story. The other half is documentation which can be tedious with standard test equipment if, once the measurement is completed, a bunch of files with cryptic names have to be renamed and diagrams have to be drawn. This is why we created a piece of software which not only allows easy configuration of a measurement. The documentation is part of the software function so that the documentation is ready in the very moment the measurement is completed.

Easy operation of the Curve Tracer not only saves time when performing measurements. It also allows unskilled personnel to perform measurements accurately, for example in a sample test line. To achieve an easy and reliable operation, not only a clear user interface is required. It is also important that the test system shows a stable performance in all operation conditions without requiring complex parameterization.

Figure 1: Traditional and Scienlab state-of-the-art Curve Tracer with integrated test chamber

Figure 2: With a clear user interface even unskilled personnel can perform precise measurements
Compliance
In order to protect the device under test (DUT), limits are set for output current, output voltage and output power of the Curve Tracer. For Curve Tracers and Source Measure Units, limits for the quantities that are not actually sourced are frequently referred to as "compliance" limits.

**Output characteristic**

- **Type:** 800 TQ 06 66 OLC
- **Lot No.:** 8809
- **Serial No.:** 123A
- **Timestamp:** 08.25.2003 06:16:34

**Figure 3:** Compliance limits for current, voltage and power protect the device under test and exclude points of operation with excessive heat dissipation from the measurement.

Blocking characteristics
The blocking characteristic is measured to determine the leakage current and the breakdown voltage of a device. Since the blocking voltage increases with increasing junction temperature, it is necessary to know the breakdown voltage for the lowest possible temperature that can occur in the application. For devices that show significant losses due to blocking current, the blocking currents at the specific blocking voltages seen in the application are of special interest. With blocking currents varying largely with blocking voltage and power dissipation.

**Blocking characteristic**

- **Type:** DP2500001700/12/01/01
- **Lot No.:** R2424/12/01/01
- **Serial No.:** 12345678
- **Temperature:** 25°C
- **Timestamp:** 17.05.2013 06:06:39

**Figure 4:** Automatic adaption of the current level enables precise measurements throughout the whole blocking characteristic curve.

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**Features:**
- Distributed Amplifying Gate Design
- Low Turn-on Losses
- Proton Irradiation Technology
- Improved Softness of Reverse Recovery
- Reduced Reverse Recovery Charge
- Low Turn-off Time

**Technical characteristics**

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*<sup>1</sup> all values are max values.*
between different devices, the automatic adaption of the current measuring range is a time saving feature that ensures precise measurements for each single point of operation. Setting a current “compliance” limit protects the device and at the same time yields the breakdown voltage measurement at the end of the blocking-current curve.

**Transfer characteristic**

**Output characteristic**

Figure 5: A power “compliance” limit protects the device from excessive heating when measuring transfer characteristics

**Transfer characteristics**

The transfer characteristic of a MOS-gated transistor shows the collector current as a function of the gate-to-emitter voltage at fixed collector-to-emitter voltage. With an active high current source, the output voltage level is held constant independently from the current level so that the transfer characteristic can be measured simply with one gate-voltage sweep. As it is typical for power devices, a collector-to-emitter-voltage in the range of 10 V to 20 V is selected for the measurement of transfer characteristics. To protect the device from excessive heat dissipation, compliance limits for the output power should be set. In order to make this limit effective, control of both current and voltage during the measuring pulse is required.

**Forward characteristic**

**Output characteristics**

The output characteristic of a transistor shows the collector current as a function of the collector-to-emitter voltage with gate-to-emitter voltage as parameter. Similar to the transfer characteristic measurement, high power is dissipated by the device under test in several points of operation due to relatively high voltage and high current occurring simultaneously. High power dissipation requires longer pause times between measurements so that the DUT is in thermal equilibrium again. To minimize measuring time, the pause time between measurements is adopted dynamically in relation to the maximum power level that has been selected.

**Forward characteristics**

Forward characteristics of power devices are required to determine the conduction losses. The output voltage level for this measurement is generally low which means that there is little heating of the device under test, but even more heating for the class-A power amplifier of the Curve Tracer. The pause time between measurements is adopted dynamically in order to protect the power amplifier and to ensure thermal equilibrium of the DUT.

Figure 7: Output characteristic up to 2500 A / 20 V with 12.5 kW power limit

**Pulse time versus stray inductance**

Since high currents heat up the devices under test, forward- and output characteristics are measured as a sequence of short pulses. Both, pulse width and the time between two pulses must be chosen carefully to avoid excessive heating of the device on the one hand side and to allow for enough settling time to achieve precise measurements on the other hand side. While pulse times down to
100 µs or even less are possible for low-power devices at low current levels, high current levels up to 2500 A require a significant time to ramp-up the current due to the parasitic inductance in the setup. For $i_C = 2500$ A output current (collector current) at $u_{CE} = 2.5$ V output voltage (collector-to-emitter voltage) and a stray inductance of $L = 300$ nH, a current-ramp-up time of

$$t_{ramp} = \frac{i_C \cdot L}{u_{CE}} = \frac{2500 \cdot 300 \text{nH}}{2.5 \text{V}} = 300 \mu\text{s}$$

is required (cp. Figure 8). This calculation makes clear that minimizing the stray inductance is very important to achieve acceptable measurements. But not only the current-ramp-up time, but also the settling time depends on the stray inductance (cp. Figure 9).

**Figure 10: High-current wiring of the DUT with low stray inductance**

Hence for a high current Curve Tracer not the pulse width, but the stray inductance is the quantity that really matters. Here the manufacturer of the measuring equipment has to make sure with the design that the DUT can be connected with a minimum of stray inductance (Figure 10).