Characterisation of Power Devices at Wafer Level

For years, power semiconductor device manufacturers have been forced to package their devices prior to characterisation and model extraction. Thus, wafer-level measurements on power devices have been fraught with unreliable or inaccurate data, extra costs, and uncertain delays in development schedules. A new power semiconductor test system finally solves this problem. **Cali Sartor, Senior Product Manager, Cascade Microtech, Beaverton, USA**

Figure 1: Typical semiconductor device development

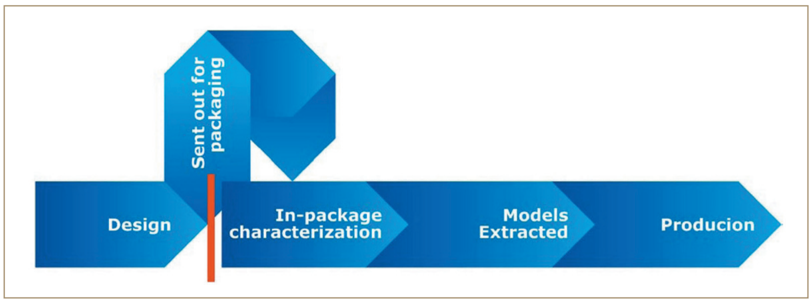

Figure 2: Typical power semiconductor device development

The world market for power semiconductors has grown from $4.94 billion in 1996 to in excess of $20 billion in 2006, and is expected to continue to experience double-digit growth for the next few years. This strong growth is largely driven from traditional power semiconductor device applications such as power transmission and traction appliances like trains. However, in the past few years increasing requirements for more efficient power utilisation in the automotive and electronics industry has created a stronger demand for power semiconductor devices. Power semiconductor devices belong to a separate segment of the mass semiconductor application market, differing both in production technology and in end-user applications. These semiconductor devices are used as switches or rectifiers in power electronic circuits, for example, switching power supplies.

The power device industry is always striving to develop the 'ideal switch', a device that blocks high-voltages in the off state, exhibits zero resistance in the on-state, includes unlimited switching speeds, low-cost and other desirable characteristics. Though the ideal is unattainable, the pursuit of ideal performance has driven the industry towards an optimisation of these parameters.

Competition is another growing factor driving the power device industry. With few other sectors growing at the double-digit rate that power devices is growing, this market is attractive for companies looking to enhance their margins by adding product lines. As production and development techniques become well-established for products such as power MOSFETs and thyristors, this market is much more accessible to new entrants. A big challenge has been safe and accurate testing of power devices.

Lack of technical capability

The current generation of wafer probe stations are designed for low-voltage and current, limiting their ability to be used in conjunction with the full capabilities of power device instrumentation (i.e. curve tracers). When power device manufacturers run measurements on-wafer they are only able to utilise a subset of the instrument capabilities with existing probe and probe station equipment.

First and foremost, power device developers are shackled with the requirement to test their devices in-package, as opposed to on-wafer. This translates into longer development times and higher cost of production. Typical semiconductor device development follows a process where the device is designed, characterised on-wafer, models are extracted, and then it heads off to production to be processed for mass manufacturing (Figure 1).

With power devices this process is slightly different. Power devices require very high voltages and currents to characterise their parameters. For instance, a power MOSFET with specs of 500V and 10 to 20A of current will need to be tested at 1000V and up to 40A of current to get an accurate model of the device parameters. Existing probe station equipment does not provide the capability to test devices at these high currents and voltages. In addition, there is no commercially available test instrumentation for on-wafer device characterisation with this magnitude of voltage and/or current. Thus, the power device is forced to follow a different path of development (Figure 2).

Power devices must be sent out for packaging prior to characterisation and model extraction. This is an extra and often time-consuming step to add to the schedule, meaning that the devices for characterisation need to compete with the devices for sale and usually get a lower priority on the production line. In fact, one researcher claims to have waited up to one year to get his devices back from packaging because of this conflict.

Safety is another big challenge for power device developers. According to IEC 61010 safety standards, any voltage over 40V is considered hazardous to operators. With power devices requiring upwards of 1000V, this becomes a dangerous task for the operator.

Thin wafers

In search of the ideal power device, the wafer has decreased in thickness over time. Average wafers today are approximately 100 microns thick and getting thinner. This adds an additional layer of complexity in on-wafer device characterisation, as thin wafers are very difficult to hold down on a wafer chuck. These thin wafers will curl at the ends or 'potato-chip'. This is very problematic for wafer probing and, in particular, in order to get low contact resistance between the wafer and the chuck.

As power MOSFET designers drive the on-state resistance to lower and lower levels in pursuit of this ideal power device, the $R_{ds(on)}$ measurement (resistance of the device between the drain and source in the on state) becomes tougher to attain and next to impossible to perform on-wafer.

Engineers are also trying to increase the amount of voltage a switch can block in the off-state. Currently, on-wafer probe station equipment can only handle up to 500V. Engineers need to characterise the power device at up to five times this amount in order to get an accurate blocking voltage curve. Although there are instruments that can support up to 1100V on-wafer, the probes and probe stations do not.

Tesla system is the power solution

In Cascade Microtech's experience, most power test labs are frustrated by the limited high-voltage/high-current power wafer test capability of their existing probing equipment. Labs needing to perform this testing typically use custom in-house-developed solutions. The designs are typically sub-optimal, expensive to create, inflexible and marginally safe. Vis-à-vis homemade solutions, the Tesla system provides a proven range of capability. In addition, the Tesla system saves diversion of manpower from the testing task, allowing engineers to focus on the measurements to be made and not on devising a plan about how to make them. Since the system is built from the ground up with on-wafer power device characterisation in mind, Tesla provides a certified safety capability.

As previously stated, current-generation probe station configurations are designed for low-voltage and current, limiting their ability to be used in conjunction with the full capabilities of power device instrumentation. The Tesla system allows power device testers to maximise the capability of their test instrumentation in on-wafer test; thus removing the requirement to perform these operations in package when they are significantly more costly. For instance, the Tektronix Curve Tracer products (model 370B) allow the tester to run measurements up to 2000V or 10A continuous. Today's probe stations can handle a maximum of 500V and less than 1A. Tesla will support a larger subset of the measurement capability for curve tracers with a voltage range up to 3000V and current handling capability up to 60A peak current. In addition, Tesla also provides improvements in low-leakage measurement capability on a triaxial connection. Today's low-leakage measurement systems for high-voltage testing can handle up to 1100V. The Tesla system unlocks this capability, allowing engineers to utilise the full range of their instruments capabilities. Engineers need to know the current leakage at high-voltages. Never before have engineers been able to measure leakage levels nearing 1pA at high-voltage. With this advancement, they can understand more of their device behaviour for leakage under the 10pA range. Figure 3 shows the triaxial measurement coverage.

Power device engineers need to make low $R_{ds(on)}$ measurements from the backside connection (drain) on wafer. The Tesla wafer chuck the chuck supports 3, 4, 6 and 8in wafer diameters and has a highly polished gold top surface with vacuum pattern, capable to hold very thin wafers down to 100µm.

The high-current probe provides the high-

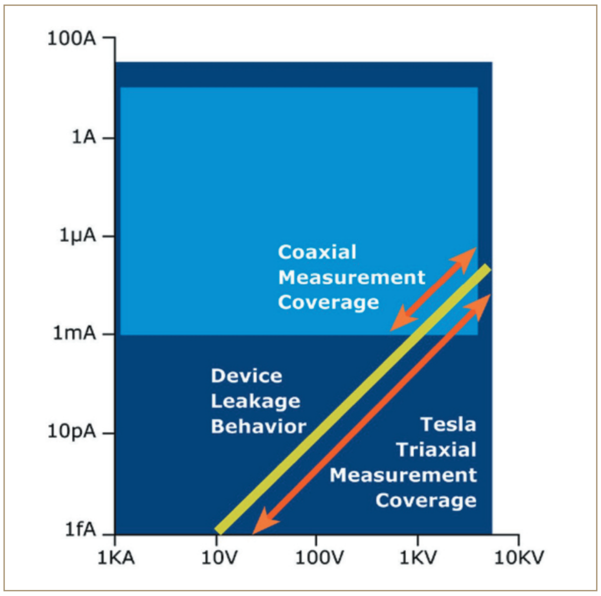

Figure 3: Tesla's coax measurement range

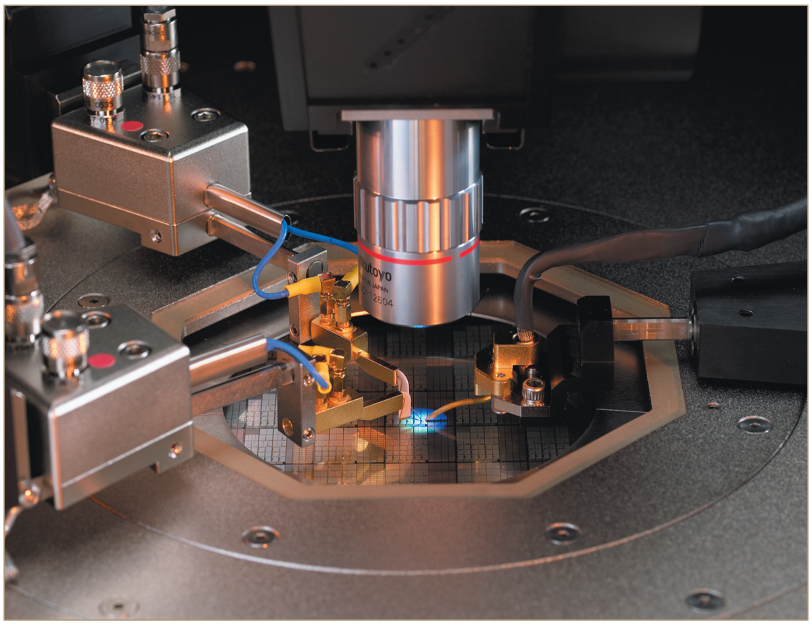

Figure 4: Wafer on the chuck and probes

current levels at a low contact resistance that is required to make the $R_{ds(on)}$ measurement. The probe can support 10A of current in continuous mode and up to 60A of current in pulsed mode. This is no small feat considering that the probe tip is designed for pad sizes as small as $800 \mu m^2$. Typically, when a high-current is applied to a device, the device will heat up. This device heating is often referred to as an isothermal effect. In order to reduce the amount of heating in a device, the engineer will often use a pulsed current measurement. Even in this case, at very high currents, on the order of 10A or greater, the device will experience some level of heating. This device heating can have a negative impact on the measurement accuracy. In order to reduce device heating, the probe tip has been designed to minimise contact resistance at the wafer to probe interface. In addition, the probe also has a means of distributing the current over a multiple contact points that are joined by metal that is used to pull heat from the probe tip. For added convenience, the probe features a replaceable tip design that can be interchanged as residues build at the tip, ensuring a low-contact resistance at the tip. Figure 4 shows a wafer on the chuck and the probes.

To complete the solution, the Tesla system takes care of the cabling from the instrument to the probe; providing highly insulated and electrically guarded and shielded cable assemblies that provide both triaxial performance and high-current/high-voltage handling capabilities. In addition to the systems cable assemblies, Tesla provides also the necessary interface panels to offer ease of measurement in a convenient and intuitive design (Figure 5). Each and every component in the measurement path and measurement environment has been designed and tested to comply with up to 3000V.

Figure 5: Tesla power semiconductor probe station with safety interlock