Comprehensive Testing with Combination Testers

Increasing quality demands require comprehensive, 100% testing of semiconductors. Static tests are no longer enough. Only supplemental dynamic testing procedures, such as switching unclamped inductive load and a double impulse test can meet the requirements. Inspection of thermal impedance is very important in the process. The simplest approach uses a test system that can perform all these tests.

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Since the IGBT die cannot be tested thoroughly before assembly, all parameters have to be tested after the module was assembled. A complete test consists not only of parameter testing, but also the thermal connection of the chip to the heatsink and the dynamic switching behaviour. Thus, a test sequence consists of a pretest measuring the cold parameters, then the stress test dynamic and thermal impedance (Z_{th}) and retest to make sure the part is still functional. To conduct all these test in one station, combination testers are available.

Parameter testing

The static parameters of power semiconductors are the most important parameters that must undergo testing after production. The I_{DSS} (drain off-state current) and $I_{GSSf/r}$ (forward and reverse off-state current of the gate) leakage currents, in particular, provide information on any possible mechanical damage to the chips. Gate threshold voltage and breakdown voltage are important indicators of doping. But is that still enough today?

Static tests are often inadequate to meet the high demands for quality in the manufacture of special-purpose machinery and in the automobile industry. Future requirements in the automotive industry are clearly moving in the direction of robust design and validation. But a robust design of components that are released according to the most modern methods does not help if process problems occur in production and nullify such efforts. To keep the required failure rate <10 ppm, advanced tests must guarantee the quality of production.

Dynamic test

Dynamic tests examine the switching behaviour of the component under load. The component will ultimately be used as an electronic switch in converters and similar units. For IGBTs, at high environmental temperatures RBSOA (reverse bias save operation) is especially critical. Components with avalanche characteristics must pass the switching unclamped inductive load test. This test destroys weak components.

Thermal impedance test

The production of heat in any noteworthy quantity is a very undesirable, yet unavoidable, property of every piece of power electronics. In this context, it is very important that the semiconductors have the ability to dissipate as much of the heat as possible from the place of origin (depletion layer) to the environment (heatsink) via the enclosure (see Figure 1).

The bubbles and voids that appear during soldering of a chip impede the required heat dissipation. The component will work for a limited time but, sooner or later, a thermal failure will occur. Measuring the thermal impedance (Z_{th}) provides information on the thermal connection of the chip. It is unnecessary to examine all of the characteristics; measurements at one or

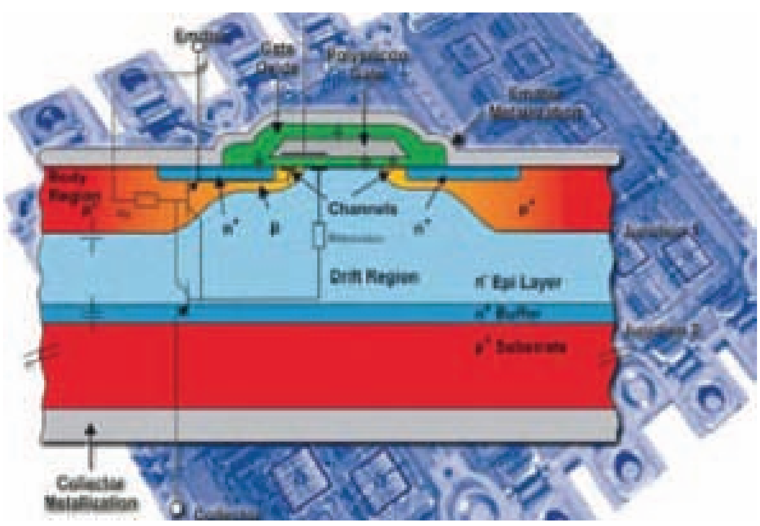


Figure 1: **Structure of an N-channel IGBT cell**

two informative measurement points are sufficient.

Only one contact

The required quality demands that these tests (switching unclamped inductive load test, RBSAO and Z_{th}) be performed as a 100% test of the components. The simplest solution would be to use specialised testers with independent contacts, possibly even for additional hot and cold tests. It is readily apparent that this approach does not make economic sense, but it is nonetheless possible to combine the tests mentioned above in one tester, despite the different ancillary conditions of each test. This approach saves the effort of multiple contacts and handling time.

And the following is also possible. First, the static parameters can be determined to deduce the processes for chip manufacture and assembly. Second, stress tests can be performed with an increasing load. The static parameters would then be measured again to ensure that the stress tests did not do any damage. And all that can be done with just one contact.

MRS' modular testers enables tailoring of the vertices (maximum test voltage, maximum current, and the required multiplex productions) to the requirements. The tests run in real time on a high-performance digital signal processor (DSP). A commercial PC is used to control the tester.

Measuring the static parameters

For the static parameters, a source instrument adjusts the test voltage or the test current and measures the variables. The measurement module works continuously. Except for the indispensable anti-alias filter, the hardware does not contain any additional filters. The DSP performs each processing of a signal. From a large assortment, the optimal FIR filter can be selected for each test. Short filter times are used for time-critical measurements. Sensitive measurements, such as leakage currents in the lower nA range, require longer filters. Digital signal processing enables very exact, reproducible measurements of leakage current, even in extremely electromagnetic industrial environments.

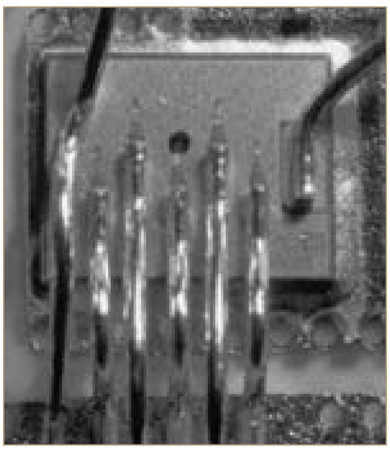


Figure 2: Failure of a transistor in a switching unclamped inductive load test

Measuring dynamic behaviour

The two dynamic tests used most widely are the switching unclamped inductive load test and the double impulse test. Both involved stress tests that destroy problematic components.

The switching unclamped inductive load test links the test to an inductive load without an override (unclamped). The transistor is switched off once the specified cut-off current is reached. Because there is no override path, the current continues to flow through the unit being tested and drives it into the avalanche breakthrough or into linear mode if an active clamp is required over the gate. Within a very short time, a very high rating in the chip is converted into heat.

In cases of inhomogeneous, defective doping or defective source or emitter gate metallisation, hot spots on the silicon develop that can lead to fusion of the crystal (see Figure 2). IGBTs, in particular have an unavoidable parasitic thyristor structure that ignites when the failures noted above occur, and that can lead to a latch-up with the resulting destruction of the component. These kinds of components may not leave production in any circumstances. FETs have only a part of these parasitic structures, so that there is no danger of a latch-up. Nevertheless, these structures are enough to cause comparable failures (a controlled increase of the parasitic bipolar transistor).

The set-up for the double impulse test is comparable to the set-up for the unclamped inductive load test, although an override path exists in this case. If complete converter modules or phase legs are being tested, the existing diode conveniently located on the opposite side of the transistor can be used as an override diode. This approach corresponds to later usage. A complete switching cycle is now run: commutation of the current into the override diode and reserve recovery of the override diode when switching back on. A test tester monitors the ancillary conditions of the test. A rapid digital storage oscilloscope can also be used to perform additional detailed analysis of current and voltage curves online.

The dynamic tests of IGBTs are especially interesting at high environmental temperatures. The current gain of both parasitic transistors increases as the temperature rises, as does the extrinsic base resistance. Both increase the danger of a latch-up. An appropriate choice of test parameters enables testing compliance with the safe operating area of each component. The transformed heat is mostly limited to the chips.

Measuring the thermal impedance

Measuring the thermal impedance can determine the amount of created heat the component can dissipate in long-term operation.

Measuring the thermal impedance occurs in three phases:

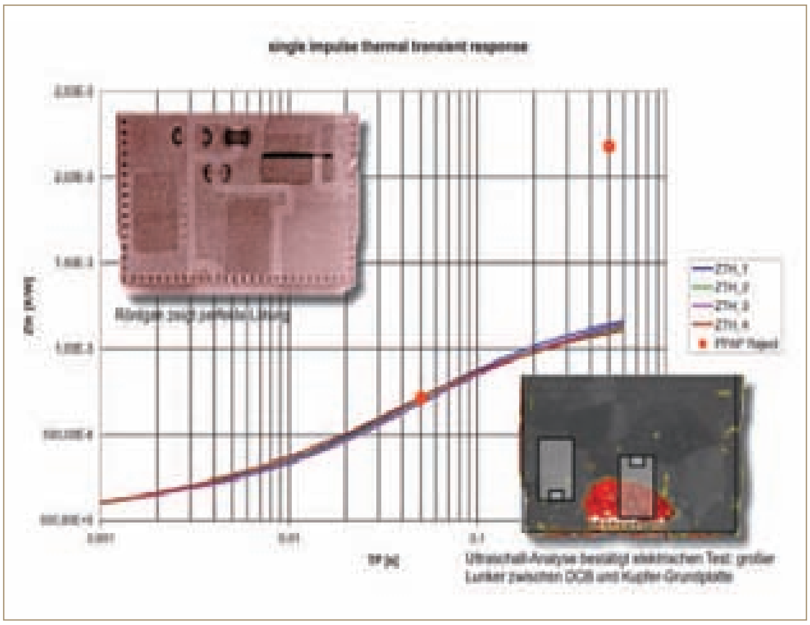
- Measurement of a temperature-dependent parameter (diode flow voltage, saturation voltage, and so on),
- application of well-defined (electric) energy,
- second measurement of the temperature-dependent parameter directly (in as short a time as possible) after the power impulse.

Application of well-defined energy means that constant power must be adjusted over a specific time. The time is determined from the thermal time constant of the structure to be tested, usually between 10 and 500ms. The power is selected to enable good measurement of the temperature difference without exceeding the maximum barrier layer temperature. The amount of warming that has occurred can be calculated from the change of the temperature-dependent parameter.

This measurement of Z_{th} corresponds exactly to reality and is clearly superior to other approaches.

Figure 3 illustrates a detailed analysis of a module that was rejected by the tester during the product part approval process (PAPP) phase. Curves ZTH_1 to

Figure 3: **Rejection of a chip with poor thermal fastening**



ZTH_4 were determined during the evaluation phase to specify the thermal behaviour of good parts. The routine test uses a power impulse that lasts 500ms. It is briefly interrupted after 50ms for an intermediate measurement of the temperature-dependent parameter. No abnormalities are seen after 50ms, but extreme abnormalities are seen after 500ms. The reason for the difference is that the chip is very well soldered with direct copper bond (DCB) and can dissipate the heat very well to the DCB.

The bubble is located between the DCB and the copper baseplate. That is why the bubble cannot be seen by an X-ray. The solid copper baseplate absorbs so much of the X-rays that the bubble disappears in the noise. Only an expensive ultrasound examination would confirm the results of the tester. Only an analysis of both Z_{th} results that are determined in a sort of inspection impulse contains valuable information for the process engineers.

This component was perfect in terms of the static parameters and passed both dynamic tests without any problems. In the field, however, it failed in a short time because of overheating.