Reliability Tests on Power Devices

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SUMMARY & CONCLUSIONS

System dependability has become an important aspect to consider because of the large number of components included in modern systems and the high availability requirements that users demand. In systems such as switch-mode power supplies, power devices like IGBTs play a fundamental role in system functionality and performance, hence the use of reliable components is key. In this paper the design of dependable systems based on reliable power devices is addressed. Reliability tests have been carried out on a set of IGBTs used in a battery charger to extract accurate reliability prediction models for this type of devices and degradation models, which can help the system designer to generate highly dependable systems. This paper describes the first phase of our research that focus on determining degradation models for IGBTs due to environmental causes. Our tests show the high resistance of the selected devices to environmental stress. None of the devices has failed the tests, and the variation in their electrical characteristics is minimal. This is an important conclusion because our final objective is the design of reliable battery chargers, which requires the use of power devices that can tolerate high stress without degradation of their characteristics. In addition, we were able to detect a flaw in our measurement methodology that helped us to improve our test and analysis flow for the second phase of our research.

1. INTRODUCTION

Reliability of semiconductor devices has become a major concern in system design because of the large number of components usually incorporated and the stress applied while in operation. The increasingly common 24x7 requirement in electronic equipment for networking, flight control, banking, or transportation, makes system design a complex task where not only functional aspects are critical, but also dependability ones.

Reliability prediction is needed in the design process to be able to build dependable systems that fulfill strict requirements regarding reliability and availability. Several models exist that are able to provide designers with an estimate of device or system reliability, however they have been found inadequate to predict the reliability of components in a number of situations (Ref. 1), leaving the design engineer without a valuable tool for estimating the reliability of a system. The lack of accuracy of the models is usually related to the difference among the factors used to generate the model and the ones found in actual applications. Only when the application is very close to the one intended in the model, reliability prediction can be done with a certain level of confidence on the results.

Among the thousands, or millions, of components that are part of even the simplest modern electronic system, power devices play a fundamental role. These components are part of the power supply circuit that feeds the rest of the system, or part of the actuators that interact with the environment as outputs of the system. In each case, power devices have to work under heavy stress conditions; hence highly reliable components are required.

At the Department of Electronic Technology in the University of Vigo, we have focused our research on power devices and switch-mode power supplies, as well as in fault tolerance of electronic systems, for more than one decade (Refs. 2-3). We intend now to approach the study of dependability from the point of view of component reliability, having as a motivation the improvement of system dependability. Our starting point is the study of failure mechanisms in power devices at high temperature and normal relative humidity conditions. We intend to extract parameters for prediction of reliability in electronic power systems using well-known techniques (Refs. 9-10). Our main goal is to characterize power devices from a reliability point of view and at the same time evaluate the techniques and models available to system designers to build dependable systems.

Section 2 presents our current research in designing highly reliable power supplies that can be used as battery chargers for electric vehicles and introduces the power devices where we have focused our research on reliability. In section 3 we provide detailed account of the tests we have conducted, and in section 4 we describe and discuss our experimental results.

2. HIGHLY RELIABLE MICRO CONTROLLER-BASED BATTERY CHARGER

Nowadays, the design of highly efficient power supplies can be accomplished using new power devices like IGBTs.

This kind of devices can be directly connected to AC power supplies and can be used at switching frequencies of up to 40 KHz, which allows for the design of power supplies with very low harmonic distortion and high efficiency. In recent years our research group has developed new schemes on this field (Ref. 4) that we are now applying to the design of battery chargers. Figure 1 shows the block diagram of a micro controller-based battery charger that uses IGBTs in the rectifier stage. Different current levels are supplied to the battery through an integrated modular DC/DC converter. The entire system is monitored and regulated by a micro controller that uses information from external sensors and an algorithm to perform an optimized charge.

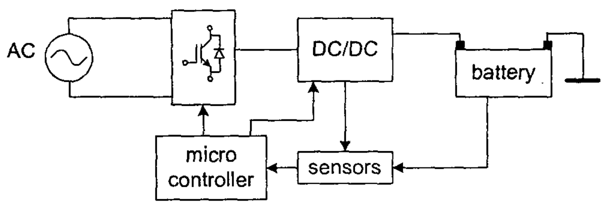

Figure 1 General diagram of a battery charger

High dependability is a fundamental requirement for this system, because of the potential harm to the environment (persons or machines) that can result from a failure. Our research focuses on the design of dependable systems through the use of highly reliable components and the application of design techniques that ensure correct operation or, in case of failure, safe outputs.

This paper describes our work on the first aspect, i.e., highly reliable components. The target device that we characterize is the Insulated Gate Bipolar Transistor (IGBT) because of its fundamental role in the system depicted in Figure 1. IGBTs combine the best features of MOSFET and bipolar transistors, delivering high output impedance (insulated gate), and low conduction loss (bipolar transistor). Typical applications are AC/DC switch-mode power supplies, high voltage DC/DC, power factor correction stages, automotive ignition systems and motor drive systems (Refs. 5-6).

3. RELIABILITY TESTS

Design of dependable systems is done on the basis of accurate reliability prediction models that help the design engineer to choose the appropriate components for every application, and impose design constraints on the system by providing the expected mean time to failure (MTTF). Prediction models such as described by MIL-HDBK-217 (US Department of Defense) or Bellcore (AT&T Bell Labs) are widely accepted in industry, however they do not provide accurate values in a number of situations (Ref. 1).

In this section we present the reliability tests that are part of the first phase of our research, where the goal is to determine degradation models for the power device presented in the previous section. Several environmental tests, as described in Ref. 7, have been applied to a set of ten IGBT pairs. Table 1 shows a short description of the tests and their characteristics.

Every test has a well-specified set of conditions, and a detailed application procedure. For instance, under test 103B, devices are exposed to high relative humidity (90 to 95 percent), at an elevated temperature (40 °C), for a period of time that depends on the test condition. There are four conditions, A, B, C, and D that correspond to lengths of 240, 96, 504 and 1344 hours each. Materials that are sensitive to moisture can deteriorate rapidly under the mentioned conditions.

Table 1 Environmental Tests

Test	Cond.	Name	Description
103B	B	Humidity (steady State)	40 °C, 240 hours
	C	Humidity (steady State)	40 °C, 504 hours
108A		Life	70 °C, 50%, 96 hours
		Life	70 °C, 50%, 504 hours
		Life	150 °C, 504 hours

Figure 2 shows our current layout to carry out the tests. Devices are placed in a climatic box, where accelerated tests take place. A programmable high-power curve tracer, attached to a PC for data analysis, is used to extract and compare the electrical characteristics of the power devices before and after each test. We evaluate not only the number of components that pass/fail every test, but also the degradation on the characteristics of the devices with time. Several software packages –some developed in our group, are used to interact with the curve tracer, store and analyze experimental data.

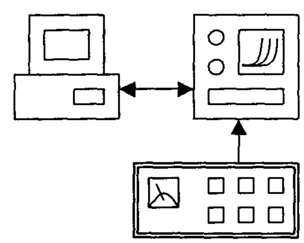
Figure 2 Test equipment and setup

4. EXPERIMENTAL RESULTS

The experiments were conducted using a sample of 20 IGBTs (model SKM 50 G 123D). These devices come in pairs enclosed in a ceramic package (see Figure 3), which makes them very resistant to environmental stress as we observed throughout our tests. We numbered every device from 1 to 10 (ten packages), A or B (two devices per enclosure); for instance, device 3-A would be the first device in package 3.

Experiments took place over a period of 5 months. Environmental tests (Temperature and humidity) were applied to the devices in a climatic box for more than 1800 hours. The electrical characteristics of each device were measured before and after every test at an environment temperature of 20°C (±5%). In addition, visual inspection was done to assess the degradation of the ceramic enclosure and metallic contacts.

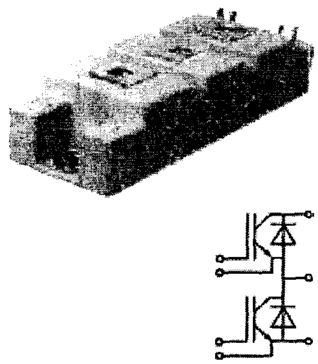

Figure 3 Ceramic enclosure and symbol of the IGBTs under test

A set of measurements was done for every device, to verify if it failed, and to extract its electrical output characteristics. Using a power curve tracer, the device was characterized at six different gate voltages (Vge in Table 2). For every Vge, 40 measurements were taken for collector-emitter voltages (Vce) ranging from 2.5V to 63V, which rendered collector currents from 1A to 70A. Figure 4 shows the measured output characteristics for device 1-A before any test was applied. The different curves correspond to several Vge values. Table 2 shows a summary of measurements for device 2-A before and after the second test (Test 103B, condition C. See Table 1). The parameter S is defined as Ic/Vge.

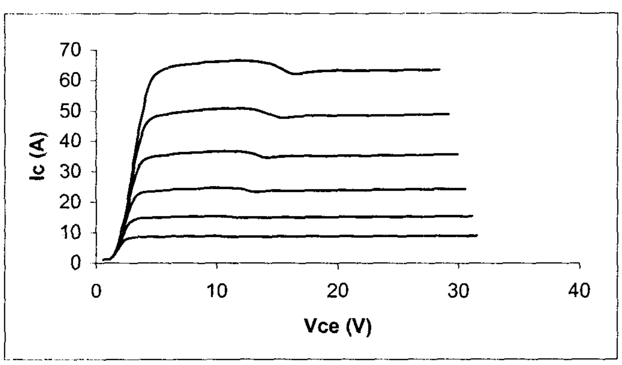

Figure 4 Measured output characteristics for device 1-A

Table 2 Summary of measurements for device 2-A before and after the second test (103B, condition C)

		Before Test		*After Test*		
Vge (V)	Vce (V)	Ic (A)	S (Ω^{-1})	Ic (A)	S (Ω^{-1})	ΔS
8.06	20.65	10.4	1.29	10.3	1.28	0.01
8.58	20.25	17.6	2.05	17.4	2.03	0.02
9.08	20.40	27.5	3.03	27.1	2.98	0.05
9.58	20.50	39.8	4.15	39.1	4.08	0.07
10.08	20.45	54.1	5.37	53.0	5.26	0.11
10.58	21.05	69.6	6.58	68.1	6.44	0.14

After analyzing the collected data, we could realize of the excellent resistance of this devices to environmental stress. None of the devices failed, or even had a noticeable variation in its electrical characteristics. Therefore, we could not conduct a more detailed analysis to obtain activation energy, MTTF, or degradation models, as it was our objective when we started this phase of our research. The devices result to be more reliable than expected, which changes our focus for the second phase of our research, where we are planning to conduct tests that stress the devices while in operation.

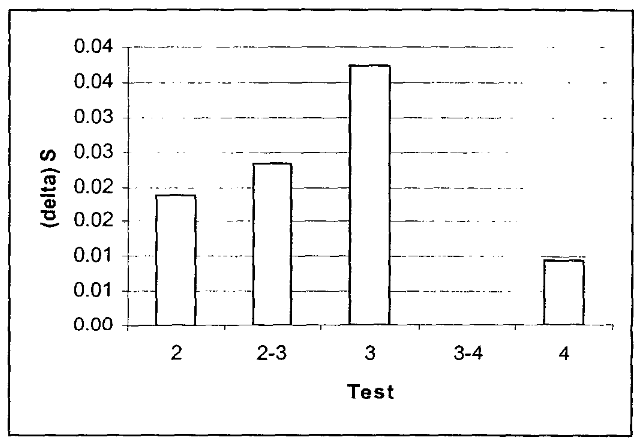

Figure 5 Maximum variation of S within a test, and from test to test

Another conclusion obtained from the data was related to the measurement process itself. The variation between the electrical characteristics of a device, measured before and after a test, is of the same order as the variation of the characteristics between two consecutive tests. This fact shows that the electrical characteristics of the devices were not affected by our environmental tests. It also surfaces a flaw in our measurement methodology. While we carefully planned the tests, characteristics to observe, and measurement conditions, we did not anticipate the small variations that the devices would show, therefore our measurement procedure was not precise enough to obtain accurate data. Figure 5 shows an example of the variation between measurements. The figure shows the maximum variation of a measurement

(S) between two consecutive tests, and within a particular test. Data for this figure is taken from device 4-A, tests 2 and 3.

The maximum variation of the conductance is below 0.04 for any particular test, while the variation between the measurements after one test, and before the following, is also in the same range (0.025 in the example of Figure 5). Because of this, we can not extract any conclusion about the possible degradation of the characteristics of the devices after applying the tests, however conductance seems to increase steadily for all devices.

Despite the aforementioned flaw in our methodology, we accomplished important objectives with our tests:

- Assess the resistance to environmental stress of the devices we selected. This is an important conclusion for our research in the design of reliable battery chargers.
- Establish and improve the flow for the second phase of our research, where we will be using the same equipment (climatic box, curve tracer, and analysis tools).

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José Manuel López Pallás is pursuing his Master of Science on Industrial Engineering. He is currently working on this Master Thesis, which main topic is the development of a quality control system for electronic components. The work is based on the use of a PC-controlled Programmable High Power Curve Tracer.

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