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APPLICATION NOTE

APPLICATION OF A NEW MONOLITHIC SMART IGBT IN DC MOTOR CONTROL FOR HOME APPLIANCES

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1. ABSTRACT

This application notes aims to outline the characteristics of a new power device that joins the peculiarities of an STMicroelectronics fast-switching PowerMESH™ IGBT with some novel protection features. A driver circuit is integrated in the power device to implement over-current protection and soft thermal shutdown. The current limitation also ensures a highly short-circuit rated device. Moreover the low threshold voltage and input current make it possible to drive the device directly from the output pin of a microprocessor. The static and dynamic behavior of the device will be illustrated and an application will be suggested.

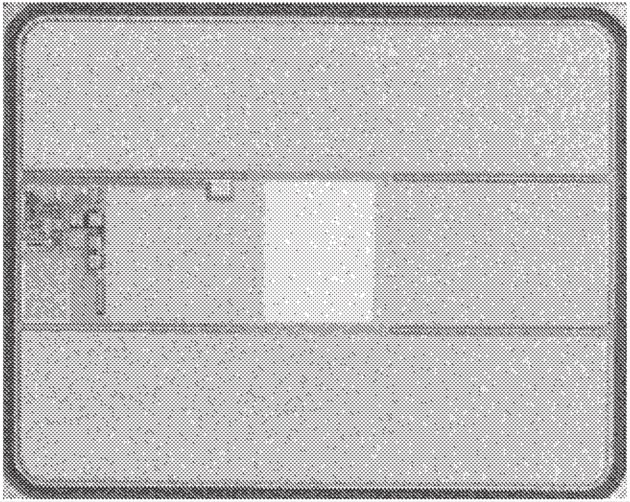
2. INTRODUCTION.

In the last few years IGBTs have been appreciated in many applications in the mid-power range, having the advantage of bipolar conduction characteristics and insulated gate control. Efficient advances in process and device technologies have improved conduction losses, working frequencies and ruggedness under inductive load conditions in hard switching applications. But nowadays requirements are becoming more and more stringent regarding ruggedness and reliability. On the other hand, the planar technology is reaching its limit in terms of performance [1]. For this reason the monolithic integration of protection features to prevent the intervention of faulty conditions represents a winning choice in order to improve a device's limits. Therefore the new trend in power semiconductor manufacturers is to provide ”system-on-chip” solutions [2].

Current literature proposes several solutions in order to obtain an intelligent switch in power conversion applications, such as full-protected high voltage MOSFETs or IGBTs for automotive electronic ignition [3,4]. But these solutions are not suitable for those applications in which conduction losses and switching speed are both important. Indeed a Power MOSFET is good for high frequency applications, but at lower current, while at the present time Smart IGBTs are available only for low frequency applications, and the research activities in the field of monolithic Smart IGBTs for fast-switching applications are really poor. Hybrid solutions are actually available, but this approach has some drawbacks like package size, complex assembly techniques and costs.

The device we are going to present (see figure 1) is very innovative in its product range, because it shows a high current density with switching performances that match well with the requirements of applications like motor control drive systems, induction heating and SMPS.

Figure 1: A Fast-Switching Smart IGBT



The proposed device is a new full-protected IGBT, packaged in a convenient three pin TO-220 package, with an active area of about 12mm^2, while the control part occupies an area of about 0.9mm^2, including the input pad and some trimming pads. Concerning the main electrical characteristics, the device has 600V of breakdown voltage and 10A of nominal current. It is a logic level switch with a gate threshold voltage of 1.5V and very low input current (1mA). These features allow direct driving from a micro controller system. In this way STMicroelectronics' intelligent switch is particularly suitable for motor control in home appliances, consumer electronics and medium power industrial servo-drive [5].

This paper will begin by giving some general information about the adopted technology and the static and dynamic electrical characteristics of the device will then follow. In this context the dynamic performances will be compared with the requirements of an experimental motor control application.

3. TECHNOLOGICAL OVERVIEW.

STMicroelectronics' fast-switching Smart IGBT is manufactured with a standard process based on its patented strip horizontal layout. This layout consists of a p-type mesh implanted over an n-type epytaxial layer. Some steps later n-type strips are then implanted over the p mesh to form the IGBT emitter. In figure 2 the 3D view of the mesh layout is depicted, while in figure 3 the cross section of the strip layout is shown.

Figure 2: Mesh Overlay 3D View

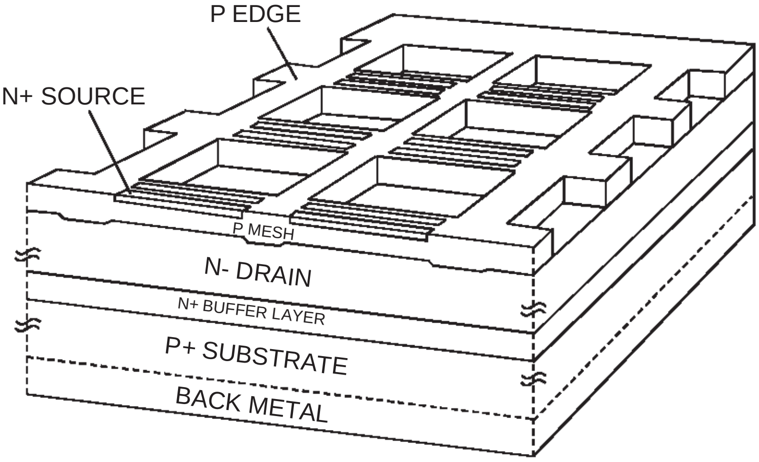
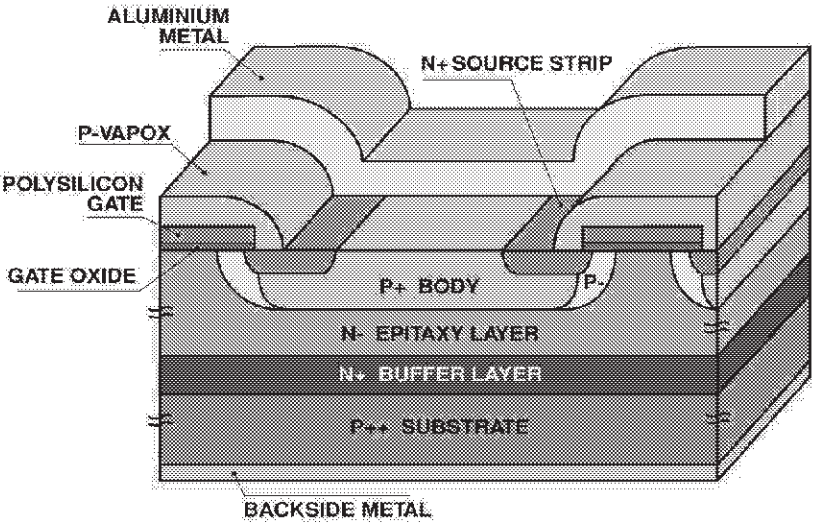


Figure 3: Strip Layout Cross Section



This proprietary process improves switching performances and latch-up immunity, moreover the introduction of gate fingers concur to reduce the gate internal resistance and to speed-up the device turn off [6]. Furthermore a proprietary lifetime killing method is performed implanting and diffusing platinum ions.

The technology design allows to integrate in the same chip the Power IGBT and a simple control circuit. This approach ensures a low-cost integration and a high value-added device, indeed only one photolithography process is added to the standard process flow.

The control circuit is implemented with:
- N-MOS enhancement-mode transistor,
- polysilicon resistors,
- polysilicon diodes.

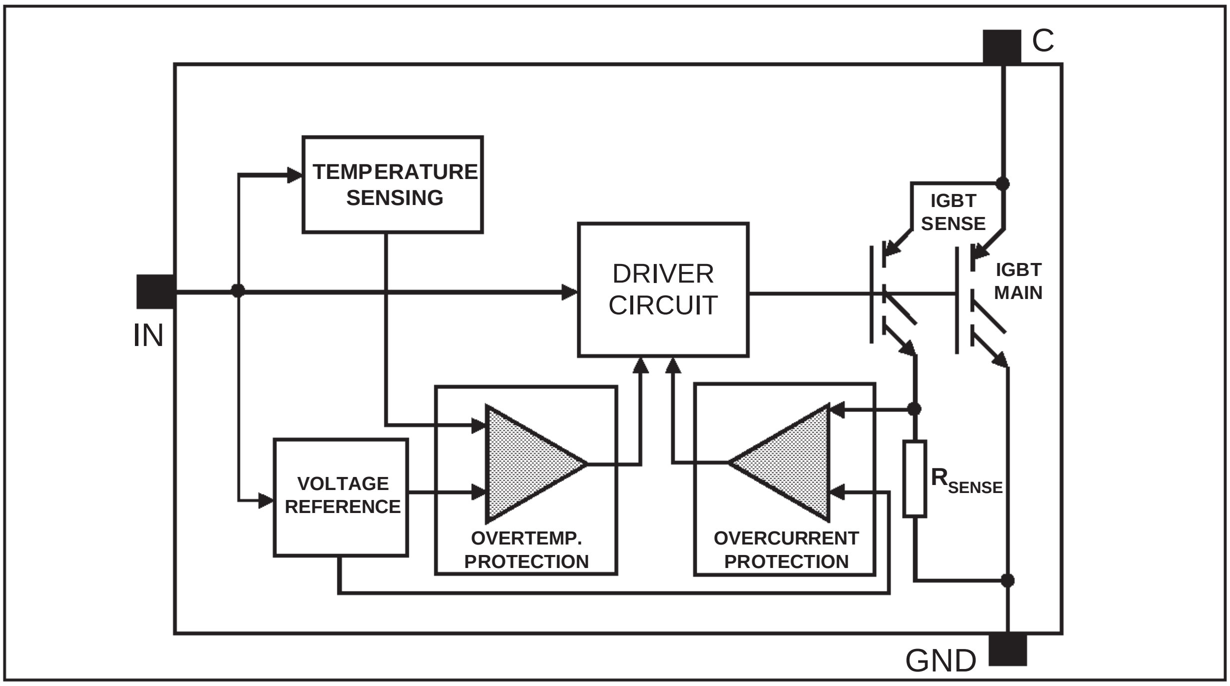
The signal MOSFET transistors are implanted in the p-type mesh, while the polysilicon resistors and diodes are insulated from the bulk by a thick field oxide.

Moreover a current sensor and a temperature sensor are integrated. Current sensing is made by insulating an emitter strip with a given sense ratio, while temperature sensing is made by monitoring the variation of the forward voltage drop of some polysilicon diodes.

4. THE DEVICE: STATIC AND DYNAMIC BEHAVIOR.

The Smart IGBT has to be considered as a global switching system. The block diagram of the device is shown in figure 4 where all the control parts are highlighted.

Figure 4: Block Diagram of the Smart IGBT For Motor Control



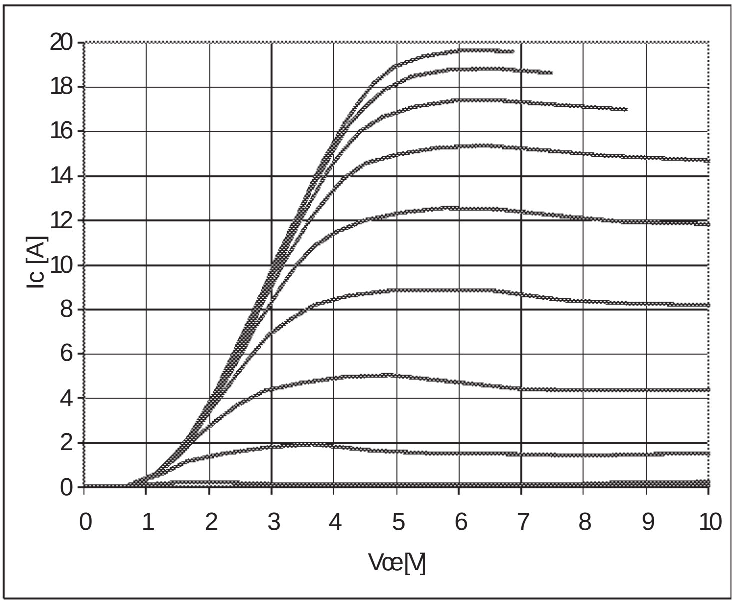
Although the exterior look of the device is very similar to a standard IGBT of the same silicon area (they are both housed in a three pin package), their electrical characteristics are slightly different due to the intervention of the devoted control circuit. The first difference of the Smart IGBT, with regard to a standard IGBT, is the input current. The gate pin of an IGBT is an insulated terminal, while the input pin of the Smart IGBT needs an input current of about 1mA at V_{IN}=5V in the steady state conditions.

The threshold voltage of the device is very low (1.5V @ I_C=250µA), but the minimum input voltage to consider the device on and correctly working is about 4V.

The output characteristics at high current are modified from the presence of the current limiter. In the knee region of the characteristics we can note an abrupt reduction in the collector saturation current due to the intervention of the current limiter (see figure 5). Moreover, the transconductance of the device is smaller with respect to a standard IGBT due to the voltage drop in the control circuit.

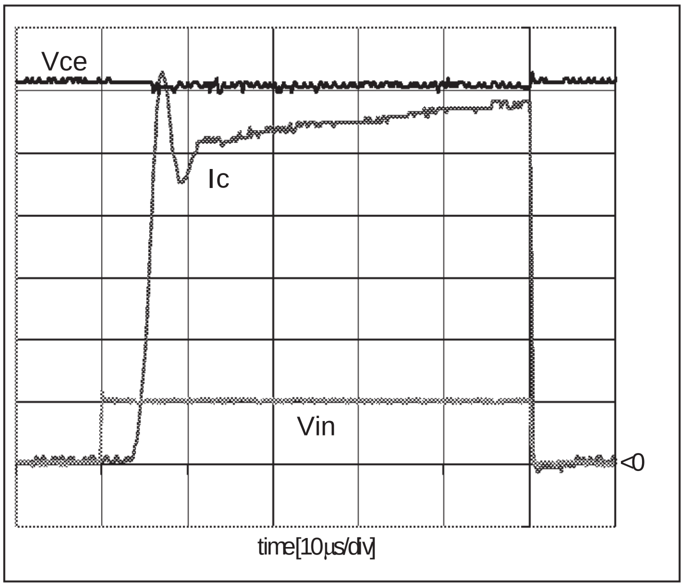
The nominal current of the device is about 10A (current density about 100A/cm^2), at which value the collector saturation voltage is about 2.5V. In future releases of the device this characteristic will be improved using further technological approaches.

Figure 5: Smart IGBT Output Characteristics



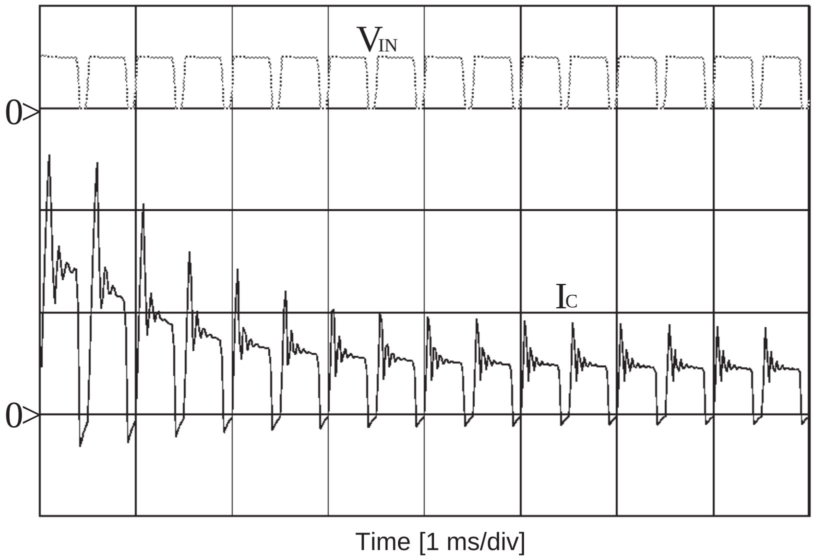
The current limitation shows a slight dependence on the value of the supply voltage and, in the application suggested in this paper, it starts at about 24A. The presence of the current limitation ensures a good immunity to several faulty conditions. For example, if a short circuit occurs under switching conditions, the collector current will be blocked at low values, several amperes below the latching current, so the device will withstand short-circuit and its immunity is limited only by the capability of the silicon chip to dissipate energy. In figure 6 a hard switching phase in short-circuit condition is shown. It is easy to understand that the device does not fail for a very long period during which an external diagnostic circuit could reveal the faulty condition and disable the input signal.

Figure 6: Hard Switching Short Circuit Conditions (V_{CE}=50V/div, I_C=5A/div, V_{IN}=5V/div)



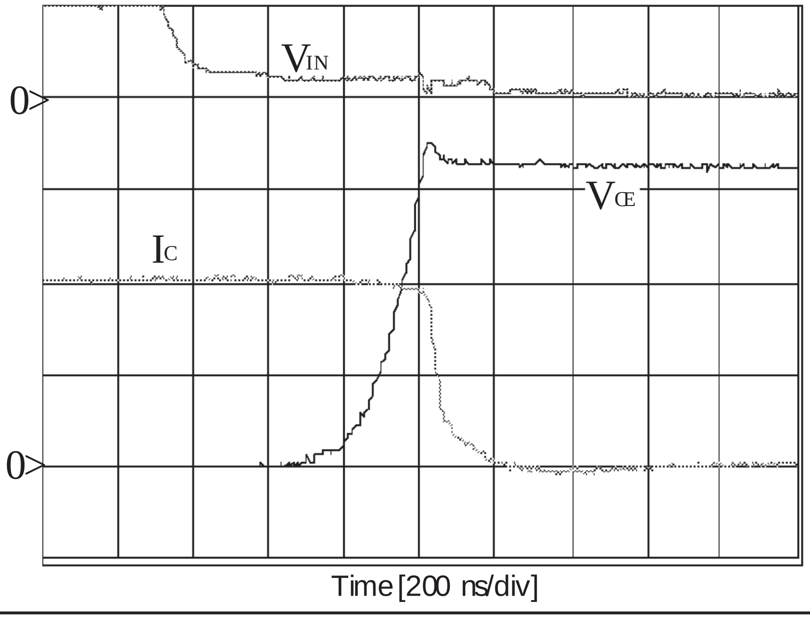
In figure 7 the initial phase of a soft thermal shutdown due to the intervention of the over-temperature protection circuit is shown. In the worst driving conditions, for example an error occurring in the frequency or in the duty cycle of the timing train of pulses, the integrated control circuit will sense the high temperature and will reduce the value of the collector current under limitation conditions.

Figure 7: Overtemperature Protection (I_C=10A/div, V_{IN}=10V/div, t=1ms/div)



With regards to switching times the device shows a current fall time of about 120ns, including current tail, and a voltage rise time of about 150ns at room temperature. In figure 9 a typical turn-off of the device is shown.

Figure 8: Inductive Turn-Off (V_{CE}=100V, I_C=5A/div, V_{IN}=5V/div, t=200ns)

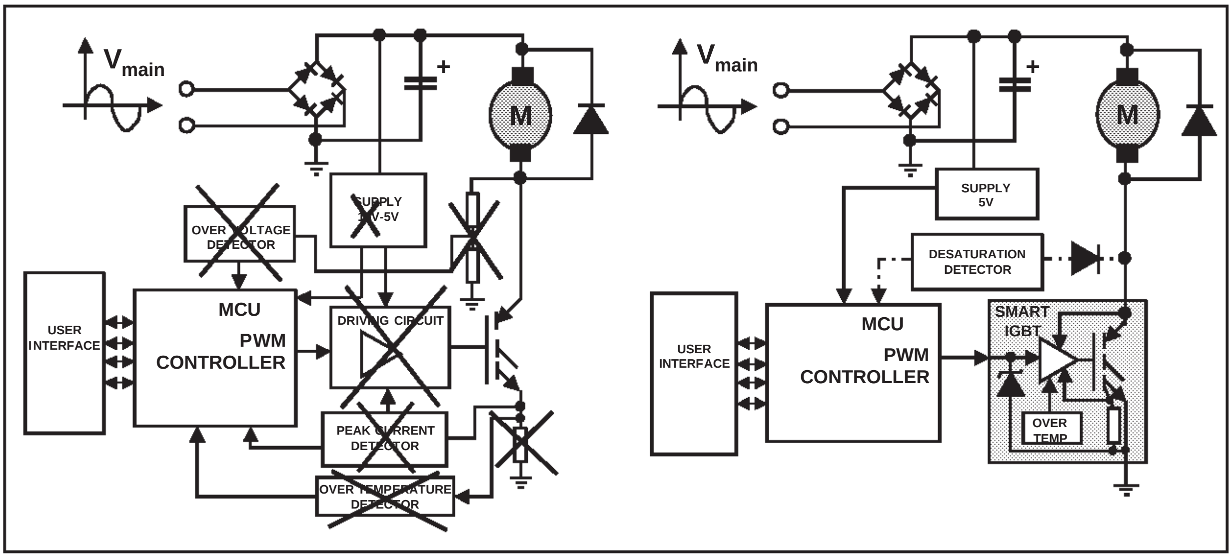


5. DC MOTOR CONTROL: AN APPLICATION CASE.

Variable speed drives have become widespread in the home appliance field and the electrical characteristics of the Smart IGBT make it suitable for motor control applications. In this field of application the Smart IGBT allows a dramatic reduction in the probability of electrical block, improving the system reliability. Furthermore the integration of the control circuit allows eliminating many external components, resulting in cost and volume reduction.

We propose an application of the device as a power switch in a chopper converter for a home appliance DC motor of 400W. The system arrangements with a standard IGBT and with a Smart IGBT are compared in figure 9. The diagram shows how the device is driven directly from the control circuit without a driver and any protection circuitry. In order to improve the system reliability in short circuit condition, the information of V_{CEsat} behavior has been supplied to MCU unit by means of a desaturation detection circuit.

Figure 9: A Comparison Of A Motor Control Application Circuit With a Smart IGBT and a Standard IGBT



Several tests have been carried out at different switching frequency (in the range from 10kHz to 20kHz).

In figure 10 the transient phase of the motor starting at a switching frequency fixed at 10kHz is shown; the supply voltage is 311V and the duty cycle is 50%. In this application the maximum collector current reaches about 4A while at steady state it reduces to about 2.3A.

A load variation during the steady state conditions is reported in figure 11. The output current both decrease and rise from light load to full load as simulation of discontinuous load applications.

In figure 12 the intervention of the over temperature protection is shown. The current has been strongly reduced with consequent temperature decreasing. The over temperature condition has been obtained without heat sink. The temperature measured in the application is about 80°C corresponding at 100°C on the junction.

Figure 10: Motor Control Starting Transient (V_{CE}=100V/div, I_C=2A/div, t=5ms)

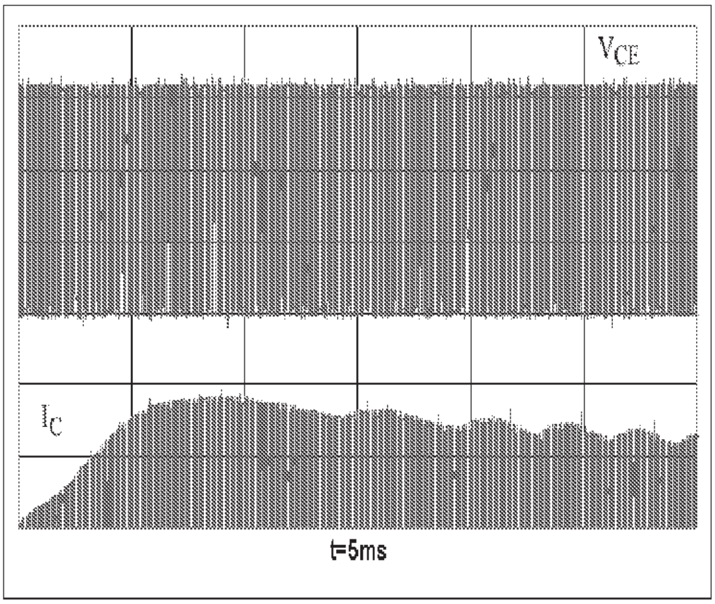


Figure 11: Load Variation Transient (V_{CE}=100V/div, I_C=1A/div, t=500ms)

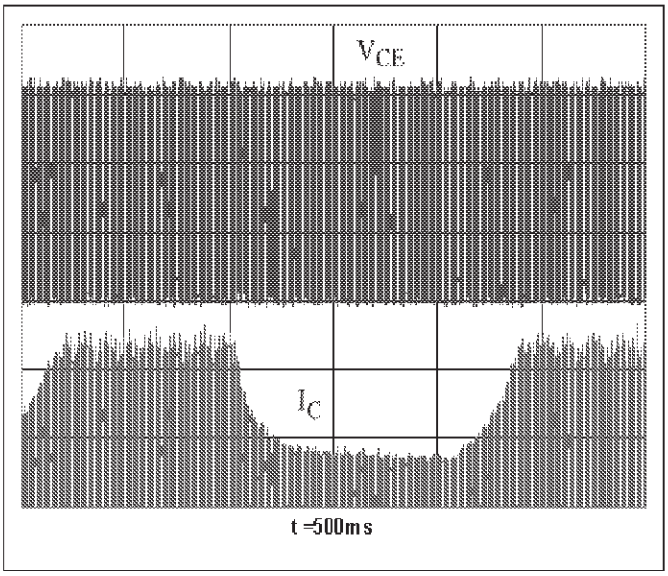
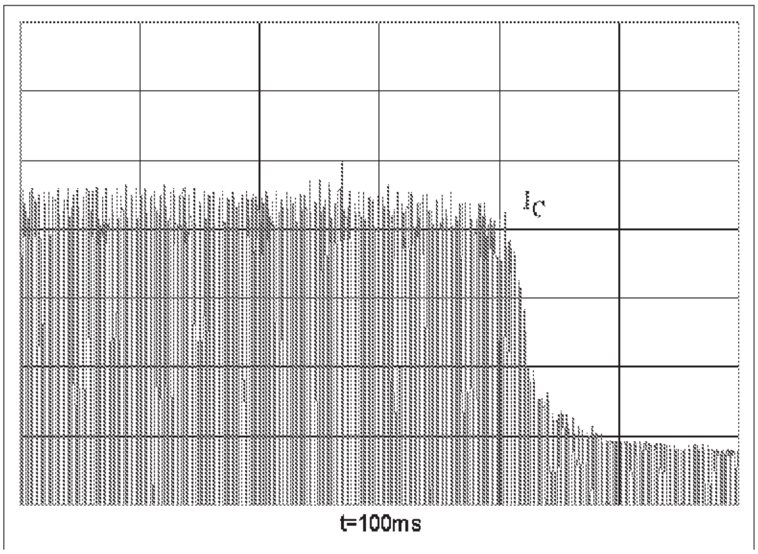


Figure 12: Overtemperature Current Reduction (I_C=0.5A/div, t=100ms)



6. CONCLUSION.

A new fast smart IGBT with a monolithic control circuit has been presented and described. The device is cost-effective because, while it has been manufactured with the same process of a standard IGBT, it offers a great deal of added value. All the protection features of the switch have been exploited; it was also shown how they improve the reliability and the ruggedness of the whole system. Moreover a switching performance of the device in a home appliance motor control application has been shown.

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