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ACOUSTIC EMISSION OF MONOLITHIC IGBT TRANSISTORS

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Abstract. Due to the increasing number of applications of power semiconductor devices, more and more attention is being paid to diagnostic methods to determine the condition of working semiconductor components. On the basis of the results of experimental research, a correlation can be observed between the transition between the on/off states of a single IGBT transistor in operation and the acoustic signal emitted by it. Acquisition of acoustic emission signals was obtained using a specialized sensor from Vallen. To record the received signal, a high resolution digital oscilloscope was used, which exported the recorded signal to a file, which enabled further digital processing of the acquired signals. The aim of the study was to determine the usefulness of acoustic emission detection methods to determine the possibility of damage to an element based on the recorded acoustic signal.

Keywords: IGBT Modules, IGBT Transistor, Acoustic Emission

INTRODUCTION

Modern electrical engineering is based to a large extent on power electronic devices. Each power electronic device consists of executive subassemblies of high power. These are various types of semiconductor systems, e.g.: thyristors, MOSFET, bipolar, IGBT (Insulated Gate Bipolar Transistor) power transistors and monolithic systems consisting of several elements mentioned above.

In addition to land applications, for example: electric urban transport, or trolleybuses, trams or underground (Yeke et al., 2016), is widely used in marine technologies. Among the marine applications, electric drive units and engines of thruster motors in rudders and generating sets deserve particular attention (Kozak et al., 2016) and offshore applications such as wind farm generators (Wang et al., 2016) (Zhu et al., 2011) and others.

Like any electronics devices, power electronics components are susceptible to damages, especially during improper operation or when operating in harsh environments. In the recent years, significant growth and progress in power electronics have been observed. Components are getting smaller and switching frequency increases along with controlled currents, which results in a significant increase in current density per square millimeter of a given semiconductor device. The temperatures at which these semiconductor junctions operate are also increasing. Phenomena occurring in such elements are related to quantum physics, which prevents effective modelling of given phenomena in the internal structure of the semiconductor and, what is often omitted, the influence of semiconductor-to-place connections to the contact on the mounting plate and the influence of the housing used in a given element.

Another important element is the heat sink that dissipates significant amounts of heat created across junction in the conducting state. The whole system: semiconductor structure, connections, housing and heat sink can be considered as an unit so the best solution is to monitor of temperature all of these elements. One of the ways is observation the acoustic emission of a given system. The changes of each element can be detected by changing the acoustic wave recorded on a given system. Analysing the received signal, one could determine whether the system is working properly or showing signs of damage, for example: poorly tightened heat sink, damage in the semiconductor structure or damage to the connections. Each, this minor damage can lead to a hardly detectable failure, e.g.: in inverters we often have more than six transistors and one damage is difficult to detect.

In addition to the possibility of detecting damage by acoustic emission, research is carried out with other methods, e.g.: some research centres conduct tests of changes in incoming and incoming currents in a given transistor. One of the ways is to monitor the currents of the transistor gate, a change in the shape of the current over time may mean a progressive degradation of the element (Zhou et al., 2013). Damaged components in certain types of inverters can be searched for by checking the so-called prohibited states of the inverter built, e.g. on IGBT bridges. When the motor is at standstill, use an appropriate algorithm to set the inverter in the prohibited state and determine the values of the flowing currents (Yeke et al., 2016).

The article presents the analysis of the acoustic emission of the transistor IGBT G4PC30F from National Semiconductor with the use of a sound emission sensor from Vallen VS600-Z1 (AE-Sensor Overview).

The research has been carried out since 2016 at the Institute of Electrical and Control Engineering of the Maritime University and are compared to the current state of knowledge on the subject in the world on an ongoing basis. This type of research is carried out by a team of Finnish scientists together with the ABB concern (Kärkkäinen, 2015), (Kärkkäinen et al., 2014). The descriptions of research carried out by this center and work (Kärkkäinen et al., 2014) do not provide full answers the questions that arise in the analysis of this problem. Due to the specificity of the conducted research for data acquisition and analysis of results, equipment and measurement methods adequate to the needs of this system were used.

The test results are to show that the obtained data can be used for further processing and detection of damage or signals indicating significant degradation of the semiconductor structure (imminent failure) of the IGBT transistor.

Figure 1 shows the internal structure of the IGBT transistor and explains the shape of the signal received over time. Analysing the structure of the transistor one can notice numerous capacities (for a transistor they are a disadvantage) that affect the signal at the exact moment of switching. These are capacities that cause the Miller effect. In addition to capacities, we also have lead inductances.

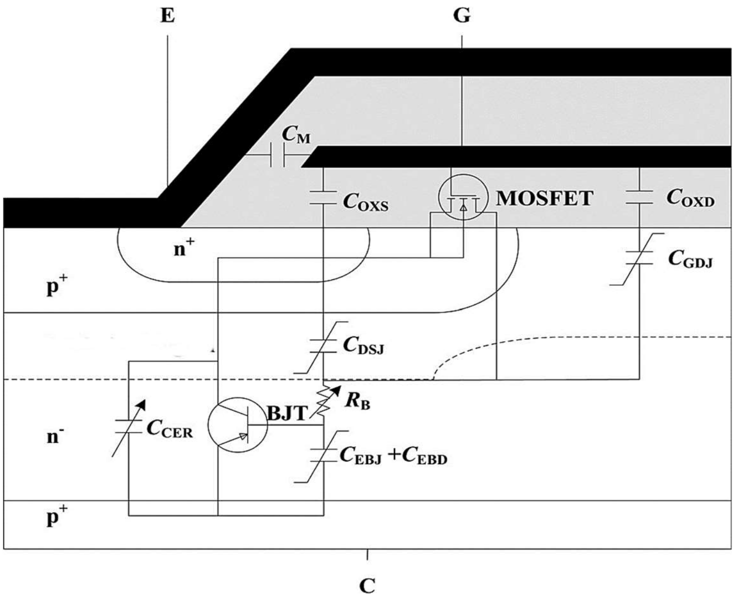

Fig. 1 Internal IGBT transistor structure

Source: (Zhou et al., 2013)

Thus, there is a chance to observe the typical charging and discharging of parasitic transistor capacities.

Based on formulas (1) from the article (Zhou et al., 2013) the dependence of capacity changes on the voltage values on individual elements of the internal structure can be determined:

$$C_{GC}=\begin{cases} C_{OXD} & V_{CE}<V_{GE}-V_{GE(th)} \\ \dfrac{C_{OXD}C_{GDJ}}{C_{OXD}+C_{GDJ}} & V_{CE} \quad V_{GE}-V_{GE(th)} \end{cases} \tag{1}$$

$$C_{GC}=\frac{A_{GD}\varepsilon_{Si}}{\sqrt{2\varepsilon_{Si}\left(V_{CE}-V_{GE(th)}\right)/q/N_B}} \tag{2}$$

where:

C_{OXD} and C_{GDJ} saturation capacity gate – drain gate

C_{GDJ} is dependent of voltage V_{CE} (collector emitter) where:

A_{GD} is the contact surface,

ε_{Si} is the silicon dielectric constant and the threshold voltage of the emitter gate $V_{GE(th)}$,,

N_B area of concentration of majority carriers.

C_{GC} is the collector-emitter electrical capacitance, consisting of the capacity at the contact point of the silicon oxide junction gate – drain

The above-mentioned formulas have the greatest influence on the shape of the obtained waveforms.

METHODOLOGY OF RESEARCH

The measurement was carried out with the use of Vallen acoustic transducer with the designation VS600-Z1, which is characterized by the transmission band of the acoustic spectrum in the range 550-730kHZ (600KHz) (Kärkkäinen, 2015) and recorded by a digital oscilloscope.

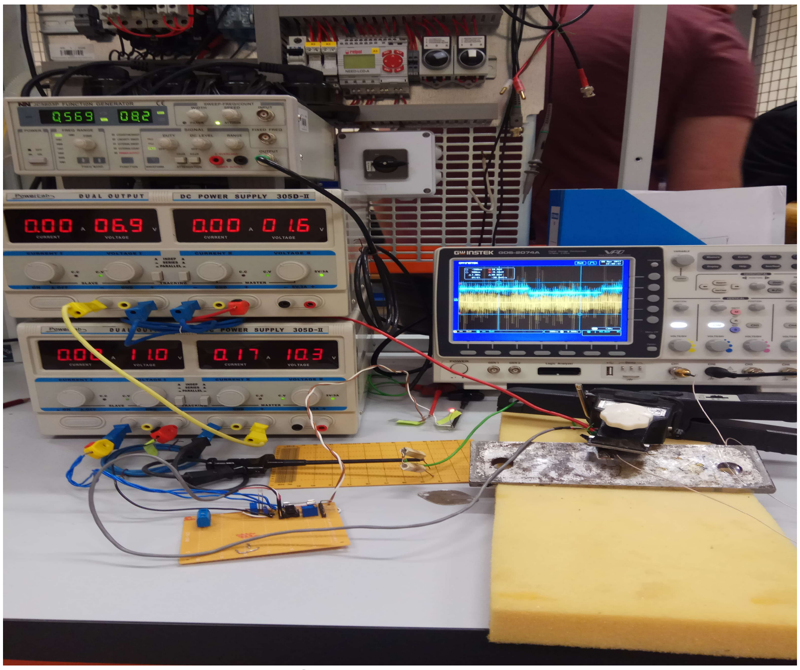

Fig. 2 IGBT transistor test stand

Source: Own study

One of the most important factor in the performing of the measurement was proper installation of an acoustic emission sensor, which had to be placed directly above the silicon structure and by special preparation of the element-sensor contact. The contact between the sensor and the component was improved by a special lubricant recommended by the sensor manufacturer, Vallen, and without it the results differed significantly from the expected (AE-sensor overview).

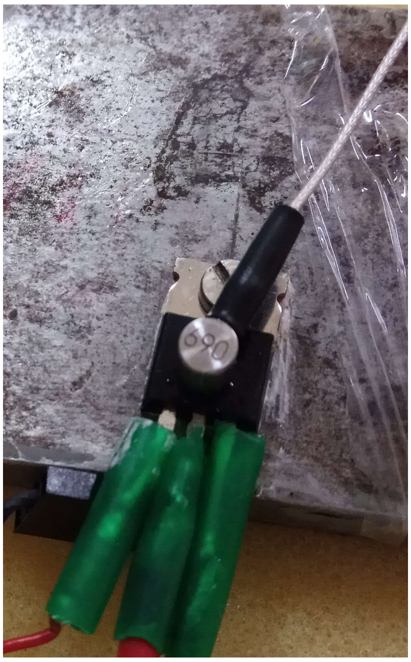

Fig. 3 Transistor with a sensor on a radiator

Source: Own study

The measurement was carried out at different values of switched current and voltage. With the increase in each parameter, the signal recorded on the oscilloscope was also proportionally larger. The schematic of the measurement system is shown in Figure 4.

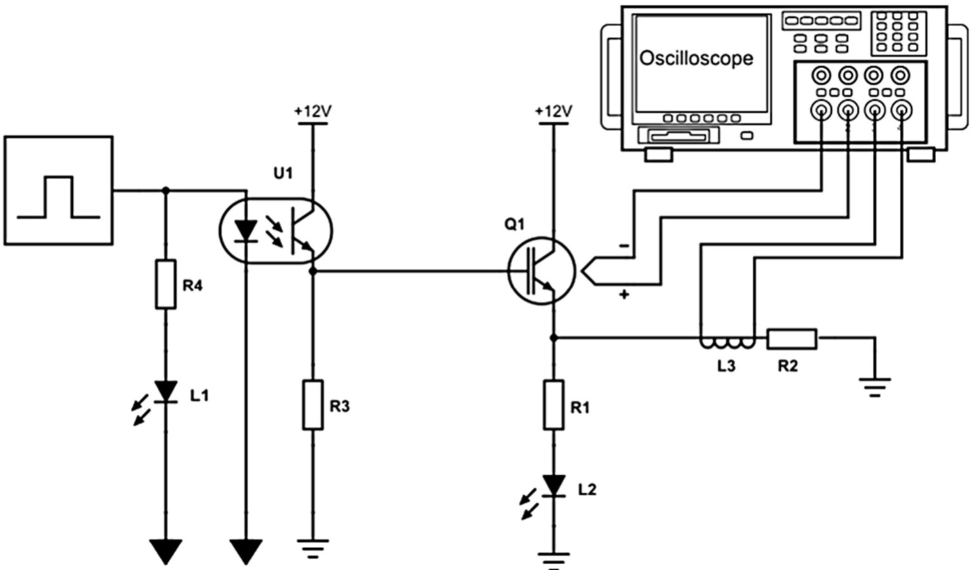

Fig. 4 Measuring system used in the experiment

Source: own study

The measured transistor was controlled (switched on and off) by a square wave signal generator. The generator signal is galvanically isolated from the measuring system by means of a 4N35 optocoupler, which results in the separation of the masses of the signal and measurement set. The L1 diode informs optically about the high or low status at the output of the generator. The optocoupler transistor controls the gate of the tested transistor. The transistor works as a key and can be in one of two stages: high or low. This means that at the output a small current flows in the state of clogging and the maximum current shows up in the state of saturation. As the load of the transistor a resistor R2 was used and a resistor circuit, L2 diode (small), which indicates switching state of the transistor. A clamping ammeter was placed on the wire connecting the emitter output and the R2 resistor, which gives the current shape to the oscilloscope input. At the second input channel of the oscilloscope, the signal from the acoustic emission sensor is directly transmitted. An example of a waveform acquired by an oscilloscope is shown in Figure 5.

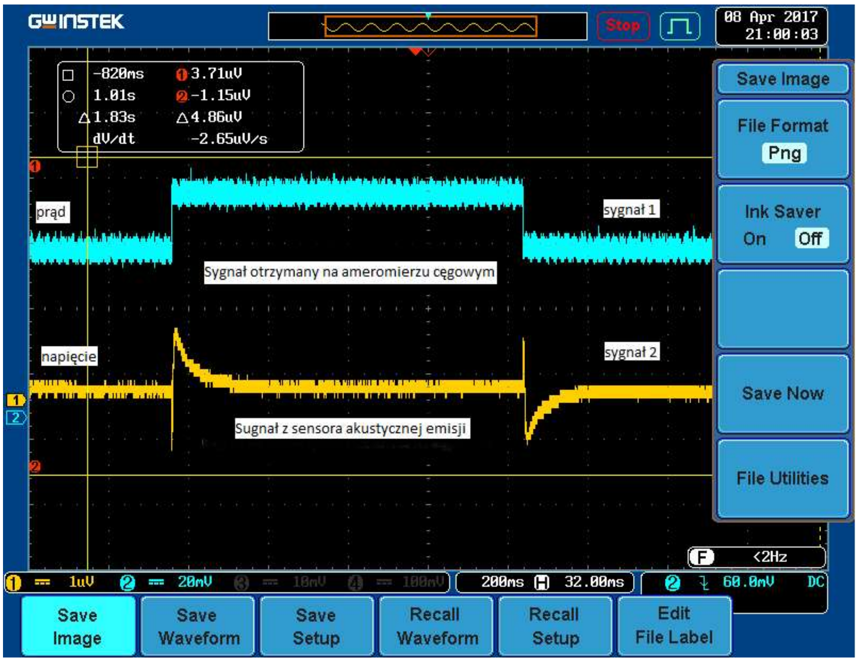

Fig. 5 The waveforms received on the oscilloscope

Source: (own study)

RESULTS

Figure 3 shows the currents measured by the clamp ammeter at the transistor output (Signal 1) and the voltage that appears at the output of the acoustic emission sensor placed on the transistor housing (Signal2).

The comparison of the output signal with the signal from the acoustic emission sensor shows a clear correlation of these signals. The change in output current corresponds to the generation of an acoustic impulse on the sensor. This fact proves that during the switching of the semiconductor there is an acoustic emission that can be recorded using the appropriate sensor and recording device, in this case the oscilloscope.

The signal received on the sensor resembles the typical charging and discharging of parasitic capacitance of a transistor in Figure 1. Due to low currents, the signal is noisy, but the capacitive response to a change in the transistor's operating state is clearly visible. The response is similar when switching from open to closed and vice versa.

This proves that it is possible to recognize the operating state of the transistor and its correct operation without invading the system. With appropriate tools it is possible to determine the size of parasitic capacitance, which allows to identify not only the damage, but also the "ageing" of the element, which would allow to determine in advance when a given component will be damaged.

This test, however, shows that the element is not damaged and acts as a switching element.

CONCLUSION

The aim of the study was to demonstrate the possibility of establishing the dependence of switching the IGBT transistor and the generated acoustic emission signals. Further processing of the signal and determination of the transistor state (good, damaged or imminent damage) will be the subject of further research.

The research has shown that the switched IGBT transistor is characterized by measurable acoustic emission signals and this signal corresponds to theoretical assumptions and can be further processed.

Measurements were carried out at relatively low voltages and switching currents to check their recording capability. The element was subject to low loads. Increasing the load should result in a better reading of the value from the sensor.

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