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Integrated IGBT short-circuit protection structure: Design and optimization

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Abstract

Generally, short-circuit protections for IGBT are provided by the assistance of analogical discrete devices which can sense and protect. In this paper, we present a new NPT IGBT structure with integrated short-circuit protection. This structure is composed of an anode voltage sensor, a delay MOS transistor, a MOS transistor allowing IGBT turn-off and a Zener diode. The structure optimization depends on the flexible technological process developed for power structures and based on the functional integration concept [1]. The protection structure optimization is presented and its functionality is verified by 2D simulations with ISE TCAD.

Keywords: Short-circuit protection; anode voltage sensor; IGBT; functional integration

1. Introduction

Power devices are usually used in a wide panel of applications. In many of them, they need to be protected from external fault conditions. That is why power system reliability and ruggedness improvement is one of the power electronics research concerns. Power semi-conductors devices must be efficient in normal and also in extreme operating modes. Extreme operating modes can be considered as unusual working conditions such as high d*I*/d*t* and high d*V*/d*t* gradients, high dissipated energy and so on…

Short-circuit is one of the most frequent reasons of system faults. When a power device works under short-circuit condition, it is submitted to high surge current with full anode–cathode voltage. After a short delay time (about 40 μs), if short-circuit mode remains, the power device may be driven out of its Safe Operating Area (SOA) and may be destroyed. Delay time is usually implemented in power device protection in order to avoid undesirable power device turn-off due to transient state conditions [2]. That is why in Power Integrated Modules, analog circuits protection against over current, over voltage, and over temperature conditions are usually implemented in hybrid way with the power device. The natural evolution is thus to integrate monolithically the protection circuits into the IGBT [3–5] in order to increase power system reliability and to reduce the size and the cost of the entire power system. Short-circuits which occur on the load are one of the main defects which can lead to IGBT destruction and, occasionally, to power system destruction [6–8].

There exists two types of short-circuits: the first one is already established when the IGBT is turned on (type I), the second one occurs when the IGBT is already in on-state (type II). When a short-circuit occurs, the current supplied by the IGBT increases abnormally with full anode–cathode voltage. In this paper, we present a protection against short-circuit which is integrated with the IGBT structure and based on the simultaneous detection of an anode voltage increase and the gate driving voltage state.

2. Anode voltage sensor

Unlike the anode voltage, the gate driving voltage can be easily detected. Actually, the anode voltage is very high (few hundreds to few thousands volts, depending on the power device voltage range) and is located on the backside of the vertical power structure. The anode voltage sensor we propose [9,5] allows to overcome these two problems.

2.1. Operation and topology

Fig. 1 shows a schematic vertical cross-section of the anode voltage sensor. It is based on two P+ wells connected to the reference voltage and a Vsensor contact located between them.

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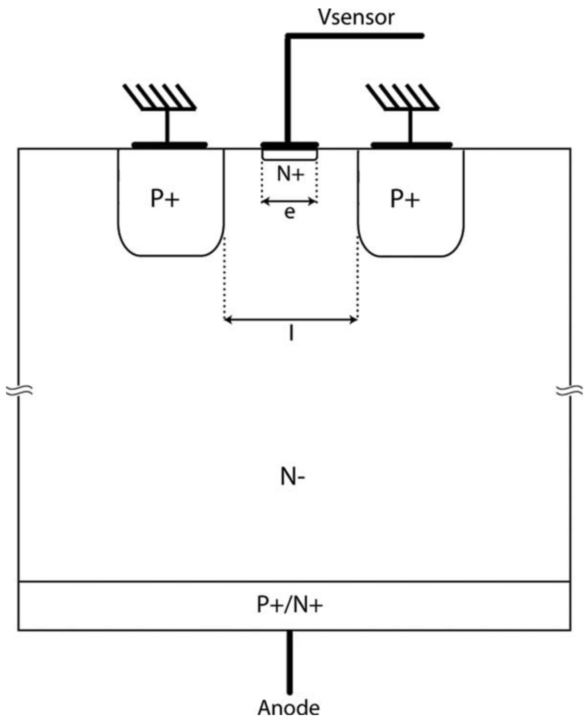

Fig. 1. Schematic vertical cross-section of the Anode voltage sensor.

When the backside anode voltage increases, the two frontside P+N junctions become reverse biased leading to self-shielding phenomenon. The Vsensor voltage thus increases simultaneously with the anode voltage.

These characteristics are used to detect the anode–cathode voltage increase when a short-circuit occurs. 2D and 3D static simulations of the anode voltage sensor have been performed using ISE TCAD. Test devices of the anode voltage sensor have been realized using an IGBT-like technological process. We have compared these first experimental results with simulations for two different values of the distance between P+ wells (Fig. 2).

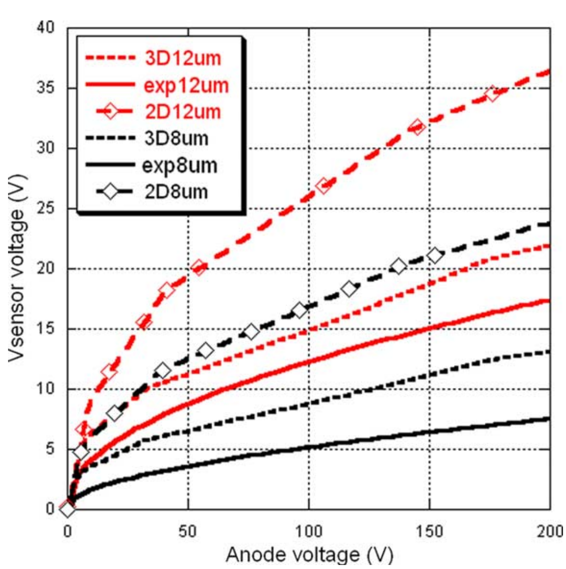

Fig. 2. Comparison between 2D and 3D simulations and experimental results.

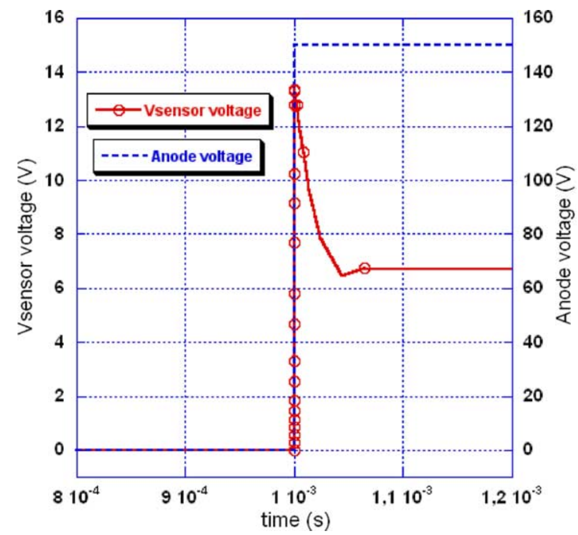

Fig. 3. Dynamic behaviour of the anode voltage sensor on 10 kΩ resistive load.

The difference observed between 2D and 3D simulations and experimental results could be explained by taking into account the surface topology of the test devices: P+ well on the top is all around the ohmic N+ Vsensor diffusion. This topology clearly increases the self-shielding phenomenon. The Vsensor potential is then quite lower in 2D simulation, which only takes into account two parallel P+ bands. The static behaviour of the anode voltage sensor indicates that the Vsensor voltage increases when the anode voltage increases but in a lower voltage range. Therefore, Vsensor provides an image of the anode voltage in a voltage range compatible with mostof MOS-based control circuits.

2.2. Dynamic behaviour

The anode voltage sensor is intended for MOS-based control circuits. Its dynamic behaviour has been thus studied on a 10 kΩ resistive load (modeling an off-state MOS channel

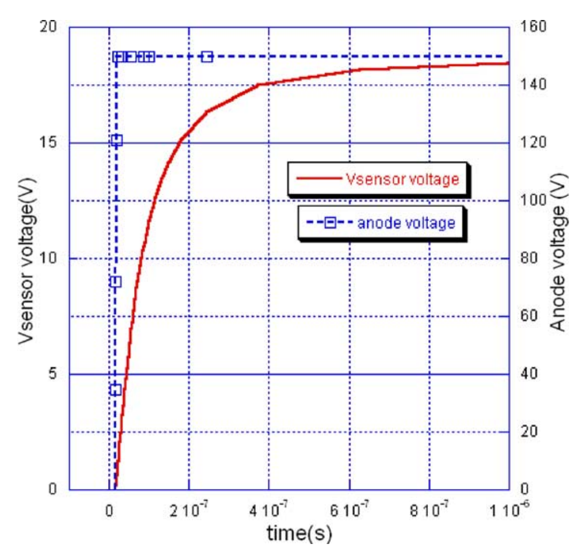

Fig. 4. Dynamic behaviour of the anode voltage sensor on 0.5pF capacitive load.