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Abstract

Magnetic Field Sensors for Non-Invasive Current Monitoring in Wire-Bond-Less Power Modules †

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Abstract: A non-invasive implementation of a planar magnetoresistive sensor on top of copper interconnected power modules is proposed. This solution allows for the real-time monitoring of the electrical current flowing across the power modules. Anisotropic magnetoresistive (AMR) sensors made of Permalloy were designed through finite-difference and finite-element simulations in the so-called barber-pole configuration and microfabricated via patterning by laser lithography and thin film deposition by electron-beam evaporation. Finally, the sensor performance was tested by measuring the magnetic field generated by the electrical current in a specific range of interest.

Keywords: magnetoresistive sensors; power packaging; current sensors

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1. Introduction

Current sensing in multi-chip semiconductor power modules (PMs) is typically performed relatively far away from the power semiconductor devices at the module terminals, i.e., externally. Thus, conventional current and magnetic field sensing solutions in the field of power electronic modules are limited in terms of temporal and spatial resolution. Two prominent technology pathways are available as state-of-the-art solutions: on-die sensing (the sensor is fabricated onto the power semiconductor dies) and external sensing (the sensor is utilized as a non-integrated solution).

The technology proposed in this work lies in the middle of these extremes, providing non-invasive, high-bandwidth information extraction without the usage of a precious semiconductor die area to implement the sensing concept. In the PM, the insulated-gate bipolar transistor (IGBT) and diode are connected via "sinterconnect" technologies where copper sinter paste is exploited as a fully printed interconnect [1]. The key feature of the proposed approach is the use of planar magnetic sensors based on the AMR effect on top of the planar interconnected PMs to monitor the electrical current flowing through the power semiconductor devices. Thanks to their micrometric size and planar shape, the solution offers the possibility to fully integrate the sensor manufacture within the whole PM fabrication procedure.

2. System and Methods

The system was composed of an AMR sensor and a PM, as shown in Figure 1a. The bottom part was the direct bonded copper (DBC) substrate, consisting of a ceramic electrical insulator material placed between two Cu layers, on top of which the diode and IGBT were fabricated (blue parts) and galvanically separated by an insulating material (green parts). The IGBT and diode were connected only from the top by means of the Cu paste layer where, due to its low resistivity, the majority of the current flowed [1]. Finally, on top of the Cu sinter paste system, an insulating layer was placed to electrically separate the magnetic sensor (red part) from the Cu paste.

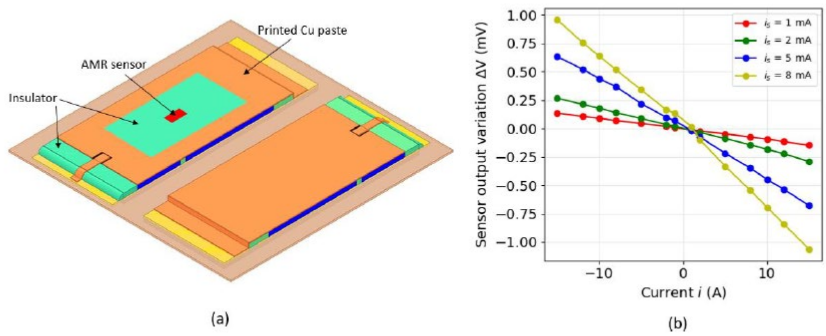

Figure 1. (**a**) Top view of the PM sub-assembly together with the planar interconnects and magnetic field sensor. (**b**) ΔV measured for different values of *i* and i_s.

The AMR sensor was designed via the finite-difference micromagnetic solver $MuMax^3$ and finite-element environment Ansys Maxwell with the aim of optimizing its sensitivity to the specific range of magnetic fields generated by the current flow intensities to be monitored. Magnetic fields were computed analytically according to the Biot–Savart law, as in [2]. The AMR sensor was designed using the barber-pole scheme to linearize its response [3]. AMR sensor samples were microfabricated via two consecutive lift-off processes, each consisting of patterning via maskless laser lithography followed by a thin film deposition step via electron-beam evaporation. In the first lift-off, Permalloy ($Ni_{80}Fe_{20}$) stripes matching the design requirements were obtained, whereas, in the second one, Ti(5 nm)/Au(50 nm) contacts were deposited to fabricate both the barber-pole shunts and the AMR sensor electrodes. For the preliminary tests, a characterization set-up was assembled where the AMR sensors (glued on a PCB) were placed onto a Cu bar and used to measure the electrical current flowing across it. A Keithley 2450 source meter was employed to supply the AMR sensors and read out their voltage response.

3. Results and Discussion

Analytical calculations show that when a DC electric current (i) of amplitude in the range of a few A flowed into the PM, a magnetic field (B) of a few Oe was generated at the sensor position.

Among the possible sensor geometries, the best sensitivity in the magnetic field range of interest was achieved with a sensor with a width w = 5 µm, length L = 100 µm and thickness t = 15 nm, where the Au stripes are 2 µm wide and separated by 2 µm. The first experimental tests were performed by measuring the voltage variation (ΔV) at the sensor terminals for different amplitudes of the current into the sensor (i_s) and in the Cu bar (from $i = -15$ A to i = 15 A), as shown in Figure 1b.

Concluding, in this work, a new approach based on the presence of a planar Cu interconnect was presented for monitoring the current flowing inside a PM. The results show that current intensity can be sensed with an AMR sensor placed on top of a PM. Future work will be devoted to measuring the current directly on the PM, including the design of a temperature-independent sensor and the study of an energy-harvesting solution to power the sensor.

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