IGBT chip current imaging system by scanning local magnetic field

著者	Shiratsuchi H., Matsushita K., Omura I.
journal or publication title	Microelectronics reliability
volume	53
number	9-11
page range	1409-1412
year	2013-10-12
URL	http://hdl.handle.net/10228/5788

doi: 10.1016/j.microrel.2013.07.092

IGBT chip current imaging system by scanning local magnetic field

H. Shiratsuchi *, K. Matsushita and I. Omura

Kyushu Institute of Technology, 1-1 Sensui-cho, Tobata-ku, Kitakyushu 804-8550, JAPAN

Abstract

An IGBT / power diode current distribution imaging system was demonstrated. This system can capture current redistribution or oscillation inside or among chips on a DBC-level sub-module. It can perform failure analysis of power semiconductors by detecting problems such as nonuniform current distribution between bonding wires. The system scans the chip's shape using a laser sensor and then records the local magnetic field near the bonding wire using a 4-axis robot coil sensor. The coil sensor has two pair of Cu patterned spiral coils symmetrically arranged on both sides of a 60-μm-thick polyimide film. The system enables the analysis of destructive current concentrations of the entire chip, among chips or a part of the chip under high current or high voltage switching conditions, without making any changes or disassembling the chip connections.

Corresponding authors:
ab. m349517h@tobata.isc.kyutech.ac.jp and omura@ele.kyutech.ac.jp
Tel: +81 (93) 884 3268; Fax: +81 (93) 884 3268

* Corresponding authors: m349517h@tobata.isc.kyutech.ac.jp and omura@ele.kyutech.ac.jp
Tel: +81 (93) 884 3268; Fax: +81 (93) 884 3268

IGBT chip current imaging system by scanning local magnetic field

H. Shiratsuchi *, K. Matsushita and I. Omura

1. Introduction

IGBT and power diode destructive current redistribution in a chip or among chips on a DBC is a roadblock to the realization of high power density inverters. Nonuniform current redistribution takes place because of the parasitic inductance [1], deviation of chip characteristics or temperature imbalance among chips on the DBC[2,3]. Although the analysis of current redistribution phenomena among IGBT or power diode chips has been performed on numerical simulations [4,5], no measurement system with a sufficiently high resolution for current density has yet been demonstrated. Furthermore, conventional methods require changes or disassembly of electrical connections or wiring to the chip for the setup [3], which may affect the current flow and thus the measured signal can be different from original one.

The system proposed in this paper (Fig. 1) enables imaging the current distribution in IGBT chips by scanning the local magnetic field near bonding wires with a patterned coil on a polyimide film. A laser sensor is used to realize precise positioning of the coil sensor to approach to the bonding wires. The system is designed to allow fully automatic control of the robot, power circuits, and digitizer using the LabVIEW GUI.

The system is able to measure magnetic fields, without making any change to the chip wiring or disassembling the electrical connections, because the coil sensor is sufficiently tiny to insert into the space between the bonding wires. The system can measure the distribution of the magnetic field with precise positioning using a laser sensor and a 4-axis robot.

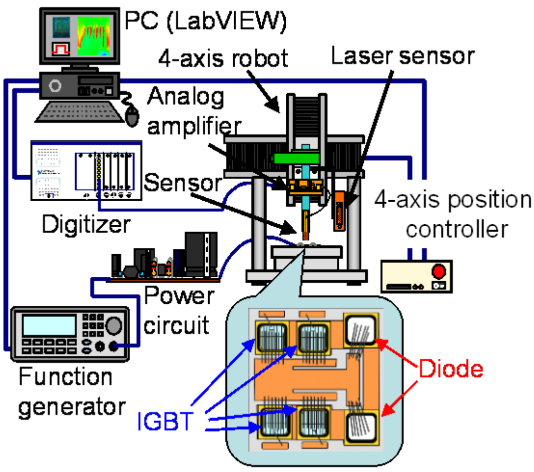

Fig. 1 Scanning system for IGBT chip current imaging

2. Current measurement system

2.1 Overview of coil sensor

The coil sensor used here has two pair of Cu patterned spiral coils symmetrically arranged on both sides of a 60-µm-thick polyimide film [6] (Fig. 2). The size of the spiral coils is 1.5 mm × 1.5 mm, and the line width of the Cu pattern is 70 µm. The coil pattern is extremely accurate because it is manufactured using the printed circuit board technology (also allowing mass production at a low price). This sensor is thinner and smaller than a Rogowski coil [7,8,9,10]; therefore, the coil sensor can be inserted between the bonding wires. Furthermore, the coil can be inserted without damaging the bonding wires because it is made of flexible polyimide films (Fig. 3). Some magnetic field sensors are based on SQUID or GMR sensors. SQUID sensors need mass cooling devices. GMR sensors have a limited measurement range because

* Corresponding authors: m349517h@tobata.isc.kyutech.ac.jp and omura@ele.kyutech.ac.jp
Tel: +81 (93) 884 3268; Fax: +81 (93) 884 3268

they detect differences in resistance between parallel and antiparallel magnetization. On the other hand, coil sensors are easy to use and do not have a limited range, as they have a simple structure. Magnetic field measurement is an efficient way to analyze current. The bandwidth of the coil sensor is 110 MHz; this bandwidth is greater than that of a Rogowski coil, which can also measure the magnetic field without making any changes or disassembling the chip connections.

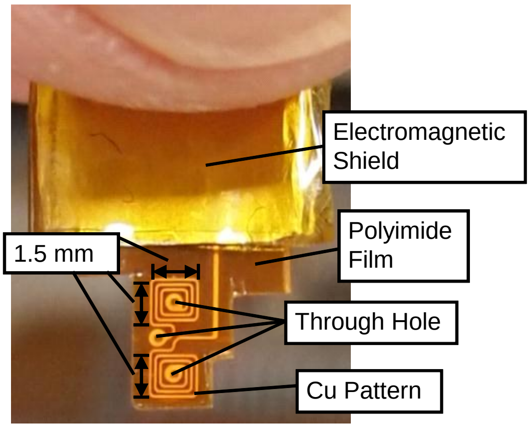

Fig. 2 Detailed picture of the coil sensor

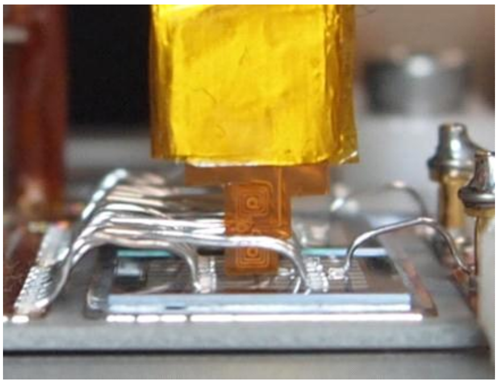

Fig. 3 Coil sensor inserted between bonding wires

2.2 Near-field coil sensor

According to Faraday's law, a potential difference (voltage) is generated by electromagnetic induction across a coil (in this case, the near field coil sensor) when it is exposed to a varying magnetic field. This coil sensor has two pair of spiral coils, which are connected each other. The output is the sum of the signals from the two pair of spiral coils. This configuration compensates for parallel magnetic fields because the two pair of spiral coils are arranged to have opposite polarities. As this acts analogously to how a dipole acts, the coil sensor only detects magnetic fields near the coil sensor. Fig. 4 shows the sensitivity of the coil sensor for a range of wire positions. This figure indicates an enhancement of the near magnetic field and a reduction in the far field noises due to the configuration of two pair of spiral coils. Fig. 5 and Fig. 6 were respectively obtained when the relative distance between the coil sensor and the position of a wire where current is flowing changes in the horizontal direction (x-axis) and the vertical direction (z-axis). The resolution (FWHM) of the Fig. 5 data is approximately 1.5 mm. In the same way, a 2 mm resolution is estimated in the vertical direction from Fig. 6. These spatial resolutions indicate the ability to isolate a specific wire from others.

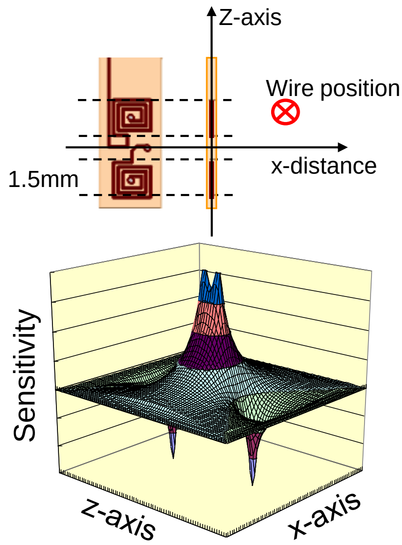

Fig. 4 Sensitivity of the coil sensor for different wire positions

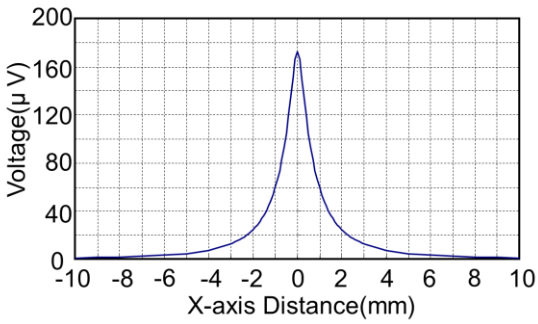

Fig. 5 Output voltage versus horizontal displacement

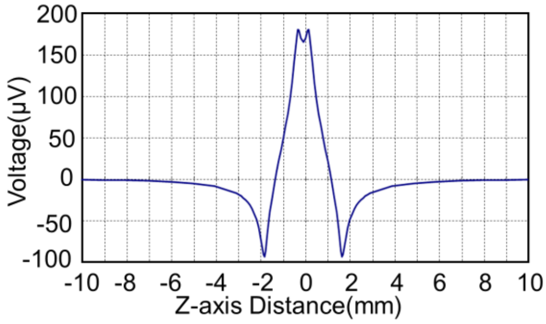

Fig. 6 Output voltage versus vertical displacement

2.3 Amplifier and digitizer

The output voltage signal from the sensor is integrated by a high-speed analog amplifier circuit and converted into a magnetic field strength. The analog circuit module is designed to be placed near the coil sensor; it is shielded to reduce noise. The amplifier bandwidth is 1 MHz; thus, the time resolution of this system is 1 μs. The 60 MS/s high-speed digitizer stores the amplifier output as digital data and sends it to the control PC with the LabVIEW GUI, as shown in Fig. 1.

2.4 Scanning robot with shape data detection

A database of the measured shape of the device under test is important to be able to determine a scan route for the coil sensor. Moreover, the relative distance between the coil sensor and the object is important to calculate the current at each bonding wire from the measurement magnetic field distribution as the future work. The shape of an object is measured by a laser sensor co-assembled with the coil sensor on 4-axis robot (Fig. 7). A 100-μm laser beam spot size and a 4-axis robot spatial resolution of 2 μm is sufficient to be able to detect the precise position of the bonding wires. Fig. 8 shows the shape of an IGBT chip, which clearly indicates the position of the plate and the bonding wires. The shape data includes the bonding wire positions, height, and chip area, which are stored on the control PC.

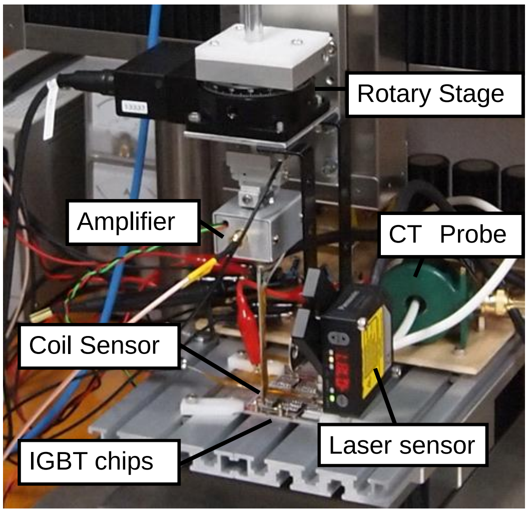

Fig. 7 Demonstration of scan system with *xyz*θ-robot, coil sensor, amplifier, laser sensor, and power circuit

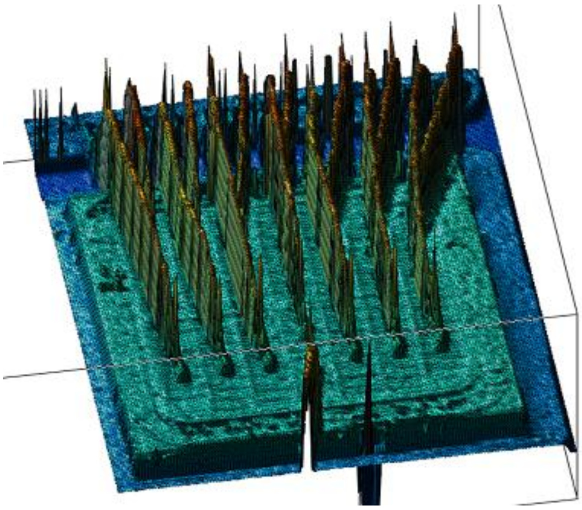

Fig. 8 Bonding wire position data detected by laser sensor (2 mm × 1.5 mm)

2.5 Measurement sequence program and graphics on LabVIEW

Fig. 9 shows the sequence of the measurements. The laser sensor is moved over the entire area of an IGBT chip to acquire its shape. Then, the coil sensor is moved to the measurement point determined from the shape data, and the digitizer outputs the magnetic field strengths measured by the coil sensor and amplified when the power circuit provides current to the IGBT chip. Then, the coil sensor is moved repeatedly to the next measurement point until all measuring points have been measured. The entire sequence of measurements is controlled from the LabVIEW GUI. 3D/2D animation of the transient changes in the magnetic field distribution is computed from the data stored on the PC.

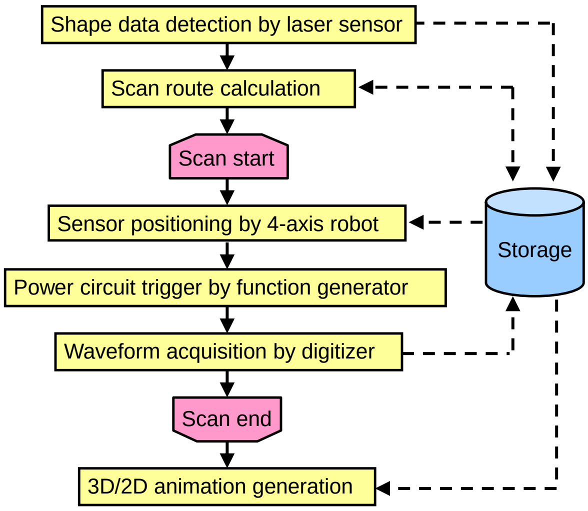

Fig. 9 The sequence of current measurement by LabVIEW

3. Measurement results

The proposed system successfully images the scanned magnetic field. The laser sensor has monitored the shape of the IGBT chip on a grid of resolution 100 μm × 100 μm before measuring and storing the data for use in the scan route calculation. On the basis of shape data, the coil sensor moved along the IGBT chips at a specified distance between the coil sensor and the chip. Then, the scanning coil moved along a grid with a resolution of 200 μm × 200 μm determined from the shape data of the IGBT chip to record a total of 7220 waveforms of sensor output voltage and store them in the HDD of the control PC. In this measurement, the influence on the magnetic fields by electromagnetic waves is negligible (200 μs at less than 10 MS/s). The magnetic field data was converted to two-dimensional images using these waveforms. Fig. 10 shows the image under 300 A switching for 4 chips DBC. This data underwent digital droop compensation [6]. The image only shows 1 chip of the 4 chips DBC. Fig. 10 shows the magnetic field distribution 1 mm above a chip at all measurement points.

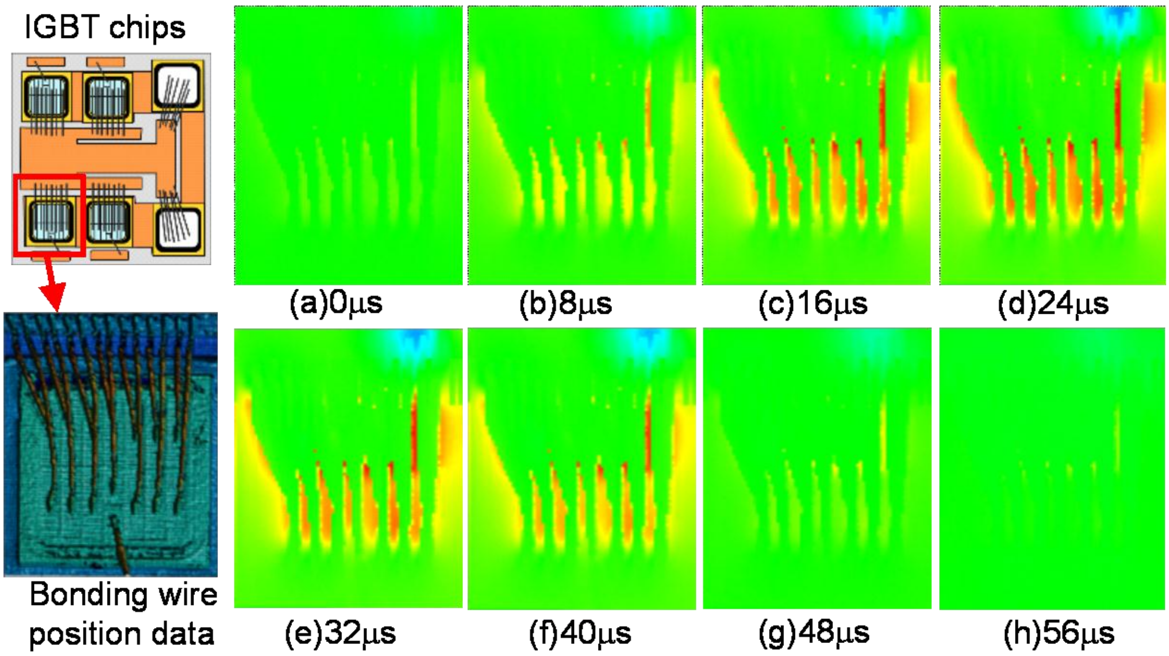

Fig. 10 Magnetic field distribution with IGBT bonding wire currents (digital droop compensated)

4. Conclusion

An automatic chip current imaging system based on the tiny coil sensor scanner using a 4-axis robot has been proposed. The system successfully captures magnetic field images which directly visualize the current redistribution inside the chip and among the chips on DBCs. Furthermore, these methods do not require any changes or disassembly of the chip connections. This system gives us useful information related to spatial and time domain current distribution. The system is a powerful tool for the analysis of destructive current redistribution phenomena in IGBTs and power diodes.

References

[1] K. Xing, F. C. Lee, and D. Boroyevich. Extraction of parasitics within wire-bond IGBT modules. Proc of APEC'98, vol. 1, pp. 497-503, 1998.
[2] M. Riccio et al. Analysis of large area trench-IGBT current distribution under UIS test with the aid of lock-in thermography. Proc. of 21th ESREF, pp. 1725-1730, 2010.
[3] Y. Iwahashi et al. Analysis of current distribution on IGBT under unclamped inductive. Proc. of 23th ESREF, 2012, pp. 2430-2433, 2012.
[4] T. Shoji, M. Ishiko, T. Fukami, T. Ueta, and K. Hamada. Investigations on current filamentation of IGBTs under unclamped inductive switching conditions. Proc. of ISPSD'05, pp. 227-230, 2005.
[5] S. Milady, D. Silber, F. Pfirsch, and F.-J. Niedernostheide. Simulation studies and modeling of short circuit current oscillations in IGBTs. Proc. of ISPSD'09, pp. 37-40, 2009.
[6] Y. Kasho, H. Hirai, M. Tsukuda, and I. Omura. Tiny-scale "stealth" current sensor to probe power semiconductor device failure. Proc. of 22th ESREF, pp. 1689-1692, 2011.
[7] W. F. Ray et al. Developments in Rogowski Current Transducers. EPE'97, Aug. 9, 1997, pp. 3.308-3.312, 1997.
[8] W. F. Ray and C. R. Hewson. High performance Rogowski current transducers. Conference Record of the 2000 IEEE, vol. 5, pp. 3083-3090, 2000.
[9] Y. Ikeda et al. Non-destructive current measurement for surface mounted power MOSFET on VRM board using magnetic field probing technique. Proc. of ISPSD '09, pp. 65-68, 2009.
[10] Power Electric Measurement, http://www.pemuk.com/products/cwt-current-probe.aspx