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# High-throughput DBC-assembled IGBT screening for power module

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## Abstract

High-throughput DBC-assembled IGBT screening equipment for a production line is under development in order to prevent early failure of power modules. The equipment has been planning to have automatic GO/NO GO judgment technology by high-throughput measurement of current signal distribution with non-contact sensor arrays with small coils over the bonding wires of IGBT chips. Basic technology and Prototypes of a sensor, an analog amplifier, digital compensation technology, a test head and power circuit have been almost completed. The authors will fabricate the sensor arrays and develop GO/NO GO judgement technology with the integration of a basic technology.

## 1 Introduction

High performance IGBT modules are widely applied to various fields, such as hybrid electric vehicles (HEVs), railway traffic and wind power generation, and are becoming a key component of a social infrastructure. Therefore, the reliability of the IGBT modules is becoming an important subject. Especially the prevention of the destruction by the imbalanced current in a chip or between parallel IGBT chips is crucial subject because imbalanced current can triggers destruction by partial high temperature or partial avalanche breakdown. Current balance in a chip or chips has been reported in research until now, and many results suggest high possibility of the imbalanced current [1-4].

Although a major cause of early failure by the imbalanced current comes from a mounting process that is wire bonding and soldering, because there is no method to measure current balance in a small space for a short time, only total current of chip and finished modules are measured in the present production line (see Figure 1). When using the present sensor for screening in a production line, there are two major problems. One is a complex measuring method of enclosing a wire, connecting a sensor between wires in series, or inserting a sensor between wires (see Figure 2) [5-10]. And another is a large sensor to bonding wire pitch and chips.

The authors have been developed high-throughput screening equipment in a production line with novel current sensing system for reliability improvement of power modules.

## 2 Configuration and requirements

The configuration of the high-throughput screening equipment with novel current sensing system is the followings (see Figure 3).

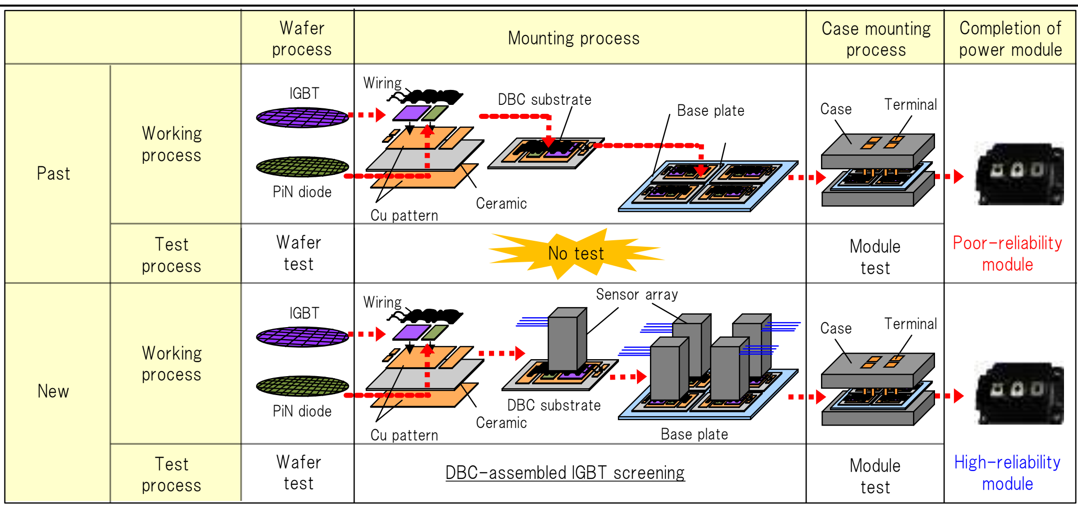


Figure 1 Target screening process of IGBT module with current sensor array in a power module production line

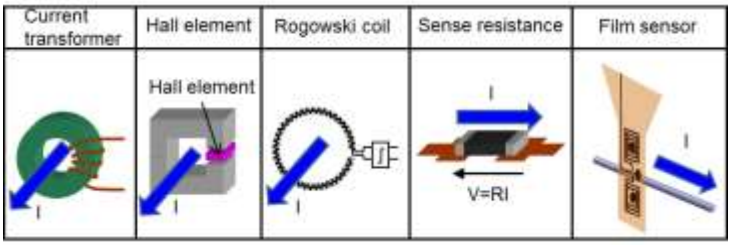


Figure 2 Measuring method of exiting sensors

1. Sensor with a small coil for high spatial resolution
2. Sensor array structure for high-throughput measurement
3. Analog compensation for low-frequency characteristic
4. Digital compensation for signal droop and the effect of nearby current
5. Test head with sensor mounts and contact pins on a copper pattern
6. Power circuit for high-voltage/high-current inductive load switching with security mechanism

For high spatial resolution, a sensor with a small coil is required because downsizing of the coil reduces the influence from nearby current [2]. On the other hand, the current signal intensity of the sensor decreases with the downsizing [2]. Therefore, the turn number of the coil has to be increased for maintaining the signal intensity. Hence, a narrow line and space (L/S) coil by advanced printed circuit board (PCB) technology or a semiconductor process technology is required for coil formation.

It is prohibited that the screening equipment limits throughput in the production line. The sensor array is expected to realize high-throughput screening since it acquires many current signals at once [3].

When the coils are downsized, its gain spectrum just shifts to a higher frequency region, whereas lower frequency gain is reduced. Therefore, lower frequency compensation is required by an analog amplifier.

It is predicted that the current signal after the amplifier contains two problems of signal droop and measurement error. The signal droop appears because sufficient low-frequency signal compensation is difficult by using only the analog amplifier and measurement error occurs under the influence of nearby current. On these problems, advanced mathematics processing by a digitizer has been developed.

A test head has sensor array mounts and contact pins for emitter/collector and gate. The sensor array mounts require adjustment system to the bonding wires and a high-density three-dimensional layout is necessary because several arrays have to be set in the test head. In addition, emitter/collector contact pins with low stray inductance is required for high di/dt screening to suppress surge voltage.

The power circuit needs high-density layout for incorporating high voltage/low voltage power supply, an inductor as load, a capacitor, a gate driver and IGBT as a security mechanism.

# 3 Basic technology and Features

## 3.1 Small coil for sensor

A small coil was formed by PCB and semiconductor process technology (see Appendix A). It was confirmed that both of the coils generate the signal expressed with the following equation.

$$V_{coil} \propto \frac{dI}{dt} \qquad (1)$$

where $V_{coil}$, I and t are induced voltage at the coil, current and time respectively. The authors will try further downsizing of a coil and decide final design by signal intensity and frequency characteristic.

## 3.2 Multi-Channel sensor array

A sensor array has been fabricated in order to acquire many current signals at once. A relative misalignment be-

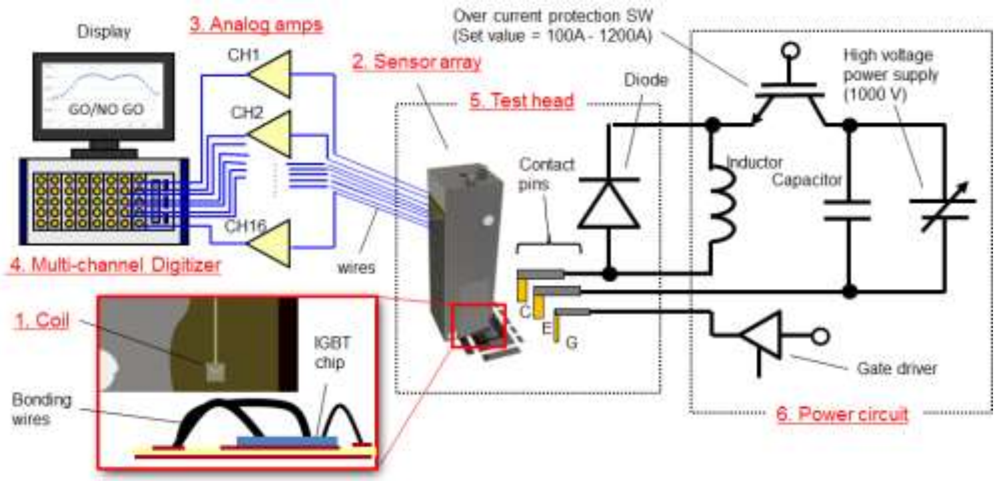


Figure 3 Configuration of high-throughput DBC-assembled IGBT screening equipment

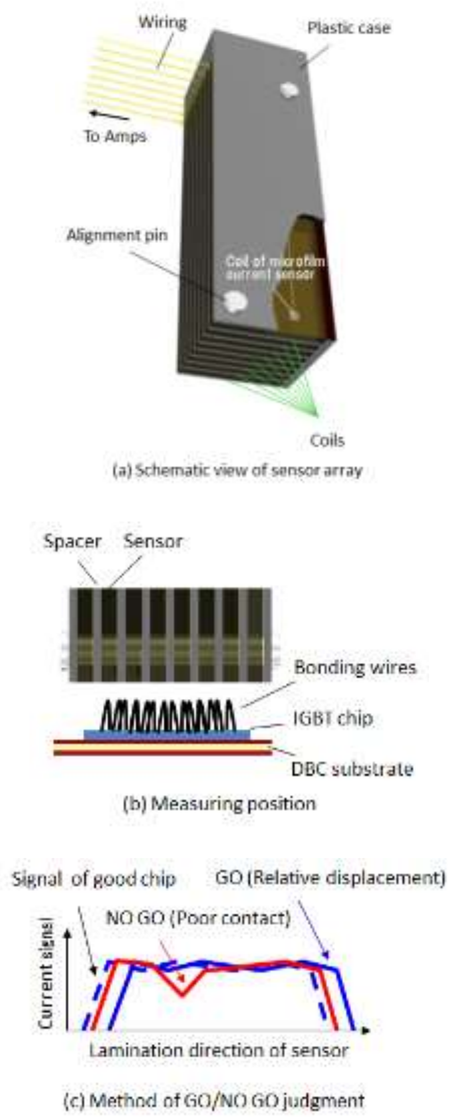


Figure 4 Schematic view of sensor array and GO/NO GO judgment

tween sensor is prevented by an alignment pin which penetrates all the sensors (see Figure 4). The failure in a mount process is judged by comparing with a normal current signal. For example, when there is a poor contact of bonding wire, a part of signal intensity should be decreased and it is judged as “NO GO”. Even if it does not agree with a normal signal, it can be judged as “GO” if it is the same signal considered to be a slight relative misalignment.

It was experimented about the possibility of signal acquisition over a bonding wire. Because the sensor array is under production, signals were acquired by scanning of a FPC board sensor along the lamination direction of sensors (see Figure 5). The current waveform signals were acquired by the short-circuit test with 100 A per chip. Basically, the current signal becomes large at the central part of chip since magnetic flux by wire current is over-lapped. However, because a gate pad exists in the central part, the chip has a high possibility that the current of the central part is smaller than both sides. Although the instantaneous

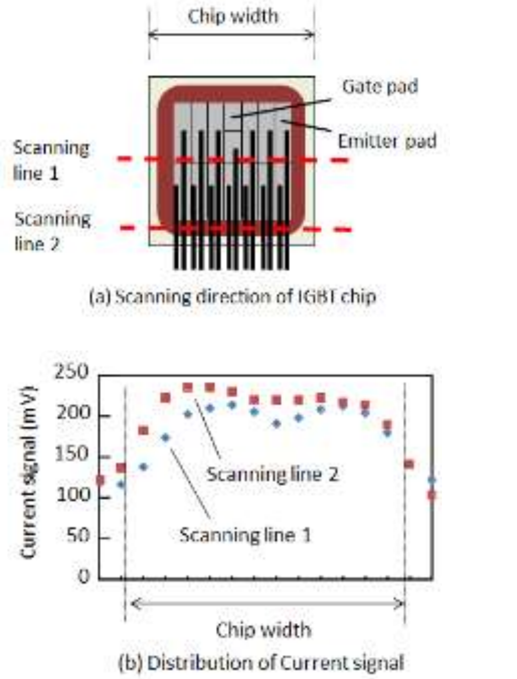


Figure 5 Experimental result of current signals over IGBT chips

values of waveforms were used for current distribution plot this time, an integration values can also be used. The validity of a current signal will be continuously confirmed by using several kinds of DBC-assembled IGBT samples from now.

## 3.3 Analog frequency compensation by amplifier

Analog amplifiers constructed by frequency compensation part and amplifier part were discussed by SPICE simulation to compensate low-frequency gain of small coils. The amplifier of the most desirable characteristic in four types was confirmed good characteristic of above 1 kHz in the experiment. However, in analog compensation, since low-frequency gain is not sufficient, the additional compensation by digital compensation is required.

## 3.4 Digital frequency compensation by Multi-Channel Digitizer

To solve the problem of droop, the authors will apply digital droop compensation by active digital data processing [6, 7]. The signal of the current distribution after analog amplifier includes the influence of offset and droop. The authors assume incomplete integration with CR time constant for the op-amp feedback circuit and digitally calculate compensation factor in the second member in right hand side of the following equation after offset correction.

$$I \propto V_{amp} + \frac{1}{C \cdot R} \int V_{amp} dt \qquad (2)$$

where $V_{amp}$, C and R are the output voltage of the op-amp, feedback capacitance and resistance respectively.

Spatial compensation is also considered if nearby current causes a problem. When these current triggers a problem, cancelling the influence is considered by the matrix calculation with a spatial correction coefficient.

### 3.5 High-density three-dimensional test head

A test head with the sample stage was placed in the central part of equipment (see Figure 6). The sensor arrays should be located over all of the chips on a DBC board. Therefore, the prototype of the test head can set up to six sensor arrays with contact pins by high-density three-dimensional design since it corresponds to the number of chips of the first sample. First, a sensor array and chip are roughly aligned each other by a DBC substrate holder in the stage. Next, perform fine adjustment of sensor arrays by a XYZ stage of the mounts. It is possible to make a fine adjustment of the sensor arrays within ±1.5 mm. On the electric circuit side, the influence of stray inductance is reduced to 29 nH by special structure of the emitter/collector contact pins, parallel plate wiring and the close layout of high side/low side DBC substrates.

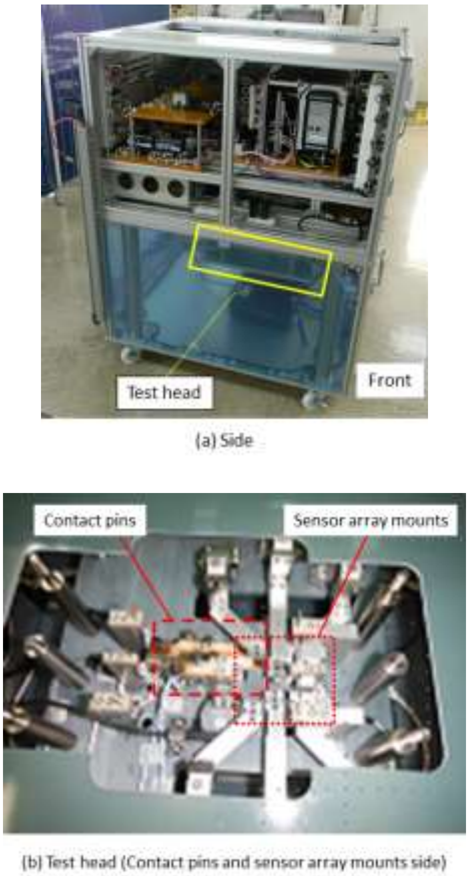


Figure 6 Prototype of screening equipment and its test head with stage

### 3.6 Power circuit with interchangeable test head

The prototype of screening equipment can apply all kinds of IGBT module by just changing a test head. The maximum DC voltage is 1000V, and the maximum current is 1200A. Inductance is changed to five steps in 50 to 500 μH. It also has security mechanism, such as an over-current protection, an electric discharge switch, and an emergency stop button.

## 4 Discussion for integration of basic technology

When measuring the current signal of a bonding wire, the influence of current of other parts can be considered. For example, the influence of the current which flows through nearby bonding wires, the emitter/collector contact pins, DBC substrates, and the inductor. After integrating basic technology, the removal of the inferences is required by direct removal of magnetic flux or indirect removal by digital processing. Moreover, reduction of the influence by a magnetic shield is also considered. If “GO” or “NO GO” judgment is possible, the method which directly uses only a magnetic signal without changing into current will also be considered flexibly.

## 5 Conclusion

High-throughput DBC-assembled IGBT screening equipment for a production line is now under development in order to prevent early failure of power modules. Meanwhile, basic technology and Prototypes of a sensor, an analog amplifier, digital compensation technology, a test head and a power circuit have been almost completed. The authors will fabricate the sensor array and develop GO/NO GO judgment technology with the integration of the basic technology. It will also become the technology of module design estimation for high-reliability towards the future.

## 6 Acknowledgements

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# 8 Appendix A

The square coil with a minimum side of 1 mm was formed with copper wiring by PCB technology on flexible printed circuit (FPC) board of thickness 0.12 mm and rigid board of thickness 0.6 mm (see Figure A1). The minimum coil on FPC and rigid board has 10 turns with 40 μm L/S and 6 turns with 50/70 μm L/S respectively. The signal of coils on FPC board is larger than the signal on rigid board because of the larger number of turns (see Figure A2).

The round coil and square coil with a diameter or a side of 1mm were tried to form a coil with more number of turns by semiconductor process technology on an oxidized 2 inch silicon wafer (see Figure A3). The coils is formed with aluminum wiring and have 22 turns with 10 μm L/S, 44 turns with 5 μm L/S and 110 turns with 2 μm L/S. The coils of 22 and 44 turns were formed successfully. However the coils of 110 turns were disappeared at wet etching. A current signal was confirmed in the same method as a sensor by PCB technology, that is, the coil generates the signal corresponding to the current value. The integrated values of the coil signal are almost the same as current for the reference (see Figure A4).

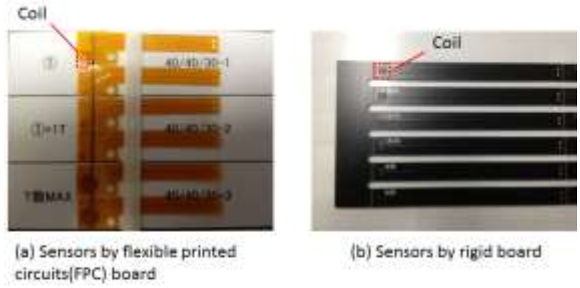


Figure A1 Sensors by advanced printed circuit board technology

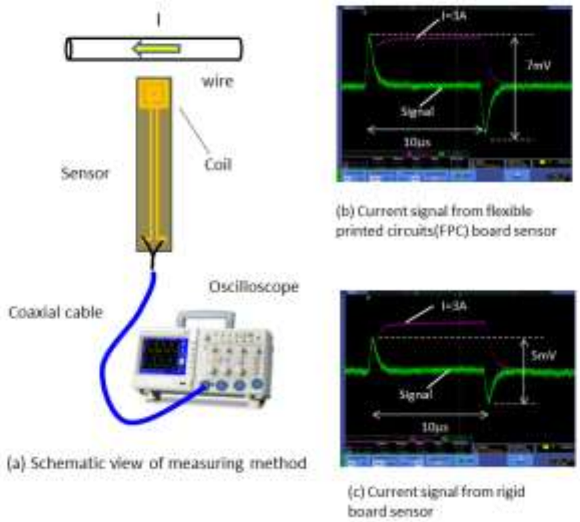


Figure A2 Experimental result of current signal by printed circuit board technology coil

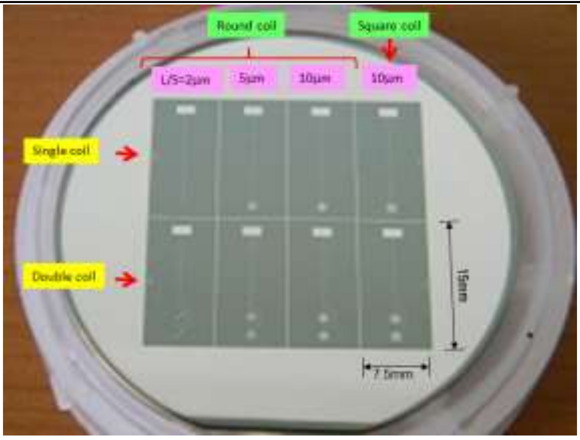


Figure A3 Sensor by semiconductor process technology on 2 inch silicon wafer

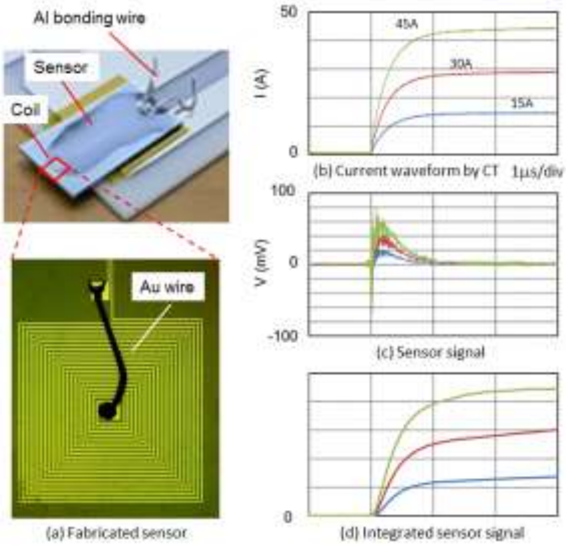


Figure A4 Experimental result of current signal by semiconductor process technology coil (L/S=10μm)