Bonding Wire Current Measurementwith Tiny Film Current Sensors

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Bonding Wire Current Measurement with Tiny Film Current Sensors

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***Abstract*—Bonding wire current measurement technique has been highly desired to analyze failure phenomena, such as short circuit and avalanche destruction of IGBT and power diode. This paper challenged to measure bonding wire current distribution in an IGBT module with the multiple tiny film current sensors and the digital calculation technique. The authors successfully measured bonding wire current under a single shot measurement.**

Keywords-component; bonding wire current mesurement; film current sensor with tiny-scale coils; high speed analog amplifiers; digital calculation technique

I. INTRODUCTION

The purpose of this work is to develop new technique to measure electric currents of each bonding wire on an IGBT or a diode chip simultaneously. The authors proposed the new approach with film current sensor (see Fig. 1), which consists of significantly tiny-scale coils printed on a polyimide film, a high speed analog amplifier and a digitizer with numerical calculation function ([5]). The new technique will establish simple yet powerful tools to analyze current re-distribution phenomena during the destructive failure.

The sensor utilized 60 μm thick polyimide film base printed coil with a small size of 1.5 mm squares which enables to insert into the gap between bonding wires. The sensor is able to measure single bonding wire current and to probe the "real" operation inside the chip without any change or disassembling the chip connection for measurement.

Table 1 summarizes the advantage of the film current sensor over conventional current measurement methods (Current Transformer and Rogowski coil). Film current sensor is extremely small and low cost yet high performance compared to prior works ([1-4]). The sensor has the equivalent performance compared to CT as shown in Fig. 2. Frequency bandwidth of the measurement system with film current sensor is sufficiently wide up to 110MHz thanks to flat coil without magnetic core with high speed amplifier and down to below kHz range thanks to the digital calculation technique.

In this paper, the authors challenged to measure bonding wire current distribution on power device chips with the 8 channel tiny-scale film current sensors.

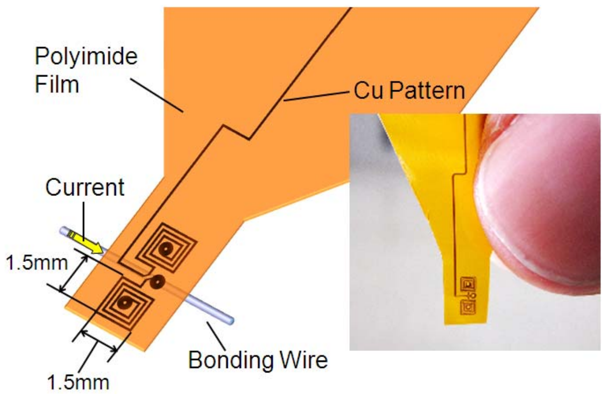
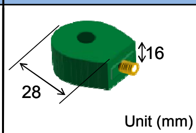
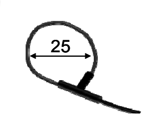
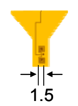


Figure1 Comparison of the performance of the proposed current sensor and conventional current measurement method (CT and Rogowski coil).

Table 1 Comparison of the performance of the proposed current sensor and conventional current measurement method (CT and Rogowski coil).

	Current Transformer	Rogowski Coil	Film Current Sensor
Size			
	Large	Small	Very Small and Thin
Accuracy	Very Good	Good	Good
Bandwidth	200MHz	20MHz	110MHz
Style	Destructive	Non-Destructive	Non-Destructive
High Current Limitation	Magnetic Saturation	Non Saturation	Non Saturation

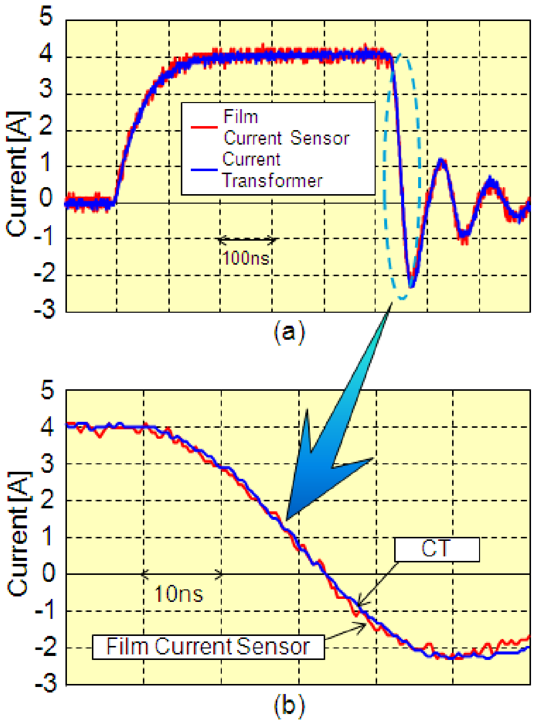


Figure 2 Measured single wire current with film current sensor and CT (a) and the enlarged view of falling edge of current waveforms (b).

II. BONDING WIRE CURRENT MEASUREMENT

Bonding wire current measurement technique consists of the 8 channel film current sensors, high speed analog amplifiers and a digitizer with active digital data processing.

A. Film Current Sensor

Film current sensor has two pair of symmetrically placed flat spiral coils on both side of a polyimide film and they are connected in series via through holes (Fig. 1). The poles of coils are inverted so that the probe senses only close magnetic-field produced by the electric current passing between the coils. In other words, the sensor is hardly affected by external magnetic field with the reversed poles. The printed circuit technology improves the accuracy of the coil pattern and cost performance.

To measure each single bonding wire current, the 8 channel current sensors are slipped into each gap between neighboring bonding wires on IGBT module chip as shown in Fig. 3. An array of the 8 sheets of the current sensors is hold by an arm fixed on an X-Y-Z stage and set onto IGBT module.

The influence of nearby wires is the important issue for the bonding wire current measurement technique. To obtain the influence of neighboring bonding wire current, we measured the relationship between the sensor output signal and the distance from measured wire to the sensor. The results when the sensor is moved horizontally or vertically from the wire are shown in Fig. 4. The sensor is influenced by nearby wires within 5 mm. The influence is reduced by downsizing the sensor coils.

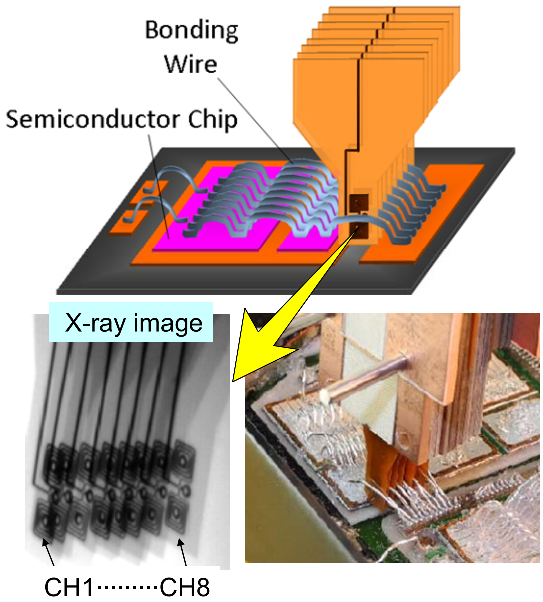


Figure 3 Measurement setup for bonding wire current distribution measurement in IGBT module.

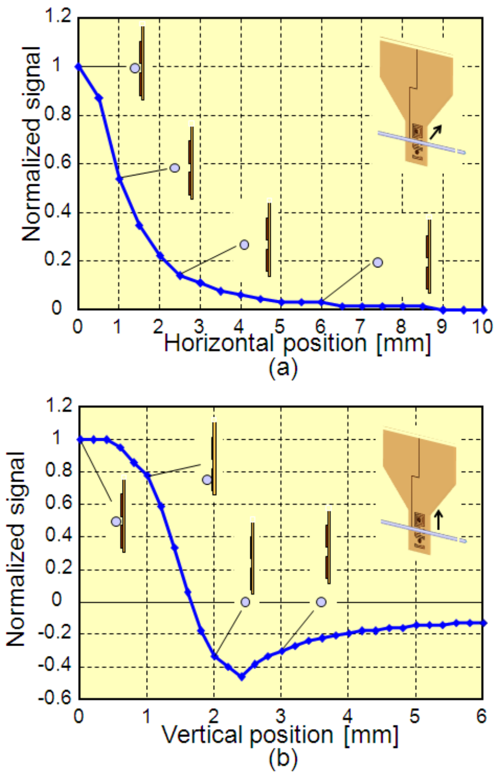


Figure 4 Normalized sensor signal as a function of horizontal (a) or vertical (b) position to wire.

B. Analog Part

Analog part design is one of the key issues since the tiny-scale coil output signal is weaker than conventional Rogowski coil. The frequency characteristics of the analog part are shown in Fig.5. When the magnetic-field coil is downsized, the gain spectrum just shifts higher frequency region with the analog part optimization. In other words, the system has better characteristics in high frequency region with the optimum analog part and the gain is reduced in lower frequency region, which appears as droop in measured waveforms.

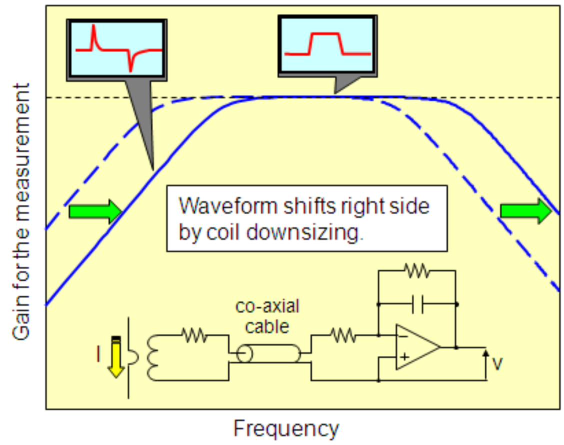


Figure 5 The frequency characteristics of bonding wire current measurement technique.

C. *Digital Droop Compensation Technique*

To solve the droop problem described above, the measurement system has digital droop compensation technique (see Fig. 6). This technique improves the frequency characteristics in lower frequency region and widens the frequency bandwidth of the system down to below kHz range.

We 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:

$$I(t) \propto V(t) + \frac{1}{CR}\int V(t)dt, \quad (1)$$

where V(t), I(t), C and R are the output voltage of the op-amp, electric current to be measured, the feedback capacitance and resistance.

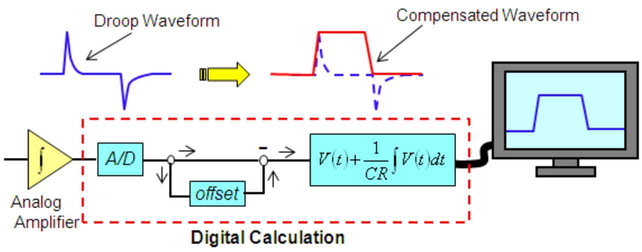


Figure 6 Digital droop compensation technique with the active digital data processing.

III. EXPERIMENT AND RESULT

We demonstrate the bonding wire current measurement technique for an IGBT module. The experimental setup is shown in Fig.7. An array of 8 sheets of current sensors is set into bonding wires on a chip. The IGBT module is connected to a high voltage circuit with a current transformer (CT) to measure the IGBT terminal current. The measurement is performed under the condition of single shot pulse.

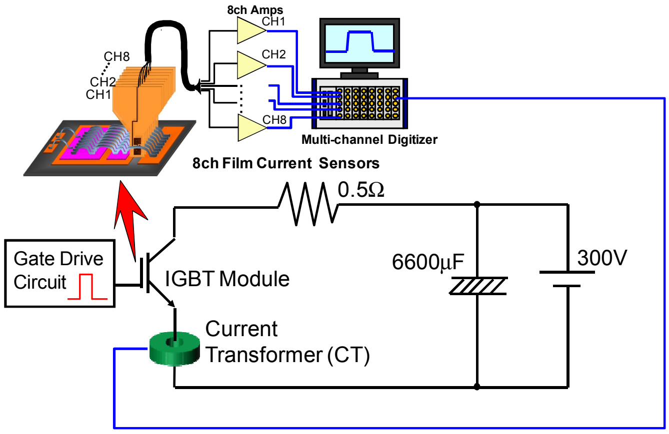


Figure 7 Power circuit condition for bonding wire current distribution measurement.

A single shot measurement successfully obtained the 8 channel signals corresponding to the magnetic-field around bonding wire as shown in Fig. 8 (a). The corresponding localized magnetic field strength measured by the sensor at the end of the pulse current is shown in Fig. 8 (b) as a function of sensor position. Theoretically obtained field strength for uniform wire current is also plotted on the same figure as a reference. Comparing the measured result and the reference, it is found that the current is concentrated in center portion of the paralleled bonding wires.

Figure 8 (c) shows the local magnetic field distribution after current turn-off at the Time 2. It is found that electric current in the bonding wires remains for about 7µs and it flows in forward direction through the center and in reverse direction in the edge, which supports the existence of current redistribution in the bonding wire.

We also compared the CT waveform and sum of signals from CH1 to CH8 as shown in Fig. 9 (a). Figure 9 (b) is the enlarged view of falling edge of current waveforms. The CT waveform and sum of signals from CH1 to CH8 coincides very well each other showing the validity of the current measurement system.

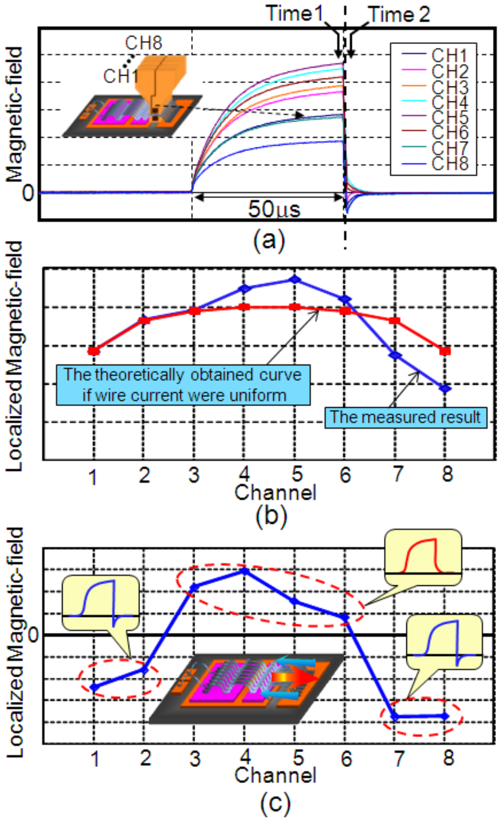


Figure 8 Measured bonding wire magnetic-field waveforms (CH1 to CH8) (a) and the localized magnetic-field distribution at Time1 (b) and Time2 (c).

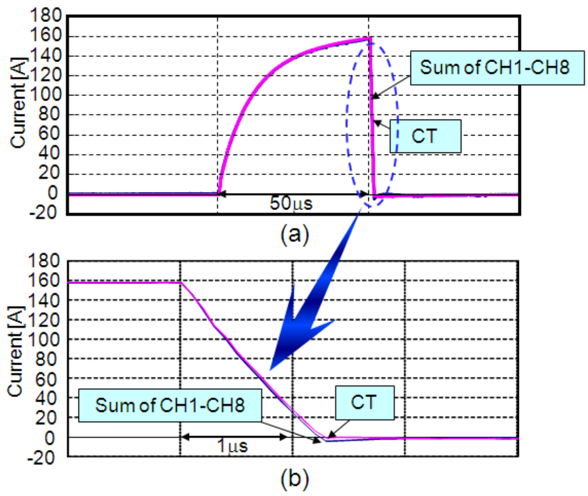


Figure 9 The comparison of sum of signals from CH1 to CH8 and CT (a) and the enlarged view of falling edge of current waveforms (b).

IV. CONCLUSION

Bonding wire current measurement technique has been highly desired to analyze failure phenomena, such as short circuit and avalanche destruction of IGBT and power diode. This paper described measurement technique for bonding wire current distribution in an IGBT module with the 8 channel tiny-scale film current sensors and the digital data calculation technique.

The authors measured bonding wire current distribution under a single shot measurement. A single shot measurement successfully obtained the 8 channel signals corresponding to bonding wire current. It is found that bonding wire current are not uniform and the current is concentrated in the center of paralleled bonding wires. Bonding wire current measurement technique will be simple yet powerful tools to analyze current re-distribution phenomena during the destructive failure.

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