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Analysis of sound and temperature fields in ultrasonic beam induced resistance change (SOBIRCH) method aiming to failure analysis for semiconductor devices

半導体故障解析を目的とした超音波刺激抵抗変動検出法における音場及び温度場解析

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1. Introduction

As a fault localization technique for semiconductor devices, the optical beam induced resistance change (OBIRCH)[1)] method is often used. The OBIRCH method observes an electric resistance change of wires in semiconductor devices which was induced by an optical beam[2)]. In general, semiconductor devices are encapsulated with mold resins, and the OBIRCH method commoly requires decapsulating the mold resin becase the mold resins significantly attenuate the optical beam. However, the decapsulation may damage the chip surface and the bonding wire. In order to avoid this damage, the authors have been proposing the ultrasonic beam induced resistance change (SOBIRCH)[3)] method in which the optical beam of the OBIRCH method is substituted with ultrasonic beam. In this study, it was investigated the influence of the mold resin layer on the intensity of the acquired signal with a simulation by considering sound field and heat dissipation.

2. Measurement system and sample

Fig. 1 illustrates the conception of the OBIRCH method. If the laser beam is on the wire, it brings out a resistance change with a temperature rise. This can be detected as ΔI in the figure. On the other hand, the SOBIRCH method employs focused ultrasound instead of the laser. **Fig. 2** shows the schematic diagram of the system of the SOBIRCH method. The focal length, the aperture radius and the center frequency of the transducer were 4000 µm, 2.25 µm and 40 MHz, respectively. To retain a high signal to noise ratio, a lock in amplifier was implemented. The ultrasound signal, 40 MHz as a carrier frequency, was modulated by a square wave of which frequency was several kHz. **Fig. 3** shows the 3-dimensional structure of the samples, and the resin thickness was defined as the distance from the top of the sample to the wire on the chip. In this study, the resin thicknesses were 320 µm, 420 µm, 620 µm and 1000 µm.

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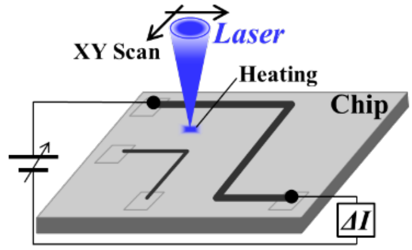

Fig. 1 Principle of OBIRCH method

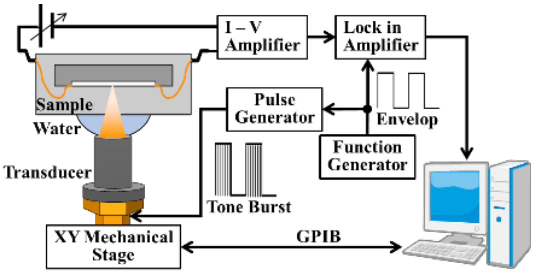

Fig. 2 Schematic diagram of the measurement system.

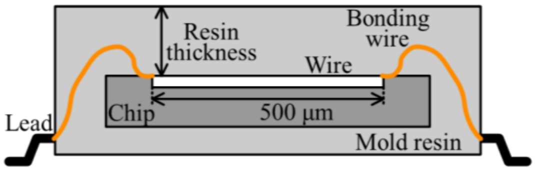

Fig. 3 The 3-dimesional structure of the sample.

3. Results and discussion

3.1. SOBIRCH images

Fig. 4 shows the measurement result for the 4 samples with different resin thicknesses. It is seen that the SOBIRCH image with the thinner resin is more obvious. It seems that the tendency is attributed to the scatter by the fillers inside the mold resin. **Fig. 5** shows the result of a comparison between the measurement and a current fluctuation analysis[4)]. The current fluctuation analysis consists of numerical simulations for the sound field and the temperature field inside the sample. In Fig. 5, each plot has been normalized by the result at 320 µm. The measurement results show a good agreement with the simulation results. The fillers inside the mold resin scatter and attenuate the sound power, the effect being more substantial with thicker mold resin. Thus, the sound power reaching to the wire becomes smaller with thicker mold resin, and the signal intensity becomes weaker. Hence, the signal intensity of thinner mold resin is stronger, leading to the stronger SOBIRCH image.

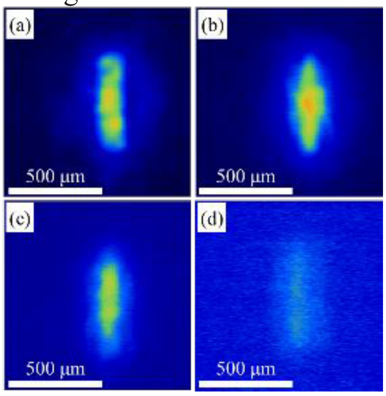

Fig. 4 SOBIRCH image with different thickness of the mold resin[3]. (a) 320 µm (b) 420 µm (c) 620 µm (d) 1000 µm.

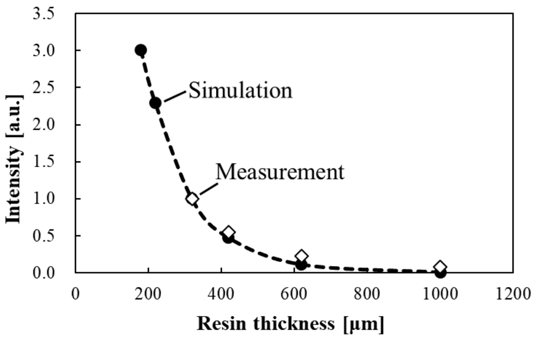

Fig. 5 Dependence of signal intensity on resin thickness. (Input power: 176 mW, Bias voltage: 500 mV, Bias current: 31 mA, Modulation frequency 1.0 kHz, Carrier frequency: 40 MHz)

3.2. Numerical simulation

Fig. 6 shows the trend of the signal intensity depending on the resin thickness and the modulation frequency. The modulation frequencies were 0.1 kHz, 0.5 kHz, 1.0 kHz, 5.0 kHz, and all values for signal intensity were normalized by the maximum in Fig. 6. It is indicated in Fig. 6 that the signal intensity for each modulation frequency shows the peak at a certain resin thickness. It is considered that the peak is originated from the balance between the absorption of sound power that is converted into heat generation, and the sound attenuation due to the scatter by the fillers.On the right-side of the peak, as the sound attenuation by scatter is more significant with thicker mold resin, the signal intensity decreases with resin thickness. In contrast on the left side of the peak, the signal intensity increases with thicker resin thickness. As long as the sound field strong enough, thicker mold resin would retain larger heat source, and easier temperature rise on the wiring surface. In other words, the mold resin converts the sound power effectively, and the signal intensity increases with thicker the mold resin on the left-side of the peaks.

This point is a good advantage of SOBIRCH method. To improve the sensitivity of SOBIRCH method, it is necessary to reduce the resin thickness by polishing. However, reducing the resin may damage the chip and the bonding wire, and would change the condition in the vicinity of the failure point. This may make it difficult to carry out the failure analysis. It is suggested that, in order to avoid damaging the chip and the bonding wire, a certain amount of the mold resin should be left, which is even more advantageous to realize a high sensitivity. From the result of Fig. 6, it seems to be possible for SOBIRCH method to improve the sensitivity and conserve the condition and the reproducibility of failures.

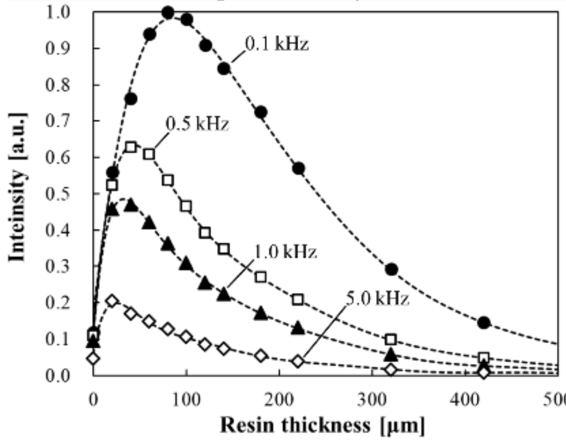

Fig. 6 Numerical analysis of the sensitivity for the resin thickness and the modulation frequency, of which 0.1 kHz, 0.5 kHz, 1.0 kHz and 5.0 kHz.

4. Conclusion

Based on the agreement between measurement and simulation results, it was indicated that the thicker resin lowers the sound power reaching to the wire and makes the signal intensity lower. As the scattering by the fillers causes this decline of the signal intensity, the thinner resin makes the sensitivity better. However, the signal intensity has a maximum at a certain mold resin thickness because the resin absorbs the sound power and effectively converts into heat generation. If the carrier frequency is fixed, the resin thickness that brings the maximum sensitivity depends on the modulation frequency. This study has suggested that the sensitivity of SOBIRCH method can be maximized by an appropriate resin thickness. For this reason, it was implied that SOBIRCH method is available for the failure analysis in semiconductor devices.

References

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