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Frequency determination in nondestructive test of semiconductor devices with ultrasound heating

超音波加熱による半導体デバイスの非破壊検査における周波数選択法

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1. Introduction

The infrared optical beam induced resistance change (IR-OBIRCH)[1,2] method is often used to localize faults on metal wires of semiconductor devices. Using the IR-OBIRCH, the faults are localized by observing current changes induced by laser heating. Prior to the localization, the IR-OBIRCH generally requires a decapsulation of mold resin that covers semiconductor devices. However, this decapsulation may damage the device, leading to a reduction in reproducibility of the failure conditions[3]. As an alternative without the need for decapsulation, the authors have proposed the ultrasonic beam induced resistance change (SOBIRCH) method replacing the laser with ultrasound. **Fig. 1** shows the concepts of the IR-OBIRCH and the SOBIRCH method. In previous papers[4,5], it was suggested that the intensity of SOBIRCH signal is significantly improved by using ultrasound resonance in the mold resin.

In some practical cases, however, since both speed of sound and thickness of mold resin are not precisely known, an exist resonant frequency cannot be obtained. In this study, to improve the signal intensity even if both parameters are unknown, a determination method of the frequency of ultrasound in the SOBIRCH was examined.

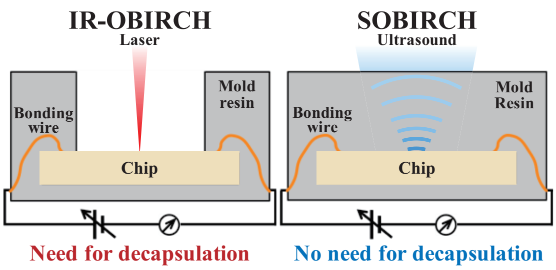

Fig. 1 Concepts of IR-OBIRCH and SOBIRCH methods.

2. System of SOBIRCH method and sample

Fig. 2 shows the measurement system of the SOBIRCH method. A metal wire of a semiconductor device is heated by ultrasound of tens of MHz amplitude-modulated by a square wave of several kHz. Under these conditions, the small current change induced by the modulated ultrasound will have the same period as the modulation. This modulated small current change can be detected by a lock-in amplifier in order to retain a high S/N ratio.

In this study, a sample was prepared. **Fig. 3** shows the structure of the sample. A part of the mold resin was thinned to 50 μm as shown in Fig. 3. Under the thinned part, there was a wire with a line width of 2 μm. This wire was observed by the SOBIRCH.

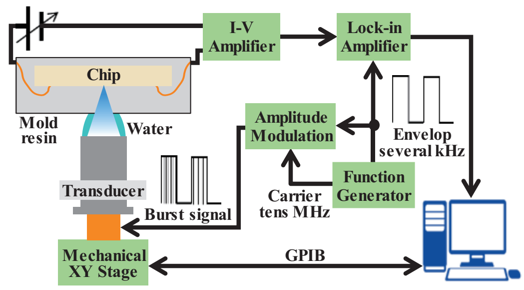

Fig. 2 Measurement system of SOBIRCH method.

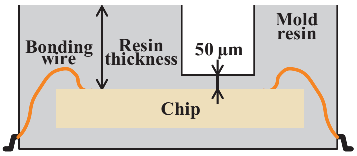

Fig. 3 Structure of sample.

3. Signal processing of frequency determination

Fig. 4 (a) shows echo signals used for signal processing. In Fig. 4 (a), the solid line shows an echo signal as a target from the sample, and the dashed line shows an echo signal as a reference from an acrylic plate with thickness of 3 mm. By applying a Fourier transform to the target and the reference signal, frequency components of the signals were calculated. The transfer function in the frequency domain was obtained by normalizing the frqeuency component of the target with the one of the reference. After the multiplication of Gaussian with its half-width at half-maximum of about 30 MHz to the transfer function, the transfer function in the time domain was obtained by an inverse Fourier transform. **Fig. 4 (b)** shows the transfer function in the time domain. There are two large peaks (peak①, peak②) in the transfer function. In Fig. 4 (b), it was expected that the peak① and the peak② would indicate the locations of the interface between water and mold resin and the interface between mold resin and chip respectively. The time of flight Δt calculated from peak① and peak② was 32.6 ns. **Eq. (1)** describes the sound intensity SI at the interface between mold resin and chip as a function of the ultrasound frequency f and the time of flight Δt when the intensity of incident sound on the resin was 1.

$$SI = \frac{Z_w}{Z_r} {t_{wr}}^2 \frac{1+{r_{rc}}^2+2r_{rc}}{1+(r_{rc}r_{wr})^2+2r_{rc}r_{wr}\cos(2\pi f\Delta t)} \qquad (1)$$

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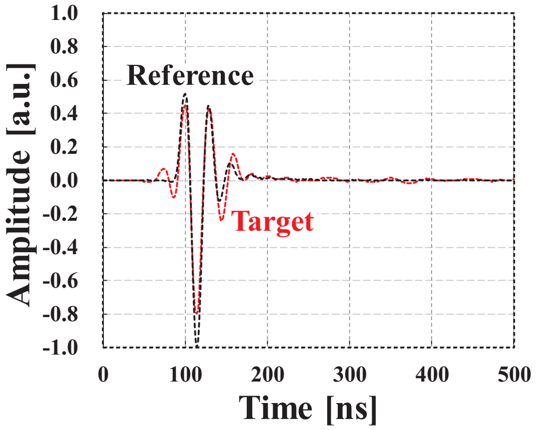
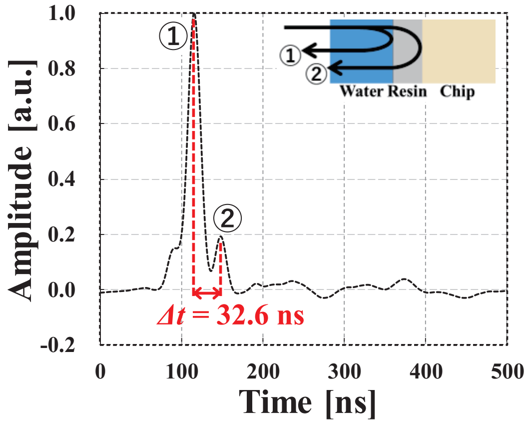
where, Z_a is an acoustic impedance of material a. r_{ab} and t_{ab} are the reflectance and transmittance of sound pressure assuming the vertical incidence of ultrasound from material a to b. The subscripts w, r, and c represent water, resin, and chip, respectively.

Fig. 5 shows the calculation result of the sound intensity SI when the time of flight Δt was 32.6 ns. As a result of Fig. 5, it was expected that the sound intensity at the interface would be maximum at 46 MHz because of the ultrasound resonance. Moreover, based on the previous paper[5], it is conceivable that the intensity of the SOBIRCH signal could be significantly improved by using this estimated resonant frequency.



(a) Raw signals in order to calculate transfer fuction. (Solid line: Target signal, Dashed line: Reference signal.)



(b) Transfer function in time domain.

Fig. 4 Analysis of time of flight in mold resin layer.

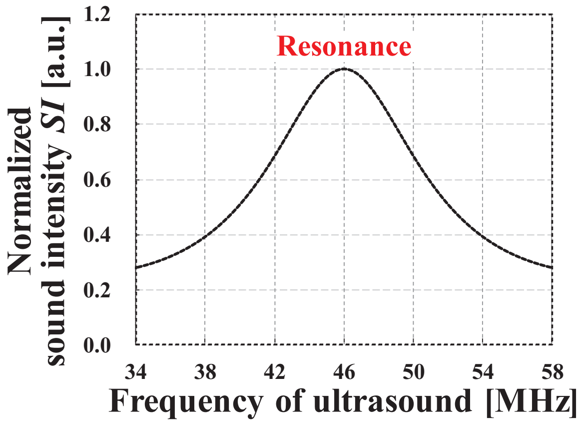
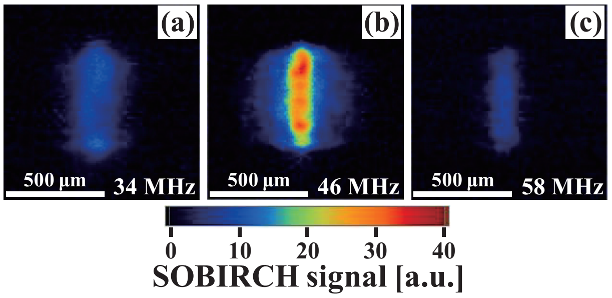


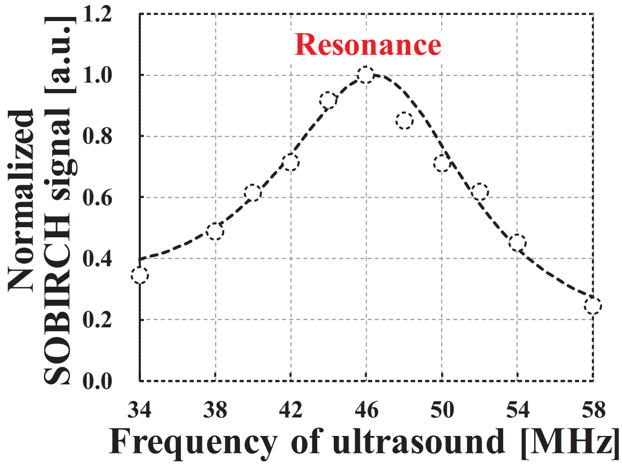
Fig. 5 Sound intensity SI at interface between mold resin and chip.

4. Results and discussion

An experiment was carried out with the sample in Fig. 3 to confirm whether the intensity of the SOBIRCH signal would improve at the resonant frequency estimated by the signal processing. Fig. 6 shows the results of observation of the sample with the SOBIRCH in the vicinity of the estimated resonant frequency. **Fig. 6(a)** shows SOBIRCH images at different frequencies. **Fig. 6(b)** shows the intensity of the SOBIRCH signal as a function of the ultrasound frequency. In Fig. 6 (a) and Fig. 6 (b), the intensity of the SOBIRCH signal was at its maximum when the ultrasound frequency was 46 MHz. The frequency that showed the highest intensity of SOBIRCH signal in the measurement agreed with the resonant frequency estimated by the signal processing.



(a) SOBIRCH images



(b) Intensity of SOBIRCH signals

Fig. 6 Frequency dependence of SOBIRCH signal in vicinity of estimated resonant frequency of ultrasound.

5. Conclusion

This research suggests that the optimum ultrasound frequency for the SOBIRCH observation can be determined by applying signal processing to the echo signal from the sample without using the speed of sound and the thickness of mold resin.

References

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