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Nondestructive Failure Analysis Technique for IC interconnection by using Ultrasound Heating

超音波加熱による集積回路配線故障の非破壊故障解析法

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1. Introduction

OBIRCH (Optical Beam Induced Resistance CHange)[1)] method is often used as a failure analysis technique for IC (Integrated Circuit) metal interconnection. **Fig. 1** shows the principle of OBIRCH method. This method observes current alteration induced by focused laser heating[2)]. This small current change ΔI is represented as

$$\Delta I = -\frac{\Delta R}{R+\Delta R} I_b \approx -\frac{\Delta R}{R} I_b \quad (1),$$

where R is interconnection's stable resistance, ΔR is resistance change following temperature rise and I_b is biasing current. Detecting the current alteration by scanning the laser beam, this method generates an image. That enables to find out several types of interconnection failure visually, such as short circuit, leakage current paths and high-resistance points.

Before applying OBIRCH method, it is necessary to open packaging resin of IC chip because the resin interrupts laser. However, not all the failures reproduce with opening it. To solve this problem, nondestructive failure analysis technique is required. In order to develop the technique, we focused on the transmission of ultrasound in solid. In this study, we suggest a nondestructive method substituting ultrasound for laser on OBIRCH method.

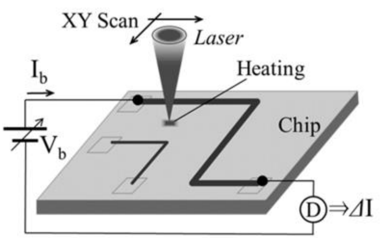


Fig. 1 Principle of OBIRCH method.

2. Measurement System

Fig. 2 shows the measurement system. At first, the system requires an ultrasound reflection image in order to fix the field of observation. Subsequently, a high frequency continuous voltage (10 – 100 MHz) is applied to transducer in order to heat and stimulate interconnection in IC chip. This voltage is subjected amplitude modulation with audio frequency (0.1 – 10 kHz). The current alteration signal ΔI is detected through a lock-in amplifier to retain high sensitivity[3)].

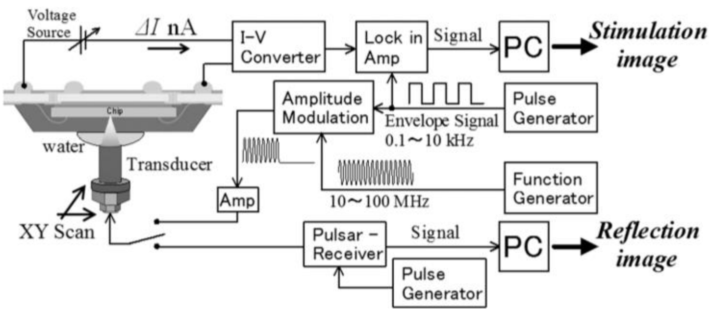
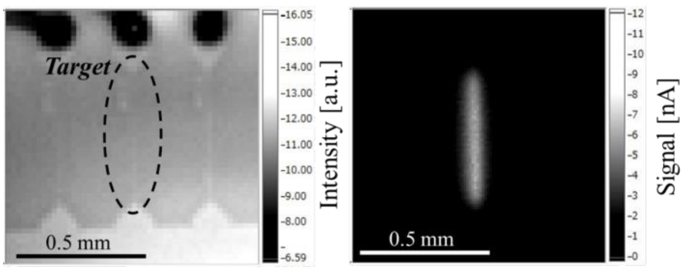


Fig. 2 Schematic diagram of measurement system.

3. Preliminary Experiment

Fig. 3 shows the results of preliminary experiment. The sample covered with transparent resin (128 μm thick) was employed in order to observe the aluminum interconnection (500 μm long, 2.0 μm wide and 0.5 μm thick) with less significant scattering. Fig. 3(a) shows the reflection image. The interconnection pattern is clearly seen. Subsequently, applying bias voltage to the interconnection marked as target in Fig. 3(a), the pattern was heated by focused ultrasound beam. Fig. 3(b) exhibits that the pattern successfully heated up effected by focused ultrasound with 100 MHz carrier frequency. Obviously, stimulation pattern corresponded to the reflection pattern.



(a) (b)

Fig. 3 Results of preliminary experiment (specimen covered with transparent resin). (a) Ultrasound Reflection image. (b) Ultrasound Stimulation image.

4. Analysis of Current Alteration

In order to make sure that the current alteration was caused by ultrasound heating, an analysis was performed by considering both sound and thermal field. The numerical model is shown in **Fig. 4**. The shape of the aluminum interconnection in Fig. 4(a) is as same as a sample used in preliminary

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experiment. The sample layers in Fig. 4(b) is approximated to Fig. 4(c) because the field of the interconnection is much smaller than Si_3N_4. Fig. 4(c) shows the numerical axial symmetry model.

Fig. 5 shows the temperature profile along r axis in Si_3N_4 with different durations of heating. It is shown that the temperature rise is created at the center of the model. The total resistance change of the interconnection was subsequently calculated assuming its local changes considering temperature dependence of resistivity. Signal intensity was finally calculated by substituting the total resistance change into Eq. (1). **Fig. 6** shows measurement and simulation results as function of ultrasound duration. The calculation results show a good agreement with the measurement results, suggesting that the focused ultrasound was successfully converted into current alteration, leading to creation of the stimulation image.

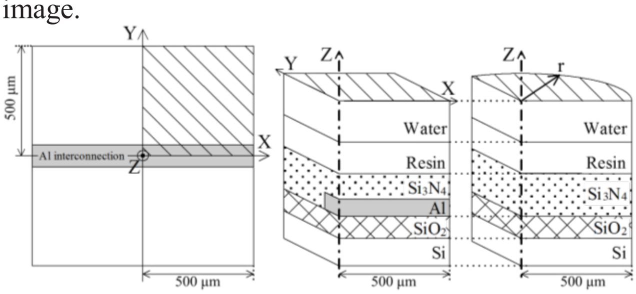

Fig. 4 Schematic model of the numerical structure. (a) Top view. (b) X-Y cross-section. (c) Numerical model assuming axial symmetry without Al.

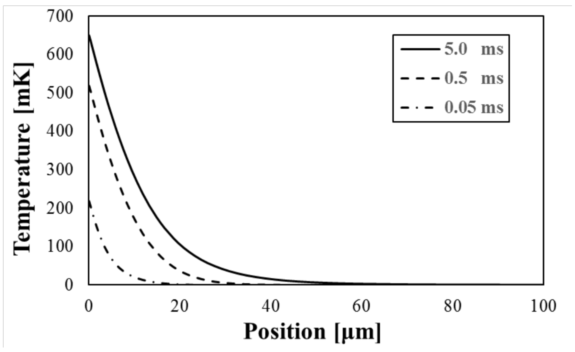

Fig. 5 Temperature profile along r axis around in Si_3N_4 with different durations of heating.
(100 MHz: Input power: 429 mW, focal diameter: 20 μm).

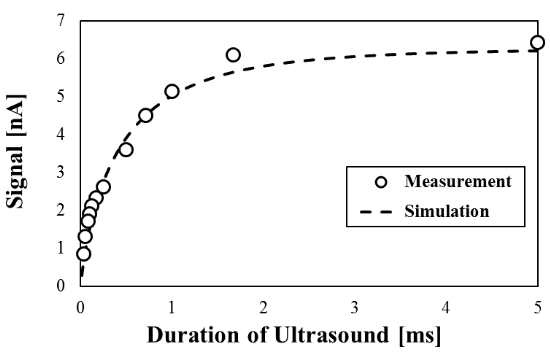

Fig. 6 Signal intensity as function of ultrasound duration.

5. Experimental Result

Commercially available resin usually includes fillers to improve its thermal conductivity, which may scatter ultrasound. In the case of this specimen average filler diameter is specified as 16 μm. This number is similar to the wavelength at 100 MHz. The mode of scattering is often classified by means of size parameter $\alpha = \pi D / \lambda$, where D and λ represent filler diameter and wavelength, respectively. When α is as large as 1, the scattering is classified as to be Mie scattering, by which wave propagation is significantly disturbed. In fact, no significant image was acquired when 100 MHz were employed as the carrier frequencies. However, when the carrier frequency had been reduced to 40 MHz, a good image was observed as shown in **Fig. 7**.

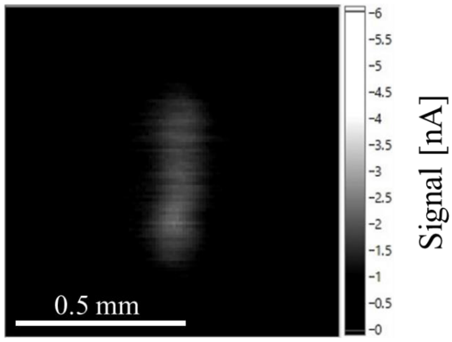

Fig.7 Ultrasound stimulation image (specimen covered with commercially available resin including filler).

6. Conclusion

In order to apply the OBIRCH method to specimens covered with non-transparent resin, stimulation by focused ultrasound instead of laser beam was proposed. An experimental system, which is similar to OBIRCH system but using modulated ultrasound, was assembled. An interconnection pattern models, covered with resins with and without filler, were successfully observed as stimulation images. Numerical simulation considering both sound field and local heating was performed and shown a good agreement with the measurement result, suggesting that the focused ultrasound was successfully converted into local temperature rise, leading to creation of the stimulation image.

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