RUBBER-COUPLED ACOUSTIC MICROSCOPY FOR INDUSTRIAL APPLICATIONS

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Abstract

This paper reports the rubber-coupled acoustic microscopy technique for cyclic inspection of industrial products in dry manner. Four kinds of rubber membranes are fabricated, and the ultrasonic transmission into the acrylic resin targets via the membrane/target interfaces, where the pressure of about 0.1 MPa is applied for improving the acoustic coupling at the contacting interfaces, is carried out. In practice, the cyclic acoustic imaging of electronic devices is demonstrated via the selected rubber membrane.

1. Introduction

Acoustic microscopy/imaging has been widely used in the electronics [1, 2] and spacecraft industries [3] for visualizing the inner defects, such as delamination, debondings, cracks and broken fibers. Commonly, this has to be performed by immersing a sample in water for transmitting the ultrasound into the sample. However, the immersion of the sample in water puts a limitation on the samples that can be analyzed, and in many situations of the industrial applications, this is undesirable as devices and materials may become contaminated through water/moisture absorption.

The dry-coupled acoustic microscopy technique (Fig. 1) has been developed for overcoming the water immersion problem of conventional acoustic microscopy [4]. The technique is capable of transmitting the high frequency ultrasound into the sample via a polymer film/sample interface with an applied pressure of about 0.1 MPa. Also by designing the film as an acoustic matching layer between water and the sample, higher quality acoustic images over the water immersion images are recorded [5]. Moreover, the technique enables us to characterize the micron-scale soft films [6]. The dry technique is quite useful, but the polymer film is unsuitable for cyclic use.

This paper describes the transduction of high frequency ultrasound via rubber membranes, which have stability as well as ductility. It is shown that the rubber membrane with low elasticity achieves the good acoustic coupling at the membrane/sample interfaces, and can be repeatedly used for the dry acoustic inspection.

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2. Experiments

2.1. Ultrasonic transmission

Ultrasound emitted with the focused ultrasonic transducer, with the nominal frequency of 50 MHz, the diameter of the piezoelectric element 6.35 mm and the focal length 12.7 mm, was transmitted into the acrylic resin targets via the rubber membranes. Four kinds of acrylic resin targets (60 × 60 × 2 mm) were prepared. The surfaces of the targets were roughened by the emery papers, see Table 1. The surface roughness of the target is expressed by b describing the height of the roughness and g describing its distribution [7]. In this paper, the arithmetical mean deviation of the profile and the profile element width were shown as the typical values of b and g, respectively.

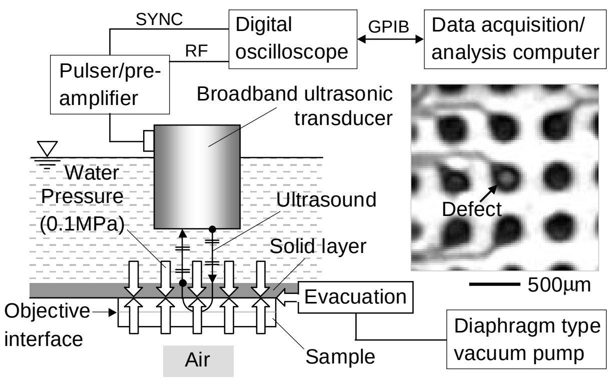

Figure 1: *Schematic of dry-coupled acoustic microscopy technique*

Table 1: Surface roughness of the sample

Sample	Emery paper grade	b (μm)	g (μm)	b / g
S0	Not abraded	0.01	17	0.001
S1	#1000	0.19	37	0.005
S2	#600	0.47	68	0.007

S3	#300	0.93	107	0.009

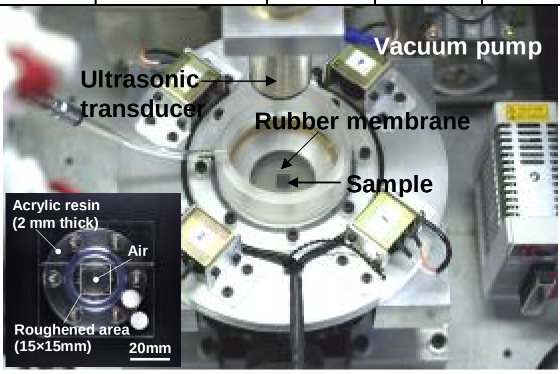

Figure 2: *Details of dry ultrasonic transmission unit*

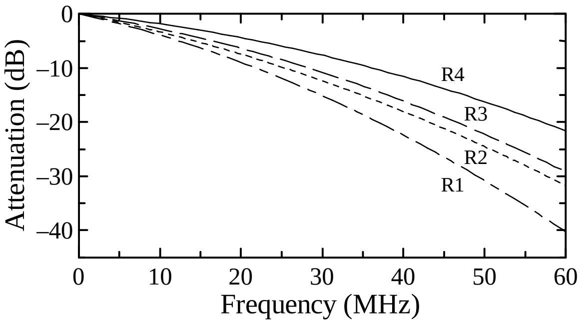

Figure 3: *Ultrasonic attenuation in the used rubber membranes*

The back-wall echoes of the acrylic resin targets were recorded by using the dry ultrasonic transmission unit [4], see Fig. 2. The amplitude spectra of the echoes with membrane, f_1, and that without membrane, f_2, were stored in computer. The waterproof jig for avoiding the water invasion was attached on the back-walls of the targets. The total signal loss accompanied with the dry ultrasonic transmission in comparison with the case of water-immersion, g, can be expressed as [8]

$$g = f_1 / f_2 = q\,x\,y\,, \qquad (1)$$

The terms x and y represent the signal losses related to the ultrasonic attenuation in the membrane and the acoustic coupling at the membrane/target interfaces, and these become unity under the no-loss condition. The term q is related to the acoustic impedance matching between water, membrane and the target.

2.2. Rubber membranes

Four kinds of rubber membranes were fabricated. The thickness of all rubber membranes were 0.202 ± 0.007 mm. To characterize the elasticity of the membranes, we carried out the cycle test of the sheet specimens (100 × 30 mm) by a tensile testing machine, and locally determined Young's modulus of the membranes from the stress-strain relation in the stress range of 0.05 to 0.15 MPa. In this paper, we call the rubber membranes R1, R2, R3 and R4

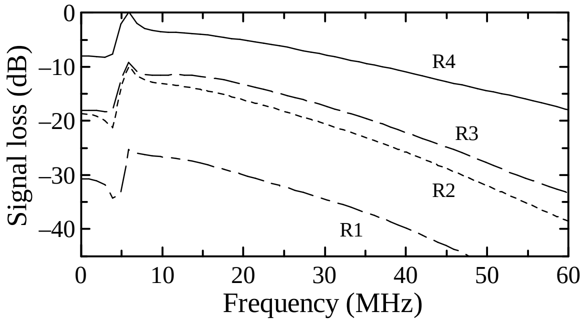

Figure 4: *Relationships between the total signal loss and frequency (S0 sample)*

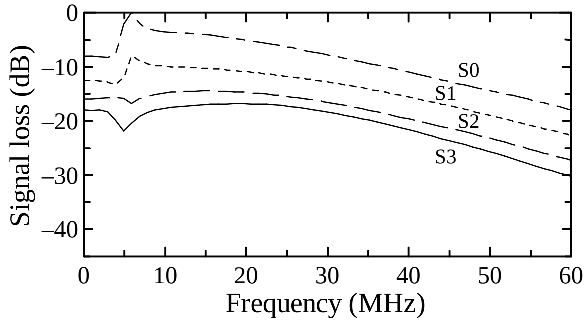

Figure 5: *Relationships between the total signal loss and frequency (R4 membrane)*

in the higher order of Young's modulus determined locally around 0.1 MPa. The values of Young's modulus of R1, R2, R3 and R4 were 9.59, 7.71, 3.09 and 0.91 MPa, respectively. The decibel representations of x for all membranes are plotted as a function of frequency in Fig. 3 [6]. The value of x of R4 in the range of 10 to 60 MHz was the largest in the used membranes, and the larger order of x corresponded with the lower order of Young's modulus of the membranes.

3. Results and discussions

The decibel representations of g in the case of S0 sample are plotted as a function of frequency in Fig.4. Figure 4 shows that the value of g of R4-coupling in the range of 10 to 60 MHz is the largest in the tried rubber-coupling, and the larger order of g corresponds with the larger order of x. The values of g of the R4-coupling for all acrylic resin targets are plotted as a function of frequency in Fig.5. The values of g of the R4-coupling in the range of 10 to 60 MHz decrease with increasing in b. Because the terms of q and x in Eq. (1) never change with the change in the surface roughness of the sample, the decrease in g is considered to be due to the decrease in y. It was found that the R4 membrane with the lowest Young's modulus among four membranes realized the most effective ultrasonic transmission for all cases of acrylic resin targets.

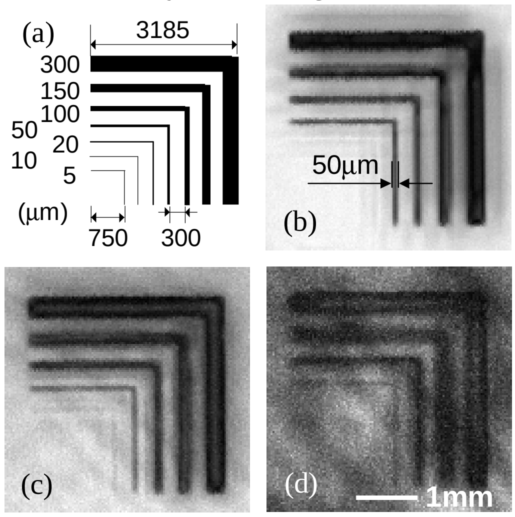

Figure 6: *Fabricated nm gaps (a), and the acoustic images of Si-bonding sample obtained under the water immersion (b), R4-coupling (c) and R1-coupling (d)*

4. Application to industrial inspection

4.1. Silicon-bonding sample

The silicon-bonding sample was prepared by bonding the two silicon [100] chips (20 × 20 × 0.5 mm), where the grooves were patterned on one of the silicon chips by using photolithography and a fast-atom-beam etching technique, as shown in Fig. 6(a). Acoustic images of the silicon-bonding sample having 10 nm height gaps recorded with the 100 MHz focused ultrasonic transducer under the water immersion, the R4-coupling, and the R1-coupling are shown in Figs. 6(b), (c) and (d), respectively. The R4-coupling image clearly shows the gaps wider than 50 µm as the water immersion one. On the other hand, the R1-copling image is inferior to the R4-coupling image in points of the clearness of the images, and the gap of 50 µm wide is obscure as compared with the others. This was due to the small values of x and y of R1-coupling.

4.2. Semiconductor package

The values of b and b / g of the examined encapsulated resin package were 0.18 µm and 0.005, respectively. The acoustic images of the package obtained by the 50 MHz focused ultrasonic transducer under the water immersion and the R4-coupling are shown in Figs. 7(a) and (b), respectively. The R4-coupling image clearly shows the delamination parts [Fig. 7(b)]. On the other hand, in the water immersion image, the delamination parts are faded by the water invasion into the package. The acoustic imaging of the package was repeatedly performed under the R4-coupling 100 times. The acoustic images, the

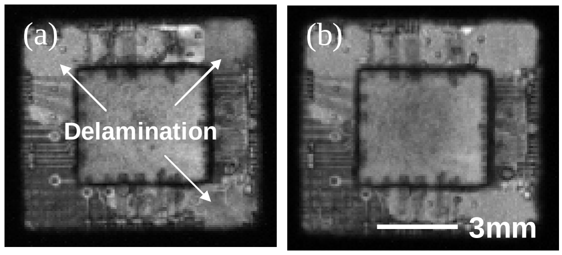

Figure 7: *Acoustic images of a plastic package obtained under the water immersion (a) and R4-coupling (b)*

quality of which was equivalent to that of the image shown in Fig. 7(b), were repeatedly recorded without breaking the R4 membrane during the 100 times of imaging.

5. Conclusions

We reported the rubber-coupled acoustic microscopy technique for realizing the cyclic acoustic inspection of industrial products without getting the products wet. The rubber membrane with low elastic modulus achieved good acoustic coupling with the acrylic resin targets with various surface roughnesses under a pressure of about 0.1 MPa subjected to the membrane/target interfaces, in addition to the low ultrasonic attenuation in the membrane.

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6. References

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