NDI of Delamination in IC Packages Using Millimeter-Waves

Yang Ju, Masumi Saka, and Hiroyuki Abé

***Abstract*—To detect delamination in integrated circuit (IC) packages, a millimeter-wave inspection system was developed. An open-ended coaxial line sensor was used as a source and also a receiver of the millimeter-wave signal that was transmitted into and reflected from the packages. The phase of the reflection coefficient was measured for inspection of the delamination. The package was scanned in two perpendicular directions on a plane parallel to the package. A two-dimensional image was created by using the raw data of the millimeter-wave measurement. The millimeter-wave image showed almost the same features as that of scanning acoustic tomography, and the delamination was readily detected without using a coupling medium. Furthermore, a graph obtained by scanning the package in one direction along the center line of the package showed a higher sensitivity for distinguishing the delamination, thereby showing a potential for the on-line detection of delamination in an IC package.**

***Index Terms*—Coaxial line sensor, delamination, IC packages, millimeter-wave imaging, nondestructive testing.**

I. Introduction

WITH the development of integrated circuit (IC) technology, the IC chip has been enlarged for increasing the level of integration, and the plastic encapsulant has been made thinner and smaller in order to raise the density of surface mount devices. The delamination that may occur in IC packages has become a key factor affecting the reliability of IC packages. It has been reported that delamination was caused by the stress and the pressure induced by thermal expansion mismatch and by moisture evaporation during the solder reflow process [1], [2]. Delamination mostly takes place at the interface between the encapsulant resin and the chip pad, and sometimes leads to cracks at the sides of the chip pad, as shown in Fig. 1. Therefore, a technique that can detect and evaluate the delamination in IC packages has become an urgent need for increasing the reliability of IC packages. Scanning acoustic tomography (SAT) is a conventional technique to detect the delamination in IC packages; however, the detected package must be placed in water. The requirement of a coupling medium, such as water, makes this technique unsuitable for on-line industrial applications. In addition, when the package is very thin, it is difficult to separate the echoes from the surfaces of the package and the delamination. Thus, a millimeter-wave inspection technique was developed for detection of the delamination in IC packages. The ability to penetrate deep inside the dielectric material and the property of complete reflection at the metal surface make the millimeter-wave detection methods highly sensitive for detection of such delaminations.

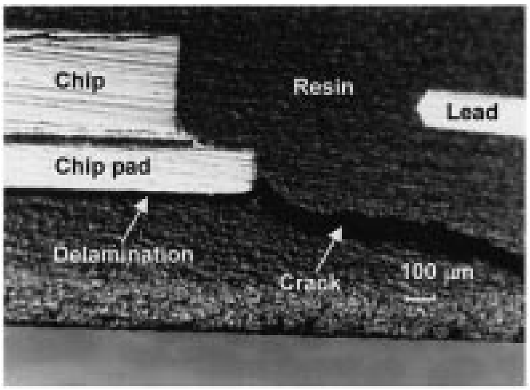

Fig. 1. Actual delamination and crack observed by microscope.

Nondestructive testing (NDT) by using millimeter-waves or microwaves has become more and more an important technique with the emergence and application of new and advanced materials. The primary advantage of this technique over other NDT techniques is that the inspection result is not based on density, but on the dielectric properties of these materials. So, much additional information about the detected objects may be obtained. In addition, in the microwave (including millimeter-wave) region, the variation of permittivity for dielectric materials is significantly larger than the contrast of density. That is why millimeter-wave inspection is more sensitive than the other techniques for testing dielectric materials. Microwave and millimeter-wave NDT has been used for testing voids, delamination, porosity, etc., in a variety of dielectric materials, including polymers, ceramics, plastics, and their composites. Usually, waveguide or a horn antenna was used as a probe to couple the signal with the materials [3]–[5]. However, for detecting the delamination in IC packages or other defects in small dimensions, these probes present a frequency limitation. The probes have a dimension-dependent cutoff frequency below which propagation of the signal is not possible. Hence, the aperture of the waveguide should not be too small, in order that the operating frequency is not cut off. In contrast with conventional techniques, an open-ended coaxial line sensor technique has been used for the detection of delamination in IC packages [6], [7]. Coaxial lines can support transverse

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electromagnetic (TEM) waves without cutoff frequency for the fundamental TEM mode. Therefore, the operating frequency band can be broad, and it is also possible to decrease the size of the sensor aperture for increasing the spatial resolution. Recently, a microwave imaging system (MIS) working at 20 GHz has been developed for direct observation of delamination in IC packages [8]. However, the shape of the delamination cannot be determined exactly due to the lack of spatial resolution. It has been known that increasing the operating frequency will improve the directivity of the radiation of the sensor, thereby increasing the spatial resolution of the MIS [9]. Recently, as described in the present paper, a millimeter-wave inspection system (MWIS) working over a (75–110) GHz frequency range and a corresponding open-ended coaxial line sensor were developed. The millimeter-wave image was created by measuring the phase of the reflection coefficient, and the delamination was readily detected. The spatial resolution of the MWIS was evaluated by using a standard resolution test target; the same order sensitivity as the SAT was obtained. In addition, scanning the packages in one direction along the center line of the package was found to have higher sensitivity for distinguishing the delamination, thereby indicating the possibility for on-line testing of the delamination in IC packages.

II. Experimental Procedure

The principle of the technique described here is based on the interaction of millimeter-wave signals with IC packages. The coaxial line sensor acts as the source of the millimeter-wave signals that are transmitted into the package and also as the receiver of the reflected signals from the package. For discontinuous mediums, reflection will take place at all the interfaces of adjacent layers. The total reflection emerging at the sensor aperture will be the sum of the components reflected from each interface. The component reflected at the surface of the chip pad, which is assumed to be a perfect conductor, carries the information about the delamination. The phase of the reflection coefficient at the sensor aperture, associated with the thickness and the dielectric constant of the delamination layer, was measured for detection of the delamination.

The configuration of the MWIS is shown in Fig. 2. A network analyzer system was used to generate a continuous wave signal fed to the coaxial line sensor and to measure the phase of the reflection coefficient at the sensor aperture. While the sensor scanned over the package, the phase information was continuously recorded corresponding to the measurement position. A computer was employed to synchronize the stage translation in the x- and y-directions and to create a two-dimensional image or one-dimensional graph using the phase of the reflection coefficient measured by the network analyzer. The open-ended coaxial line sensor of the MWIS is shown in Fig. 3, where the sensor has the inner and outer radii, 0.15 mm and 0.47 mm, respectively. In the experiment, the package sample was placed in the near field of the sensor aperture, and the backside of the package was faced toward the sensor. So, the delamination layer was located between the sensor aperture and the chip pad.

For evaluation of the spatial resolution of the MWIS, a standard resolution test target was used. Fig. 4 shows the photograph of the test target. A part of the target was measured by the MWIS, where the scanned area was 2×2 mm with a pitch of 0.1 mm. The operation frequency was 109 GHz and the standoff distance was 0.5 mm.

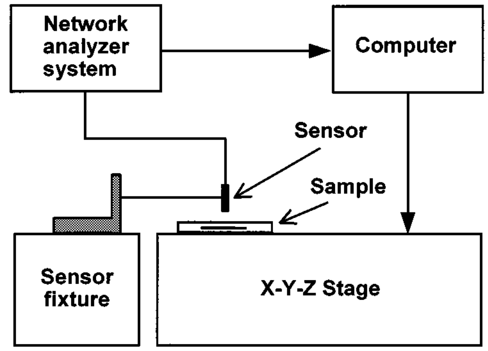


Fig. 2. Configuration of the millimeter-wave inspection system.

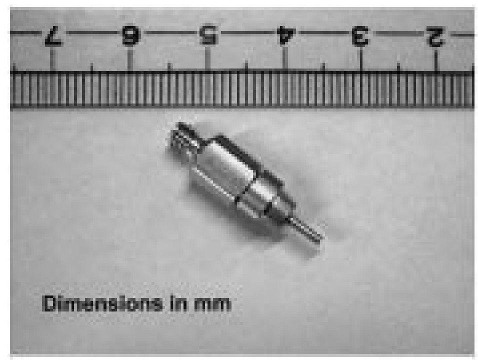


Fig. 3. Photograph of the open-ended coaxial line sensor of the MWIS.

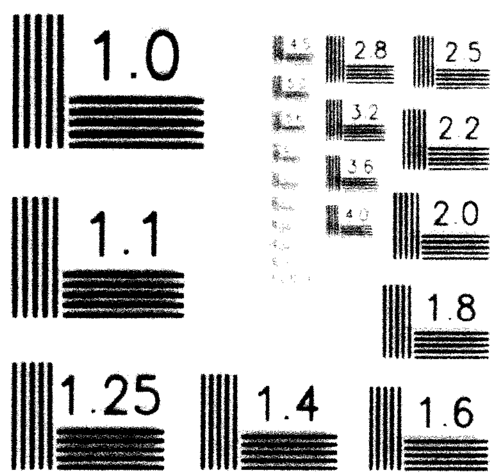


Fig. 4. Photograph of the standard resolution test target.

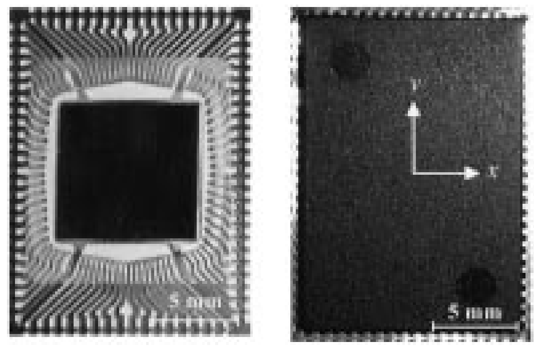
For verifying the capability to detect the delamination in IC packages, package samples were prepared in four categories as shown in Table I, where in each category two packages were included. These were formed by encapsulating the chip and lead frame with the epoxy resin filled with silica powder. Fig. 5 shows the photograph of the lead frame and the encapsulated package. The dimensions of the package are $14 \times 20 \times 2$ mm. The size of the chip pad is 9.5×9.5 mm with the resin of 0.7 mm thickness above it. The size of the IC chip is $9 \times 9 \times 0.35$ mm.

The package resin is assumed to be homogeneous, isotropic, and nonmagnetic. These were hardened for 2 h at 448 K and exposed to the post cure for 8 h at 448 K. For introducing delamination, C2 to C4 were treated for moisture absorption in the different environmental conditions of 358 K/85% RH, 358 K/60% RH, and 303 K/60% RH, respectively, with the same exposure time of 168 h. The thickness of the delamination is known to increase with the increase of the absorbed moisture. Category C1 was free from the moisture absorption. Both devices were then treated to infrared reflow for 10 s at 513 K.

All the samples were measured by the SAT and the MWIS. In the case of the SAT, a 25 MHz focused ultrasonic probe was used and the scanning pitch was 0.09 mm. The duration time for scanning a whole package was about 5 min. The image obtained by the MWIS was with a scanning pitch of 0.2 mm, the operation frequency was 109 GHz, and the standoff distance between the sensor and the sample was 0.5 mm. In this case, the duration time for scanning a whole package was about 20 min, due to the moving speed of the stages being lower than the case of the SAT.

TABLE I
PACKAGE SAMPLES ABSORBED MOISTURE IN DIFFERENT ENVIRONMENTAL CONDITIONS WITH THE SAME EXPOSED TIME

Package category	Environmental conditions	Exposed time, hours	Moisture content, %
C1	-	0	0
C2	358K/ 85% RH	168	0.1786
C3	358K/ 60% RH	168	0.1018
C4	303K/ 60% RH	168	0.0406



(a) (b)

Fig. 5. Photograph of (a) lead frame and (b) package sample.

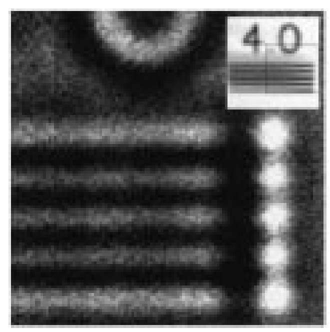


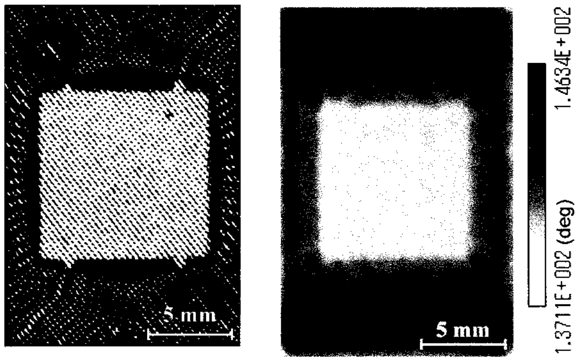
Fig. 6. Image of a part of the resolution test target obtained by MWIS.

III. RESULTS AND DISCUSSION

The image of the MWIS obtained by measuring the resolution test target is shown in Fig. 6. The five metal lines, with a thickness of approximately zero, having a width of 0.125 mm with a gap of 0.125 mm, can be observed clearly. Hence, the resolution of the MWIS was evaluated to be 0.125 mm for the operating frequency of 109 GHz and the standoff distance of 0.5 mm. It is noted that when the standoff distance is increased, the resolution will be decreased due to the diffraction property of millimeter-waves.

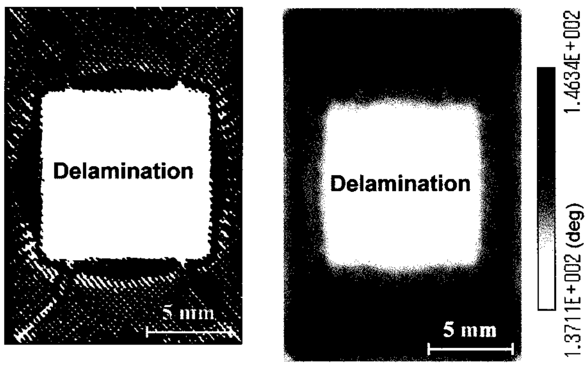
For detection of delamination in IC packages, all of the package samples were measured. Since the same results were obtained for the same category packages, only the results obtained from one of the packages in each category are shown and discussed. Fig. 7(a) and (b) show the images of C1 without delamination obtained by both the SAT and the MWIS. The Fig. 7(b) image was created from the raw data of the millimeter-wave measurement without any image processing. In both images, the shape of the chip pad was observed clearly. The chip pad is observed in grey color, which means no existence of delamination in the sample. However, in the case of the MWIS, since the spatial resolution is still lacking, the metal leads in the package cannot be observed clearly. The images of C2 with delamination obtained by the SAT and the MWIS are shown in Fig. 8(a) and (b), respectively. The white region corresponding to the part of chip pad indicates a complete delamination between the chip pad and the encapsulant resin. The result of the image obtained by using the MWIS is almost the same as that of the SAT. In the case of the package containing a delamination with smaller thickness, the images of the C3 package obtained by the SAT and the MWIS are shown in Fig. 9(a) and (b), respectively. The delamination can be distinguished readily. However, in the case of the MWIS, the delamination at the corner of the chip pad cannot be observed effectively due to the lack of spatial resolution. With the further decrease of the delamination thickness, both of the images obtained by the SAT and the MWIS cannot show the delamination effectively. The images of C4 measured by SAT and MWIS are shown in Fig. 10(a) and (b), respectively. The images observed are almost the same as the images of Fig. 7.

It is noted that, when the delamination level tends to be small, both of the images obtained by the SAT and the MWIS cannot show delamination effectively due to little change in gray based on the delamination in contrast to the range of gray for the package. However, the delamination can still be detected effectively if we pay attention to the graph with respect to the phase distribution obtained from the MWIS. Fig. 11 shows the graph obtained by scanning the samples C1 without and C4 with delamination, from $y = -11$ mm to $y = 11$ mm along the center line of $x = 0$, where all the conditions were the same as in the case of the MWIS image described above. The shape of the curves reflects the total interaction of millimeter-waves with the package including delamination, lead frame, and the edge of the package. At the region corresponding to the chip pad,



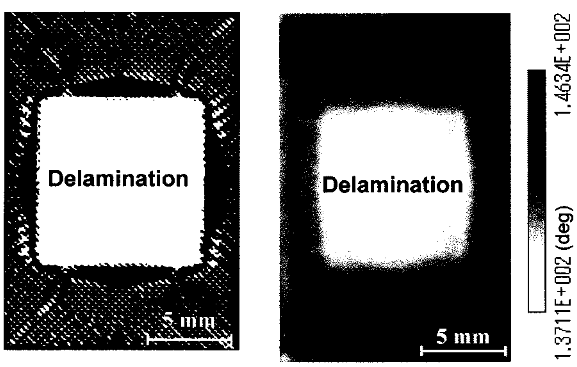
(a) (b)

Fig. 7. Images of package C1 obtained by (a) SAT and (b) MWIS.



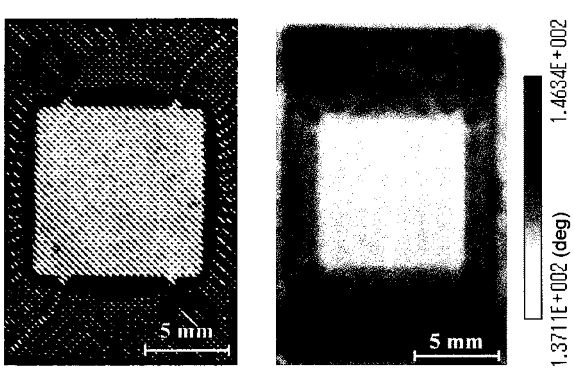
(a) (b)

Fig. 8. Images of package C2 obtained by (a) SAT and (b) MWIS.



(a) (b)

Fig. 9. Images of package C3 obtained by (a) SAT and (b) MWIS.



(a) (b)

Fig. 10. Images of package C4 obtained by (a) SAT and (b) MWIS.

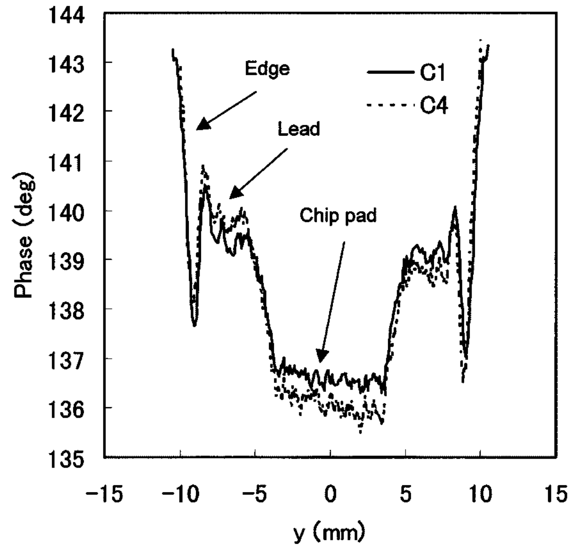


Fig. 11. Phase measured by scanning the packages C1 without and C4 with delamination in the y-direction at $x = 0$.

the phase measured for the sample with delamination is significantly smaller than that of the sample without delamination. The difference in these phases is observed to be about 0.5 °, which is only due to the delamination. The uncertainty (smaller than 0.1 °) of the measured phases, due to a little change in set up of the samples, is sufficiently smaller than the 0.5 ° phase difference. This small uncertainty, together with the phase resolution of the network analyzer being high enough (0.01 °) for measuring such a phase difference, allows the thickness of delamination to be evaluated by using the measured phase difference. The small variations are due to the noise of the system. These variations can be eliminated easily by using smooth signal processing. The graph with respect to the phase distribution shows a higher sensitivity than SAT for distinguishing delamination in IC packages. Such phase sensitivity may be used for on-line detection of delamination in IC packages.

IV. Conclusions

Delamination in an IC package was detected readily by using millimeter-waves. Millimeter-wave imaging by using an open-ended coaxial line sensor was confirmed to be an effective tool to detect delamination in IC packages. The image obtained by the MWIS shows the same capability as SAT, and the graph with respect to the phase distribution generated by the MWIS has a higher sensitivity than SAT for the detection of delamination in IC packages. Several advantages have been shown in contrast to the SAT method: a) a coupling medium such as water is not needed; b) capability to inspect thin encapsulant IC packages; c) possibility for on-line testing; d) possibility to evaluate the thickness of the delamination. The advanced technique provides a new experimental method for integrity assessment of an IC package, thereby supplying the capabilities to improve the design, as well as the reliability, of IC packages.

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