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Identifying of Delamination in Integrated Circuits using Surface Acoustic Microscopy

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Abstract – **In this paper we approbate a procedure for identification of delamination in integrated circuits mounted on printed circuit boards. It consists of consistent application of the following type of scans: A-scan, C-scan and C-scan with RTG option of surface acoustic microscopes. Our results are in coherence with other studies and techniques published in the literature and are better in terms of credibility of delamination detection.**

Keywords – **SAM; A-scan; C-scan; RTG; delamination.**

I. INTRODUCTION

Delamination is a defect in integrated circuits that occurs due to mechanical stresses, abrupt change in ambient temperature, etc. Usually, it is not detected in the initial functional and electrical tests, but it leads to failures in device operation and critically affects long-term reliability.

For this reason, a reliable and credible method of imaging diagnostics for delamination detection is necessary. Among the available diagnostic methods (optical microscopy [1], X-ray analysis [2], acoustic analysis [3]) the most effective is acoustic microscopy and in particular ultrasound diagnostics. Scan techniques are used not only for failure detection but also in other areas such as personal implants [4].

Acoustic microscopy uses high to ultra-high frequency ultrasonic sound (3 MHz to 3 GHz). Acoustic microscopes are non-destructive and sound waves penetrate most solid materials to produce a visible image of the internal structure, including defects such as voids, cracks, delamination, closed air cavities and other separations that occur in glued parts, especially after heat treatment. [5]

Acoustic microscopy works by directing focused sound from a transducer, which converts electrical pulses into ultrasound along the *X* and *Y* axes above the sample. The sample is immersed in a contact liquid, usually water, but if the sample is sensitive, we use moisture, oils, alcohols, or glycerin. Immersion is necessary because high-frequency sound waves cannot be spread in the air and there is a difference in acoustic impedance between air and solids. The contact fluid displaces the air, allowing more waves to penetrate the object so that a usable ultrasound signal can be obtained. When making precise measurements, the immersion method is often used. In this case, the transducer and the sample are immersed in the contact liquid. This method makes it easier to maintain contact while moving and manipulating the sensor or sample.

The frequency varies from 5 to 300 MHz for semiconductor applications, such as chip capacitors, chip resistors, discrete semiconductor devices, ceramic and plastic encapsulated integrated circuits, hybrid integrated circuits and other electronic components. When the ultrasonic pulse hits the interface between two materials, parts of the signal are reflected and analyzed [5].

Piezoelectric transducers are used to study bundles in integrated circuits. Piezoelectrics are crystalline materials with unique properties. When an external voltage is applied to the piezoelectric, the material deforms. Similarly, when the piezoelectric material is subjected to physical stress, an electric charge is generated.

The SAM voltage is applied to the piezoelectric transducer, which emits an ultrasonic wave due to the deformation of the crystal. This ultrasound interacts with the object and is then captured by the same transducer (or, depending on the scan mode, captured by a second transducer) and converted into an electrical signal that can be processed to generate an image [6].

The transducer emits a short ultrasonic pulse and then captures the echo. If the object is defective, there will be two signals, from the near and far surface. If there are internal defects such as closed air cavities or delamination, the inverter will detect an additional feedback signal. This signal is directly related to the depth of the defect. In addition, acoustic images from several depths can be obtained simultaneously, revealing defects of each interface in an electronic device [5].

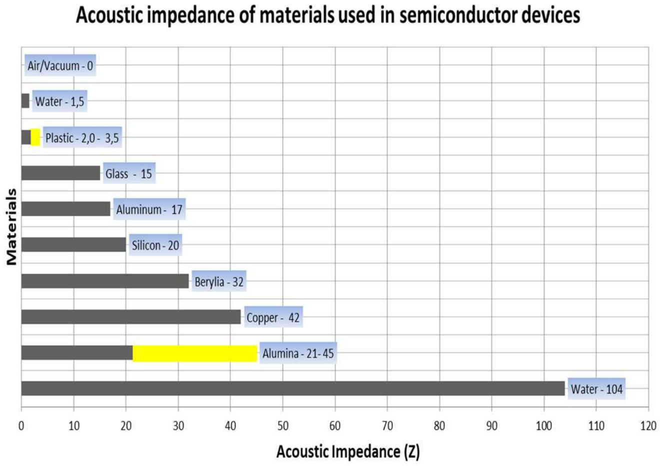

Fig 1. Acoustic impedance of materials used in semiconductor devices [7].

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Acoustic impedance figures are given in Fig. 1.

Table 1 shows the thickness of penetration at different operating frequencies of the piezoelectric transducer, how much delamination can be seen in depth the focal length. Acoustic microscopy method is non-destructive, quick, and cheap.

TABLE 1. RESOLUTION AND PENETRATION DEPTH OF AN ACOUSTIC MICROSCOPE [8]

Frequency [MHz]	Penetration depth [mm]	Theoretical lateral resolution [µm]	Focal length [mm]
5	15.0	300	19.0
10	10.0	150	15.0
15	5.1	100	19.0
20	4.1	75	15.0
25	4.1	60	15.0
30	3.4	50	12.7
40	5.4	38	20.0
75	3.4	20	12.7
80	2.2	19	8.0
100	0.4	15	1.5
110	2.2	14	8.0
120	2.2	12	8.0
200	0.3	8	7
1000	0.025	1.5	0.08
2000	0.010	0.7	0.05

In this paper, we will investigate ICs are mounted on a circuit board for SAM delamination. We will examine the sequence and procedures of actions to ensure correct results. This is very important from methodical point of view, not only in concrete failure analyses, but also in broader sense when such failure techniques are part of systematic project management [9].

II. MATERIALS AND METHODS

To carry out the study we use a scanning acoustic microscope OKOS Vue 400-P [10] (shown in Fig. 2), which has a digital Pulser Receiver and Ultrasonic Digitizer up to 12 GHz and aperture diameter 6 mm. We also use a 35 MHz transducer with a focal length of 12.7 mm [11], [12] (shown in Fig. 3). In order to perform the test, it is necessary to immerse the tested samples in a liquid (most often – distilled water).

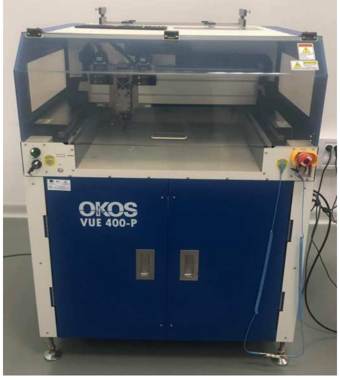


Fig. 2. SAM microscope.

Fig. 3. Transducer

The measurement of the reflected ultrasonic sound can provide information about amplitude, phase, and time. The degree of reflection depends on the acoustic impedance, because when a sudden change in acoustic impedance occurs, such as at the material boundary, part of the sound is reflected, and the remainder propagates across the boundary [5].

The acoustic impedance $Z=\sqrt{Kp}$, where K is the modulus of compressibility (the property of a substance to resist compressibility) and p is the density. The SI unit of measurement for acoustic impedance is the Rail. One rail is equal to 1 Pa s m^{-1}or equivalent to 1 N s m^{-3}. In SI base units this is kg·s^{-1}·m^{-2}.

$$1\,Ray = 1\frac{N.s}{m^3} = 1\frac{Pa.s}{m} = 1\frac{kg}{s.m^2} \tag{1}$$

At the interface between two materials, the acoustic energy (E_0) is divided into reflected (E_R) and transmitted (E_T). They are calculated in the following ways, where $Z_2 - Z_1$ are the acoustic impedances of the two materials.

$$E_R = \left(\frac{Z_2-Z_1}{Z_2-Z_1}\right)^2 \tag{2}$$

$$E_T = \frac{4Z_2-Z_1}{(Z_2-Z_1)^2} \tag{3}$$

$$E_R + E_T = 1 \tag{4}$$

Identical Eqs are used for non-absorbent thin optical layers on a transparent substrate. The reflected amplitude of the wave is calculated by:

$$A_R = \frac{(Z_2-Z_1)}{(Z_2+Z_1)} \tag{5}$$

The amplitude of the wave transmitted in the second material is calculated by:

$$A_T = \frac{2Z_2}{(Z_2+Z_1)} \tag{6}$$

The above method for acoustic diagnostics is applied to mediums with different objects – boards with mounted components (usually chips). The density of components and the board (on which they are mounted) is different. When scanning the surface (the board and components), the transducer scans over objects with different density – dense-to-rare and/or rare-to-dense. The scanning acoustic microscope detects the change of objects' density by producing signal with changed amplitude and phase. The phase changes where delamination is detected. In the case of optical layers being scanned, there is an additional cause of possible change in phase of the reflected wave; it cannot be described using Eqs. (2) and (3). However, there is inversion of the signal when transducer goes over delamination area. Phase inversion occurs when the transducer passes over regions with high to low acoustic impedance; there is no inversion when the transducer passes over regions with low to high impedance.

Therefore, for the case of transition between sealing material (dense medium) (Z_M) and air cavity (rare medium) (Z_A) there is a decrease of the acoustic impedance Z ($Z_M > Z_A$). The fully reflected wave (echo) indicates phase inversion. For the case of transition between polymer and silicon, Z increases ($Z_M > Z_{Si}$) and there is no phase inversion in the reflected wave [13].

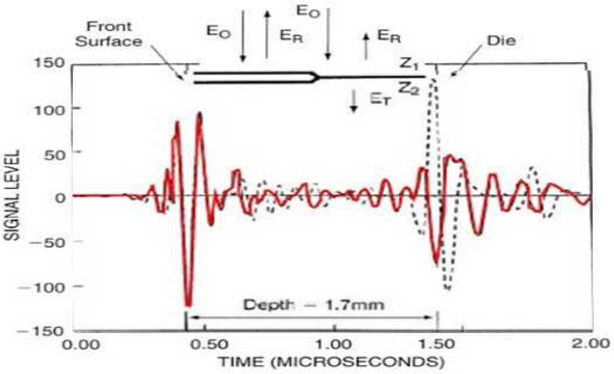
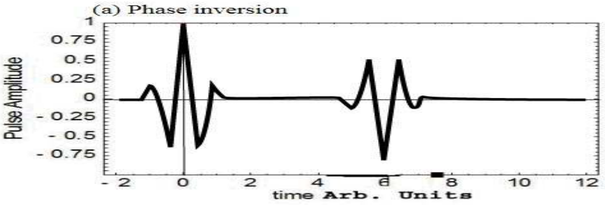


Fig. 4. shows an acoustic echo signal from a region with good adhesion (solid line) and a layered region (dashed line) [13].

The delamination detection using an acoustic microscope depends on many other variables. Fig. 5 shows this the case of phase inversion signal, i. e. delamination. If there is a delamination or void, the signal is inverted as shown in Fig. 5 (a). If there is no delamination or void, the interface signal stays positive as shown in Fig. 5(b); Fig. 5(b) is the represent the normal (non-inverted) phase signal [14]. Dephasing occurs when we have a signal transition from dense to rare. A semiconductor chip is made of different materials and in the most common case we have (from bottom to top) epoxy resin-body from below, copper pad, silicon wafer, epoxy resin-body from above. Delamination can occur by peeling these layers apart. That is, obtaining a cavity between these layers – the presence of air (rare medium). When moving from a dense to a rare medium, dephasing occurs.

(a) Phase inversion



(b) Normal signal

Fig 5. (a) Schematic diagram of a phase inversion, (b) schematic diagram of a normal phase signal [14].

Two scan modes are used for the study of integrated circuits. A-scan and C-scan. A-scan provides information on the amplitude percentage of screen height, phase, and time depth [5]. C-scan is a scanning mode for analyzing the internal structure at a fixed depth within a given thickness. It generates a stratified image of the component. Better contrast is obtained at higher intensity of the acoustic waves reflected at air interfaces and defects. C-scan is especially sensitive to voids and delaminations [15].

The third mode is using an RTG Gate (RTG stands for Relative Threshold Gate). It can be used for detection of gaps between layers. Detection is performed by looking for phase inversions in the signal. When delamination is detected, the RTG Map shows the results in different bright color.

III. RESULTS AND DISCUSSION

To carry out the experiment, we investigate printed circuit board with mounted IC components. The PCB is depicted in Fig. 6.

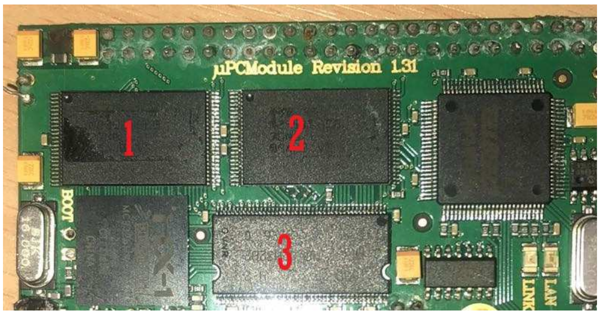
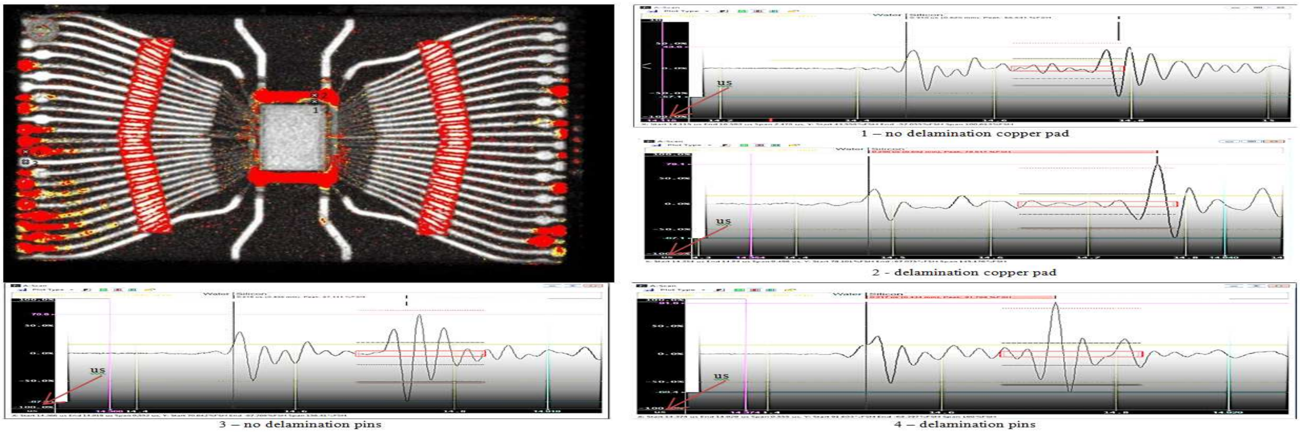


Fig. 6. Printed circuit board with the studied integrated circuits.

Fig. 7 in the upper left corner shows the test sample by C-scan on already obtained A-scan. For the resulting image with C-scan, the additional software setting (RTG) was used to detect bundles. To determine if there is phase outage, the signals (A-scan) from the resulting image (C-scan) are compared in two different areas of the received image. Respectively, markers 1 and 2 compare whether there is delamination in the copper substrate, and markers 3 and 4 compare whether there is delamination in the pins. The colored areas in red indicate delamination. When comparing the signals in two adjacent areas of the same test area of the test object, the signal in the corresponding phase can be observed at 180 degrees. From the performed research it can be noticed that the obtained effect is observed.

The next test chip shown in Fig. 8 is presented in a similar manner. Accordingly, marker 1 indicates the presence of delamination in the copper substrate, and markers 2 and 3 compare whether there is delamination in the pins. The colored areas in red indicate delamination. In this case there is no zone without delamination in the copper substrate. From the study in Fig. 5, we concluded that when the signal passes from a dense medium (epoxy resin) and a thin medium (air), the larger amplitude in the signal spectrum is at the top. This can be seen from the A-scan reading on marker 1. Again, the signal is out of phase 180 degrees.



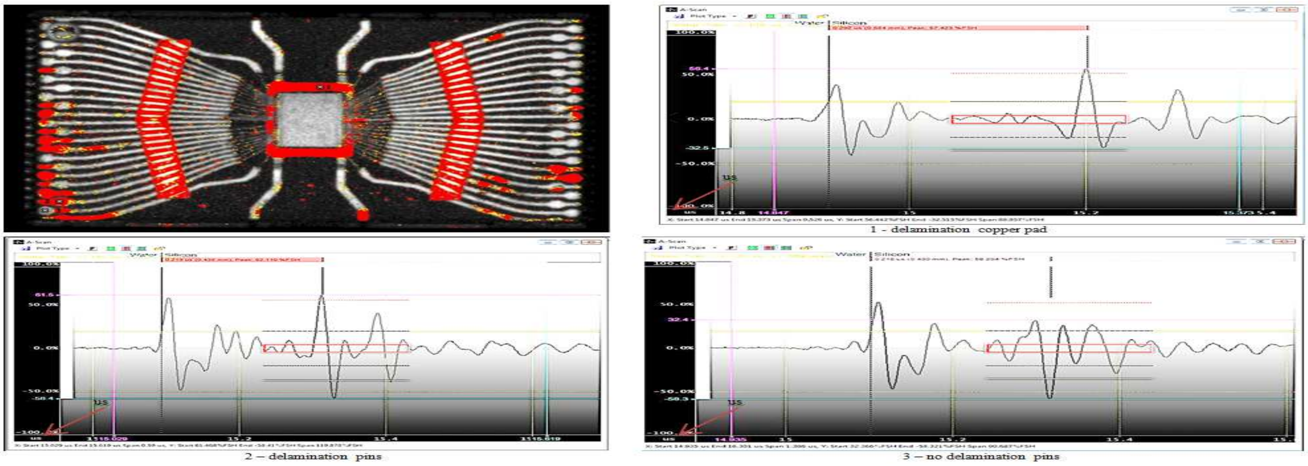
1 – no delamination copper pad

2 - delamination copper pad

3 – no delamination pins

4 – delamination pins

Fig. 7. Integrated circuit #1.



1 - delamination copper pad

2 – delamination pins

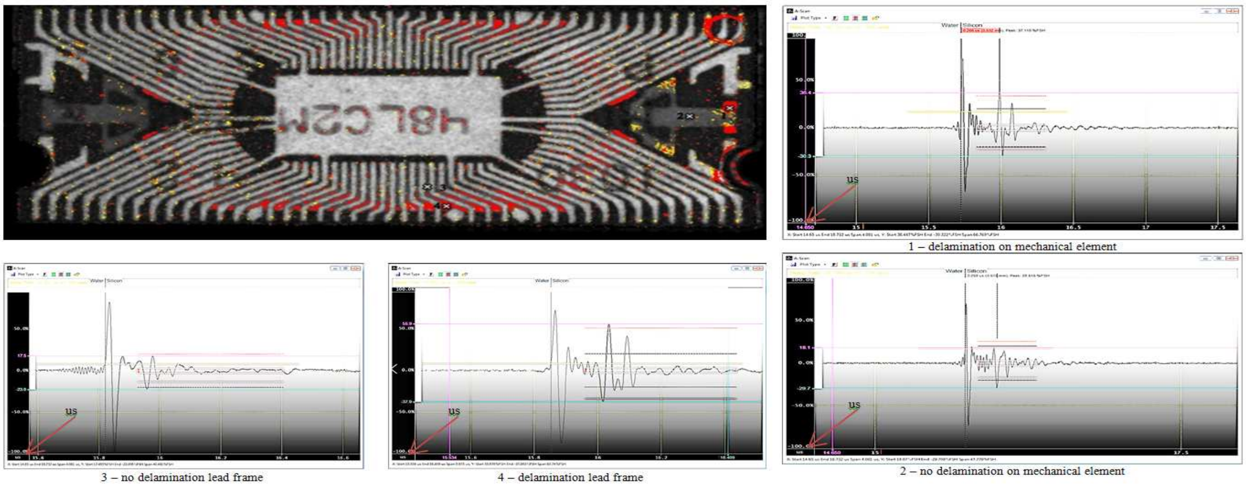
3 – no delamination pins

Fig. 8. Integrated circuit #2.

After applying the above-described types of scans, different images of the examined sample are visualized.

In the same way, the next tested chip shown in Fig. 9 is presented. Respectively, markers 1 and 2 compare whether there is delamination in the mechanical element, and markers 3 and 4 compare whether there is delamination in the lead frame.

The colored areas in red indicate delamination. Again, the dephasing of the signal at 180 degrees can be seen.



1 – delamination on mechanical element

3 – no delamination lead frame

4 – delamination lead frame

2 – no delamination on mechanical element

Fig. 9. Integrated circuit #3.

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We proved that the approach of applying a sequence of A-scan and C-scan with additional setting for color visualization gives reliable results for detecting delamination in semiconductor chips.

Our results are comparable to the results in the work of Yao Qiu and Sujuan Zhang [16] for delamination of pins in ICs. Our accuracy is higher because we are using the RTG of the C-scan for coloring the delamination areas and because we select different adjacent areas for verifying the dephasing (the latter is based on S-scan (transmission scanning)).

IV. CONCLUSION

The applied technique of surface acoustic microscopy for identifying delamination proved to be viable. Our sequence of consecutively applying A-scan and C-scan with RTG option, gives credible results for integrated circuits mounted on PCBs. The achieved results confirm the industrial applicability of surface acoustic microscopy scanning to delamination detection.

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