EXPERIMENT STUDY OF IMPERFECT INTERFACE IN IC PACKAGING

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Abstract

Air gap such as disbond and crack can be successfully detected by ultrasonic testing. But imperfect interface evaluation is still a challenge. The challenge arises from the uncertainty of formation mechanism, boundary condition and acoustical response.

In the paper, samples of structure Die (Silicon)/ Die-attach (Adhesive)/ Lead-frame (Copper), typical in IC packaging, are manufactured with two adhesives, degraded through temperature-humidity cycling, examined by acoustical waveform and C-imaging, and compared to optical microscopy image and failure shear strength.

1 Introduction

The integrated circuit (IC) plastic packaging has structure of mould compound/ Die (Silicon)/ Die-attach (Adhesive)/ Lead-frame (Copper). Thickness of Die/Die-attach/Cu Lead-frame is less than 1 mm. Imperfect interfaces in IC packaging often occur prior to other defect types during fabrication process, and could cause failure in packaging progress and subsequent service. Therefore, the imperfect interface evaluation in IC packaging plays a key role in the reliability testing of IC packaging. Wong et al (2002 gave analysis on imperfect interface of derivation mechanism and factors, and mechanical boundary condition. Cho et al (1997) studied the oxidation of Cu-based leadframe on the interface compound. Kim (1991) analyzed the adhesion role in IC packaging. Sato and Yoloi (2000) visualized melt flow in IC packaging progress. Hashimoto (2003) investigated the bond durability for different adhesives and bonding procedures.

Ultrasonic method is a useful in bond evaluation. Ultrasonic A-scan waveform and C-scan image together with advanced signal processing are employed in IC packaging inspection (Jian et al 2001, Guo et al 2002). Lavrentyev and Rokhlin (1998) studied imperfect contact interfaces between a layer and two solids using ultrasonic spectrum. Although ultrasonic method has been applied with much success in disbond detection, there are still many problems to solve in imperfect interface evaluation. The difficulties arise from lack of exact mathematic description of formation mechanism of imperfect (temperature-humidity cycling, prosperity of Die-attach, Leadframe and packaging materials, solder reflow), and acoustical response on wide varieties of imperfect sources.

2 Methods

2.1 Spring Interface Model

Interface spring model (Lavrentyev and Rokhlin, 1998) has been used to describe imperfect interface condition, where the interface condition is represented by spring stiffness. Reflection coefficient of imperfect interface at normal incidence is given by

$$R_{12} = \frac{Z_2 - Z_1 + i(w/K_n)Z_1 Z_2}{Z_2 + Z_1 - i(w/K_n)Z_1 Z_2} \tag{1}$$

Where Z_1, Z_2 are acoustical impedance of layer 1 and 2, w and K_n are angle frequency of incident waves and normal spring stiffness of interface relating to interface condition respectively. Figure 1 shows reflection coefficient and phase shift of interface at interfaces in IC packaging. Solid and dashed-dotted curves are real part of reflection coefficients while dashed and dotted curves are phase shift. At interface Die/Die-attach ($Z_1 > Z_2$), reflection coefficient increase with interface degradation (decrease in K_n), but phase shift is small and happens in imperfect condition mainly. At interface Die/Lead-frame, reflection coefficient increases with interface degradation from around 0.7 to 1 in amplitude and 0 to π in phase.

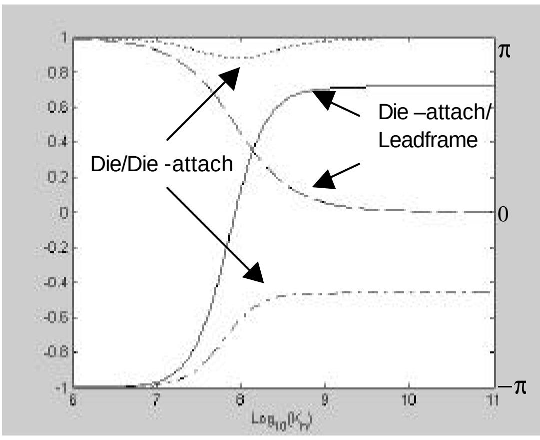

Figure 1 Reflection coefficient

2.1 Sample preparation

Two adhesives are used in sample fabrication. Both are Silver based conductive for bonding in IC packaging. Copper lead frame is of dimension 40*25*0.25 mm, and Silicon Die is of dimension 8*8*0.615 mm. The material properties are shown in table 1. A specially designed mold is designed and manufactured in sample fabrication to keep constant thickness of Die-attach, around 80 micrometers.

Table 1 Material property of structure

	Silicon	Ad1	Ad2	Copper
ρ (kg/m^3)	2279	2652	2180	8920
C_l (m/s)	7892	2525	2231	4520
C_t (m/s)	5505	1449	1210	2142
H (μm)	615	80	80	250

The copper and silicon pieces are washed with soaped liquid, and then with fresh water. After dried with pressed air, they are washed with silicone. After cleaning, copper piece is put in mold, adhesive is employed, and put silicon on. Mold lid put on. Then put mold in oven for curing. Curing process takes 50 minutes at temperature 120 degree according to product instruction.

The fabricated samples are assumed with perfect interface condition. The two kinds of samples experienced different degradation processes. Degradation process of first kind of samples is put in chamber 1 of temperature 0 Celsius degree for 5 seconds, then in chamber 2 of temperature 20 Celsius degree for 5 seconds, then chamber 3 of temperature 100 Celsius degree for 5 second. That is one cycle. The samples can reach the temperature of chamber within 5 seconds. Samples experience 100 cycles per day. To get varied interface condition, samples were divided and experience degradation cycle of 0, 400, 500, 600, 680, 760, 820, 880 cycles respectively. Another kind of samples fabricated by us later, were put in chamber of relative humid of 85% and temperature cycle from –20 to 180 Celsius degree within 8 minutes. Samples are divided into groups with experience of thermo-cycle of 0, 24, 48, 60, 72, 82, 90, 96 hours respectively.

2.3 Acoustical Measurement

Sphere-focus wideband transducer of labeled center frequency 100MHz is used. Its focus labeled length, beam size and active diameter are 3.2 mm, 0.015 mm and 3.2 mm respectively. Samples of varied interface are put in water for C-scan imaging and A-scan waveform acquisition. Ultrasonic waves are incident from Die.

Shown in figure 2 is C-scan image of a sample of first kind. The color map at the left side of each image shows amplitude and polarization of gated pulse with color. If the amplitude of gated pulse increases from 0 to 128, image color will change from black (0) to bright (127). If the amplitude of gated decrease from 0 to –128, the color will change from black (0), yellow to red (-128). Image pair a1 and a2 are measured at same position and after same degradation. Image a1, b1, c1 and d1 are at interface Die/Die-attach, while image a2, b2, c2 and d2 at interface Die-attach/Lead-frame, having experienced degradation cycles of 500,

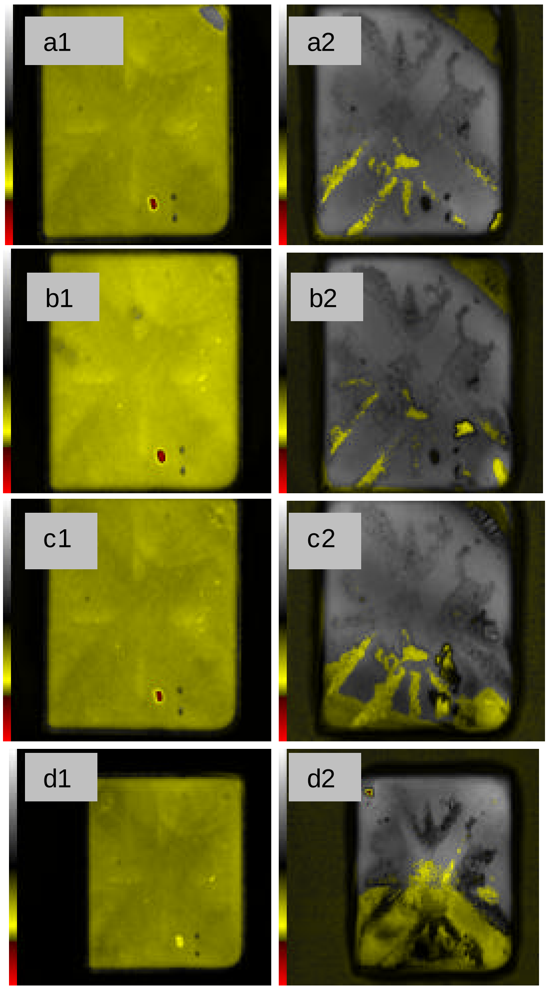

Figure 2 C images of first and second interfaces

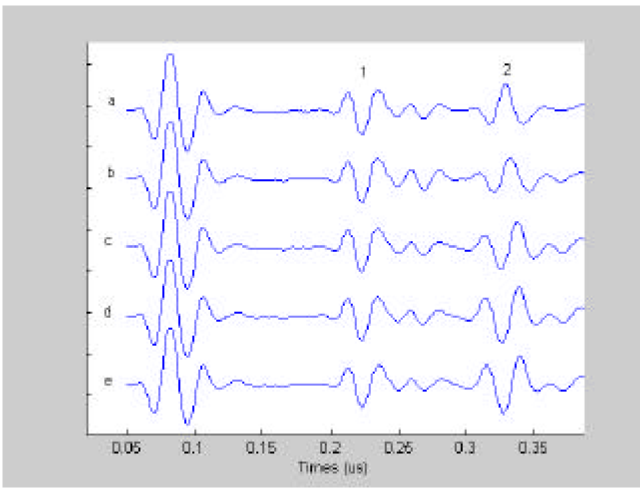

Figure 3 Waveform with interface degradation

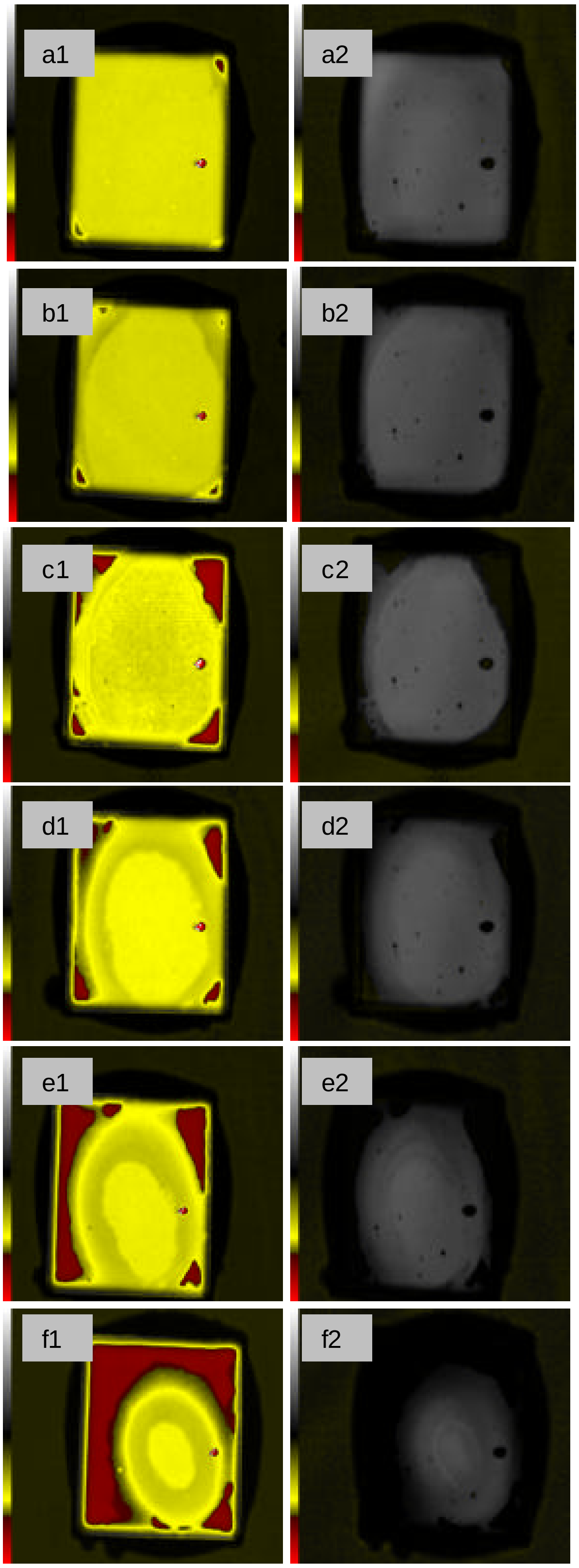

Figure 4 C images of first and second interfaces

600, 680 and 760 respectively. Yellow area (inverse phase) increases from image a2 to d2 indicating increasing degradation. Disbond happened during degradation cycle 761- 820. Shown in figure 3 are echo trains at fixed position. Mark "1" and "2" indicate echoes at interface Die/Die-attach and Die-attach/Lead-frame respectively. Echo trains (a) to (e) correspond to degradation cycle number of 0, 400, 500, 600 and 680 respectively. Echo at Die-attach/Lead-frame change from good bond (a), imperfect (b, c and d) to disbond (e). The echo of b (imperfect) is smaller than that of a (perfect), and the echoes of b, c and d (imperfect) are not same as those of a (perfect) and e (disbond). Imperfect interface evaluation only by echo amplitude might result in incorrect or inaccurate result. The echo shape information must be fully be used. It challenges traditional polarization imaging.

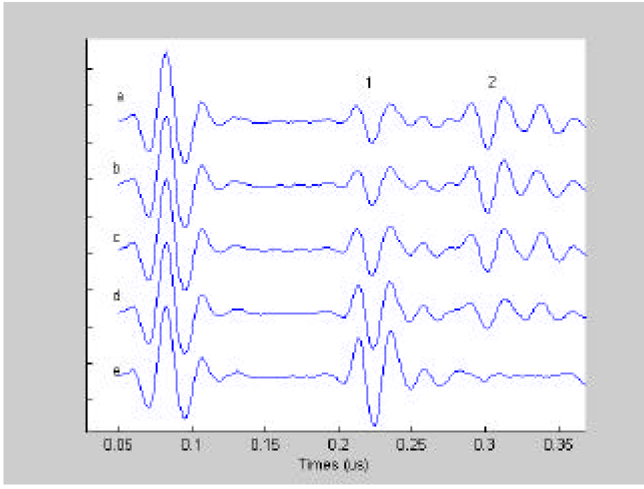

Figure 5 Waveform with interface degradation

Figure 4 shows C images of a sample of second kind. Left and right image columns are at interface Die/Die-attach and Die-attach/Lead-frame respectively. Image pairs a1 and a2, b1 and b2, …, to f1 and f2 correspond to degradation hours of 48, 60, 72, 82, 90 and 96 respectively. Red area grows with degradation form image a1 to f1, and dark area grows from image a2 to f2 because degraded interface Die/Die-attach tend to allow less ultrasonic wave passing through and less ultrasonic wave is reflected from deeper interface Die-attach/Lead-frame and received. Figure 5 shows echo trains at fixed position at interface Die/Die-attach. Echo trains (a) to (e) correspond to degradation hours of 0, 60, 72, 82 and 90 respectively. Echo of interface Die/Die-attach grows steadily with degradation from (a) to (e), while shape doesn't change. Echo at Die-attach/Lead-frame decreases due to degradation of top interface allowing fewer waves to get though, but its shape doesn't vary.

2.4 Failure shear strength

Lead-frame is much bigger than Die in area, As a result, the disbond failure shear strength measurement at interface Die-attach/Lead-frame can be measured more easily than that at interface Die/Die-attach. For the strength measurement a special jig is constructed. Show in table 2 is the average failure shear strength. At each interface condition, 10 samples were used for failure shear strength measurement. The first two rows are results of first kind of samples, and the second two rows are results of second kind of samples.

Table 2 Failure Shear Strength

Cycle No.	0	500	600	680	760
Strength (MPa)	8.6	8.0	7.1	5.6	2.5
Cycle Hrs.	0	60	72	82	90
Strength (MPa)	6.5	5.9	5.5	4.8	3.6

2.5 Optical microscopy image

The disbond samples after failure strength is studied under optical microscopy. Figure 6 is optical microscopy image of Die-attach surface contacting Lead-frame of a sample of first kind. Dark shadows in figure 6 are cavities. Die-attach remaining is found in Lead-frame surface at position corresponding to cavity in Die-attach surface. Such existences tell the bond strength at interface is bigger than cohesive strength within Die-attach. So the cavities are indication of good bond line condition originally. It mightn't indicate good bond at time instance of disbond action, but at least it doesn't imply bad bond.

It is very interesting that such cavities distribute mainly along the cross in C-image shown in figure 2. And imperfect condition happens also along the cross area too. The cross shape in C image is formed during curing phase, and might be because of heat transferring within Die-attach between Die and Lead-frame depending on manufacturing mold, properties of Die-attach, geometry of Die and applied temperature. It should be noted that such cross doesn't appear in C images of 2nd kind of sample in figure 4.

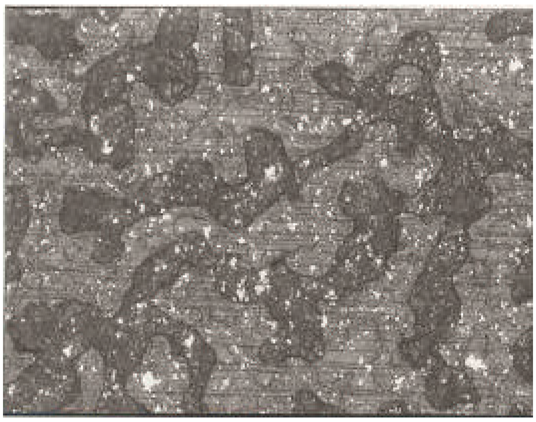

Figure 6 Optical microscopy of disbond samples

3 Conclusion and discussion

Two adhesives are used to fabricate samples of structure Die (Silicon)/ Die-attach (Adhesive)/ Lead-frame (Copper), typically in IC packaging. Although both adhesives are silver-based for use in IC packaging, samples of 1st kind degrade and disbond automatically during thermo-cycling at interface Die-attach/Lead-frame while samples of 2nd kind degrade at both interfaces occurring from edge gradually to center, but disbond automatically at interface Die/Die-attach.

Acoustical response with interface degradation at interface Die/Die-attach and Die-attach are different. At interface Die/Die-attach, reflection wave increases with interface degradation steadily in amplitude while shape nearly doesn't change. At interface Die-attach/Lead-frame, although echo of disbond is bigger than that of imperfect and perfect, echo of imperfect may be either bigger or smaller than that of perfect. So echo amplitude can't be used to evaluate imperfect interface alone. However, echo shape changes with interface degradation, and can be used to evaluate imperfect interface.

The cavity in Die-attach surface might be indication of good bond line. The remaining of Die-attach in Lead-frame indicates the force of interface bond line bigger that cohesive strength within Die-attach.

In the study, acoustical response reasonably agrees with degradation extent as well as failure shear strength. It demonstrates that acoustical testing is still effective method in imperfect interface. But both amplitude and shape information of ultrasonic interface echo should be used to give good evaluation. Quantification of imperfect interface is still a challenge, and advanced signal processing will help to find the solution (Jian and Guo, 2002).

Acknowledgement

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