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Scanning Acoustic Microscopy Investigation of Adhesive Cure Degree

Jakob Janting[a], Dirch Hjorth Petersen[b]

[a]DELTA Danish Electronics, Light & Acoustics, Venlighedsvej 4, DK-2970 Hoersholm, Denmark
e-mail: jaj@delta.dk, Fax: +45 72 19 40 01,URL: http://www.delta.dk
[b]MIC, Building 345, DK-2800 Lyngby, Denmark

1. Introduction

The motivation for this work has been to gain a fast and reliable Compression UnderFill (CUF) based flip-chip interconnection process for MEMS components. In this process electrical contact between bumps and pads is established mechanically by the high curing shrinkage of the underfill (fig. 1).

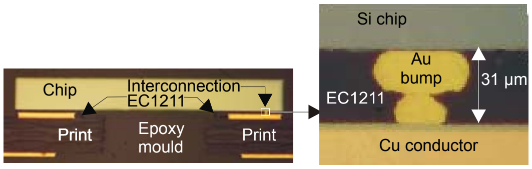

Fig. 1. Cross section through bump – pad electrical interconnection between flip-chipped MEMS pressure sensor chip and print.

Although the studied CUF material EC1211 has been cure characterised by Differential Scanning Calorimetry (DSC), the actual temperature environments experienced by the underfill in the flip-chip process might be much different than expected. When trying to run the process as fast as possible it could be that the CUF is not uniformly cured. Using DSC for evaluation is tedious and destructive because samples of the CUF will have to be taken out for the analysis. A better alternative is Scanning Acoustic Microscopy (SAM). Here detection of cure degree relies on the big mechanical (stiffness E) differences between cured and uncured material and the great advantages are that the inspection is 2D and non-destructive.

2. Results

Two approaches for determining the degree of CUF curing degree have been studied. First it was attempted to determine the cure degree from differences in sound speed. This requires knowledge about the CUF thickness and reflection time delay between the top and bottom interfaces. The method turns out not to be feasible for typical CUF thicknesses (30 µm – 70 µm) because of too low depth resolution. Even with thick bond lines and therefore well separated reflections from top and bottom interfaces it is difficult to determine the speed with sufficient accuracy because the waves do not have the same form and the points on the waves to measure from / to are not well defined. Though, using C-scan grey tone values good results can be achieved.

2.1 Acoustic impedance calculations from C-scan grey tone values

The advantage of this approach compared to the speed of sound method is that only the degree of reflection at the same depth between different materials e.g. cured / uncured CUF is measured. Depending on the situation two different calculations can be used to determine the acoustic impedance of a material placed under another:

- The acoustic impedance Z_1 of the top material is unknown.

Calculation of Z_x is based on the approximation that R_{12} has a linear dependence on Z_2. Then Z_x is given by:

$$Z_x = Z_b + (g_x - g_b)\frac{Z_b - Z_a}{g_b - g_a} \tag{1}$$

i.e. to determine Z_x two reference acoustic impedances Z_a, Z_b for materials placed under the top material are needed. Their grey tone values and the value for the studied material x are measured in the C-scan picture.

- The acoustic impedance Z_1 of the top material is known

Calculation of Z_x is based on the linear dependence of g_x on R. Then Z_x is given by:

$$Z_x = Z_1 \frac{g_a(Z_a + Z_1) + g_x(Z_a - Z_1)}{g_a(Z_a + Z_1) - g_x(Z_a - Z_1)} \tag{2}$$

i.e. to determine Z_x in this case only one reference acoustic impedance Z_a for a material placed under the top material is needed. Again the corresponding grey tone value g_a and the value for the studied material g_x is found in the C-scan picture.

2.1 Test 1: Determination of acoustic impedance of isopropanole

To test the methods of determining acoustic impedances isopropanole, air, water, and adhesive were placed between two microscope slides (glass) with the purpose of determining the acoustic impedance of isopropanole. Isopropanole and air were entrapped in small aluminum pans used for DSC measurements.

The sample was put in the SAM inspection vessel. The vessel was filled with water and a gate was placed for a C-scan covering the whole reflected wave from the bottom interface of the microscope slide. The C-scan was performed and grey tone values determined with KSI WINSAM 200 software. The acoustic impedance as determined from (1) and (2) are shown in table 1. Good agreement with tabulated values is found in both cases.

Table 1. Acoustic impedance of isopropanole.

Z_x(isopropanole) / MRayl		
Equation 1	Equation 2	Table
0.95	0.97	0.92

2.2 Test 2: Flip chip with CUF

Cured / uncured epoxy EC1211 CUF material between a 2 cm x 2 cm x 0.35 mm test flip-chip with approximately 30 µm bumps and a Printed Circuit Board (PCB) were studied. Again to get the grey tone values a gate is placed covering the whole reflected wave at the chip / CUF / PCB interfaces. The acoustic impedances are shown in table 2. Good agreement is observed between the determined acoustic impedance and tabulated typical values for epoxy.

Table 2. EC1211 and typical epoxy acoustic impedances.

EC1211 acoustic impedances / MRayl		
Equation 2		Table (typical epoxy)
Z_x(cured)	Z_x(uncured)	Z(cured)
3.0	1.8	3 - 4

3. Discussion

The speed sound in the [111] direction of single crystalline silicon is 8.4 µm/ns. i.e. sound travels forth and back in the 350 µm flip-chip within 83 ns. The broad gate for grey tone determination starts about 20 ns later. Low pre-determined threshold level for surface detection can be the explanation for this. Further the explanation might be the roughness of the unpolished top side of the chip. The speed of sound in cured epoxy is around 3 µm/ns. The wave length at 50 MHz is 60 µm. With a bump height of 30 µm the reflections from the chip / EC1211 and EC1211 / print interfaces with a time delay of around 20 ns cannot be resolved. Though, this interference from the EC1211 / print interface reflection is not critical as the two materials are acoustically well matched, which means that most of the sound is transmitted. This is also evidenced by the fact that A-scan wave forms in the flip-chip test case resembles the A-scan wave form in the isopropanole test case where the thickness of the adhesive is 2 mm.

4. Conclusion

It has been demonstrated that SAM can be used to determine acoustic impedances of materials in layered structures. Two equations have been verified. The usability of one equation depending on knowledge about the top layer acoustic impedance and only one other acoustic impedance of a material in the same depth as the analysed one has been demonstrated on a CUF flip chip with 30 µm bump height. A clear difference between cured / uncured CUF can be observed.

5. Acknowledgement

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