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THE QUALITY OF BGA SOLDER JOINT WITH UNDERFILL

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Anotace:
Tento článek se zabývá výzkumem mechanických vlastností (síly ve střihu) u pouzdra s kulovými vývody (BGA) s a bez výplně mezi pouzdrem a nosnou deskou (*underfill*) na substrátech FR4 a Al2O3. BGA pouzdro zapájené na FR4 (ENIG) dosahovalo větší hodnoty střihové síly než BGA zapájené na keramickém substrátu s vodivou tlustou vrstvou. Výsledky experimentů byly použity pro validaci virtuálního modelu a simulací v programu ANSYS Workbench. Tyto simulace budou použity pro predikci termomechanického namáhání BGA pouzder zapájených na keramickém substrátu a organickém substrátu FR4.

This paper deals with investigation of mechanical behavior (shear strength) of soldered BGA package with and without underfill on FR4 and Al2O3 carriers. BGA soldered on FR4 (ENIG) had higher value of shear strength than BGA soldered on alumina substrate with conductive thick film layer. Results was used for validation of virtual model and simulation in ANSYS Workbench. This simulation will be used for prediction of thermomechanical behavior of BGA packages soldered on alumina substrates and on organic substrates FR4.

INTRODUCTION

Nowadays there is a great development in microelectronics technology, especially in the electronic packaging. The main requirement for IC´s is high performance but small size. The interaction and combination of these requirements generates big complication from the perspective of thermal management and thermal stress in the solder joint. In fine pitch packages and wafer level packages is used a small amount of solder. It´s not possible full compensate thermal stress generated by a different coefficient of thermal expansion, which creates between substrate, components and package. For this reason is necessary to use a substrate with as similar as possible TCE as package, to avoid thermal stress in the solder joints. Most faults in the soldered joints are formed as cracks arising due to thermal stress. For this complication was created underfill. Underfill is filler material between package and substrate. Underfill adds the missing strength of joint. Fig. 1a shows BGA ball without underfill. Different TCE generates thermal stress and causes cracks in solder joints. Fig. 1b shows BGA ball with underfill and can be seen compensation in shear. Even in this case bend can be seen at the edge of the substrate due to the expansion of the substrate.[1], [2], [3]

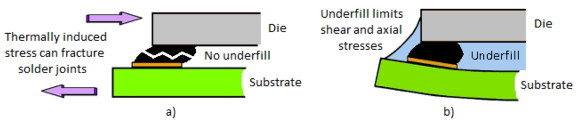

Fig. 1: Effect of thermal cycling on BGA ball a) without underfill b) with underfill [4]

The four most used underfills are capillary (CUF), no flow (NUF), wafer-lever underfill (WUF) and molded underfill (MUF).
The first one UCF, is the most common filling material already for decades. This type is dispensed and applied retrospectively, ie. after soldering or connection. After coating is cured at a temperature lower than the soldering temperature. The advantage of this type is less thermal stress because repairs are possible at lower temperatures than NUF about 150 ° C, depending on type. Thus this type is used for expensive and large chips.
Next type is NUF. This type is pre-dispensed. Underfill is dispensed before connection or soldering and cured with same temperature profile like soldering. This is the biggest advantage of NUF type because is possible to save many technological steps, time and energy in serial production. The main problem is higher TCE than CUF underfill. This generates mismatch in TCE of the substrate, package and underfill. Next disadvantage is higher chance to generate air trap in underfill due to higher viscosity. NUF underfill is used for cheap and small chips.

Another type is the newest technology WUF. Underfill for wafer level packages WUF is a very complex technology with big demands on the material. This type undergoes by the biggest development.[1], [2], [3]

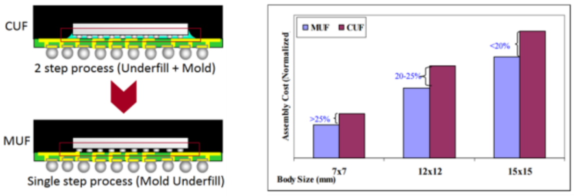

Fig. 2: Difference between CUF and MUF technology [5]

The last type is MUF. The main advantage is a lower price than CUF. Fig. 2 shows main difference between CUF and MUF underfill technology. There can be seen that MUF have simpler technology process than CUF. Because CUF technology is made in two steps: underfill and mold. But MUF technology consists of one step: mold-underfill. Fig. 2 shows difference in price too.

METHODOLOGY

Samples parameters and fabrication

Two cases of samples were fabricated, FR4 and alumina substrates. Pattern is shown in figure 3. There are marked positions for BGA packages assembly. Both substrates had the same conductive pattern. Solder pads were designed with defined solder mask (SMD). Diameter of solder mask opening was 400 µm. Surface finish for FR4 was ENIG. Alumina had solder pads made from conductive thick film layer. All parameters of those substrates are described in Tab. 1.

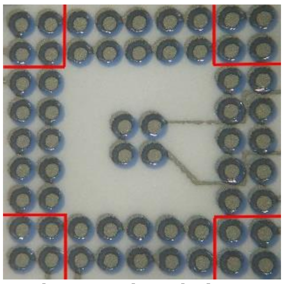

Fig. 3: Alumina substrate with marked positions of place for BGA assembly

Tab. 1: Parameters of test samples (carriers)

Substrate	Thickness [mm]	Surface finish	Solder pad size [µm]
FR4	1,5	ENIG	400
Al2O3	0,625	AgPd thick film	400

Dummy BGA was made with dimensions 4 x 4 mm and four solder pads. Solder pads were defined by solder mask (SMD) with diameter 400 µm. Base material was FR4. Surface finish of solder pads was the same like carrier made from FR4, ENIG. Thickness was 1,5 mm. Samples of dummy BGA with soldered solder ball is shown in figure 4.

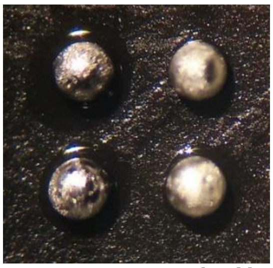

Fig. 4: Dummy BGA with solder balls

Connection between dummy BGA and carrier (FR4 or Al2O3) was realized by SAC305 solder balls (NeVo®). There was used ROL0 flux for better solderability (NeVo®).

Loctite 3536 (Sanmina – SCI) was used as underfill for BGA packages. This underfill is capillary flow what determines the method of application. Cure time for this type of underfill was 5 minutes in 120 °C.

Process flow of sample fabrication:

1. Application of solder flux (ROL0) on solder pads of dummy BGA.
2. Assembly of solder balls (SAC305) on solder pads of dummy BGA.
3. Reflow of solder balls (SAC305) on solder pads of dummy BGA.
4. Assembly of dummy BGA on carrier (FR4 or Al2O3).
5. Soldering dummy BGA on carrier (FR4 or Al2O3).
6. Application of underfill with capillary flow effect (Loctite 3536).
7. Curing of underfill (120 °C / 5 minutes).

Figure 5 shows soldered BGA (red square) on alumina with underfill.

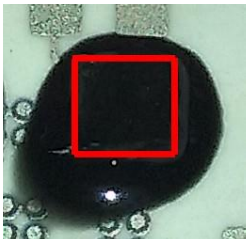

Fig. 5: Soldered BGA on alumina with underfill

Test equipment and parameters

Soldering of solder ball and assembly of BGA were provided by reflow system Essemtec RO300FC. Temperature profile was designed following a recommendation for soldering of solder alloy SAC305 with ROL0 flux.

As it was mentioned in the beginning of this article, shear strength was the observed parameter of soldered BGAs. For testing was used DAGE PC2400. This machine can provide shear and pull test for solder joints and bonding wire. Parameters of shear test is described in Tab. 2. Shear tool had 4 mm width, which is the same like dimension of dummy BGA.

Tab. 2: Shear test parameters

Test speed	300 µm/s
Test height	300 µm
Over travel	50 µm

EXPERIMENTAL PART

Results of shear tests for FR4 and alumina carries are shown in figure 6. BGA soldered on FR4 had higher shear strength than BGA soldered on alumina. This behaviour could be explained by effect which is called leaching. Leaching is type of diffusion of thick film pad (conductive thick film layer) to melted solder. This hypothesis is based on failure mode (pad lift) which was occurred during shear test.

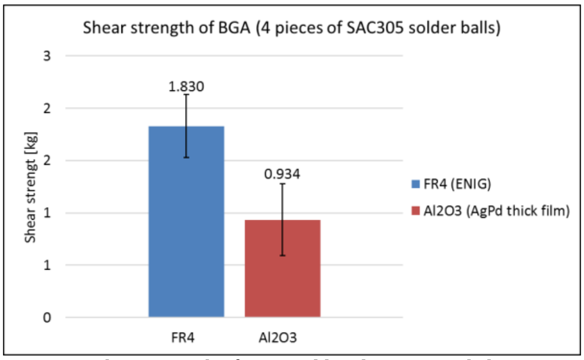

Fig. 6: Shear strength of BGA soldered on FR4 and alumina substrates

There was also observed shear strength for BGA soldered on alumina. Measured value is shown in figure 7.

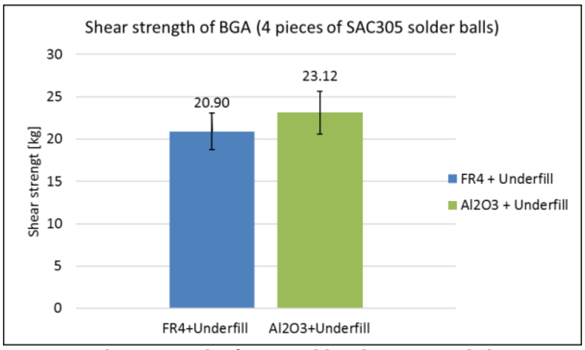

Fig. 7: Shear strength of BGA soldered on FR4 and alumina substrates with underfill

SIMULATION PART

The simulation software is useful tool for finding mechanical behavior of structures. In this case was used Ansys Workbench Structural. The main goal was found out influence of underfill to structure. This simulation is theoretical behavior of this structures and shows Equivalent.

Stress at solder balls with 100N shear force from the left to the right. Figure 8(left) shows equivalent stress at solder balls without underfill. Substrate was Al2O3 and package was represented by 4 x 4 mm FR4 substrate. Value of stress was 636 MPa and the biggest stress was at outside edge of the solder balls. It was caused by shear force and it´s not possible compensation of this force. Figure 3 shows equivalent stress at solder balls with underfill. The shear force same in this case 100N.The value of the stress was 21 MPa and the biggest stress was at inside edge of the solder balls. It caused due to underfill. Underfill filled internal section of the package rather BGA balls and the whole assembly behaved as one part. Difference was thirty times between substrate with underfill and substrate without underfill. This value indirectly copy experimental shear test. The substrate without underfill was torn about 0,934 kg compared to that substrate with underfill was torn with 23,12 kg. Final impact of underfill was enormous.

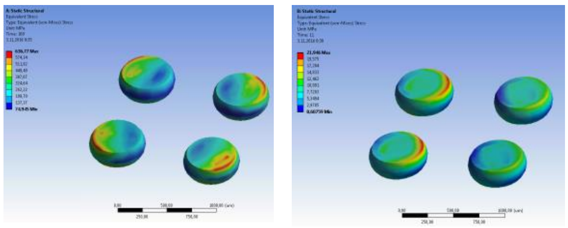

Fig. 8: Equivalent stress at solder balls without underfill (left) andwith underfill (right)

CONCLUSIONS

Results from experimental part are briefly described:

- SAC305 solder balls soldered on FR4 PCB with ENIG surface finish had higher shear strength (1,83 kg) than solder balls soldered on AgPd thick film pad (0,934).
- BGA with underfill had shear strength 23,12 kg.

In simulation part, there were used all obtained results from shear tests for verification and optimization of simulation/model parameter settings. Virtual model and simulation was established for the related work.

Next investigation will be focused on reliability test. For this purpose, there is suitable thermal cycling followed by shear testing. Obtained results could help in usage of underfill in hybrid integrated circuit (alumina with thick film pattern).

ACKNOWLEDGEMENTS

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