# Influence of Material Combinations on Delamination Failures in a Cavity-Down TBGA Package

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***Abstract*—In this study, we have examined the occurrence of different failure types depending on the compound and die-attach material choice in a cavity-down tape ball grid array (TBGA) package. Qualification of the different products is performed by temperature cycle tests to trigger the different failure modes. Samples are decapped to examine the occurrence of passivation crack, wire shift, and/or wire break. Scanning acoustic microscope measurements are performed to examine the occurrence of delamination. Meanwhile, a parametric three-dimensional finite element model is developed to predict the delamination driving stresses for the different material combinations in the cavity-down TBGA package. In some combinations of compound and die-attach, the package performed poor with only one combination without failures. The results of the finite element calculations indicated the possibility of interfacial delamination for different material combinations. Our results show that the reliability of the cavity-down TBGA package is strongly depending on the material combinations, and the developed simulation models can be used to assess the possibility of delamination failures as the consequence of using different material combinations. Using these simulation techniques, cost- and time-expensive reliability tests can be reduced to a minimum.**

***Index Terms*—Delamination, design and test for reliability, die-attach material, tape ball grid array (TBGA) package.**

## I. INTRODUCTION

MATERIAL choices are of major importance for reliability of micro-electronic packages. Moreover, the difference in coefficient of thermal expansion (CTE) of the different packaging constituents is one of the determining factors for its thermo-mechanical behavior. Making the wrong material choice may result in various kinds of failures, such as passivation crack, wire shift, and/or wire break. There is evidence that these three failure mechanisms are related with the occurrence of delamination at the integrated circuit (IC) and compound interface.

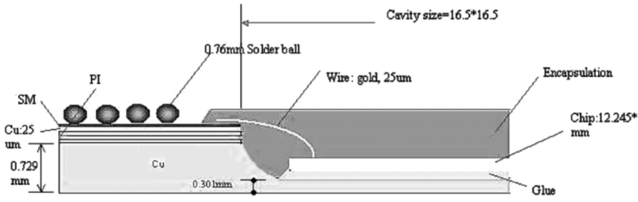

Fig. 1. Cross section of a cavity-down TBGA package.

TABLE I
INDICATION FOR BILL OF MATERIALS (BOM)

| | **Compound Material** | |
|---|---|---|
| **Die-attach Material** | Type 1 | Type 2 |
| Type a | *BOMA* | *not done* |
| Type b | *BOMB* | *not done* |
| Type c | *BOMC* | *BOME* |
| Type d | *BOMD* | *BOMF* |

TABLE II
OBSERVED FAILURE INDICATION AFTER TESTING WITH PRECONDITIONING AND 1000 TMCL CYCLES

| **BOM** | **Observed Failure** |
|---|---|
| A | Serious Corner Delamination, Passivation Crack, Wire Ball Shift, see Figure 2 |
| B | Corner Delamination, Passivation Crack, Wire Ball Shift / Lift, see Figure 3 |
| C | Serious Delamination, Passivation Crack, Wire Ball Shift, see Figures 4-5 |
| D | Serious Delamination, Passivation Crack, Wire Ball Shift, see Figures 4-5 |
| E | None, see Figure 6 |
| F | Delamination, No Passivation Crack, Wire Bond Break, see Figure 7 |

IC packages subjected to thermal loads and/or moisture during processing and testing are vulnerable to delamination at all possible interfaces [1]–[3]. Prediction of the initiation and propagation of interface delamination, as well as the response of the package to the delamination is vital for the micro-electronic industry [4]. Studies have been performed to calculate interface delamination, based on linear fracture mechanics [5] and micro-mechanics [6], [7] approaches. These studies have found that differences in coefficients of thermal and moisture

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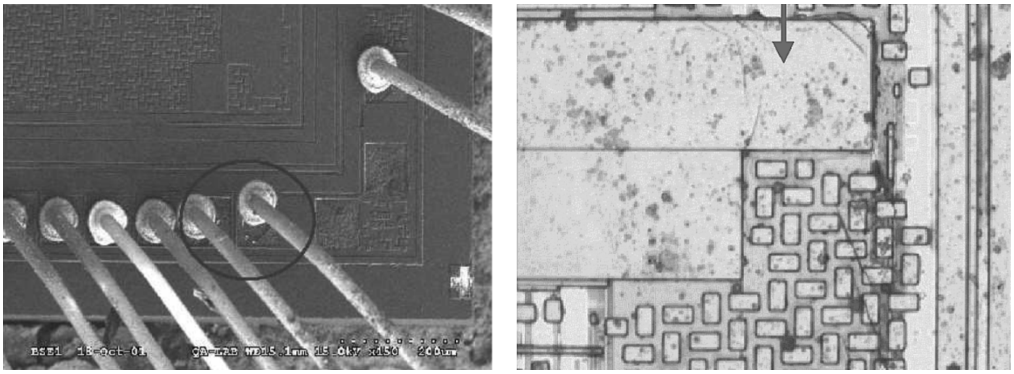


(a) (b)

Fig. 2. BOMA: (a) ball bond shift and (b) passivation crack after 1000 TMCL cycles.

expansion are the driving factors for interface delamination in micro-electronic packages.

Cavity-down tape ball grid array (TBGA) was developed and patented by VLSI in 1995 [8]. In comparison with a normal BGA, this package's substrate is a 1-Cu layer flexible substrate laminated to a thick heatslug so as to enhance the thermal performance. Potting material is used to encapsulate the die area instead of over-mold it. The typical structure of this package is shown in Fig. 1. Based on the experience of this specific package with regular materials, assembly houses and material suppliers continue their cooperation to develop green material solutions for this package to fulfill the thermal and thermo-mechanical demands. Since no solution is available at the time, qualifications tests are performed for different compound and die-attach material combinations. A parametric three-dimensional (3-D) finite element model (FEM) is constructed to calculate the driving stresses thereby predicting the reliability of these different material combinations. The FEM results will enable an improved interpretation of the process and product qualifications needed to qualify manufacturing processes, and to improve the lifetime and successful operation of the product [from ITRS 2001 roadmap].

## II. PRODUCT QUALIFICATION AND OBSERVED FAILURES

Six different material combinations for the cavity-down TBGA package are selected for qualification tests. Qualification data from subcontractor companies for this package are also available [9], [10]. The bill of materials (BOM) is indicated in Table I. The package features a cavity size of $16.5 \times 16.5$ mm$^2$, with an IC size of $12.2 \times 13.4$ mm$^2$. Standard tests based on general quality specifications (GQS) for micro-electronic packages are performed, including moisture sensitivity level tests (MSL), temperature cycling tests (TMCL), etc. Notice that for the TMCL test, a preconditioning step is proceeded inducing moisture to the product, to test the effect of moisture driven delamination on other types of failures. At several steps during the process, scanning acoustic microscope measurements (SAM) are performed. After manufacturing of the package, construction analyses are performed to indicate any geometrical mismatch. For all BOMs, this construction analysis showed no abnormalities.

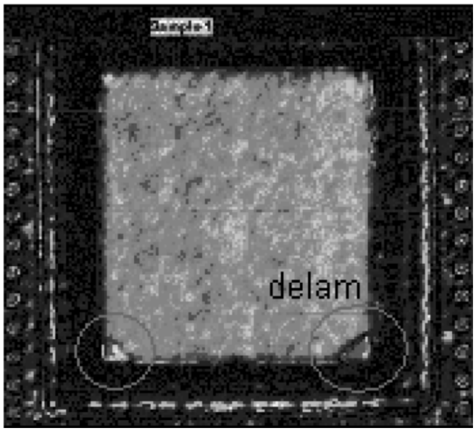


Fig. 3. BOMB: Corner delamination after 1000 TMCL cycles.

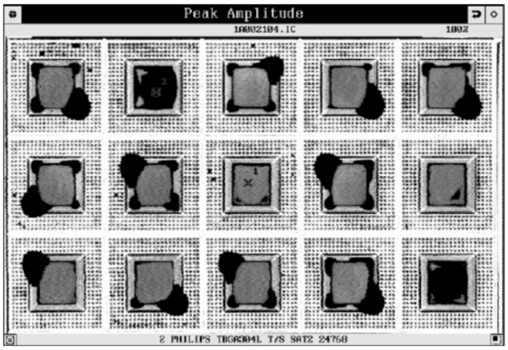


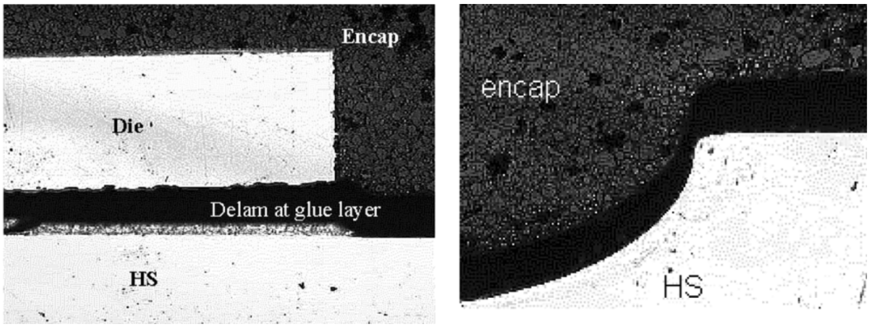
Fig. 4. Typical through-scan detection for BOMC and D.

For all BOMs, samples are taken after the GQS testing and inspected for failure occurrence by:

1) visual inspection to observe global cracks;
2) SAM measurement for delamination;
3) decapping to observe i) passivation cracks, ii) wireball shift, and/or iii) wirebond break.

The results of the inspections are listed in Table II. Details are described as follows.

For BOMA, failures are detected after 500 and 1000 TMCL cycles. The failure modes are corner delamination, passivation crack, and wire ball shift (see Fig. 2).



(a) (b)

Fig. 5. Typical (a) glue/die and (b) encapsulant/heatslug delamination after precondition and 1000 TMCL cycles for BOMC and D.

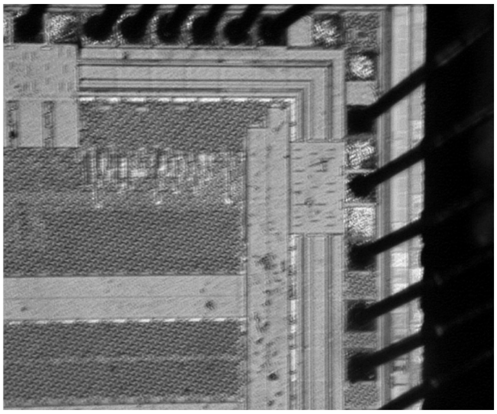


Fig. 6. Typical die surface condition of BOME samples after TMCL 1000 cycle. No crack observed.

For BOMB, the result showed that similar defect modes, including corner delamination and ball lift, as found in the BOMA package, are found. Fig. 3 shows the delamination in the two lower corners at the IC–compound interface. The delaminated area is correlated with the occurrence of passivation cracks in the IC.

After precondition, no matter MSL level 3 or 5, a common failure mode happened for both BOMC and BOMD. Through SAM, serious delamination, not only at corners but also extending at the complete package, is detected for almost all samples (see Fig. 4). Cross-sectioning is used to further identify the failure modes after subsequent 1000 TMCL cycles. Some failure modes, including i) glue/die delamination, ii) glue bulk, iii) encapsulant/heatslug delamination, and iv) substrate layers delamination, are detected by cross-sectioning (see Fig. 5).

All sub-groups of BOME passed preconditioning and 1000 TMCL cycles. No delamination is found at all interfaces. In all parts of the package, including glue, compound, no defects are detected. One remarkable point is that after TMCL cycling, there is no passivation crack or ball bond shift. The typical die surface condition is as shown in Fig. 6.

For BOMF defects (delamination, circuits open) are detected after testing (preconditioning and 1000 TMCL cycles) and wire bond break is found by decapping failed samples (see Fig. 7). In addition, there is no passivation crack or ball bond shift at the samples after 1000 TMCL cycles.

The following can be concluded from the reliability data:

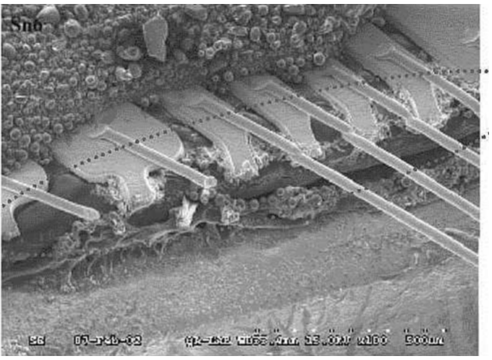


Fig. 7. Wire break is found in BOMF after preconditioning.

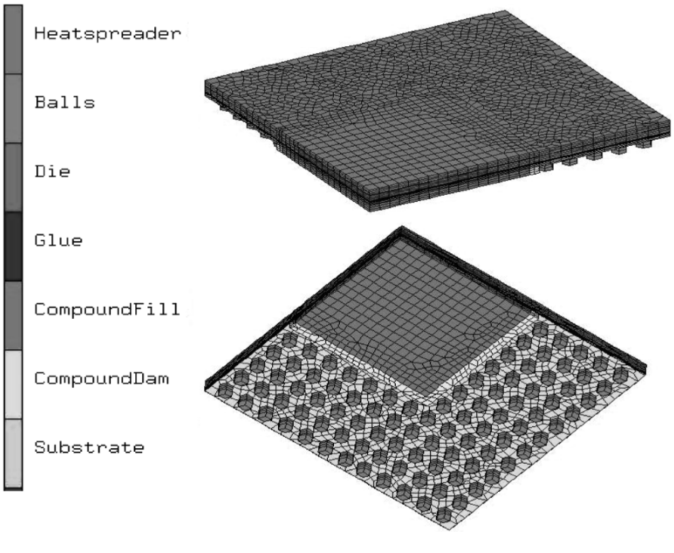
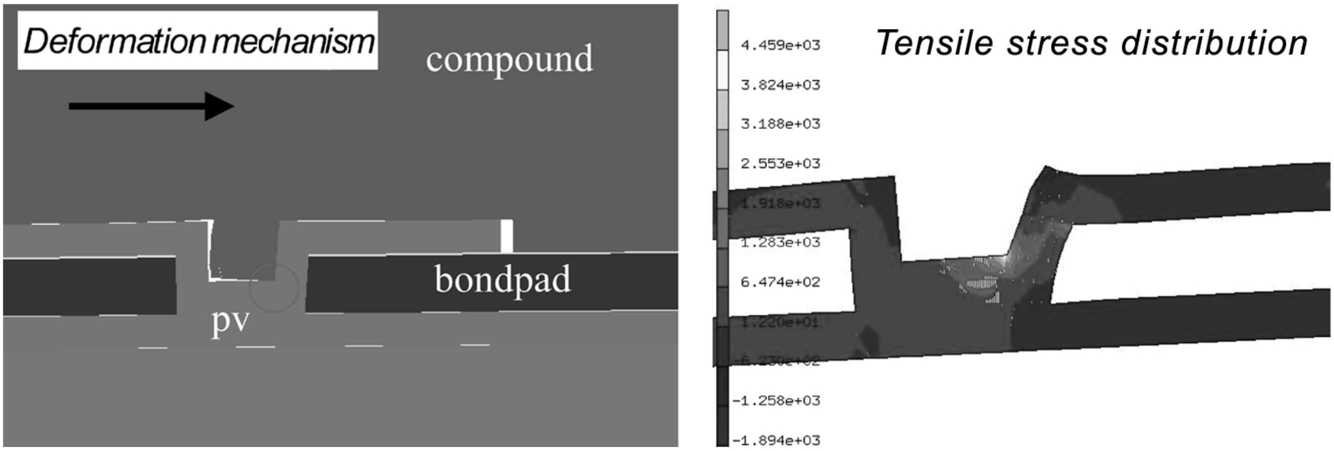


Fig. 8. The $1/4$ FE model for the cavity-down TBGA.

1) for all BOM combinations, except for BOME, different failure modes are detected;
2) there is evidence that passivation cracks are associated with the occurrence of delamination. All cracked ICs showed delamination, and in only BOMF delamination is found without any cracks;
3) ranking from worse to best turns out to: BOMA (worst)—C/D-B-F-E (best).



(a) (b)

Fig. 9. (a) Local deformation between the compound and the top passivation (pv) layers of the IC and (b) resulting stress distribution. The figure shows that the delamination at this interface provokes the compound to push the top layer structure. Increased stress levels are the results and a crack will occur in the indicated area (circle).

TABLE III
TYPICAL MATERIAL PROPERTIES FOR THE DIE-ATTACH AND COMPOUND MATERIALS

| **Material** | **Tg** [°C] | **$CTE_1$** [ppm/°C] | **$CTE_2$** [ppm/°C] | **Young's Modulus** [MPa] |
|---|---|---|---|---|
| **Die-attach** | | | | |
| Type a | -10 | 72 | 170 | 860 @ 25°C |
| Type b | 60 | 70 | 180 | 500 @ 25°C |
| Type c | 15 | 60 | 180 | 2500 @ 25°C |
| Type d | 33 | 65 | 114 | 3060 @ 25°C |
| **Compound** | | | | |
| Type 1 | 169 | 17 | 72 | 1000 @ 25 degC |
| Type 2 | 145 | 17 | 67 | 1300 @ 25 degC |

## III. RELIABLE FEM

Parametric 3-D FEM models representing the cavity-down TBGA package are developed. Because of symmetry, only one quarter of the package is modeled. The effect of element sensitivity is explored by using several distributions and/or discretizations. In total, the model consists of approximately 20 000 eight-noded elements (see Fig. 8). Appropriate boundary conditions are used along the symmetry axis. The single crystal silicon die is modeled as temperature independent anisotropic [11]. For the compound and die-attach constituent, supplier info, and/or temperature dependent properties are used [11]. For the copper heatspreader material, ideally plastic model is assumed. For the Upilex substrate, temperature dependent properties are used. Table III lists some typical material properties for the different die-attach and compound combinations. Based on the data listed in the table it is hard to estimate which combination would perform the best.

For the loading in the model, the complete time and temperature profile during manufacturing is used in the simulations, followed by the GQS conditions.

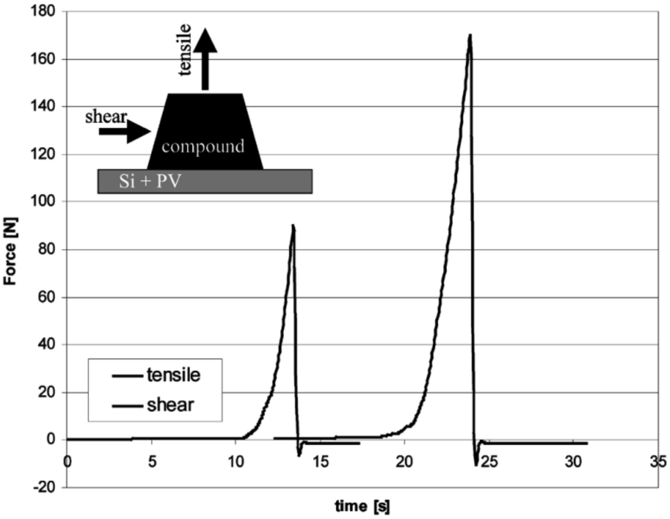


Fig. 10. Typical force versus time recording of a button shear/pull experiment to assess the strength of the compound–passivation interface.

To develop reliable and efficient thermo-mechanical prediction models for the product/process designs of electronic packaging, various justified simplifications and assumptions are needed. In this paper, the following simplification and assumptions are used.

1) The warpage/stress free state is assumed for the silicon die, diepad, glue, heatspreader, and substrate at 150 °C. The choice for this temperatures is based on curing measurements for the die-attach. For the encapsulate a warpage/stress free temperature of 170 °C is assumed, which is the processing temperature for the compound. For the solder balls, a warpage/stress free temperature of 183 °C is assumed, which is the temperature of eutectic solder to solidify.
2) Isothermal loading conditions are used for the modeling of both the packaging processes and GQS testing conditions. This assumption is valid since thermal cycle dwell times are 15 min, times where steady state thermal distributions are well reached.

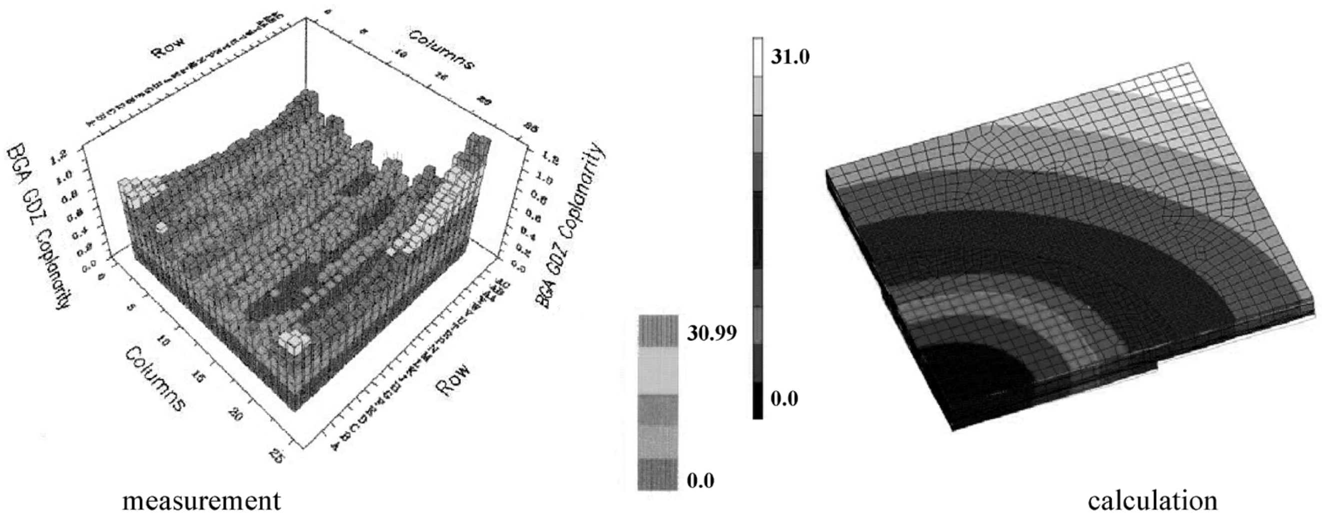


Fig. 11. Example warpage at 25 °C of measurement (top) and FE model (bottom).

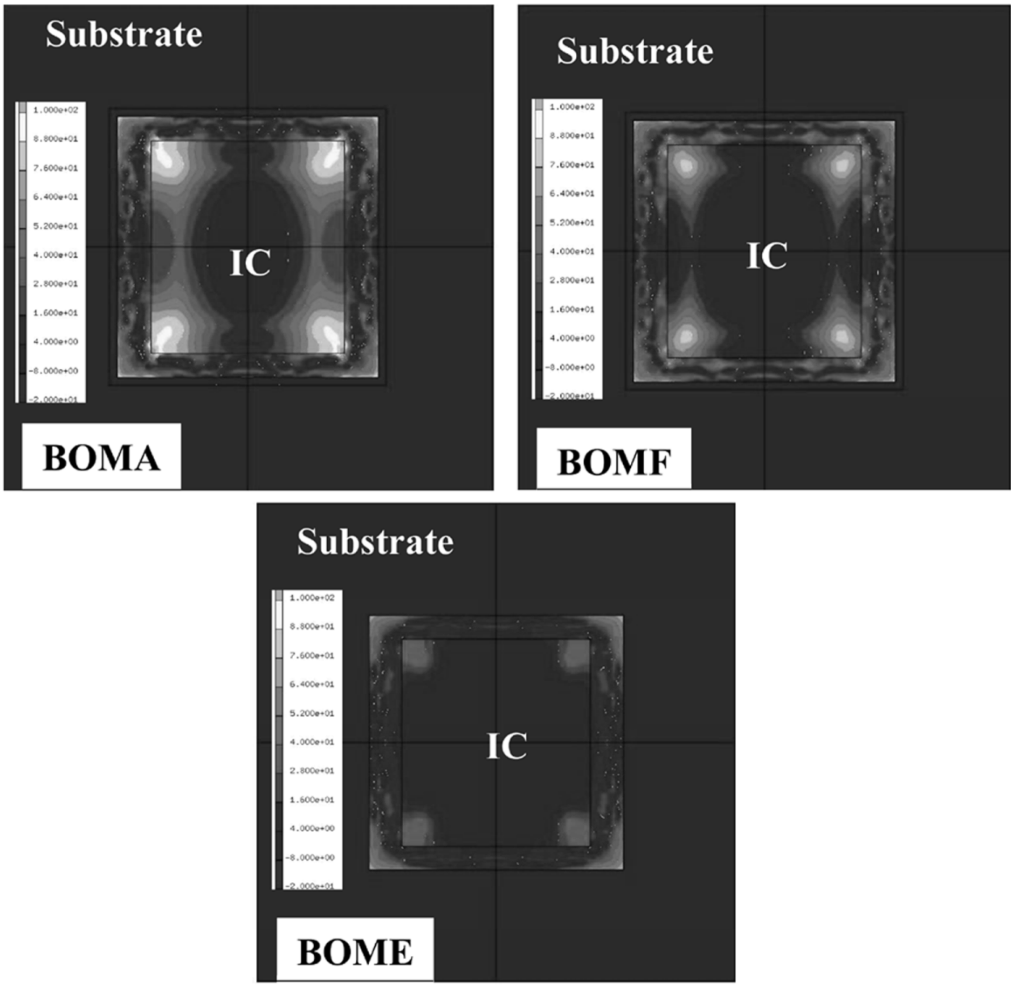


Fig. 12. IC-compound interfaces stress (maximum principal stress) for BOMA, BOMF, and BOME.

3) The initial die warpage/stress is neglected. Although these warpage/stress values can be significant, they are neglected in this study.
4) Perfect adhesion is assumed between all constituents.
5) The curing process induced stresses are neglected. Curing effects in compounds may lead to very significant stress levels, but this effect is neglected here since the failures are observed after testing and not after mould curing.

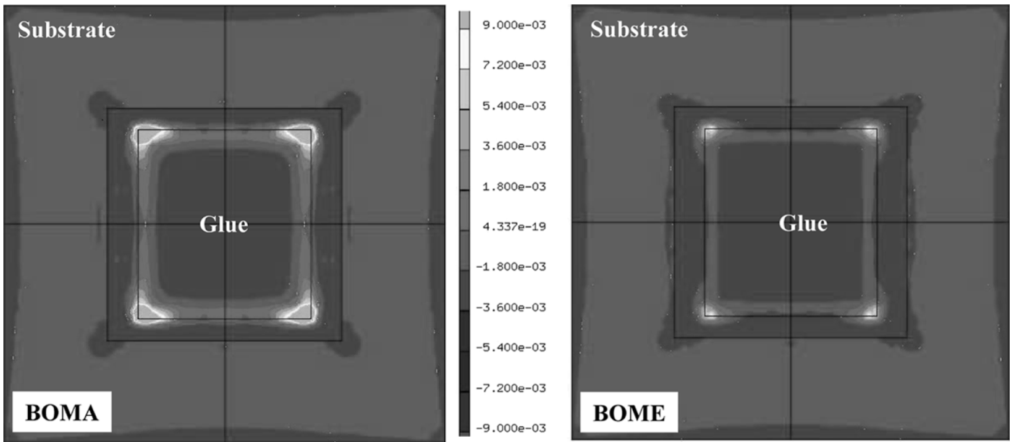


Fig. 13. IC-die-attach interfaces stress (maximum principal stress) for BOMA and BOME.

6) Time effects such as material degradation are not taken into account.

## IV. RESULTS AND DISCUSSION

### A. On Delamination and Passivation Crack

After the GQS tests, such as temperature cycling, cracks in the thin passivation layers of the IC are found in BOMA-D. In all BOMA-D, it is found that the passivation cracks are associated with delamination between IC and moulding compound. We have studied the influence of interfacial delamination on the passivation crack systematically by using $J$-integral methods, see [12]. The mechanism of the effect of delamination on passivation cracking is depicted in Fig. 9. The delaminated compound will push the passivation layer in such a way that it initiates and propagates cracks in this layer. Our study shows that delamination and passivation cracking are one and the same failure mechanism. Or in other words, the occurrence of delamination during manufacturing and/or testing (reflow) may predict the occurrence of passivation cracking in a later stage (temperature cycling).

### B. On Delamination and Interface Strength

Interfacial delamination inside an IC package occurs because of the large differences in material behavior (read differences in CTE) between materials such as polymer and metal and polymer and passivation. However, no effective methodologies, models, and tools are available for the prediction of the interfacial strength of these material combinations. We have studied the interfacial strength of different passivation materials and a typical compound material by combining experiments with simulation methods [13]. Forces from the measurements are taken as an input for the FE model, where we have used $J$-integral approach to calculated the interface strength. Two types of tests are investigated, i.e., the button shear/pull test and four-point bending with pre-notch crack. A typical recording of a button shear/pull experiment is shown is Fig. 10. Our study shows that by tensile loading the strength of the compound—passivation interface is much lower as by shear loading. Combining these test results with dedicated FE models, it is possible to quantify the strength of interfaces.

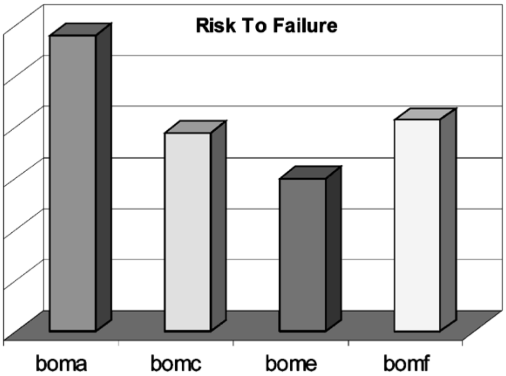


Fig. 14. Ranking for different BOMs in terms of accumulated risk to failure.

### C. On Reliable FEM Modeling

To check the reliability of the FE model for the cavity-down TBGA package, warpage measurements are performed. For this, 35 samples are built by BOME and used to check it's warpage and co-planarity. Fig. 11 shows an example of the measured together with the calculated deformations at 25 °C. In the measurement, an average warpage of $37.8 \pm 13.7\ \mu$m is found, in the FE model, for this BOM, a warpage of $31.0\ \mu$m is calculated. In both cases, a smiley-faced deformation is found.

### D. On Material Choices

Tensile interface stress levels (maximum principal stress) should not exceed threshold values to prevent interface delamination. Figs. 12 and 13 shows the interface stress distribution after cool down to $-55\,^{\circ}$C at the IC compound and IC die-attach interface for three material combination:

1) BOMA, a package with severe reliability problems (see Table II);
2) BOMF, a package with less reliability problems;
3) BOME, a package with no reliability problems.

Much lower stresses are found at the IC-compound interface for BOME, which in reality also behaves much better. Since the delamination provokes passivation cracking, for BOMA a much worse reliability is anticipated from this modeling result. Fig. 14 shows the ranking for different BOMs in terms of an accumulated risk to failure. Again, very clear is the extreme low risk for BOME, which is about 50% lower that for the worst-case combination BOMA.

## V. CONCLUSION

In this study, we have examined the occurrence of different failure types depending on the compound and die-attach material choice in a cavity-down TBGA package. Qualification of the different products is combined with 3-D finite element calculations to predict the delamination driving stresses for the different material combinations in the cavity-down TBGA package. In some combinations of compound and die-attach the package performed poor, with only one combination without failures. The results of the finite element calculations indicated the possibility of interfacial delamination for different combinations. Our results show that the developed simulation models can be used to assess the possibility of reliability problems as the consequence of using different material combinations. Using sophisticated simulation techniques cost- and time-expensive reliability tests can be reduced to a minimum.

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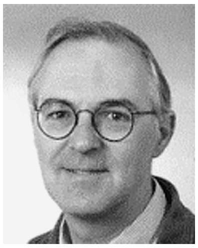

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