1. Introduction

Photosensitive resins are used widely as insulating layers for the redistribution layers of semiconductor packages because the excellent mechanical properties of these resins allow a substantial streamlining of the distribution pattern formation\(^1\). However, there are concerns that thermal stresses generated in the redistribution layer during the operation of the semiconductor and the process of package manufacturing can fracture the insulating films and cause peeling of the interface between the insulating layers and the wiring metal. Therefore, the present authors have measured experimentally the interfacial fracture toughness of that interface and studied the method for judging the peeling of the insulating films on the wiring metal by thermal stress analysis using a simplified three-dimensional finite-element (FE) model focusing on the solder-bump periphery structure of the semiconductor package\(^2\), \(^3\). However, in evaluating the reliability of semiconductor packages, analyzing the subsequent crack propagation path after peeling during temperature cycling is just as important as the peeling criteria. In the present study, for a more detailed investigation of fractures on the redistribution layers in semiconductor packages that has been reported to date\(^2\), \(^3\), a three-dimensional FE model was used to perform a fracture-mechanics study of the crack propagation path during temperature cycling in addition to peeling judgments in temperature cycling and the cooling stage of the reflow process. Also, based on these results, the mechanical properties of the insulating-film materials for preventing fractures were examined.

2. Procedure

2.1 Evaluation of interfacial fracture toughness of insulating film on wiring metal

2.1.1 Test method

Evaluating the peeling of the insulating film layer in the wiring structure requires the interfacial fracture toughness \(G_{c_i}\) (critical energy release rate at the interface) of the insulating-layer/wiring interface, and in this study a peeling test was used to find \(G_{c_i}\). The photosensitive resin of the insulating layer used for the evaluation was of three types, i.e., polyimide, polybenzoxazole, and phenol (hereinafter PI, PBO, and PH, respectively). A 10-μm-thick layer of photosensitive resin was formed on the Cu film on the Si wafer using a spin coater and was processed to make peeling test specimens. The Si wafer was then cut to a width of 5 mm, and the edge of the photosensitive resin layer was partially peeled off to obtain a test specimen. Fig. 1 shows a peeling test specimen schematically. A 180° peeling test was carried out under displacement-rate control. The displacement rates were 0.002, 0.017, 0.17, and 1.7 mm/s, and the test temperatures were 298,
schematically, and the parameter is the peeling angle; and
film and the work hardening coefficient of each thin film;
strain at yielding, stress, and elastic modulus of each insulating
348, and 398 K. For details of the test method, see elsewhere\(^2\), 3\).

2.1.2 Calculation of interfacial fracture toughness
The interfacial fracture toughness \( G_{ia} \) was calculated from\(^6\)
\[
G_{ia} = \frac{P}{b} \left( \frac{1}{2} \epsilon_y \cos \theta - \frac{1}{2} \epsilon_y \right) f_i(k_0) \\
= \frac{1}{2} \epsilon_y \cos \theta f_i(k_0) \\
\]
where \( P \) is the peeling load of the thin film measured in the
peeling test; \( \epsilon_y \), \( \epsilon_y \), \( \sigma \), \( E \), and \( n \) are respectively the elastic strain,
strain at yielding, stress, and elastic modulus of each insulating
film and the work hardening coefficient of each thin film; \( \theta \)
is the peeling angle; and \( b \) and \( h \) are the width and thickness,
respectively, of each film. Fig. 2 shows the peeling front
schematically, and the parameter \( k_0 \) determined by the angle \( \theta_0 \) at
the peeling front was calculated from
\[
k_0 = \frac{3}{4} \epsilon_y \\
\]
where \( G_{ia}^{ex} \) is the interfacial fracture toughness when the peeling
arm is assumed to be only elastic. In Eq. (1), the interfacial
fracture toughness \( G_{ia} \) was obtained by subtracting the energy
spent for tensile deformation and bending deformation of the
thin film from the total work to peel the thin film from the base
material. The mechanical parameters necessary for calculating the
tensile deformation and bending deformation of each thin
film were determined by using the two linear approximations of
the stress-strain curves of the respective insulating films obtained
from the tensile test. The tensile test specimens of the insulating
films were then peeled as 5-mm-wide and 20-mm-long strips of
insulating films formed on the Cu film on the Si wafer.
The displacement rates and test temperatures were the same
as those in the peeling test. A mechanical testing machine was
used (LMH207-10; Saginomiya Seisakusho, Japan). Other than
the one at 298 K, the tensile tests were performed by controlling
the ambient temperature using a hot-air circulation system. Fig. 3
presents the stress-strain curves of the respective insulating films.
As shown in Fig. 3, PI is ductile, while PBO and PH are brittle.
For each insulating film, the stress-strain curve depends on the
displacement rate and temperature, and \( \epsilon_y \), \( E \), and \( \alpha \) obtained using
the two straight-line approximations are presented in Table 1.

2.2 FE analysis
2.2.1 FE model
To perform fracture analysis of the insulating films in the
redistribution structure during temperature cycling and the
cooling of the reflow process, an FE model with a simplified
three-dimensional structure was created focusing on the solder-
bump peripheral structure in the semiconductor package shown
in Fig. 4. The depth of the FE model was 350 μm, equivalent to
the pitch of the solder bump, and the lengths of FR-4 and Si were
determined so that the nominal shear strain of the solder bump
during temperature cycling was 1%. Displacement constraints
were applied to the FE model so that it became a 1/2 symmetric
cantilever beam due to thermal deformation. To perform the
peeling evaluation through fracture mechanics, an initial crack
is necessary. In this study, introduced as an initial defect of
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Minimum size sufficient for the element meshing was a 1-μm-long crack on the resin/Cu-wiring interface at the position of crack front angle 2 as shown in Fig. 4, which is an often-reported case.

The material properties used in the analysis are given in Table 2. The solder bump (Sn-3.0 mass%Ag-0.5 mass%Cu) was defined as an elasto-creep body, and the other materials were elastic bodies. The insulating films were defined as temperature-dependent elastic bodies. The relationship between the elastic modulus $E$ [GPa] and the absolute temperature $T$ [K] was

$$E = E_0 - \beta T \times \exp \left( \frac{-T_c}{T} \right)$$  \hspace{1cm} (6)

where $E_0$, $\beta$, and $T_c$ are material constants. The material constants of the respective insulating films are given in Table 3. The coefficient of thermal expansion (CTE) of each insulating film was defined as being temperature dependent, and Fig. 5 shows the relationship between temperature and the CTE of each insulating film.

2.2.2 Temperature profile and peeling judgment

The conditions of temperature cycling and reflow cooling temperatures were chosen as the temperature profiles shown in Fig. 6 (a) and (b) by referring to JEITA ET-7407B. In the reflow profile, the solder state was reproduced from a molten state to a solid state by applying the birth-death function to the FE model elements. Assuming that the solder was completely solidified at 473 K, the settings were chosen so that the stiffness of the solder element remained zero while molten. To calculate the energy release rate $G_{ij}$ of the resin/Cu interface, the virtual crack closure

![Table 1 Material properties of each resin used to calculate $G_{ij}$.

| Temperature | PI | PBO | PH |
|-------------|----|-----|----|
| 298 K       |    |     |    |
| $v$ [mm/s]  | 0.002 | 0.017 | 0.17 | 1.7 |
| $E$ [GPa]   | 2.071 | 2.748 | 3.091 | 3.228 |
| $\nu$       | 0.338 | 0.334 | 0.333 | 0.337 |
| $n$         | 0.066 | 0.038 | 0.028 | 0.028 |
| $\varepsilon_y$ | 0.044 | 0.040 | 0.039 | 0.038 |
| $\eta$      | 0.065 | 0.065 | 0.065 | 0.065 |
| $\varepsilon_y$ | 0.032 | 0.033 | 0.033 | 0.039 |
| $n$         | 0.033 | 0.033 | 0.033 | 0.033 |

| 348 K       |    |     |    |
| $E$ [GPa]   | 1.422 | 1.605 | 1.722 | 1.950 |
| $\nu$       | 0.038 | 0.036 | 0.034 | 0.032 |
| $n$         | 0.065 | 0.065 | 0.065 | 0.065 |
| $\varepsilon_y$ | 0.032 | 0.034 | 0.036 | 0.037 |
| $n$         | 0.033 | 0.033 | 0.033 | 0.033 |

| 398 K       |    |     |    |
| $E$ [GPa]   | 1.432 | 1.765 | 2.079 | 2.176 |
| $\nu$       | 0.025 | 0.024 | 0.026 | 0.030 |
| $n$         | 0.048 | 0.026 | 0.023 | 0.023 |
| $\varepsilon_y$ | 0.036 | 0.035 | 0.034 | 0.035 |
| $n$         | 0.065 | 0.065 | 0.065 | 0.065 |
| $\varepsilon_y$ | 0.023 | 0.026 | 0.026 | 0.027 |
| $n$         | 0.033 | 0.033 | 0.033 | 0.033 |

![Table 2 Material properties used in FEM analysis for each material.

| Material | Property | Elastic modulus [GPa] | Poisson’s ratio | CTE [ppm] |
|----------|----------|-----------------------|----------------|-----------|
| Resin    | Temperature dependence | 0.3            | Temperature dependence |
| Cu       | 129.8    | 0.34                   | 17             |
| FR-4     | 22       | 0.28                   | Temperature dependence |
| SR       | 2.6      | 0.29                   | Temperature dependence |
| UBM      | 199.5    | 0.3                    | 13.1           |
| Si       | 168      | 0.35                   | 2.6            |

![Table 3 Material constants of Eq. (6).

| Resin | $E_0$ | $\beta$ | $T_c$ [K] |
|-------|-------|---------|-----------|
| PI    | 2.79  | $9.5 \times 10^4$ | 403       |
| PBO   | 2.30  | $8.1 \times 10^4$ | 445       |
| PH    | 4.93  | $7.5 \times 10^4$ | 98        |

![Fig. 4 Three-dimensional finite-element (FE) model of redistribution structure around solder bump.

Fig. 5 Coefficient of thermal expansion (CTE) of each photosensitive resin.

modulus $E$ [GPa] and the absolute temperature $T$ [K] was

$$E = E_0 - \beta T \times \exp \left( \frac{-T_c}{T} \right)$$  \hspace{1cm} (6)

where $E_0$, $\beta$, and $T_c$ are material constants. The material constants of the respective insulating films are given in Table 3. The coefficient of thermal expansion (CTE) of each insulating film was defined as being temperature dependent, and Fig. 5 shows the relationship between temperature and the CTE of each insulating film.

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technique (VCCT)\(^7\)\(^8\) was used; \(G_i\) was calculated by averaging the values of the node groups at the respective crack fronts. The general-purpose solver ANSYS ver. 18.1 was used, and the elements were 20-node hexahedral ones. For peeling judgments, the normalized energy release rate \(G_i/G_c\) (i.e., normalizing \(G_i\) in the redistribution structure calculated by the FE analysis with the interfacial fracture toughness \(G_c\) obtained from the peeling test) was used as the evaluation parameter. Although \(G_i/G_c\) does not correspond directly to delamination, \(G_i/G_c\) was adopted as a guide for delamination in this study.

2.3 Fracture toughness of insulating films

After peeling, to judge whether the crack propagated in the interface or in the insulating films, both the interfacial fracture toughness and the fracture toughness of the insulating films are required. Therefore, the values of the fracture toughness \(K_{ic}\) of the respective photosensitive resins were found experimentally. As with the peeling test, the specimens were miniature ones in the shape of 5-mm-wide and 25-mm-long strips, each made by peeling the respective films formed on the Cu film on the Si wafer. Each strip had a notch introduced on one edge; the specimen is shown schematically in Fig. 7. A fatigue pre-crack was allowed to propagate from the notch tip by means of high-cycle fatigue testing. The pre-crack was introduced at ambient temperature. The control wave of the high-cycle fatigue test was a sine wave with a frequency of 2 Hz and a stress ratio of 0.1. The crack length \(a\) was measured by in situ observation using a microscope installed on the upper part of the specimen fixing jigs. The crack was allowed to propagate to a length of 860-1050 \(\mu\)m including the notch. After introducing the pre-crack, displacement was loaded at ambient temperature and with a displacement rate of 2 mm/s until the crack growth became unstable. \(K_{ic}\) was calculated as a plane stress problem of the single-edge notched specimen from the critical load \(P\). Because the energy release rate \(G\) was used for the fracture mechanics in this study, the fracture toughness \(K_{ic}\) of each insulating film was converted to the critical energy release rate \(G_c\), and the equations for calculating \(K_{ic}\) and \(G_c\) are Eqs. (7)-(9). When a miniature specimen is used for fracture toughness testing, it is possible that a localized plastic deformation in the entire specimen cannot be ignored\(^9\). However, in this study, each of the insulating films fractured within the linear domain of the load-displacement curves, therefore the effects of plastic deformation on the calculation of fracture toughness were ignored.

\[
K_{ic} = \frac{P}{B\sqrt{W}} f\left(\frac{a}{W}\right) \tag{7}
\]

\[
f\left(\frac{a}{W}\right) = \sqrt{\frac{2\tan \frac{\pi a}{2W}}{\cos \frac{\pi a}{2W}}} \left[0.752+2.02\left(\frac{a}{W}\right)\right] + 0.37 \left(1-\sin \frac{\pi a}{2W}\right)^{1/3} \tag{8}
\]

\[
G_c = K_{ic}^2 E \tag{9}
\]

where \(P\) is the critical load (fracture load), \(B\) is the thickness of the specimen, \(W\) is the gauge width of the specimen, and \(E\) is the elastic modulus of the photosensitive resin.

3. Results and discussion

3.1 Interfacial fracture toughness of insulating films

The interfacial fracture toughness \(G_{ic}\) of each insulating film is shown in Fig. 8. In each insulating film, the interfacial fracture toughness \(G_{ic}\) increased with increasing displacement rate and decreased with increasing temperature. At 298 and 348 K, PI had the highest \(G_{ic}\), followed in order by PH and PBO. At 398 K, PH...
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had the highest $G_{c_i}$, followed in order by PI and PBO. At any temperature, PBO had the lowest $G_{c_i}$ in this study. Regarding the temperature dependence, however, PI exhibited the highest dependence. Because the Cu film surface on the Si wafer is extremely flat, the bonding strength of the interface between the insulating film and Cu is dominated by the secondary bonding. The dependence of $G_{c_i}$ on temperature and displacement rate shown in Fig. 8 is considered to indicate the viscoelastic property that bonding of the interface between the insulating film and Cu film is attributable to van der Waals bonding. Assuming that $G_{c_i}$ is viscoelastic, the temperature-time shift factor holds, and $G_{c_i}$ can be described by a master curve regardless of temperature and time. Assuming that the shift factor of the Arrhenius-equation type holds, the results of replotting $G_{c_i}$ are given in Fig. 9. For each insulating film, $G_{c_i}$ can be described by a master curve, and the relationship between $G_{c_i}$ and the displacement rate $v$ holds,

$$G_{c_i} = A v^B$$

(10)

where $A$ and $B$ are constants. The Arrhenius-type shift factor $a_T$ is

$$a_T = \exp \left( \frac{Q}{R \left( \frac{1}{T} - \frac{1}{298} \right)} \right)$$

(11)

where $Q$ is the activation energy, $T$ is the absolute temperature, and $R$ is the gas constant. The reference temperature is 298 K, and the constants $A$, $B$, $C$, and $Q/R$ of the interface between each insulating film and the Cu are given in Table 4. These equations enable the calculation of the interfacial fracture $G_{c_i}$ of each film at arbitrary selected conditions.

3.2 Peeling judgment of insulating layer in temperature cycling and reflow process

In making a peeling judgment, firstly the energy release rates $G_i$ of crack tips (shown in Fig. 4) were compared with each other to predict where the crack was most likely to propagate. Fig. 10 presents $G_i$ for each crack tip in the temperature cycling profile of PI. $G_i$ was highest at crack tip 2 and lowest at crack tip 3. Thus, it was found that the peeling propagated mainly in the $y$ direction, and the crack tip found as the peeling location was crack tip 2.

Fig. 11 shows $G_{c_i}$ and $G_{c_j}$ in temperature cycling and the reflow process of each insulating layer. Since the thermal shrinkage of the constituent material around the crack during the temperature drop process resulted in maximum crack opening at room temperature, $G_{c_i} / G_{c_j}$ was highest at the minimum temperature in each insulating film and each temperature profile. The driving force for the fracture is the energy release rate at maximum crack opening, only $G_{c_i} / G_{c_j}$ at the minimum temperature is

Table 4 Material constants of Eq. (10) and (11).

| Resin | $A$  | $B$  | $C$  | $Q/R$ |
|-------|------|------|------|-------|
| PI    | 155.0| 0.066| 3.04 | 13212 |
| PBO   | 34.2 | 0.202| 1.09 | 2481  |
| PH    | 101.0| 0.036| 0.95 | 3574  |

Fig. 10 $G_i$ for each crack tip position of PI at minimum temperature of temperature cycling.
described. $G_i / G_{c_i}$ of PBO was the highest regardless of the temperature profile, followed in order by PH and PI. $G_i / G_{c_i}$ of PBO used in this study exceeded unity in the cooling stage of the reflow process and was close to unity in the temperature cycling, so there is a concern about peeling of PBO film during the manufacturing process and its use. On the other hand, because $G / G_{c}$ is nearly zero for both PI and PH, excellent reliability can be expected. Focusing on the magnitude correlation of $G_{c_i}$ of each film obtained from the peeling test, PI (233 K: 166.9 J/m²; 298 K: 89.3 J/m²) was the highest followed by PH (233 K: 72.8 J/m²; 298 K: 71.8 J/m²) and then PBO (233 K: 4.6 J/m²; 298 K: 5.2 J/m²), and this shows a strong correlation between $G_{c_i}$ and $G_i/G_{c_i}$. On the other hand, as Fig. 12 shows, only minor differences in $G_j$ (which is the driving force for crack propagation) were observed depending on the type of insulating film, and there was no correlation between $G_j$ and $G_j/G_{c_j}$. $G_j$ depends on the mechanical properties of the insulating films. In the temperature cycling, $G_j$ is correlated with the elastic modulus of the respective insulating films, and for PBO with the lowest elastic modulus, $G_j$ is the highest. In the cooling stage of the reflow process, $G_j$ is correlated with the CTE of the respective insulating films, and for PI with the highest CTE, $G_j$ is the highest.

In the scope of this study, however, $G_{c_i}$ at ambient temperature or below is dominant over $G_i / G_{c_i}$. Therefore, to prevent peeling problems, the material design must ensure high values of $G_{c_i}$ at ambient temperature or lower.

### 3.3 Prediction of crack propagation path after peeling

For the case in which peeling progresses during temperature cycling and reaches the corner of the Cu wiring where the stress concentration is the greatest, an investigation has been performed to find whether the crack propagates in the insulating layer or in the interface between the insulating film and the Cu. The analysis model used for the investigation is shown in Fig. 13. Prepared were two types of analysis models in which cracks propagated a distance equivalent to one element from crack tip 2 in the interface between the insulating film and the Cu and inside the insulating film. The angle of the crack front was $8^\circ$, and the direction of the crack propagating toward the inside of the insulating film was perpendicular to the direction of the first principal stress. By using these models, the energy release rate $G_s$ in the insulating film and the energy release rate $G_i$ of the interfacial crack were obtained by using the VCCT. Fig. 14 shows $G_s$ and $G_i$ of each insulating film. $G_s$ was 1.5-1.7 times higher than $G_{c_i}$, and the driving force of crack propagation was higher.
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in the insulating film than at the interface. However, whether the crack propagates into the insulating film or at the interface was determined by the ratio of $G_{c,b}$ or $G_{c,i}$ to $G_b$ or $G_i$. **Fig. 15** shows $G_{c,b}$ of the respective insulating films. PI had the highest $G_{c,b}$, followed in order by PH and PBO. PI had values of $G_{c,b}$ that were three times higher than those of the other insulating films and an order of magnitude higher than $G_{c,i}$. **Fig. 16** shows the ratio of energy release rate to fracture toughness, $G'/G_c$, for each crack propagation path. In each of the insulating films, $G'/G_c$ was higher when the crack was propagating into the interface than into the insulating film. It can be predicted that the crack propagation during temperature cycling is taking place at the interface. When focusing on the types of insulating film, $G'/G_c$ of PBO was the highest for all of the crack propagation paths, followed by that of PH and PI. The results show that PI, with its high interfacial fracture toughness, has excellent reliability even after considering the crack propagating after peeling has occurred. Even when the crack propagates into the insulating film, PI with its high fracture toughness excels in reliability, and PI was the best and most reliable material as an interlayer insulating film.

3.4 Effective material design for preventing interface peeling

It was predicted that a crack in the redistribution structure of the semiconductor package would propagate more easily in the interface between the insulating film and wiring metal than in the insulating film. Consequently, it is important that the material design produces interfacial fracture toughness, and also lowering $G_j$ of the driving force for crack propagation is necessary in the insulating-film design. Here, the effects of elastic modulus $E$ and CTE $\alpha$ of the insulating film are examined. The analysis model was that shown in **Fig. 3**, and the temperature profiles were two different types of temperature cycling and the cooling stage of the reflow process. The levels of $E$ and $\alpha$ are given in **Table 5**, where level 0 corresponds to the property of the PI used in this study, and levels −1 and 1 are magnifications of level 0. **Fig. 17(a)** shows the effects of $E$ and $\alpha$ on $G_j$ in the temperature cycling, and **Fig. 17(b)** shows their effects in the cooling reflow process (both were at minimum temperature). $G_j$ was lowest when $E$ was low and $\alpha$ was low in the reflow process, and when $E$ was high and $\alpha$ was low in the temperature cycling. Under all conditions, $G_j$ was lowered when $\alpha$ was low. How $E$ affects $G_j$ involves a trade-off.

![Table 5](image)

|            | level | level | level |
|------------|-------|-------|-------|
| $E$        | $\times 0.5$ | $\times 1$ | $\times 1.5$ |
| $\alpha$   | $\times 0.7$ | $\times 1$ | $\times 1.3$ |

![Fig. 15](image) $G_{c,b}$ (bulk) for each insulating film.

![Fig. 16](image) Comparison of $G'/G_c$ for each crack growth direction of each insulating film.

![Fig. 17](image) Effect of $E$ and $\alpha$ on $G_j$ for thermal cycle and reflow process.
upper part of the redistribution layer was related to the opening of the crack at the interface. In the temperature cycling, $G_1$ decreased as $E$ of the insulating film increased, this being due to the suppression of the deformation of the redistribution layer that occurred because of the solder-bump deformation. On the other hand, in the cooling stage of the reflow process, heat shrinkage of the insulation layer was dominant over the crack opening at the interface. Consequently, when $E$ is low, the stress generated in the insulating layer by heat shrinkage is lowered and $G_1$ is lowered. Accordingly, how $E$ affects $G_1$ involves a trade-off between the cooling stage of the reflow process and the temperature cycling. However, Fig. 17(b) shows that there is an interaction between $E$ and $\alpha$ in the reflow process. When $\alpha$ is low, the sensitivity of $E$ to changes in $G_1$ is low, so increasing $E$ by decreasing $\alpha$ does not increase $G_1$ easily, thereby resolving the trade-off in how $E$ affects $G_1$. Therefore, material design to enable high elastic modulus and low CTE of the insulating films is effective for preventing them from peeling in both the reflow process and temperature cycling.

4. Conclusions

1) From the FE analysis using a simplified three-dimensional structure of a semiconductor package, the ratio $G_1/G_{1c}$ of the driving force for crack propagation at the interface between the insulating film and Cu film to the interfacial fracture toughness was the highest in PBO in both the temperature cycling and the cooling stage of the reflow process, followed in order by PH and PI. This result is correlated with the interfacial fracture toughness $G_{1c}$ at room temperature or below, and increasing $G_{1c}$ at ambient temperature or below is effective for preventing insulating films from peeling.

2) The fatigue crack propagation path after peeling has occurred was predicted from the result that the ratio of the driving force for crack propagation to the critical energy release rate (fracture toughness) was higher at the interface than in the insulating film, from which it was presumed that the fatigue crack propagation path would be at the interface.

3) The ratio of the driving force for fatigue crack propagation to the critical energy release rate was the highest in PBO, followed by PH and PI. PI was the most reliable material for insulating films.

4) Even for the reflow process and temperature cycling, it is effective to design the insulating films for the redistribution layer to have high elastic modulus and low CTE, as well as increasing the interfacial fracture toughness at ambient temperature or below.

Reference

1) K. Fukukawa and M. Ueda: “Kankousei Poriimido-Kankousei Poribenzuokiszaru no Kaikatsu (Development of Photosensitive Polyimides and Photosensitive Polybenzoxazoles)”, Japanese Journal of Polymer Science and Technology, 63, (2006), 561-576.

2) K. Ono and Y. Kariya: “Failure Analysis of Redistribution Layer Interface Semiconductor Package Structure”, Proceeding of 26th symposium on “Microjoining and Assembly Technology in Electronics” (mate2020), 26, (2020), 171-174.

3) Y. Okada et al.: “Reliability Simulation with the Finite Element Analysis (FEA) of Redistribution Layer in Fan-out Wafer Level Packaging”, Journal of Photopolymer Science and Technology, 33, (2020), 171-176.

4) A.J. Kinloch et al.: “The Peeling of Flexible Laminates”, International Journal of Fracture, 66, (1994), 45-70.

5) Y Kanda et al.: “Visco-elastic Effect of Underfill Material in Reliability Analysis of Flip-Chip Package”, ASME InterPACK’09, (2009), 755-759.

6) Japan Electronics and Information Technology Industries Association, JEITA Standard ET-7407B, (2012), 9-13.

7) T.-C. Chiu and H.-C. Lin: “Analysis of Stress Intensity Factors for Three-dimensional Interface Crack Problems in Electronic Packages using the Virtual Crack Closure Technique”, International Journal of Fracture, 156, (2009), 75-96.

8) J. Augersperg et al.: “VCCT and Integral Concepts of Bi-material Interface Fracture in Low-K Structures Going to Understand Relation”, 12th Electronics Packaging Technology Conference, (2010), 632-636.

9) T.L. Anderson: “FRACTURE MECHANICS Fundamentals and Application Fourth Edition.”, CRC Press, (2016), 51-55.

10) R. Viswanathan and F. Masuyama: Kouon Kiki Buhin no Sonsyou Mekanizumu to zyumyou hyouka (Damage Mechanisms and Life Assessment of High Temperature Components), Nikkan Kougyou Shinbunsya, (1993), 47-56

11) Y. Naka et al.: “Assessment for Delamination Strength of a Thin Film in a Hard Drive Head by Peel Test”, Journal of the Society of Material Science, Japan, 49, (2000), 170-174.

12) Y. Nonaka: “Settyaku Hakai no Reorozi (Rheology of adhesive fracture)”, The Society Polymer Science, Japan, 19, (1970), 485-490.

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