Study on Peeling Behavior in Pick-up Process of IC Chip with Adhesive Tapes*

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Abstract
A method to evaluate pick-up performance of four kinds of adhesive tape materials with different thickness has been studied numerically and experimentally. Needles peel an IC chip with an adhesive film off the base material in the pick-up process, by pushing the back of the base material. In our evaluation method, the dependence of the peel energy on the peel speed was measured using a peel test. The finite element method was applied to calculate the energy release rate of the pick-up process for various peel lengths. The pick-up time was obtained from the results of the peel tests and the finite element analysis. Our results indicate that the peel energy is the dominant property influencing the pick-up performance, and the difference in energy release rate in the pick-up process between the samples is not significant. Furthermore, the minimum needle displacement was estimated from the calculated pick-up time using our method. The minimum needle displacement of the experimental pick-up values was in good agreement with the estimated result.

Key words: Adhesive, Peel Test, Polymer Materials, Electronic Materials, Interface

1. Introduction

Increasing market demand has driven the semiconductor industry to miniaturize all the materials used in semiconductor packaging (Fig. 1). The adhesives that bond IC chips to the substrate have also followed the market trend towards miniaturization. Film adhesives are able to satisfy this demand, and are now widely used, having replaced conventional liquid adhesives. Such adhesives are thinner and more uniform than liquid adhesives, and this is the reason why film adhesives enable smaller, higher functionality devices through chip stacked technology as shown in Fig. 1(1).

![Fig. 1 Chip stacked package](image)

![Fig. 2 Manufacturing process: (a) dicing, (b) pick-up](image)
Film adhesives are generally provided as an adhesive tape composed of an adhesive layer and a base material. The tape is laminated on a wafer during the semiconductor manufacturing process. Then, the wafer is divided into IC chips using a rotary blade (Fig. 2). The IC chip and the attached film adhesive are peeled away from the base material using protruding needles in a process called "pick-up"\(^2,3\).

Peel tests have been widely used to measure the peel force of adhesive tapes as a way of evaluating their peeling behavior, e.g., the 90° or 180° peel tests used to assess compliance with the JIS Z 0237 standard. Kim and Aravas\(^4\) evaluated the peel force by taking the elastoplasticity of the base material into consideration. Omiya and Kishimoto\(^5\) proposed a multistage peel tester, and Masuda et al\(^6\) proposed a multiaxis peel tester to evaluate the peel energy at various peel angles.

The pick-up performance is optimized if a chip can be peeled off completely within the specified process time, where the process time is the time needed to pick-up a chip. The pick-up process is stable if the pick-up time is shorter than the process time. Here, the term "pick-up time" denotes the time taken to peel off a chip completely using the protruding needles. However, we cannot estimate the pick-up time directly from the peel force.

Cheng et al.\(^7,8\) estimated the needle force in the pick-up process for dicing tapes using both experiments and numerical analysis\(^9\). The adhesive layer of the dicing tape was removed along with the base material in the pick-up process, and so another liquid adhesive was used for bonding. Chong et al.\(^10\) investigated the relationship between the needle force and the needle displacement for dicing tapes. However, there have been few reports on

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**Fig. 3 Pick-up performance evaluation**

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Input: Adhesive materials / Pick-up conditions

Experiment

Peel test

Peel force (F)

Peel speed (V)

Base material

Adhesive

Output (a): F(V)

Output (b): Peel energy Gₐ(V)

Analysis

Pick-up

Adhesive

Chip

Base material

Needle

Peel length (L)

FEM analysis

Output (c): Energy release rate G(L)

Output (d): V=V(L)

Output (e): Total pick-up time

Comparison with process time

Longer than process time

Shorter than process time

Appropriate condition

(Play condition to actual pick-up process)
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adhesive tapes and the pick-up time.

In this work, we propose an evaluation method to estimate the pick-up time. Our evaluation method was examined numerically and experimentally using four types of adhesive tape materials with different thicknesses.

2. Experimental and Calculation methods

2.1 Method for evaluating the pick-up performance

The method used to evaluate the pick-up performance is shown in Fig. 3. The dependence of the peel force on the peel speed, \( F(V) \), was measured using peel tests in the experimental part of our investigation (Output (a)), and then, the value of \( F(V) \) was transformed into the peel energy, \( G_c(V) \) (Output (b)). In this work, the correlation between the peel force and the energy release rate, which was calculated using two-dimensional finite element method (FEM) analysis, was used as an intermediary for the transformation. The dependence of the energy release rate on the peel length in the pick-up process, \( G(L) \), was calculated by using a three-dimensional FEM analysis (Output (c)).

The peel speed of various peel lengths on the pick-up process, \( V = V(L) \), was acquired from both experimental and analytical results (Output (d)). The pick-up time was calculated from the value of \( V(L) \) (Output (e)).

The calculated pick-up time was compared with the process time. The pick-up time was deemed successful if the calculated pick-up time was shorter than the process time. If the calculated pick-up time equaled the process time, then the needle displacement was regarded as being the minimum needle displacement, \( H_{\text{min}} \), for the pick-up process.

2.2 Samples

Material properties and thickness of the materials used are listed in Table 1, and the composition of the adhesive tapes is given in Table 2. The adhesive tapes are made by laminating a film of adhesive and the base material, as described in a previous paper\(^{11}\). The film adhesives were made of acryl resins and epoxy resins. The base materials were made of polyolefin. The UV-curable samples included a UV-curable resin. The purpose of UV curing is to reduce the interfacial strength between the adhesive layer and the base material. In the case of the UV-curable samples, the material properties listed are those after UV irradiation (240 mW/cm\(^2\), 200 mJ/cm\(^2\)).

<table>
<thead>
<tr>
<th>Table 1 Material properties</th>
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<tbody>
<tr>
<td>Materials</td>
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<tr>
<td>Chip</td>
</tr>
<tr>
<td>Adhesive 1</td>
</tr>
<tr>
<td>Adhesive 2</td>
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<tr>
<td>Adhesive 3</td>
</tr>
<tr>
<td>Adhesive 4</td>
</tr>
<tr>
<td>Base material 5</td>
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<tr>
<td>Base material 6</td>
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</tbody>
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1) Young’s modulus, 2) Poisson’s ratio, 3) Adhesive1, 2 and 3 are UV-curable type

<table>
<thead>
<tr>
<th>Table 2 Composition of the adhesive tapes</th>
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<tbody>
<tr>
<td>Name</td>
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<tr>
<td>Sample A</td>
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<tr>
<td>Sample B</td>
</tr>
<tr>
<td>Sample C</td>
</tr>
<tr>
<td>Sample D</td>
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2.3 Peel tests

The peel force was measured at an angle of 90°, in compliance with JIS Z 0237 (Fig. 4). A strip of a 25 mm-wide adhesive tape was laminated on a glass board. The UV-curable-type adhesive tapes were irradiated with UV (240 mW/cm², 200 mJ/cm²) before peeling. Then, the base material was peeled using a peel rate of 0.15–17.0 mm/s, which was within the specification limits of the measurement equipment. The peel force for peel speeds > 17.0 mm/s was extrapolated using the least-square method in our pick-up performance evaluation procedure.

2.4 Pick-up tests

The apparatus used for the pick-up tests is shown in Fig. 5. A holder used a vacuum of 0.07 MPa to support the adhesive tape. The needles were moved at a speed of 3.0 mm/s to the target needle displacement value (0.15–0.40 mm) and maintained at this displacement. The total process time was adjusted to 1 s, which included the time required for the needles to protrude and reach the target displacement. The needle force during the pick-up test was measured using a load cell that was attached to the bottom of the needles. The minimum needle displacement for a successful pick-up of a chip, \( H_{\text{min}} \), was examined by changing the needle displacement at 0.01 mm intervals.
2.5 FEM analysis

Numerical analysis was conducted under quasi-static linear elastic conditions using the ABAQUS Ver.6.7 finite element code. A two-dimensional plain strain was assumed to calculate the correlation between the energy release rate and the peel force in the peel tests. The peel force obtained in the experimental peel tests was applied to the tip of the base material at an angle of 90°.

The pick-up process was analyzed using a three-dimensional model. The analytical model used is shown in Fig. 6, and was used to calculate the energy release rate of various peel lengths in the pick-up process. One of the components was simulated by taking a symmetrical shape into consideration, as shown in Fig. 6(b). The needle displacement was applied to the base material directly. The shape of peel front was designed in the form of concentric circles from the center of the needle position, as shown in Fig. 7(a). Fig. 7(b) is the magnified view around chip corner of the initial state of peeling (observed area: red square dot line in Fig. 7(a)). The frontal shape was modeled based on observations of the actual pick-up behavior, as shown in Fig. 7(b). The peel length was defined as the length from a chip corner to the peel front along the side that included the needle position.

3. Results and Discussion

3.1 Peel tests

Peel tests were conducted to obtain the peel energy, \( G_c(V) \). The peel force at various peel speeds is shown in Fig. 8. The peel force of Samples A, B, and C increased as the peel speed increased, as shown in Fig. 9. The peel force of Sample D remained relatively constant.

The dependence of the peel force on the peel speed is shown in Fig. 8. The peel force of Samples A, B, and C increased as the peel speed increased, as shown in Fig. 9. The peel force of Sample D remained relatively constant.

The FEM analysis of peel tests is shown in Fig. 10. The energy release rate and peel force are plotted against the peel speed. The peel energy on the peel speed is shown in Fig. 11. The peel energy increased as the peel speed increased.

\[
G_c(V) = \frac{F}{L} \quad \text{for} \quad F < F_c
\]

Fig. 8 Dependence of the peel force on the peel speed

Fig. 9 A peel test showing a variation (Sample D)

Fig. 10 FEM analysis of peel tests

Fig. 11 Dependence of the peel energy on the peel speed, *(): \( G_c(0) \) [J/m²]
speed increased while the peel force of Sample D showed an unstable behavior below a peel speed of 1 mm/s. The maximum and minimum variation of the peel force in Sample D is shown in Fig. 9. There was significant variation at peel speeds below 1 mm/s in the same experiment and even in the same specimen. It is thought this variation is caused by the deformation of the adhesive layer. Mitoh et al. investigated the peel speed dependence of peel behavior of adhesive tapes experimentally and reported as follows. The failure mode of low peel speed area was cohesive failure. The failure mode changed from cohesive failure to interfacial failure by increasing peel speed and unstable peeling behavior was observed at that time. This behavior was observed in case that the modulus of adhesives were low.

The adhesive layer of Sample D had the lowest Young's modulus, and so it was more likely to deform than the other samples. The other samples did not show any significant variation in the peel force under the test conditions used.

The correlation between the energy release rate and the peel force calculated from the FEM analysis is shown in Fig. 10. The energy release rate was almost same as the peel force: the reason for this is thought to be that a peel angle of 90° was employed.

The dependence of peel energy on the peel speed, $G_c(V)$, obtained from the data shown in Fig. 8 and Fig. 10 is shown in Fig. 11. The unstable peeling area (<1 mm/s) of Sample D

![Graph showing the correlation between energy release rate and peel force.]

Fig. 12 FEM analysis of the pick-up process at a needle displacement of 0.35 mm: (a) Calculated energy release rate and (b) deformation of Sample A
was excluded. The value of $G_c(1)$ did not change at low peel speeds in Samples A, B, and C. The peel energy in the stable area is regarded as being equal to $G_c(0)$. Regarding Sample D, the minimum peel force was defined as $G_c(0)$ in the stable peeling area. It is expected that the peel length will not increase if the energy release rate of the pick-up process is less than $G_c(0)$.

![Graph 1](image1.png)

**Fig. 13** A reciprocal plot of the peel speed at a needle displacement of 0.35 mm

![Graph 2](image2.png)

**Fig. 14** Needle force of Sample A: Chip thickness = 100 µm

![Graph 3](image3.png)

**Fig. 15** Needle force at a needle displacement of 0.35 mm: Chip thickness = 100 µm
3.2 FEM analysis of the pick-up process

The energy release rate for various peel lengths, $G(L)$, was calculated using three-dimensional FEM analysis. The value of $G(L)$ at a needle displacement of 0.35 mm is shown in Fig. 12(a). There was no significant difference between the adhesive tapes, compared to the difference observed in the peel energy. The energy release rate increased notably for $L = 5.5$ and 6.5 mm. The deformation behavior for various peel lengths of Sample A is shown in Fig. 12(b). The vacuum of the holder kept the base material in contact around the chip center when the non-peeled area was wide enough ($L = 3.5$ and 4.5 mm). The non-peeled area decreased as the peel length increased. The base material around the chip center was separated from the holder for $L = 5.5$ mm. The peel opening angle of the base material detached from the holder for $L = 5.5$ and 6.5 mm looked much larger than the peel opening angle of the base material attached to the holder for $L = 3.5$ and 4.5 mm. This is thought to be the reason why the energy release rate increased as the peel length increased.

3.3 Evaluation of the pick-up performance

Both the peel energy of the adhesive tapes, $G_c(V)$, and the energy release rate of the pick-up process, $G(L)$, were obtained from the result mentioned above. The values of $V(L)$ and the pick-up time were obtained from $G_c(V)$ and $G(L)$. For example, a peel speed $V_1$ corresponds to a peel length $L_1$, where $G_c(V_1) = G(L_1)$. The correlation between the inverse of the peel speed, $1/V$, and the peel length, $L$, obtained from $G(L)$ (Fig. 12(a)) and $G_c(V)$ (Fig. 11) is shown in Fig. 13. The area under the curve in Fig. 13 denotes the pick-up time. The ordinate axis, $1/V$, follows the order: Sample A $>$ Sample B $>>$ Sample C $\approx$ Sample D. Therefore, it is expected that the pick-up time will be in the same order. Furthermore, the minimum needle displacement was obtained by comparing the calculated pick-up time with the manufacturing process time that will be discussed hereinafter.

3.4 Pick-up tests

Experimental pick-up tests were performed to validate our proposed method. The needle force of Sample A for needle displacements of 0.30-0.40 mm is shown in Fig. 14. The point in the plot denoted by the “×” marker is the point where the chip was peeled off completely. The pick-up did not complete within the manufacturing process time in the case where the needle displacement was 0.30 mm. The pick-up time decreased and the needle force increased as the needle displacement increased. As a result, in Fig. 14, a needle displacement of 0.35 mm was regarded as the value of $H_{\text{min}}$. The needle forces of Samples A,
3.5 Validation of our pick-up performance evaluation method

Our pick-up evaluation method was validated by comparing the value of $H_{\text{min}}$ obtained from actual pick-up tests and those from our evaluation method. The value of $H_{\text{min}}$ of the adhesive tapes is shown in Fig. 16. Our evaluation method was in good agreement with the actual data. The estimated values of $H_{\text{min}}$ (open symbols) were slightly lower than those of the actual pick-up data (filled symbols). The peel behavior was assumed from observations using a video camera, as shown in Fig. 17. Our proposed evaluation method does not include any status of the deformation of the sample, Fig. 17(a), to the initiation of peeling, Fig. 17(b). We can use the difference between the estimated value of $H_{\text{min}}$ and the actual value of $H_{\text{min}}$ of one sample to adjust the estimation from a practical point of view, although examining the influence of the initial state on the pick-up behavior is the subject of future work to improve the accuracy of our evaluation method.

4. Conclusions

In this paper, we have discussed a method to evaluate pick-up performance and have examined numerically and experimentally four types of adhesive tape materials with different thicknesses. In our evaluation method, the pick-up time and the minimum needle displacement required for pick-up were estimated from the peel energy of the adhesive tapes and the energy release rate of the pick-up process. The estimated results were validated by comparing the data with actual pick-up process data. The following conclusions were reached in this study.

1. There are adhesive tapes that show stable peel behavior in peel speeds of 0.15–17.0 mm/s, and also adhesive tapes that show an unstable peel behavior at low peel speeds.

2. The pick-up performance of adhesive tapes that show an unstable peel behavior at low peel speeds can be estimated by applying only the peel energy of the stable peel area.
3. The energy release rate of the pick-up process increases with increasing peel length.
4. The difference in energy release rate of the pick-up process between adhesive tapes was less than the difference in peel energy.
5. The estimated minimum needle displacement was in good agreement with the data from actual pick-up tests.
6. The reason for the slightly smaller estimated needle displacement than the data from actual pick-up tests was that our evaluation method did not take the initial state of peeling into consideration.

References