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Study in IC chip failure during pick-up process by using experimental and finite element methods

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Abstract

Stress contours of an IC chip and the displacement contours of the adhesive between an IC chip and blue tape in the pick-up integrated circuit (IC) chip process are obtained using experimental and finite element methods. The physical and mechanical properties of the material used in FEM are determined by pre-experimental tests. Some factors that importantly influence the failure of a pick-up IC chip during the pick-up IC chip process are proposed. The pre-experimental material properties are manifest in the practical behavior of material, so the post-experimental results are approximately consistent with the FEM results. Post-experiments further demonstrated that the findings of this study can be used to increase the success rate of the pick-up IC chip process.

Keywords: Pick-up; Adhesive; IC chips; FEM; Success rate

1. Introduction

The IC industry is developing rapidly. Electric products, such as notebook, portable electric devices, personal digital assistants and cell phones, among others have become lighter and easily portable, and IC chips are becoming smaller. Accordingly, IC chips easily fail during IC manufacture. Fig. 1 depicts the IC manufacture procedure [1], to elucidate the reasons for failure. A wafer is stuck in tape, and polished thinner and flatter. Then, it is removed from the tape and stuck to the blue tape. The wafer can be fixed by adhesive with the blue tape, and cut into pieces, called IC chips. Sequentially, in the pick-up IC chip process, the IC chip must be pierced and broken off using the piercer, before being separated from the blue tape without any cracks.

However, an IC chip can easily fail due to cracks or incomplete separation from the blue tape, when it is subjected to the pick-up force from the piercer. In particular, as the size, thickness and weight of electric products is now becoming much smaller, thinner and lighter, the failure rate of IC chips in this process clearly increases. The factors that determine the failure of IC chips are many, and too complicated to be fully understood. This investigation studies the complicated relationships among these factors.

The distribution of stress and displacement of the adhesive between the blue tape and the IC chip are very important. The distributions of stress and displacement are critical to determining whether IC chip can be successfully picked up and separated from the blue tape in the pick-up IC chip process. The following studies address stress and are drawn upon herein to help to build up FEM models. Goland et al. first proposed and analyzed the adhesive single-lap joint, strip beam overlapping and sticking beams together [2]. Using the beam theorem, they modeled three layers (two beam layers, and an adhesive layer) and solved the adhesion relations between the strip beams. Based on the theories of Goland et al., Carpenter applied FEM to determine the peeling and shear stresses in the single-lap joint of the adhesive [3]. Ojalvo and Eidinoff used a rather complete shear-strain/displacement equation for solving the single-lap adhesive joints. The shear stresses are highest at two anti-symmetrical adherend-bound interface points of the layer; the growths of joint failures that originate from these points are approximately identical to those obtained experimentally [4]. Chen and Cheng [5] analyzed the adhesive-bounded single-lap joints by minimizing the functional of the variational principal of complementary energy. A closed-form solution that satisfies all the boundary stress conditions is obtained.

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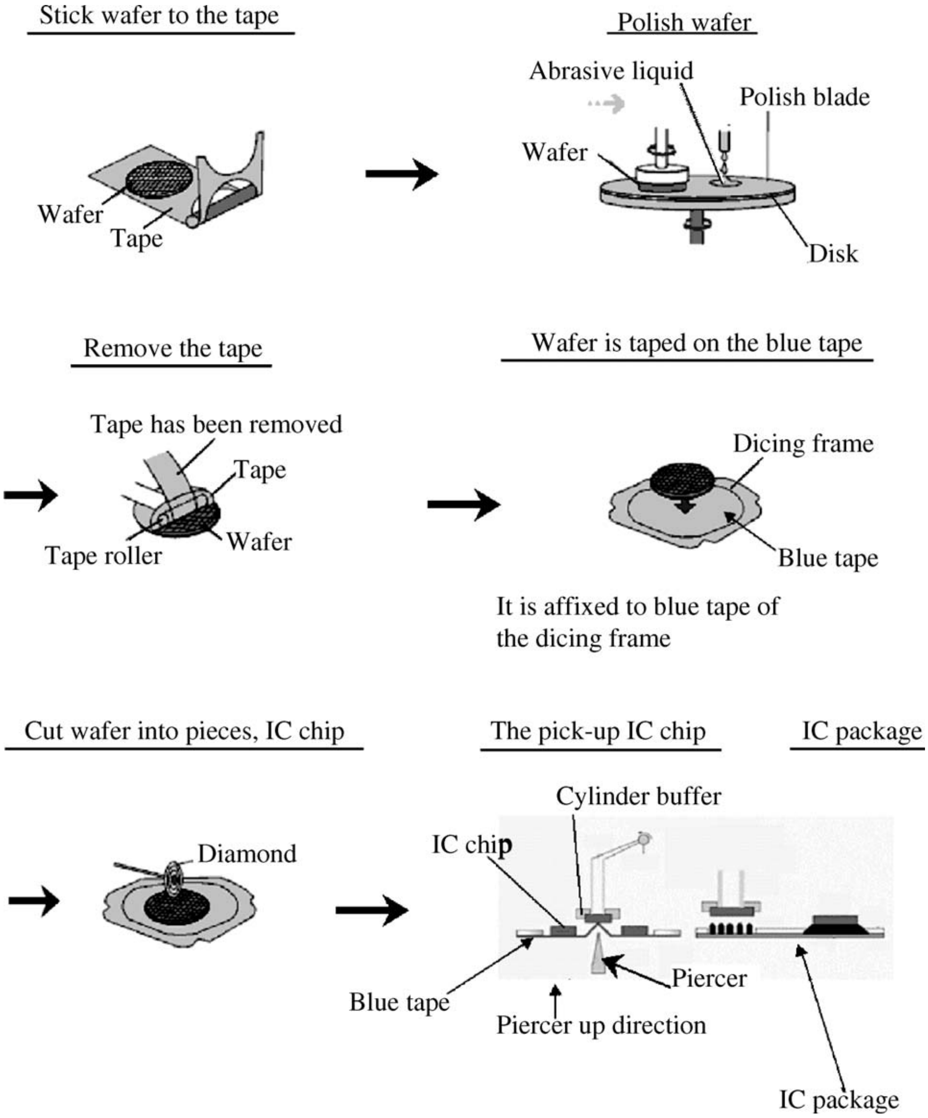


Fig. 1. Processes in the IC manufacturing procedure [1].

The experimental data concerning the extreme fiber strains in the adherends were compared with the results obtained by FEM [6]. A closed-form solution, which satisfies the stress-free boundary conditions, was obtained by applying two-dimensional elasticity theory in conjunction with the variational theorem of complementary energy [7]. Suhir [8] found that a bi-metallic, physical model subjected to uniform heating or cooling behaves similarly to a single-lap joint, which exhibits the pealing and shear stresses. Suhir [9] also discussed both the longitudinal and transverse interfacial compliances of bi-metallic thermostat strips based on elementary beam theory. Lin and Lin [10] proposed that the formulations of FEM derived from the variational principle yielded the relations of the adhesive layer and could determine the peeling and shear stresses. Oplinger [11] showed the effects of transverse shear and thick adherend deflections in single-lap joints. Tsai and Morton [12] presented and validated discrepancies among, and controversies about, theories of the single-lap joint by using numerical analyses. The thickness of the adhesive and the non-identical adherends affected the extreme stress of the adhesive. Basaran and Zhao [13] proposed the FEM model of multi-layered structures, incorporating thermo-viscoplastic characteristics and damage analyses, and considered the mesh sensitivity of the FEM in layered stack problems. David and Lazar [14] empirically tested joints between two different materials stuck by adhesive including their strength, thermal resistance and tightness. They found that some major factors affected the strength of a bonded joint. These factors included the mechanical properties of the adherend, its geometric shape and kinds of adhesive.

In this study, the properties of the IC chip and the Poisson's ratio are adopted from material data [16]. Data on the physical and mechanical properties are obtained by performing some pre-experimental tests. These values were used in material or real constants of the FEM model including the IC chip, the adherend and the blue tape layer. The FEM solutions were compared with the post-experimental data. Furthermore, the success rate of the pick-up IC chip separated from the blue tape can be thus improved and the effect of some major factors on its tendency to fail is validated and demonstrated.

2. Finite element model

2.1. Modeling

Fig. 2 depicts pick-up IC chip machine, MIRL CP602, produced by the Industrial Technology Research Institute (ITRI). Fig. 2(a) shows a sketch diagram of the pick-up modules of the machine. Fig. 2(b and c) present some modules and components of the pick-up IC chip machine. In the pick-up IC chip process, firstly, the sucking module descends until its cylindrical buffer comes into contact with the upper surface of the IC chip. Fig. 2(a) presents some vacuum-sucked holes in the pierced cap, in which the vacuum pressure is generated by the vacuum pump. The vacuum sucks and presses the blue tape over the vacuum-sucked holes in the pierced cap. Blue tape is stuck and fixed around the edge of the frame, and pulled outward under tension toward the frame. Then, the server motor rotates the eccentric wheel, which drives the links to make the piercer ascend, to pierce the blue tape and IC chip, which are therefore subjected to the pick-up force. The cylindrical buffer simultaneously exerts a cylinder buffer force on the upper surface of the IC chip; resists the pick-up force on the IC chip, which causes it to move upward. The IC chip can be successfully picked up and sent to the traps if it is fully separated from the blue tape without any cracks.

The FEM model makes some assumptions. First, the reciprocal effects, which result from the pick-up force, are too small to be neglected between the IC chips. Second, the shear stress of the adhesive is negligible because it is much smaller than the normal stress in the pick-up IC process because in blue tape experiences a pick-up force causes the IC chip to be similarly subjected to a bending moment. Third, this model is assumed to hold in quasi-static equilibrium conditions, to simulate the transient dynamics. Fourth, the spring constant between the blue tape and the pierced cap is constant. Fig. 3 illustrates the FEM model under these conditions. The IC chip is stuck to the blue tape by adhesive, such as glue. Fig. 3(a) shows three layers, including that of an IC chip, adhesive and blue tape. The dimensions of the IC chip are $\mathrm{d} \times \mathrm{d} \times \mathrm{d}$ (mm × mm × mm), length × width × thickness. The radius and thickness of the blue tape are r (mm) and b (mm). Fig. 3(b) presents an A–A cross-section diagram, corresponding to the top view of the model, shown in Fig. 3(a). When the IC chip is picked up, the pick-up force, F, pierces upward from the bottom of the blue tape. The piercer at the piercing seat of the pick-up IC chip module, set up under the blue tape in Fig. 4(a), as shown in Fig. 4(b), exerts the pick-up force.

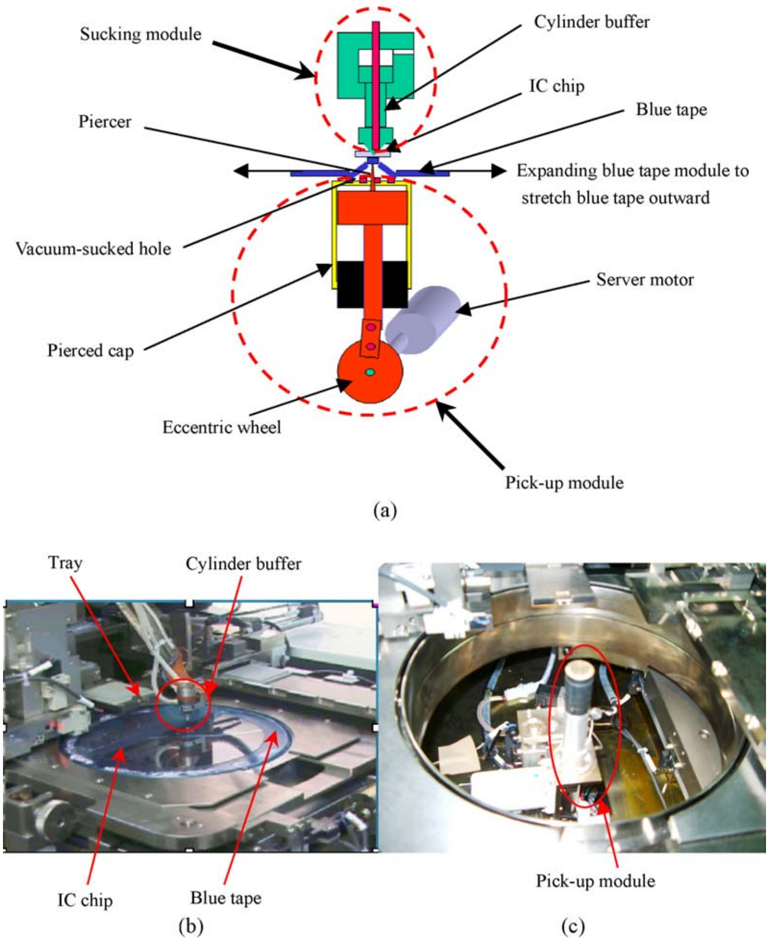


Fig. 2. The pick-up IC chip machine, MIRL CP602. (a) The sketch diagram, (b) machine and (c) pick-up module.

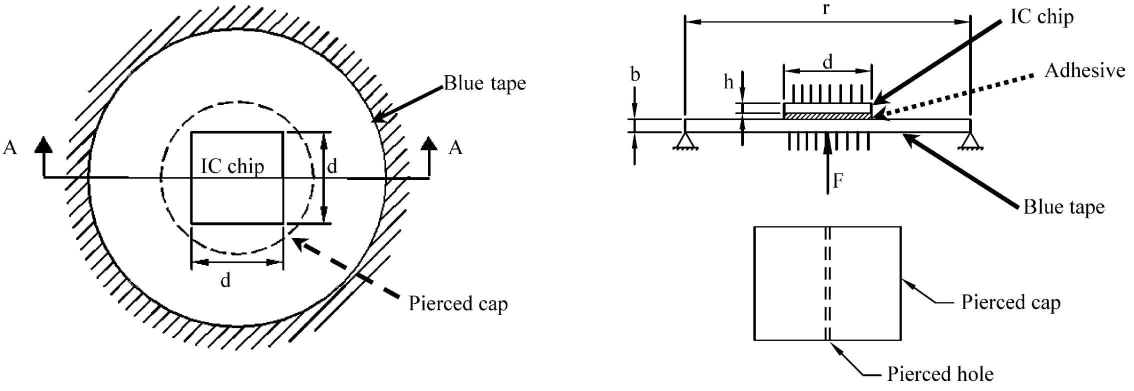


Fig. 3. Finite element model. (a) Model and (b) A–A cross-sectional diagram.

2.2. *Elements in model, material properties and loading conditions*

Table 1 summarizes the types of element; required real and material constants in the FEM model. The IC chip and blue tape are meshed by the Shell63 element. Shell63 is an element with six degrees of freedom (d.f.) and four nodes in ANSYS. The adhesive between the IC chip and the blue tape is modeled as a non-linear-elastic spring element, defined by the Combine39 element in ANSYS with three degrees of freedom and two nodes, connecting the IC chip to the blue tape. The Contac52 element in ANSYS is applied between the piercing seat and blue tape. It is a 3D point-to-point contact element.

Real and material constants are used in ANSYS. Material constants, which refer to elements of the IC chip, are determined from the chip's mechanical properties. The mechanical properties of an IC chip made of silicon, are taken from a table of data [16]. Table 2 lists its mechanical properties, Young's modulus, Poisson's ratio and dimensions. Others are obtained by performing the pre-experiments.

The pre-experiments elucidate the material properties and loading conditions, including the mechanical properties of the blue tape, the non-linear spring constant of the adhesive, the loading conditions for picking-up the piercer, the vacuum-sucking force from the vacuum-sucked hole of the pierced cap, the cylindrical buffer force exerted by cylindrical buffer, and pre-tension force of blue tape, as shown in Table 3.

2.3. *Material properties*

Fig. 5 shows the mechanical properties of blue tape that is made of PVC and fixed in the fixtures, measured by performing a simple tension test instrument. Fig. 6 plots the force versus displacement. The force is approximately proportional to the displacement of the blue tape. Its elastic modulus is derived using the above linear equation and used in the Shell63 element of the blue tape. Table 2 shows the Poisson's ratio of PVC, used in the Shell63 element.

The experimental data include the non-linear spring constants of the adhesive under ultraviolet rays. Fig. 7 depicts the experimental method [17]. Fig. 8 plots the non-linear curve of the adhesive force against the displacement, obtained from the adhesive experiment for IC chips of area 3 mm × 3 mm and 5 mm × 5 mm. The data curve can be input to the material data table in ANSYS and used as real constants of the Combin39 element. The spring constant of the Contac52 element between blue tape and the pierced cap, depends on the vacuum-sucking force on the pierced cap divided by the displacement of the piercer. This spring constant is 1.78 kN/m.

2.4. *Loading conditions*

The load cell and oscilloscope are used to measure the pick-up force exerted by the piercer during the pick-up IC process. The mechanism of the piercer of the pick-up IC chip modulus was redesigned, as illustrated in Fig. 4(a). The load cell is set in the mechanism of the piercer assembled in the pick-up IC

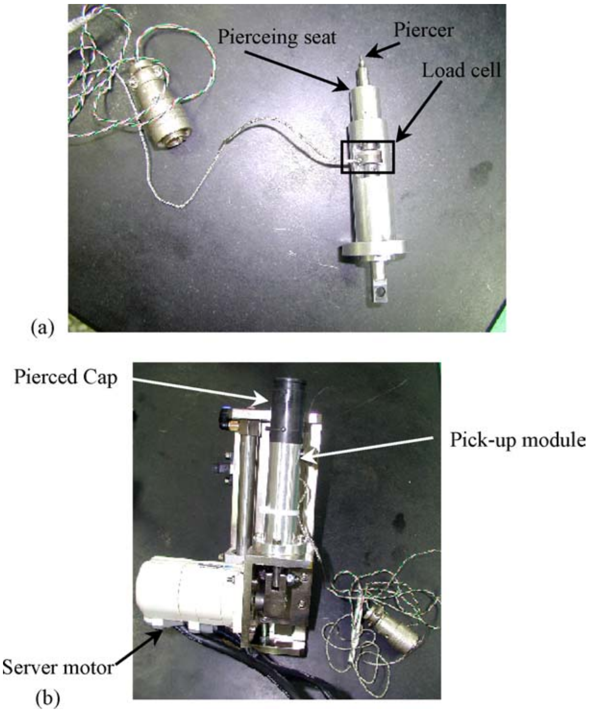


Fig. 4. Redesign the pick-up module. (a) Redesigned the mechanism of piercer, the load cell is set up and (b) the piercer driven by the servor motor and its mechanism.

Table 1
Element types for ANSYS [15]

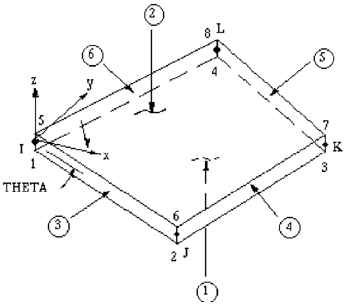
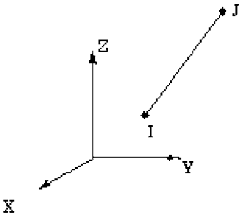
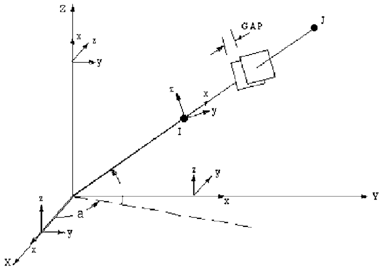
Item	IC chip (Si)	Blue tape	Adhesive	Pierced cap
Elements type	Shell63, 4 nodes, 6 d.f.	Shell63, 4 nodes, 6 d.f.	Combin39, 2 nodes, 6 d.f.	Contact 52, 2 nodes, 3 d.f.
				
Real constant of elements	Young's modulus and Poisson's rate		Non-linear spring constant	Spring constant
Real constant obtained from		Pre-experiment and Table 2	Pre-experiment	Assumption

Table 2
The mechanical properties and dimensions for IC chip and blue tape [16]

Material	Young's modulus (MPa)	Poisson's ratio	Thickness (mm)	Dimension (mm)
IC chip (Silicon)	1.29×10^{11}	0.28	0.1 or 0.34	5 × 5, 3 × 3
Blue tape UE-1085GX	3×10^{9}	0.38	0.07	$r = 15$

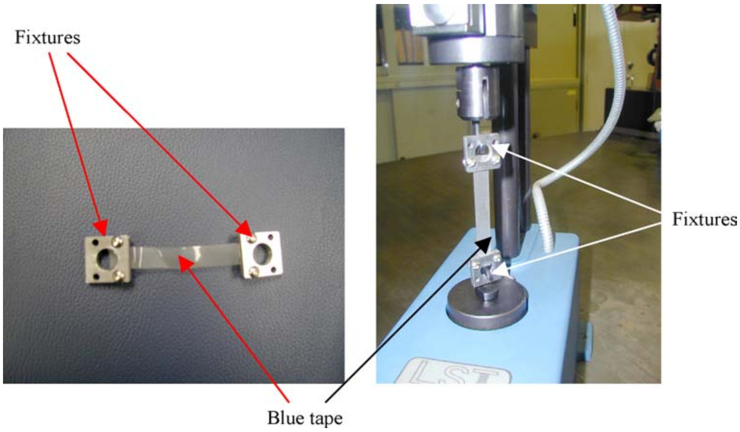


Fig. 5. The fixtures and tension test instrument for the blue tape.

chip module, as shown in Fig. 4(b). The load cell, Sensolec 11, measures the pick-up force, F. It is set up below the piercing seat driven by the eccentric wheel and servomotor, as shown in Fig. 5(b). Its output is connected to an amplifier, and the amplified signal is transferred to a Tektronix TDS 3054 oscilloscope and recorded. The output of the load cell relative to the amplified signal is first tuned and corrected precisely using 0.1 g standard weights. The displacement of the piercer is calculated and derived from the eccentric wheel mechanism, driven by the servomotor supplied by pulse generator. The trajectory profile of the eccentric wheel mechanism is proportional to the servomotor's pulse, and so the piercer's displacement can be obtained. The value of the pulse is converted to time and verified against the oscilloscope voltage–time diagram. Fig. 9 displays the piercer's

Table 3
Loading conditions

Loading conditions	Pick-up force piercer	Vacuum-sucking force	Cylindrical buffer force	Pre-tension force
Items of Force		Pierced cap	Cylindrical buffer	Blue tape
Method	Pre-experiment	Pre-experiment	Pre-experiment	Pre-experiment and ANSYS

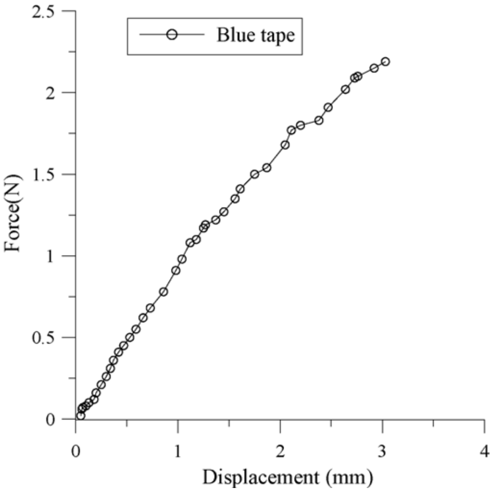


Fig. 6. Force and displacement curve for blue tape in tension test.

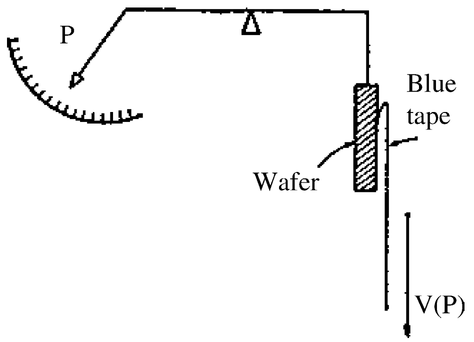


Fig. 7. The equipments for obtaining spring constant of adhesive [17].

displacement against the pulse. The relationship between pulse and piercer's displacement is nearly linear. Fig. 10 plots the relationship between the pick-up force and the displacement of the piercer in the pick-up IC chip process. The profiles of the pick-up forces at 40 kpps (10^3 pulses per second) and 5 kpps piercing velocities are similar. The velocity of the piercer did not significantly affect this model. The pick-up force at a piercing velocity of 5 kpps was only 0.2–0.6 N (Newton) greater than that at a piercing velocity of 40 kpps.

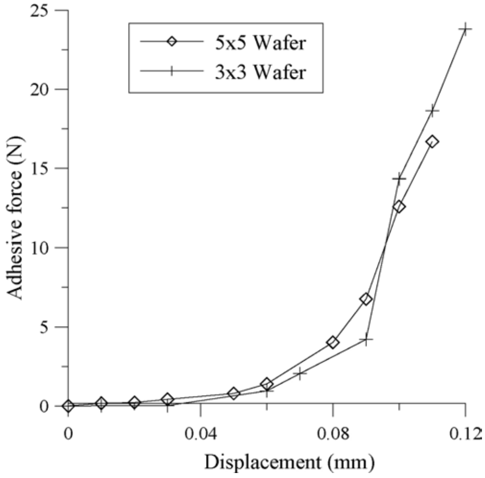


Fig. 8. The adhesive force and displacement curves for adhesive.

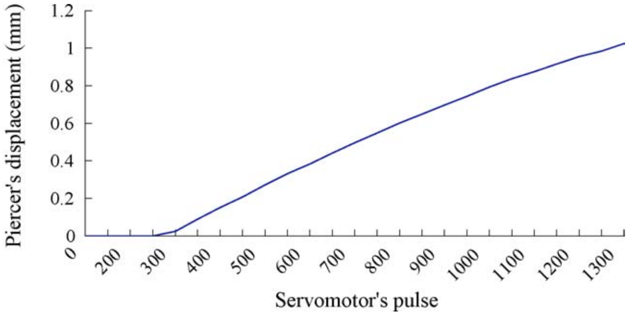


Fig. 9. The piercer's displacement and pulse plot.

In measuring vacuum-sucking force, when the pick-up force of the piercer applying to the blue tape on which an IC chip cannot stick, was obtained under the vacuum and non-vacuum conditions. The vacuum-sucking force equals the pick-up force under the vacuum, minus another pick-up force measured in the blue tape not sucked by the vacuum. When the displacement of the piercer is 0.79 mm, the maximum pick-up forces with and without the vacuum are 2.6 and 1.2 N, respectively. The vacuum-sucking force is approximately 1.4 N. The vacuum pressure is approximately 5 kPa, obtained as the vacuum-sucking force divided by the area over which the vacuum is applied, calculated using the radius, 10 mm, of the circular area on the upper surface of the pierced cap.

The cylindrical buffer force is assumed to be constant because the maximum displacement of the piercer is only about 1 mm. When only the piercer moves upward, the cylindrical buffer and blue tape are not set up in the CP602 device, and the measured pick-up force is the cylindrical buffer force. The cylindrical buffer force is about 0.4 N when the piercer's displacement is 0.79 mm.

The pre-tension force on the blue tape is determined from the results that are simulated under the same experimental conditions described below and solved by ANSYS. In the experiment, the pick-up force on the blue tape was 2.6 N and the piercer's displacement was 0.79 mm, as obtained from Fig. 11, which plots the measured pick-up force on blue tape on which the IC chip does not stick, against the displacement of the piercer. The

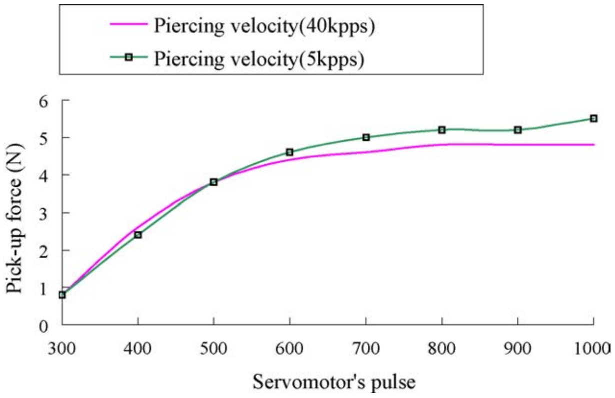


Fig. 10. The picked-up force and servomotor's pulse diagram.

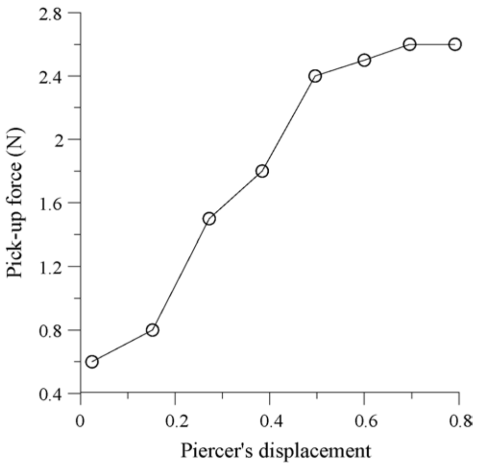


Fig. 11. Pick-up force from blue tape and piercer displacement curve without IC chips.

pre-tension force on the blue tape is about 80 N, as determined using ANSYS under the earlier conditions.

Two boundary conditions are applied in this model. The first is that the blue tape is fixed in the *x*, *y* and *z* directions around the edge. The other is that the pierced cap is rigid and its displacement is zero.

3. Results

The analysis addresses factors that influence the pick-up of the IC chip, such as its size and the thickness, the spring constant of the adhesive, and the magnitude of the pick-up force. For a 4.8 N pick-up force on the IC chip (5 mm × 5 mm × 0.1 mm), Fig. 8 presents the spring constant, of the adhesive, that results from the slope of the adhesive force against the displacement and Table 2 presents the properties of the blue tape and the IC chip. Figs. 12 and 13 show the contours of stress and displacement, respectively. Table 4 lists the results obtained by ANSYS. The Von-Misses stress is maximum, 121 MPa where the pick-up force acts on the blue tape and the IC chip. The stress at the corner of the IC chip is clearly much smaller than that of the point of action due to the piercing force. The stress is rather smaller farther from the point at which the pick-up force acts. The displacement, 0.078 mm of the adhesive in the corner exceeds that, 0.051 mm, in the center. The IC chip is similarly subject to a bending moment that results from the difference between the displacement of the adhesive at the corner and that in the center of the IC chip. The internal forces in the adhesive layer due to the bending moment exceed those at the center; the IC chip was successfully picked up and began to peel from the four corners of the IC chip toward the central of the chip.

The stress contours are similar to the displacement contours for the thicker IC chip (5 mm × 5 mm × 0.34 mm), as presented in Figs. 12 and 13. Table 4 presents the results for the thicker IC chip subject to a pick-up force of 3.5 N. The maximum value, of Von-Mises stress, about 10 MPa, is 10 times lower than the critical value of the IC chip but the corner and the central displacements, of the IC chip, 0.079 and 0.046 mm, respectively, are very close to those of the IC chip, (5 mm × 5 mm × 0.1 mm). A thicker IC chip has a lower maximum Von-Mises stress and a corner displacement that differs more from the central displacement. Therefore, the success rate of picking up a thicker IC chip is higher.

Fig. 8 presents the adhesive spring constant obtained from the ratio of the adhesive force to the displacement. The adhesive spring constant varies a range from 0.5 to 2. Figs. 14 and 15

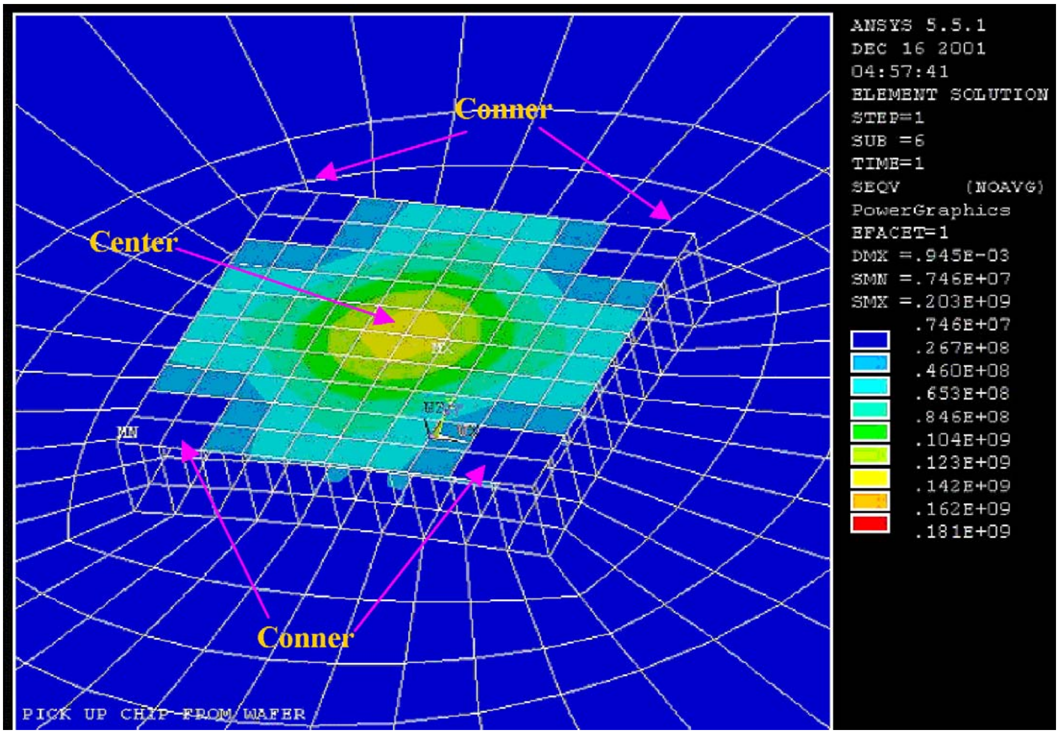


Fig. 12. Von-Mises stress contour for the IC chip.

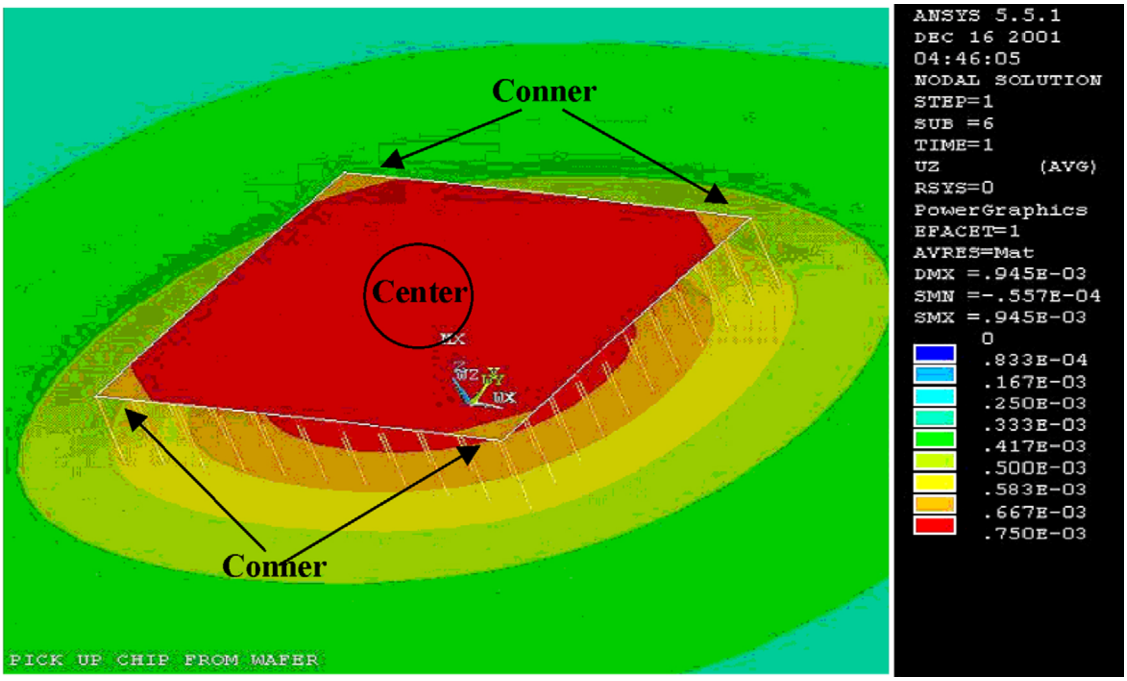


Fig. 13. Displacement contour for the IC chip.

plot the non-dimensional stresses of the IC chip and the spring displacement ratio (corner position/central position) of the variously sized specimens. The non-dimensional stress is defined as $\frac{\sigma d^2}{F}$, where σ, d and F represent the maximum Von-Misses stress, the size of the IC chip and the piercing force. In Fig. 8, the adhesive spring constant weakly influences the non-dimensional stress of the IC chip because the adhesive force is only slightly varied, over a range of displacements from 0 to 0.06 mm. The thickness and the length of the IC chip crucially affect its stress and determine whether the IC chip can be successfully picked up. Fig. 14 shows a thicker IC chip with a smaller stress; Fig. 15 presents it with the greater spring displacement ratio of an IC chip of size 5 mm × 5 mm. As the spring displacement ratio increases, the thicker IC chip exhibits a larger moment of inertia and smaller stress due to the bending moment. Therefore, a thick IC chip can be successfully and easily peeled in the pick-up process. The IC chip that is 3 mm × 3 mm × 0.1 mm long is much easier to peel than the chips that are 5 mm × 5 mm × 0.1 mm and 5 mm × 5 mm × 0.34 mm long because its non-dimensional stress is smaller and the spring displacement ratio is larger.

Table 4
The results for 5 mm × 5 mm × 0.1 mm and 5 mm × 5 mm × 0.34 mm IC chips

Items	Specimens	
	5 mm × 5 mm × 0.1 mm	5 mm × 5 mm × 0.34 mm
Pick-up force of piercer (N)	4.8	3.5
Displacement of piercer (mm)	0.73	0.468
Displacement of adhesive in the corner of IC chip (mm)	0.078	0.079
Displacement of adhesive in the center of IC chip (mm)	0.051	0.043
Maximum value for Von-Misses stress of IC chip (MPa)	121	10

Critical stress of IC chip failure is 130 MPa.

In this study, ANSYS took about 15–25 min on a PC (Intel PIII 650 MHz, RAM 256 M byte, and 80 G byte hard disk) to yield solutions.

3.1. Post-experiments

The picked-up IC chip machine, shown in Fig. 2(b) was also used in post-experimental tests. After the components in Fig. 4(a) were assembled into a pick-up IC chip module,

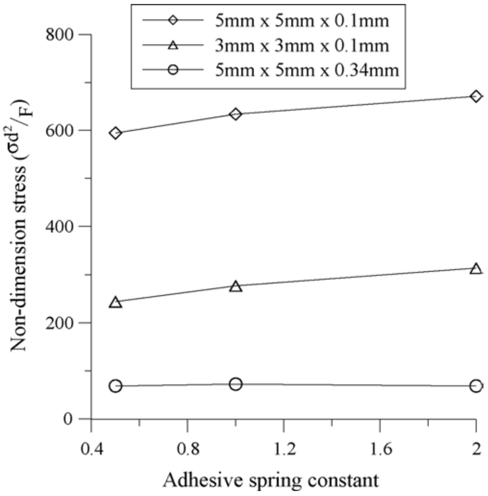


Fig. 14. The relationship between non-dimensional stress of IC chip and adhesive spring constant.

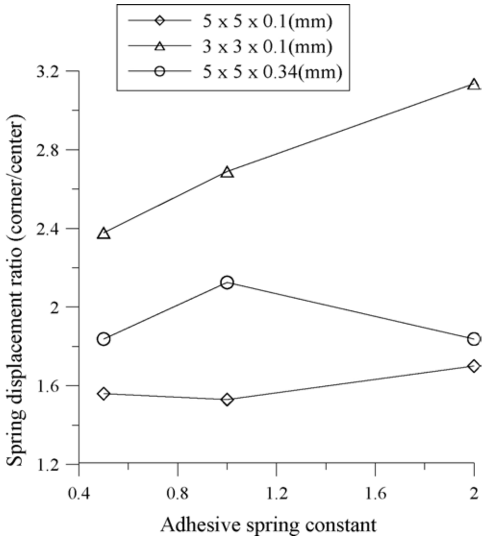


Fig. 15. The relationship between spring displacement and adhesive spring constant.

this module was established below the blue tape, as shown in Fig. 2(c).

Fig. 16 plots the success and failure rates relative to the displacement of two specimens of IC chips at a piercing velocity of 40 kpps. The failure of pick-up IC chips is defined as their exhibiting cracks or not being separated from the blue tape. Two IC chips—5 mm × 5 mm × 0.34 mm and 5 mm × 5 mm × 0.1 mm were used as specimens; the success rate of the pick-up of the thicker IC chip was nearly 100%, and was independent of the displacement of the piercier from 0.6 to 1 mm. However, the thinner IC chip was sensitive to the displacement of the piercier. The success rate of the pick-up IC chips was greater with the displacement of the piercier from 0.65 to 0.9 mm. A thinner or larger IC chip deforms more in the pick-up process. The above results follow from the higher bending moment that easily yield the fracture of the IC chip. Conversely, a thicker and smaller IC chip has smaller stress, smaller deflection and a much greater displacement of the adhesive between the IC chip and the blue tape. The success rate of removing the thicker IC chip from the blue tape exceeds that of removing the thinner IC chip. The previous solutions obtained by ANSYS, presented in Table 4 – a maximum Von-Mises stress of the IC chip with dimensions 5 mm × 5 mm × 0.1 mm, was 121 MPa – approaches the critical stress, 130 MPa, at which the pick-up force and the displacement of the piercer are 4.8 N and 0.73 mm, respectively. Similarly, in Table 4, the IC chip of dimensions, 5 mm × 5 mm × 0.34 mm has a lower maximum Von-Mises stress and a larger difference between the corner and central displacements. It is successfully and easily separated from the blue tape. The FEM solutions are validated by the post-experimental results as shown in Fig. 16. The success rate of picking up the IC chip, 5 mm × 5 mm × 0.1 mm clearly varies violently because of the maximum stress near the critical stress when the displacement of the piercer is close to 0.73 mm.

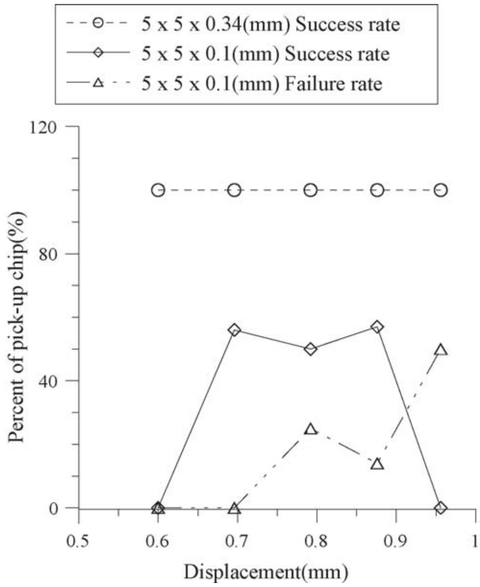


Fig. 16. Successful and failure rate distribution due to pick-up displacement in pick-up chip process at 40 kpps piercing velocity.

During the pick-up IC chip process, the separation of the IC chip from the adhesive can be elucidated from the numerical solutions of FEM and demonstrated by the post-experiments on the picking up of the IC chip. The presented results indicate that when the IC chip is peeled and separated from the blue tape, the four corners of the IC chip are first split from the blue tape, so the IC chip may be successfully picked up. However, the maximum Von-Misses stress of the IC chip at the center of the IC chip should not exceed the yielding stress of the IC chip, to ensure that the pick-up of the IC chip does not fail.

4. Conclusions

The pick-up IC chip process is important in manufacturing ICs. In this work, the factors that strongly affect the success rate are the pick-up force, the displacement of the piercer, the elastic modulus of the blue tape, the thickness and size of the IC chip and the spring constant of the adhesive.

The success rate of picking up a thicker and smaller IC chip is higher. However, the success rate of picking up a thinner and larger IC chip depends on the displacement and the pick-up force of the piercer.

The adhesive spring constant hardly influences the non-dimensional stress of the IC chip. However, the variance of the adhesive spring constant affects the ratio of the corner displacement to the central displacement for a larger IC chip. The non-dimensional stress of a small IC chip is much lower than its critical stress, and so can be successfully picked up and easily separated from the blue tape.

FEM simulations of the pick-up of a thin IC chip are run, and experiments performed to establish which factors to dominate the failure of the IC chip in the pick-up process. In this work, the success rate of the pick-up of the IC chip was increased by performing pre-experimental tests to determine the material properties that answer to the actual model. The effects of the major factor were determined by comparing the FEM solutions with the results of the post-experiments.

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References

[1] Takatori Corporation, Semiconductor Machinery Division/Introduction to the manufacturing process, http://www.takatori-g.co.jp/e_top.html (2003).

[2] M. Goland, N.Y. Buffalo, E. Reissner, The stresses in cemented joints, ASME J. Appl. Mech. 11 (1944) A17–A27.

[3] W. Carpenter, Finite element analysis of bonded connections, Int. J. Num. Mech. Eng. 6 (1973) 450–451.

[4] I.U. Ojalvo, H.L. Eidinoff, Bond thickness effects upon stresses in single-lap adhesive joints, AIAA J. 16 (1978) 204–211.

[5] D. Chen, S. Cheng, An analysis of adhesive-bonded single-lap joints, ASME J. Appl. Mech. 50 (1983) 109–115.

[6] W.C. Carpenter, Stress in bonded connections using finite elements, Int. J. Num. Methods Eng. 15 (1980) 1659–1680.

[7] D. Chen, S. Cheng, An analysis of adhesive-bonded single-lap joints, ASME J. Appl. Mech. 50 (1983) 109–115.

[8] E. Suhir, Stress in bi-metal thermostats, ASME J. Appl. Mech. 53 (1986) 657–660.

[9] E. Suhir, Interfacial stresses in bimetal thermostats, ASME J. Appl. Mech. 56 (1989) 595–600.

[10] C.C. Lin, Y.S. Lin, A finite element model of single-lap adhesive joints, Int. J. Solids Struct. 30 (1993) 1679–1692.

[11] D.W. Oplinger, Effects of adherend deflections in single lap joints, Int. J. Solids Struct. 31 (1994) 2565–2587.

[12] M.Y. Tsai, J. Morton, An evaluation of analytical and numerical solutions to the single-lap joint, Int. J. Solids Struct. 31 (1994) 2537–2563.

[13] C. Basaran, Y. Zhao, Closed form vs. finite element analysis of laminated stacks, Finite Elements Anal. Des. 32 (1999) 163–179.

[14] E. David, A. Lazar, Adhesive bonding between aluminium polytetrafluoroethylene, J. Mater. Process. Technol. 143–144 (2003) 191–194.

[15] ANSYS Inc., ANSYS Help Manual Release 5.5, SAS IP Inc., 1998.

[16] Callister D. William, Materials Science and Engineering: An Introduction, fourth ed., John Wiley & Sons, New York, 1997.

[17] A.J. Kinloch, Adhesion and Adhesive: Science and Technology, Chapman and Hall, London, 1987.