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EFFECT OF CAPILLARY TIP SHAPE ON DEFORMATION AND BONDABILITY IN AU WIRE BONDING

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Abstract

Au wire bonding is a process for connecting a lead frame and a semiconductor chip in electronic packaging. In Au wire bonding, an Au ball is pressed into an Al terminal by a capillary. It is required to reduce the bonding area to as small as possible while maintaining the strength of bonding. This paper shows effects of capillary tip shape on bondability and deformation of Au ball and Al film in Au wire bonding. To study the change of bonding condition along with the change of capillary shape, typical capillaries were selected and their bonding processes were analyzed. Bonding reliability tended to become high as the maximum ball height became small, namely, as the volume of the collapsed periphery became large, and also as the bulge at the periphery of bonding and the contact pressure became large. The superiority of these capillaries can be roughly evaluated.

Key words: wire bonding, bondability, capillary tip shape, deformation analysis, Au ball

1. INTRODUCTION

Wire bonding is a process of interconnection between a semiconductor chip and a lead frame by a metal wire. Various studies for wire bonding have been carried out [Lee et al., 1993; Huang et al., 1991; Ikeda et al., 1999; Harman & Leedy, 1973; Horowitz et al., 1980; Charles et al., 2003; Ishizaka et al., 1997; Nakane et al., 1987; Cohn, 1976; Lianga et al, 1998]. Trends toward high quality, high interconnection density, high lead counts and fine pitch in integrated circuit (IC) packages reduce the bonding pad spaces and the size of the ball radius in wire bonding. This process is an important step in the manufacturing process of IC packages and many problems occur in the process. In Au wire bonding, an Au ball is pressed into an Al film by a capillary. It is required to reduce the bonding area to as small as possible while maintaining the strength of bonding. Therefore, it is important to optimize this process so that reliability of the bonding can be improved. The capillary tip shape has an effect on material flow of both Au ball and Al film. The material flow influences the bondability between Au ball and Al film. In this study, we investigated the effect of capillary tip shape on material flow and bondability in Au wire bonding.

2. EXPERIMENTAL AND CALCULATION CONDITIONS

Figure 1 shows schematics of the Au-Al bonding experimental setup used in the experiments. The vertical displacement of the capillary, applied load and the temperature of a die pad were measured during bonding under all experimental conditions.

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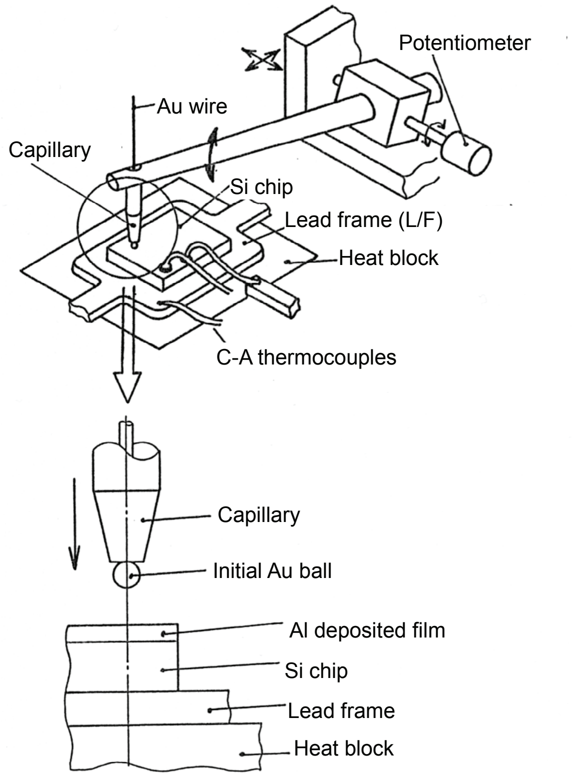
An outline of the Au wire bonding procedure is shown in figure 1. Au ball was bonded onto an deposited Al film only by thermocompression without ultrasonic oscillation.

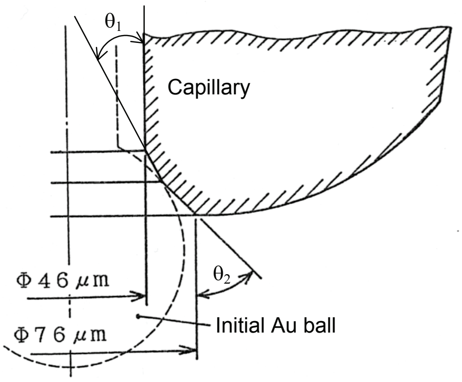


Procedures of Au wire bonding
(1) The Au wire is melted by discharge at the capillary tip.
(2) An initial Au ball is formed.
(3) The initial ball is pressed into the Al film.
(4) The Au wire is connected to the lead side.
(5) The capillary is lifted.
(6) The Au wire is cut.
Steps (1) to (6) are repeated.

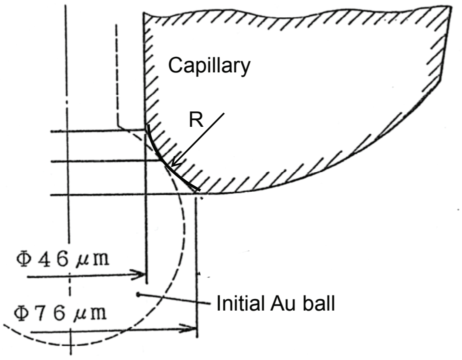
***Fig. 1.** Experimental setup and bonding procedures.*

***Table 1.** Experimental bonding conditions.*

Thickness of Al deposited film	(μm)	2
Diameter of Au wire	(μm)	30
Average initial diameter of Au balls	μm	68
Capillary tip shape (θ_1,θ_2)	(°)	25-30°, 25-45°, 25-60°, 45-60°
Capillary tip shape R	(μm)	10, 20, 30
Si chip temperature	(°C)	250 ±5
Bonding time	(msec)	70
Compression velocity	(mm/sec)	17
Setting load	(N)	0.2-1.59
Impact load	(N)	0.34-1.81



(a) Parameter: taper angles θ_1, θ_2



(b) Parameter: radius R

***Fig. 2.** Capillary tip shapes.*

In the experiments, to investigate the effect of the capillary tip shape on the deformation of Au ball and Al film, capillary tip shapes as shown in figures 2(a) and (b) were used. Taper angles (θ_1 and θ_2) and radius R were changed. Hereafter, the combination of taper angles is denoted as θ_1-θ_2. Thus, the combination of θ_1=25° and θ_2=45° is shown as 25-45°. The capillary tip shapes used were 25-30°, 25-45°, 25-60°, 45-60°, R10, R20 and R30. The experimental conditions are shown in table 1.

In numerical analysis, the deformation of Au ball and Al film was analyzed as an axisymmetrical problem using the rigid-plastic FEM simulator that was developed in our laboratory. Quadrilateral isoparametric elements with four nodes were used in the analysis. A local automatic remeshing function was incorporated. When Au ball and Al film contacted each other, nodal points at the bonding boundary were treated as common nodal points and sliding between the Au ball and the Al film was assumed not to occur. In addition, Au ball and Al film was assumed not to detach after contacting each other. The Al film was divided into appropriate elements in advance in order to reduce mismatch between nodes of the Al film and the Au ball. The friction shear factor between the capillary and Au ball was assumed to be 0.2. Measuring the deformation resistance of the Au ball is difficult; therefore, the load-elongation curve obtained in the tensile test of Au wire at an ambient temperature of 250°C was used as the flow curve of Au ball. The flow curve was approximated as $\sigma_{Au} = 206(\varepsilon + 0.0001)^{0.07}$ MPa.

3. RESULTS AND DISCUSSION

3.1. Bonding load and diameter of bonded ball

Figure 3 shows the relationship between the diameter of the compression-bonded ball and the bonding load. The diameter of the compression-bonded ball after bonding was measured using an optical microscope. Also, the state of the Au-Al bonded interface was observed by etching the Al film and peeling it from the Au-Al alloy area. The area of bonding between Au ball and Al film was calculated by image processing. In the case of experimental results, bonding load indicates impact load. It is seen that bonding diameter increases linearly with increasing bonding load for three capillary shapes. Comparing the calculation result for tip shape 25-45° with that obtained by experiment, the two curves do not agree very well when the diameter of the compression-bonded ball is small; however, they agree well when the diameter is large. The deformation of Au ball can be estimated roughly by analyzing the deformation of Au ball and Al film by rigid-plastic FEM.

Figure 4 shows the photograph of the Au-Al bonded surface observed from the interface of the compression-bonded ball after etching the Al film. The dark grey area in the photograph was good bonding area and the region of the alloy of Au and Al. It can be considered that the good bonding area was formed by the strong contact of the newly generated surfaces of Au ball and Al film. Figure 5 shows deformation pattern obtained from FE analysis. When the Au ball was pressed into the Al film, both the Au ball and Al film deformed accompanied. In the contact interface, both materials flew toward the periphery in the radial direction. The Al film was thinned by the pressing and the bulge of Al material was formed at the periphery of the bonding area. When the Au ball and Al film deformed each other, new surfaces of both Au ball and Al film were generated in the contact interface. The strong contact of the new surfaces of both materials induced the adhesion and the diffused agglutination between Au ball and Al film.

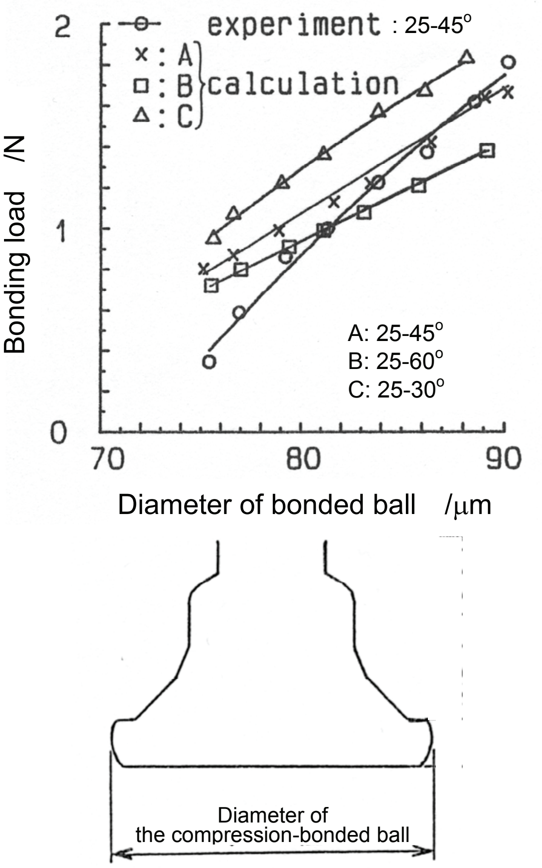


Fig. 3. Relationships between bonding load and diameter of bonded ball.

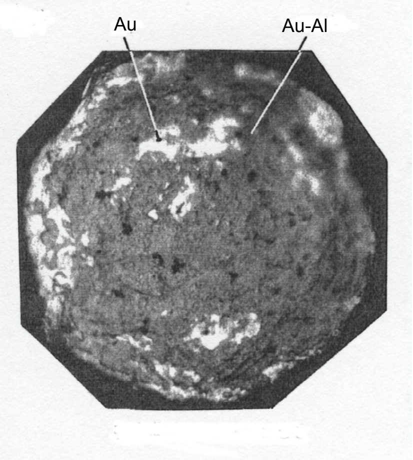


Fig. 4. Bonding interface of Au ball (magnification: x800, bonding load: 1.9N).

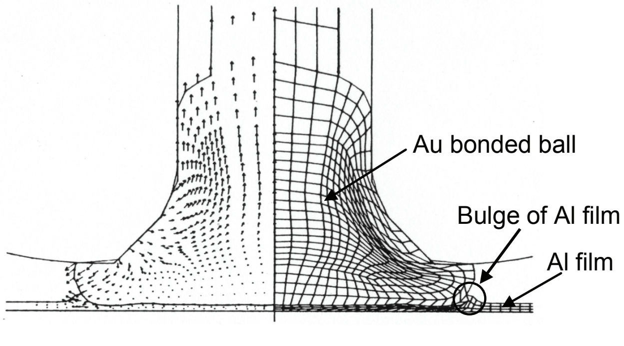
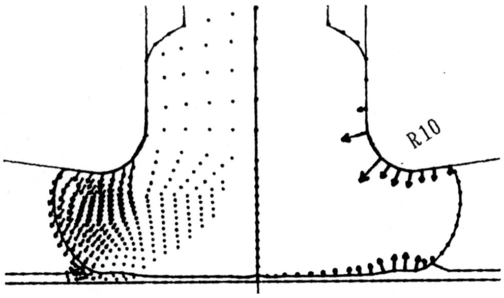
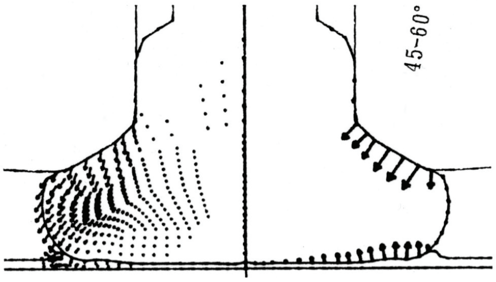


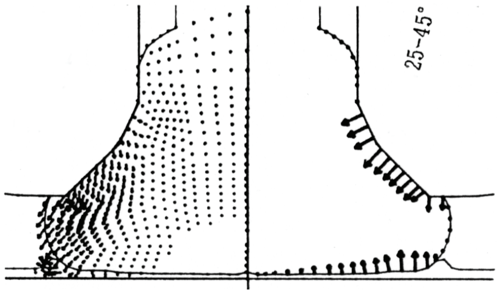
Fig. 5. Deformation pattern of Au ball and Al film (reduction: 34μm, σ_{Al}=78MPa, m=0.2).



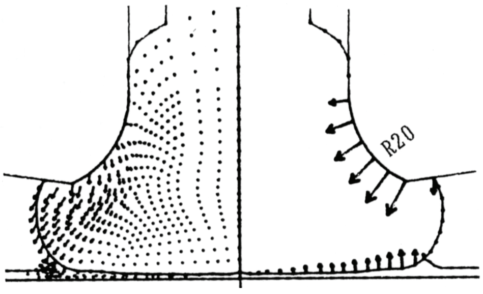
(a) Capillary shape: R10



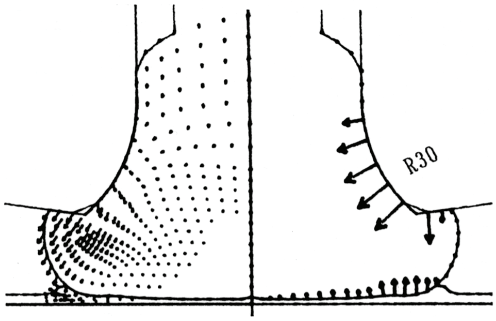
(b) Capillary shape: 45-60°



(c) Capillary shape: 25-45°



(d) Capillary shape: R20



(e) Capillary shape: R30

Fig. 6. Deformation of Au ball and Al film for each capillary shape (left part: distribution of velocity, right part: distribution of contact pressure, the diameter of bonded ball: 85 μm, Al film thickness:2μm, σ_{Al}=59 MPa).

3.2. Capillary tip shape and deformation patterns

To study the change of bonding condition along with the change of capillary shape, typical capillaries were selected and the deformation of both Au ball and Al film was analyzed. Figures 6(a)-(e) show the simulation results of the deformation for the five types of capillary tip shape. The velocity distribution of material flow is shown in the left part of each figure. The distribution of contact pressure is shown in the right part of each figure. Deformation features including the minimum thickness of Al film, the bulge height of Al film and Au ball height were compared at the stroke in which the maximum radius of the compressed-bonded Au ball became 85 μm.

The findings are summarized in Table 2. Bonding reliability in Table 2 shows the probability of complete bonding and was evaluated from bonding experiments. Bonding reliability tended to become high as the maximum ball height became small, namely, as the volume of the compressed periphery became large, and also as the bulge of Al film at the periphery of bonding area and the contact pressure became large, i.e., as Al film was thinned. It is seen that the bonding efficiency was better in cases

***Table 2.** Bonding states evaluated for each capillary shape.*

Capillary shape	Stroke /μm	Minimum thickness of Al film /μm	Bulge height of Al film /μm	Ball height /μm	Bonding reliability / %
R10	32	1.00	1.66	52.3	20
45-60°	30	0.99	1.52	51.1	35
25-45°	28	0.96	2.14	52.0	55
R20	30	0.99	2.01	52.5	95
R30	30	0.98	1.73	54.6	95

shown in figures 6(c)-(e) than in cases in figures 6 (a) and (b). Figure 7 shows influence of capillary tip shape on accumulation of relative slip with respect to Si chip. The accumulation of relative slip for each capillary shape was calculated corresponding to each case shown in figure 6. Comparing bonding reliability in table 2 with accumulation of relative slip in figure 7, it is found that the accumulation of relative slip has an effect on bonding reliability. The increase in the accumulation of relative slip can improve bonding reliability. The superiority of capillary shapes was estimated using the rigid-plastic finite element analysis. It was found that the accumulation of relative slip in the contact interface was an important parameter for estimating bondability.

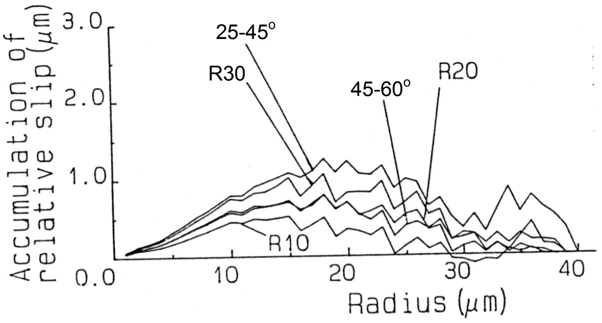


Fig. 7. *Influence of capillary tip shape on accumulation of relative slip with respect to Si chip.*

4. CONCLUSIONS

The effects of capillary tip shape on material flow and bondability in Au wire bonding were investigated. The state of the Au-Al bonded interface was also examined. The obtained results are as follows.

1) The strong contact of the newly generated surfaces of Au ball and Al film during bonding process induced the adhesion and the diffused agglutination between Au ball and Al film.
2) Bonding reliability tended to become high as the maximum ball height became small, namely, as the volume of the compressed periphery became large, and also as the bulge of Al film at the periphery of bonding area and the contact pressure became large.
3) The accumulation of relative slip with respect to Si chip improved had an effect on bonding reliability and was an important parameter for estimating bondability.
4) The increase in the accumulation of relative slip improved bonding reliability.
5) The superiority of capillary shapes was estimated using the rigid-plastic finite element analysis.

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WPŁYW KSZTAŁTU KAPILARNEJ KOŃCÓWKI NA ODKSZTAŁCENIA I ZDOLNOŚĆ DO SPAJANIA DRUTÓW ZE SREBRA

Streszczenie

Lutowanie drutem srebrnym jest procesem używanym do łączenia elektronicznych układów scalonych z ołowianą ramą. W tym procesie srebrna kulka wychodząca z kapilarnej końcówki jest wciskana przez tą końcówkę w film aluminiowy. Celem optymalizacji procesu jest ograniczenie powierzchni lutu do jak najmniejszej przy zachowaniu odpowiedniej wytrzymałości połączenia. W artykule pokazano wpływ kształtu kapilarnej końcówki na jakość połączenia oraz na odkształcenie srebrnej kulki i filmu aluminium. Typowe kształty kapilarnych końcówek zostały wybrane do badań zmiany warunków lutowania. Najwyższą niezawodność połączenia uzyskano kiedy maksymalny wymiar srebrnej kulki był najmniejszy, to znaczy kiedy objętość związana z obwodem zapadającego się obszaru pod lutem była duża. Wtedy wybrzuszenie na obwodzie połączenia było również duże. Zalety takich połączeń zostały oszacowane.

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