Analysis of conductive particle electric characteristics for anisotropic conductive adhesive film

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Abstract

The electric characteristics connected by anisotropic conductive adhesive film were significant affected by the deformation of the conductive particle. In this study, the theory model was set up to calculate the conductive particle resistance after ACF bonding. The effects of the deformation of the conductive particle on its resistance were analysis. The result compared with the experiments was fit well. The rebound of the conductive particle under the high temperature and humidity environment was simulated using FEM, and the deformation was determined. The effects of the rebound of the conductive particle of ACF on its resistance were investigated, and the effects of the number of the conductive particle on the total electrical properties were also studied. The optimal deformation of the conductive particle connected by ACF and the effects of the thermal and humidity ambience on its electric characteristics were obtained.

Keywords: Anisotropic conductive adhesive films, Conductive particle, Electric characteristics, Numerical simulation

1 Introduction

Currently tin lead solder was commonly used in electronics packaging industry. However, as a harmful substance to the human heath and environment, tin will be banned in the world. A more convenient, environmentally friendly, low-cost connection Material - anisotropic conductive adhesive film is becoming popular[1]. The anisotropic conductive adhesive film (ACF) can be used to meet the need of a higher density (minimum spacing 37μm) and can be easily automated manufactured [2,3]. Moreover, ACF can meet the IC device with a large number of pins and use a very small conductive path shelf, so ACF has a small influence on the chip and the substrate

ACF is a kind of thin conductive adhesive film with two layer structure and consists of conductive particles, adhesives and additives. ACF is also a kind of electron and electricity anisotropic polymer film which has the characteristics of electric conductivity, adhesion and insulation. ACF is endowed with electrical conductivity and connectivity respectively by conductive particles and adhesives [4]. There are many factors which affect the reliability of adhesive performance of ACF, such as bonding temperature, curing time, bonding pressure, conductive particles content, metal salient points, flatness of the substrate welding zone and the elastic modulus of the ACF, etc. At present, the method of traditional reliability failure rate and the method of failure physical were applied to evaluate electrical reliability. Based on the reliability experiments and its analysis of failure mechanism, the adhesive reliability of ACF is evaluated by the Arrhenius Model, Coffin Manson Model and Hallberg Peck Model[5].Adhesive structure by ACF is widely used in microelectronic packaging, however its adhesive reliability is low in the temperature and humidity environment. In the action of temperature and humidity load, the adhesive intensity of ACF adhesive interface will decrease because the micro-cracks, bubbles and other defects continue to expand, which will also cause the deformation of the conductive particles and affect the conduction performance of ACF [6, 7]. So, It is very significant to understand the impact on the resistance because of the deformation of the conductive particles and the environment impact on electrical properties, which is helpful to the research and use of ACF.

In this article, the factors that affected the electrical properties of ACF during the bonding process were studied by the method of theoretical analysis, such as the deformation of conductive particles, cracking and other factors. The rebound of the conductive particles in high-temperature, high-humidity environments was analyzed using the finite element method. The impacts to the total resistance caused by the rebound deformation of the particles and by the number of particles were comparatively analyzed, which made it clear that controlling the deformation of particles was very important in the manufacturing process of ACF.

2 Resistance theoretical analysis of conductive particles

ACF contained a large of conductive particles and the total resistance of adhesive ACF consisted of 4 constriction resistance ($R_{constriction}$), 2 tunneling resistance ($R_{tunneling}$) and 1 particle resistance ($R_{particle}$), as shown in Fig.1. Particle resistance was the main part of the total resistance. Therefore, the emphasis of research was mainly laid on the particle resistance.

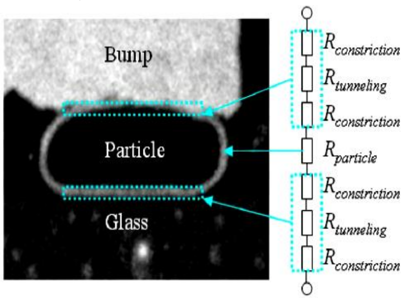

FIGURE 1 Components of particle resistance after ACF bonding

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After the bonding of ACF, nickel polymer particles usually took on a drum shape and there were 2 circular faces on the top and bottom, which respectively were contacted with the gold salient points and glass. Particle resistance can be composed with round face resistance and ring resistance. Nickel plating resistance can be expressed as follows:

$$dR = \frac{dy}{\sigma_N S}\ , \tag{1}$$

where, dy was the full height of the current path; σ_N was the nickel conductivity rate; S was the area of perpendicular to the direction of the current path. R_{circle} can be calculated by the following formula:

$$R_{circle} = \frac{1}{\sigma_N \pi}\int_{\frac{h}{2}}^{\frac{h}{2}+t} \frac{dy}{\left[\sqrt{\left(\frac{h}{2}+t\right)^2 - y^2} + r\right]^2} \tag{2}$$

Assuming two circular contact surfaces were not cracked, the ring resistance can be expressed as follows:

$$R_{ring} = \frac{2}{\sigma_N \pi}\int_0^{\frac{h}{2}} \frac{dy}{\left[\sqrt{\left(\frac{h}{2}+t\right)^2 - y^2} + r\right]^2 - \left[\sqrt{\left(\frac{h}{2}\right)^2 - y^2} + r\right]^2}\ , \tag{3}$$

where, h was the height of the central portion of the polymer; t was the thickness of the nickel plating layer and r was the radius of the circular resistance, as shown in Fig. 2. The height h and radius r were changing at the different bonding pressures, but the thickness t kept constant.

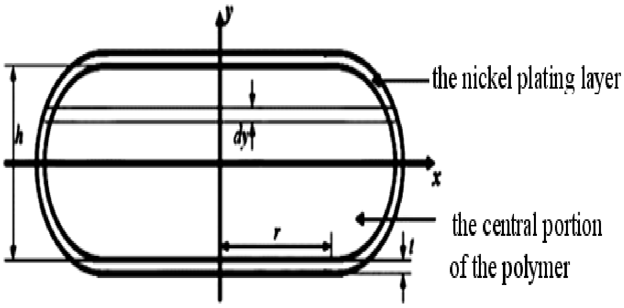


FIGURE 2 Profile of a nickel-coated polymer particle

If the nickel layer appeared cracks when the particles were deformed, the resistance of drum shape of the nickel plating was no longer a ring resistance. So, the resistance of drum shape of the nickel plating was shown as crack resistance R_{crack}. To calculate R_{crack}, a new parameter $R_{virtual}$ was introduced by formula (4), as follows:

$$R_{virtual} = \frac{2}{\sigma_N \pi}\int_0^{\frac{h}{2}} \frac{dy}{\frac{\theta_{crack}}{360}\left\{\left[\left(\frac{h}{2}+t\right)^2 - y^2\right] - \left[\left(\frac{h}{2}\right)^2 - y^2\right]\right\}}\ , \tag{4}$$

wherein, θ_{Crack} was the crack angle. R_{crack} can be calculated by (5), as follows:

$$\frac{1}{R_{crack}} + \frac{2}{R_{virtual}} = \frac{1}{R_{ring}}\ , \tag{5}$$

So, $R_{particle}$ can be calculated by formula (6), as follows:

$$R_{particle} = R_{crack} + 2R_{circle}\ , \tag{6}$$

Formula (6) was applicable for ACF assembly with whatever metallic coatings and polymers center.

3 The Influence on $R_{particle}$ Caused by the Deformation of Particles

The resistance of a compressed single conductive particle was composed of 2 circle face resistance R_{circle} and a ring resistance R_{ring}. By the formula (2) and (3), when t = 0.15μm, the resistance of the conductive particles $\boldsymbol{R_{particle}}$ can be calculated by (7), as follows:

$$R_{particle} = \frac{2}{2.5\pi}\int_0^{\frac{h}{2}} \frac{dy}{\left[\sqrt{\left(\frac{h}{2}+0.15\right)^2 - y^2} + \frac{\pi(3.7-h)}{4}\right]^2 - \left[\sqrt{\left(\frac{h}{2}\right)^2 - y^2} + \frac{\pi(3.7-h)}{4}\right]^2}\ , + \frac{2}{2.5\pi}\int_{\frac{h}{2}}^{\frac{h}{2}+0.15} \frac{dy}{\left[\sqrt{\left(\frac{h}{2}+0.15\right)^2 - y^2} + \frac{\pi(3.7-h)}{4}\right]^2} \tag{7}$$

wherein, h =(1/3～1)d; d=3.7μm and d was the diameter of the center of the polymer particles.

The comparison of theoretical calculation and experimental test was shown in Fig.3 and the calculation results agreed well with experimental results. When particles had small changes in height, it was very difficult to measure the change of the resistance. If the pressure was too large, the particles would be crushed and the resistance would be very large. From the Fig.3, we can see that in the action of the load pressure of the adhesive, the resistance of the particles $R_{particle}$ was 34% reduction when the height h of the particle was lowered 18.92%.So, it can be seen that the amount of the deformation of the particles had a large influence on the change of the resistance. When the adhesive pressure was too large, I.e., the height of the particle was lower than crack limit, conductive particles may be crushed. So, the circuit may be off. Therefore, it was necessary to control the amount of deformation of the conductive particles reasonably. The desirable particle deformation was maximum compression of the conductive particles but not broken.

4 The Influence to $R_{particle}$ Caused by the Rebound of the Particles

The amount of deformation of the particles had a large influence on the resistance of the ACF adhesive line. In temperature and humidity environment, the rebound of the conductive particles would occur. In order to study the influence on the resistance of the conductive particles caused by the rebound, the analysis model of ACF structure was constructed by FEM. The normal working environment of the conductive particles was 20℃ The constructed model at 85% RH and 85 ℃ environment was shown in Fig.3.

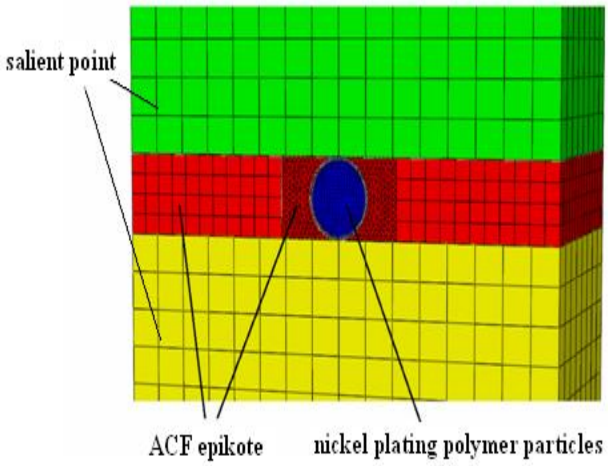


FIGURE 3 Finite element model

Since the model is symmetric, the model shown in Fig.3 was half of the total model. The size of each part in the model was shown in Tab.1.

TABLE 1 Geometric parameters of the all parts

Components	Length (μm)	width (μm)	Height (μm)	diameter (μm)	Thickness (μm)
salient point	30	30	15	/	/
center of the polymer	/	/	/	3.7	/
Nickel plating layer	/	/	/	/	0.15
IC	160	90	90	/	/
glass	160	90	90	/	/

The structure of ACF was composed of glass substrate, integrated IC chip, epoxy colloidal, gold salient points and a conductive particle. The physical properties of the parts were shown in Tab.2.

The symmetry Y-Z plane was restricted by the constraint condition U_1=U_{R2}=U_{R3}=0. The X-Y plane of the bottom surface of the glass substrate was restricted by the constraint condition U_3=U_{R1}=U_{R2}=0. The interconnection constraint between the nickel plating layer and the center of the polymer was set as binding constraints. The interconnection constraint between the nickel plating layer and the epoxy colloidal was also set as binding constraints. The symmetry X-Z plane was restricted by the constraint condition U_2=U_{R1}=U_{R3}.

TABLE 2 Material parameters of the FEM simulation

material	elastic ratio (GPa)	poisson's ration	expansion coefficient (10^{-9} m/K)
IC	131	0.266	4.2
epikote	0.01 (non-solidification) 1(solidification) 3 (cooling)	0.25	70（293K） 70（410K） 150（413K） 150(493K)
gold salient point	77.2	0.3	14.4
glass	70	0.19	/
nickel	207	0.31	15
polymer	4.5	0.33	60

In this model, the grid unit type of the nickel plating, IC chip and glass substrate were C3D8R and the structure was hexahedral grid mesh. The grid unit type used by polymer was C3D8R and the number of the grid unit was 13978.The grid unit types of the salient points of IC chip and glass were all C3D8R.The grid unit type of ACF was C3D8R and the refinement part used the tetrahedral grid mesh and the grid unit type was C3D4.

In the bonding pressure, the simulation results of the deformation of the epikote colloid and conductive particles were shown in Fig.4. In the high-temperature, high-humidity (85 ℃ and 85% RH) environments, The change of the adhesive structure of ACF was shown in Fig.5.. In the above two cases, the contrastive results of the deformation of the conductive particles were shown in Fig.6.

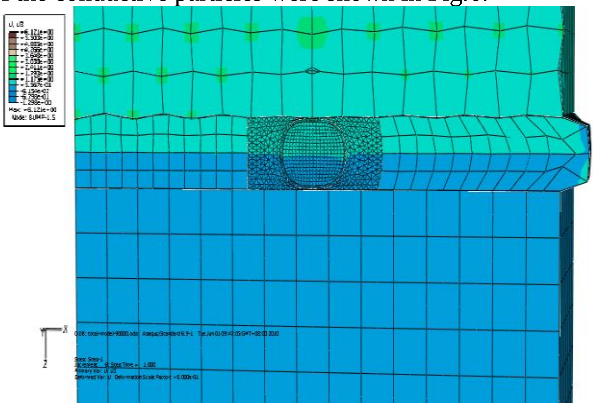


FIGURE 4 Deformation degree under bonding pressure

From the simulation results, we can see that the height of compressed conductive particles increased 0.08μm and the contact area of the conductive and metal of weld would decrease. From the formula (6), the resistance of a single conductive particle increased to 1.3mΩ. In the actual production, the number of the conductive particles in a line was generally 5 or more and the electrical properties of the ACF would be affected if the number of the conductive particles was below 5.Assuming that the resistance of each particle was equal. Since the connect way of each resistance was parallel, the total resistance $R = \boldsymbol{R_{particle}} / n$. With the increasing number of particles, the total resistance decreases. In the environment of the high temperature and high humidity, the resistance of single circuit including 5 conductive particles would increase to 0.26 mΩ.

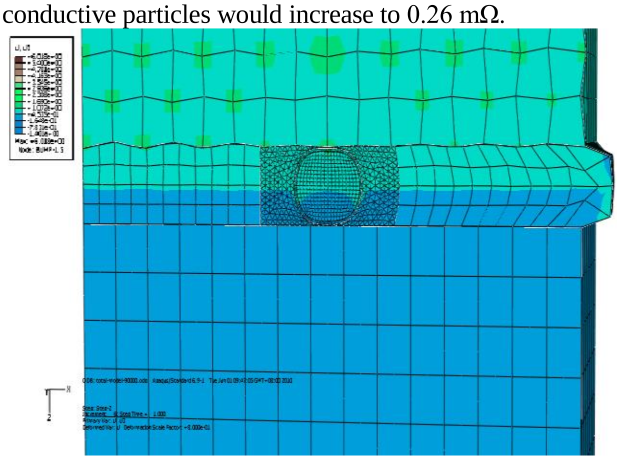
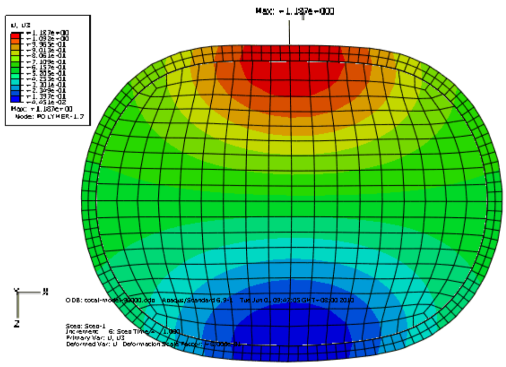
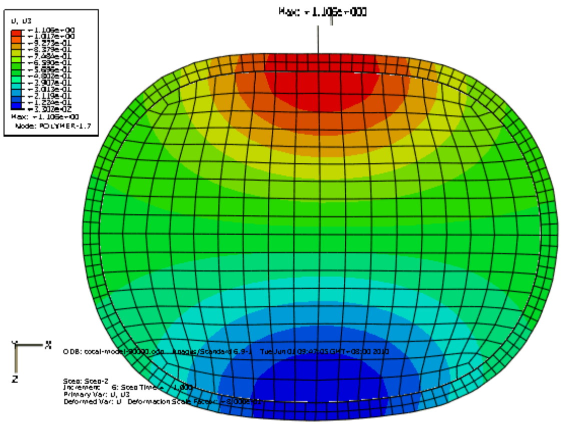


FIGURE 5 Rebound of the conductive particle under 85℃ and 85%RH ambience



(a) after pressure



(b) after Rebound

FIGURE 6 Simulation of the particles

5 Conclusions

This paper analyzed the conductive mechanism of conductive particles of adhesive ACF and the mathematical model was established in order to calculate the resistance of the conductive particles in both cases of cracking and not cracking of the nickel plated layer. The calculated and experimental results agreed well with the model, which indicated that this model can be used to calculate the resistance of deformed conductive particles. It can be found that the amount of deformation of the conductive particles affected its resistance greatly by the analysis on the theoretical model. In the case of not been crushed, the conductive particles should be compressed possible flat to the best so that the the conductive resistance particles were smaller. The rebound of the conductive particle was simulated by FEM under the high temperature and humidity environment. The increment of resistance of a single particle and a separate circuit were calculated, which had significance to the use and further study of ACF.

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