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High-temperature wire sweep characteristics of semiconductor package for variable loop-height wirebonding technology

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Abstract

This paper studies the elevated-temperature sweep characteristics of wire bond during the transfer molding process for semiconductor packages. The material properties of gold wire are obtained experimentally at various temperatures. A set of sweep experiments is also performed to acquire the sweep stiffness of wire bond for several bond spans and bond heights. The linearity of the load–transverse displacement curves from sweep experiments indicates that the ranges of the allowance bond pitch in most semiconductor packages may be within linear elasticity limits. The elastic numerical analysis may be applied to predict the sweep behavior of the wire bond. In order to predict the elevated temperature behavior of wire bond sweep, a methodology is proposed in this study. With the aids of geometry factor defined in Eq. (6) and the three drag force models, Lamb's, Sherman's and Takaisi's, the predictions of the elevated-temperature sweep deflections of wire bond can be tested. The results show that the increase of the sweep deflections is more related to bond span than bond height.

Keywords: Wire sweep; Multi-chip module; Wire bonding; Elevated temperature

1. Introduction

The development of electronics packaging aims to lower cost, increase the packaging density, and improve the performance while still maintaining or even improving the reliability of the circuits. A multi-chip module (MCM) or 3-dimensional package can combine multiple ICs into a single system-level unit, capable of handling an entire function. Two different bonding technologies, wire bonding technology and flip chip technology, are usually adopted for MCM and 3-D package. The former provides versatile and reliable chip-connection technology. What's more, it is a low cost process. In these stacked chips, their wire bonds usually possess longer and higher interconnections than conventional individual chip packages. Reliability concerns on wire sweep inducing device shorting and current leakage arise [1].

Wire sweep usually denotes visible wire deformation, typically a lateral movement in the direction of the compound flow through the cavity. Wire sweep failure can be caused by any of the following reasons: high resin viscosity, high flow velocity, unbalanced flows in the cavities, void transport, late packing, and filler collision. An excellent and detailed review for the right selection of microelectronics package and interconnection system can be found in the website of the Nordic electronics packaging guideline [2].

There have been studies on wire-sweep analysis: Nguyen et al. [3,4] examined the parameters including the material flow properties, the mold cavity/leadframe aspect ratio, the wire modulus, and the wire bond configuration (e.g., diameter, length and orientation). A functional relationship between the wire sweep behavior and the various processing parameters was presented. X-ray scanning was used to reveal the entire shape inside the package. Tay, Yeo and Wu[5–7] utilized a 2-D creep flow model to predict the velocity distribution and the flow load acting on the wire bond. The buckling and plastic deformation of wire bonds

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with in-plane flow load was also studied. Han and Wang [8,9] studied drag forces of the gold wire sweep by using a video system and a three-stage wire sweep analysis (global-flow analysis, local-flow analysis and wire-sweep deformation analysis) was brought up by them. Lo et al. [10] studied the wall effect on drag forces in molding flow using optical fiber sensing data. Their results indicate that the effect of the wall cavity is significant in the calculation of the drag forces and needs to be considered in molding.

The main objectives of this research are to obtain elevated-temperature material properties of gold wires experimentally and to predict the wire sweep of various bond spans and bond heights subjected to drag force in the compound flow during transfer molding. Based on the analysis results of ANSYS, the effects of bond span and bond height on wire sweep in the elevated-temperature environment can be obtained. Then, the elevated-temperature deflections of wire sweep can be predicted.

2. Wire sweep experiments

In order to predict the behavior of wire sweep during packaging process, the material properties of gold wire have to be obtained firstly. The gold wire used in this study is AW-23, a product of Kulickle & Soffa Co., with 50 μm in diameter. The elastic modulus of AW-23 gold wire provided by the material sheet of Kulickle & Soffa Co., is 60 GPa. However, based on the stress-strain curves of AW-23 50 μm gold wire performed in our laboratory, the elastic modulus obtained is 34.13 GPa which is only 57% of the value given by the AW-23 material sheet [11,12].

In order to obtain the accurate elastic modulus of AW-23 gold wire, a set of tensile tests is conducted in this study. The diameter of the gold wire is so small that the measurement of displacement seems impossible using traditional extensometers or strain gauges. Obtaining the accurate elastic modulus is not easy. Hence, the specimen grips should be well-designed to insure the occurrence of uniform deformation and failure within gauge length. The load–displacement curves of the gold wire can be obtained.

The load cell used in HT-8296 micro-tension machine is MINEBEA NMB-U3S1 with 1 Kg capacity. The load cell is calibrated with standard weight and fulfills the accuracy requirements. The displacement of the micro-tension machine was measured with a Mitutuyo LVDT with 0.0001 mm resolution.

Three testing speed rates are chosen to find the effect on the elastic modulus. The testing speed rates are 5, 20 and 60 mm/min. The gauge length of gold wire specimens is 108 mm. At least three specimens for each test are performed to guarantee that the measurement results are consistent. Because the molding temperature of semiconductor package is in the range of 175 °C, high-temperature tension tests are conducted at 100, 125, 150 and 175 °C to obtain the high-temperature material properties of AW-23 50 μm gold wire.

To the author's knowledge, experiments on wire sweep have not been found in the literature. The home-made micro wire sweep machine is shown in Fig. 1. The load cell and displacement indicator of the micro wire sweep machine are calibrated as those of the micro tension machine are. The specimen geometry and notations of wire sweep experiment are presented in Figs. 2 and 3. L and H are the bond span and the bond height of wire bond, respectively. P_Z is the transverse concentrated force and δ_Z is the corresponding deflection. Since the possible maximum transverse deflection might happen in the Z direction, only the wire sweep experiments perpendicular to the profile of wire sweep is considered. Two bond spans, 5mm and 10 mm, and three different ratios of bond height/bond span, 0.5, 0.25 and 0.125, are selected for the specimen geometry of wire sweep experiments. For 5 mm bond span specimens, the three different bond heights are 2.5, 1.25 and 0.625 mm. For specimens with 10 mm bond span, the bond heights are selected to be 5, 2.5 and 1.25 mm.

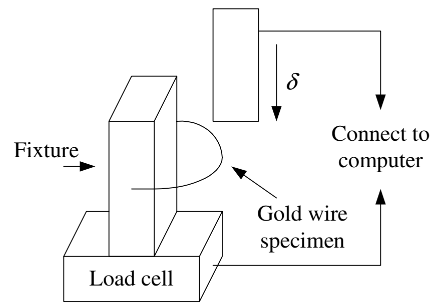

Fig. 1. The micro wire sweep machine.

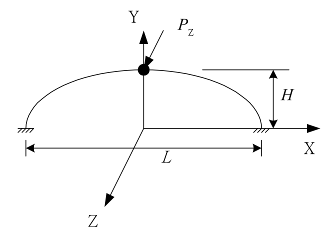

Fig. 2. Specimen geometry of wire sweep experiment.

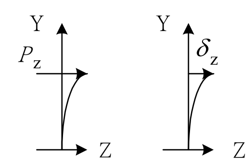

Fig. 3. Notations of wire sweep experiment.

3. Numerical analysis of wire sweep deformation

The objective of the finite element analysis is to address the deflection prediction of wire sweep subjected to drag forces during transfer molding process. The beam and pipe elements of ANSYS, a commercial FEA software, are used to numerically simulate the wire bond response on the deflection [13,14]. A concentrating force, summation of