

Effect of bonding force on the reliability of the flip chip packages employing anisotropic conductive film with reflow process

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Abstract

Thermo-mechanical reliability of flip chip packages employing anisotropic conductive film (ACF) was investigated in terms of the effect of bonding forces on the failure mode of the packages. Conventional reflow process was conducted to evaluate the reliability of the package. Two kinds of failure modes were detected in this study. The first one is formation of a conduction gap between conductive particle and Ni/Au plated Cu pad, while the second one is delamination of the adhesive matrix from the plated Cu pad on flexible substrate. The determination of the failure mode was mainly affected by the variation of the bonding force. In case of the ACF joints with lower bonding forces, a conduction gap was the main failure mode of the reflowed joints, while the delamination of the adhesive matrix was frequently observed in case of the joints with higher bonding forces. The difference in failure mode was discussed in the main text.

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1. Introduction

The evolution of electronic packaging has resulted in an increasing number of Input/Output (I/O) connections on integrated circuits as semiconductor devices become more sophisticated. As the number of interconnections increases, there are equally difficult demands placed on packaging engineers to develop small and high-density packaging for today's sophisticated microelectronics technologies. One of the most promising technologies of today's chip-level interconnection is flip chip technology, which has emerged as a high density and high performance interconnection method for integrated circuit chips [1–6]. Several flip chip technologies such as solder bumping flip chip, stud bumping using isotropic conductive adhesives (ICAs) and alloy bonding have been developed to accommodate the trend of microelectronics [7].

Recently, another potential revolutionary technology of attaching devices by flip chip using anisotropic conductive film (ACF) was introduced as a promising flip chip alternative [8–15]. ACF consists of an insulating adhesive polymer matrix with

dispersed conductive particles. In ACF interconnections, electrical conduction is provided through the conductive particles trapped between the mating I/O pads when the heat and force are applied. The function of the adhesive matrix, most frequently thermosetting epoxy resin, is to provide electrical insulation, to protect the metallic contacts from mechanical damage, and to provide stable adhesion. This arrangement allows the material to conduct in the *z*-direction while remaining insulation in the *x*–*y*-plane. ACF has many distinct advantages that solder alloys cannot offer. It is flexible, capable of fine pitch interconnections, environment friendly, cheaper to manufacture and a lower temperature process. However, the drawback of this technology compared with solder bumping flip chip technology is the lack of data for optimized bonding parameters and reliability.

In previous studies concerning the bonding parameters of the ACF flip chip joining, it was reported that the electrical properties of the ACF flip chip package are highly affected by the bonding temperature and force [11,14,16]. Especially, the contact resistance of the ACF joints is highly related with the deformation of the conductive particles induced by force applied during the bonding process. This is because if the particles are too spread out between adjacent bumps or pads, caused by too much force applied, they may end up contacting each other creating the same effect as short-circuiting; whereas if the bonding

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force is too low, the particles may not be able to make contact between the connecting bumps and pads [11]. However, in most of the previous studies concerning the bonding parameters, only contact resistance with varying bonding force was investigated, while various failure modes and mechanism which could be obtained with the reliability tests were not seriously discussed.

Another reliability problem of ACF flip chip assemblies is complicated by the fact that ACFs and solder are often used on the same device [10]. In general, manufacturing process of the ACF assemblies, the first process is usually the ACF flip chip bonding to achieve high accuracy for fine pitch placement of components, and the second process is the conventional reflow process to join various surface mount components. Therefore, the ability of the ACFs to survive in the typical reflow process is very important in this manufacturing process. However, the studies on the thermo-mechanical reliability of the ACF joints during the reflow process which are mainly focusing on the failure modes and mechanism variations with bonding force are very rare [10]. Therefore, this study focuses on the effects of the reflow process on the failure behavior of the ACF joints which are joined with various bonding forces. Scanning electron microscope (SEM) was used to investigate the failure behaviors of the ACF joints.

2. Experimental and analysis procedures

Fig. 1 shows the schematic structure of the ACF joint between Si chip and flexible printed circuit (FPC) board made of polyimide. The dimensions of a test chip are $5000\ \mu\text{m} \times 5000\ \mu\text{m} \times 700\ \mu\text{m}$ with a total of 144 Au bumps arranged along the periphery. The dimensions of the Au bumps are $80\ \mu\text{m} \times 80\ \mu\text{m} \times 17\ \mu\text{m}$. The polyimide based FPC substrate in thickness of $50\ \mu\text{m}$ was used with formation of the Cu pad in thickness of $25\ \mu\text{m}$ on the substrate. The Cu pad was coated with Ni/Au surface finishes in thickness of $5\ \mu\text{m}$. A commercial 2-layer type ACF was employed in this study. The adhesive matrix of the ACF was made of thermosetting epoxy type containing Ni/Au coated polymer spheres with a mean particle size of $5\ \mu\text{m}$. The ACF flip chip bonding was carried out with varying bonding forces as shown in Table 1. Toray Semi-Automatic Flip Chip Bonder (Toray SA2000) was

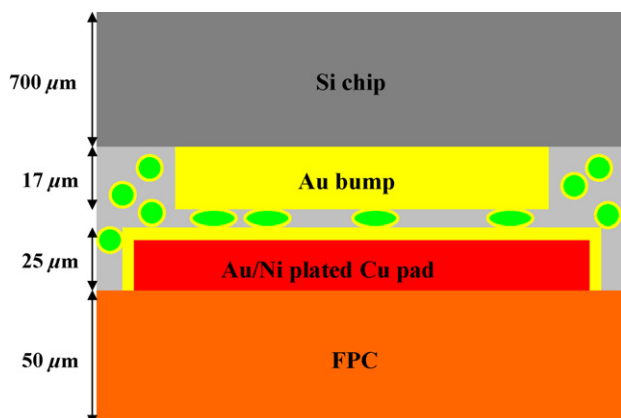


Fig. 1. Schematic structure of the ACF flip chip interconnection.

Table 1
Bonding forces used

Bonding force (N)	40	45	50	55	60	65	70	75	80	85	90
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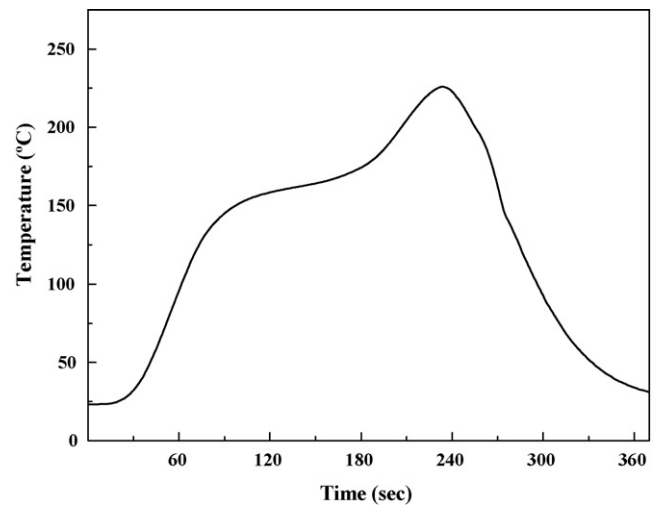


Fig. 2. Temperature profile of the reflow employed in this study.

used to join the flip chip on substrate. The pre-bonding process was conducted with a temperature of $100\ ^\circ\text{C}$ followed by final bonding at $190\ ^\circ\text{C}$ for 20 s. After the flip chip assemblies were made, the chip on flexible substrate (COF) were placed on the FR4 substrate and then reflowed two times. Fig. 2 shows the temperature profile of the reflow employed in this study. The peak reflow temperature and reflow time were set to $220\ ^\circ\text{C}$ and 60 s, respectively. The reflowed assemblies were mounted in epoxy, and then the cross-sectional studies were carried out by grinding with SiC papers followed by subsequent polishing with 1 and $0.3\ \mu\text{m}$ alumina powders. The cross-section was conducted through the outer array of Au bumps. The microstructural observation was conducted with SEM.

3. Results and discussion

Fig. 3 shows the typical cross-sectional SEM image of the ACF joints after flip chip bonding. Numbers in Fig. 3 are denoting the location of the ACF joints from the edge of the package to the package center. Therefore, ACF joint of No. 1 is the outermost corner bump joint, while joint of No. 7 is the closest one to the package center. Every individual ACF joint will be designated with the numbers from 1 to 7, and these numbers mean the distance of the joint from the package edge. The ACF joints in Fig. 3 were bonded with bonding force of 65 N. Bumps of relatively bright gray are Au bumps and rather dark gray ones are Cu pad on the FPC. It could be observed that the Au bumps were well aligned and bonded to the Cu pad. For more accurate investigation of the joints, enlarged SEM images were taken with varying bonding forces.

Fig. 4(a–d) shows the cross-sectional views of the corner ACF joints (No. 1) which were bonded with bonding forces of 45, 55, 65 and $75\ \text{N}$, respectively. All of the conductive particles

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