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Bonding wire characterization using automatic deformability measurement

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ABSTRACT

A promising way to control underpad chip damage in IC packaging caused by wire bonding forces would be to use new wire chemistries that produce softer free-air balls (FABs). The number of new wire types that can be tested is limited by the available resources. The conventional FAB hardness characterization method is the microindentation test, a labour intensive and off-line task requiring cross-sectioning of a large number of samples. To accelerate FAB hardness characterization, an innovative on-line method is studied and presented here, enabling the fast comparison of different wire types. Collection of data from an instrumented wire bonder allows comparison of the deformability, i.e. the average amount of FAB deformation under a defined load. Increased deformability implies a softer FAB. The influences have been studied of changes in capillary, bonding substrate metallization and substrate temperature on the results obtained. It is found that these influences need to be held constant during a comparison study.

1. Introduction

The thermosonic wire bonding process has been the most widely used interconnection technology for IC packaging [1]. The electronics packaging industry is currently in process of an ongoing shift from the previously dominant Au wires to more economical Cu wires. Cu wire bonds can be more reliable than Au wire bonds and have better mechanical, thermal, and electrical properties [2–5]. However, they give rise to various practical production challenges. One of these challenges concerns the increased downtime caused by more frequent tail lift stoppages of the equipment [6,7]. Another challenge concerns the FAB hardness. Compared to Au wire, the Cu wires have lower deformability which leads to higher working stresses in bonding, which in turn can cause more chip damaging issues [8]. Therefore, the development of new Cu wire chemistries or manufacturing processes to obtain wires and FABs that are softer and have high deformabilities would be highly desirable.

Conventional characterization methods for bonding wires include tensile and microindentation tests, which require exacting and time-consuming sample preparation, testing techniques, and data collection [9–11]. Furthermore, the recrystallization of the wire during the electrical flame off (EFO) process in which the FAB is formed changes the wire microstructures and leads to different deformabilities. Hence it can be necessary to characterize not only the wire deformability, but also the deformability of the corresponding FAB for each soft wire candidate, which in turn increases labour required for a full characterization. In order to minimize the development time for new wire formulations, an efficient method for the deformability characterization of a bonding wire and its FAB is needed.

In this paper, a new method is presented for rapid comparison of the deformabilities of wires and their FABs, enabling the characterization of large numbers of different wire samples in a matter of hours or less. The amounts of wire and FAB deformation under specific deforming forces exerted by the capillary are measured using the on-line *z*-position signal delivered by the wire bonder's *z*-encoder. These in situ deformation data are indicators of the wire and FAB deformabilities.

2. Description of the on-line method

An ESEC WB3100 wire bonder is used to record the in situ force and *z*-displacement signals during bonding. Fig. 1 shows a schematic diagram of parts of the bondhead structure. An encoder at one end of the rocker arm measures the bondhead displacement in the *z*-direction with sub-micron precision. The *z*-position of the capillary tip is derived from this encoder measurement. A proximity sensor attached to the wire clamps measures distance change to the horn, a value proportional to the bonding force. Following is a description of the essential features of the measurement method.

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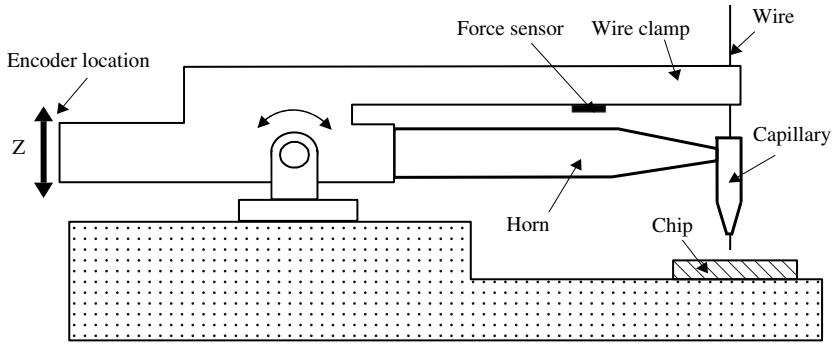

Fig. 1. Schematic drawing of the *z*-position measurement structure and the proximity force sensor location. Dimensions not to scale.

Within a wire bonding cycle modified for this study, FAB balls and bonding wires are first deformed with specific deforming forces and then bonded with bonding forces and ultrasound. During the process sequence, the *z*-position of the capillary tip is recorded. The modified wire bonding cycle is illustrated by Fig. 2a–f. Recognizing that the flatness of substrates is not perfect, the *z*-positions of different areas on a substrate may vary, creating a potential source of error. To correct for substrate surface-induced effects on the *z*-position measurement, an additional procedure is introduced involving the making of reference bonds, as shown in Fig. 2a. Ultrasound is used to form reference wedge bonds with the capillary touching the substrate. The *z*-position is recorded after the bonds and stored as ball reference height, z_{BR}. After the electrical flame off (EFO) process, the newly formed FAB is moved to a test area which is less than 200 μm from the reference wedge bond area. To avoid plastic deformation, the FAB touches the substrate with a minimized impact force and then is plastically deformed with the specific controlled deforming force, as shown in Fig. 2b and c. The *z*-position is stored as deformed ball height, z_B. Finally the ball is bonded using ultrasound. Due to the short distance between the test ball bond and the adjacent reference wedge bond, the substrate surface position measured in reference wedge bonding will be that at the ball bond within an error of less than 1 μm.

After ball bond formation, the capillary then loops the wire to the measurement wedge bond position, again touching down with a very low impact force to avoid plastic deformation, as shown in Fig. 2d. The wire is then plastically deformed by the capillary with a specific controlled static force, as shown in Fig. 2e, and the deformed wire height z_W is recorded. It is then bonded with the set of optimized bonding parameters, as shown in Fig. 2f. At the end of the wedge bond the capillary touches the substrate while the wire reference height z_{WR} is recorded.

Fig. 3 shows an example of the on-line forces, ultrasound envelope, and *z*-position signals recorded during a modified bonding cycle. Each part of the test sequence starts with touchdown of ball or wire on the substrate with an impact force of less than 60 mN, a value low enough that the FAB and wire deformations caused by this very small impact force can be assumed to be negligible. The normal force applied by the capillary is then increased without the application of ultrasound in order to determine the amount of deformation. This is followed by a bonding period with both force and ultrasound. Periods of zero ultrasound and low force are programmed before, between, and after the deformation and bonding periods to determine the relative *z*-position after each period.

The ball height (BH) and the wire height (WH) after the controlled plastic deformation but before ultrasonic bonding are obtained with Eqs. (1) and (2):

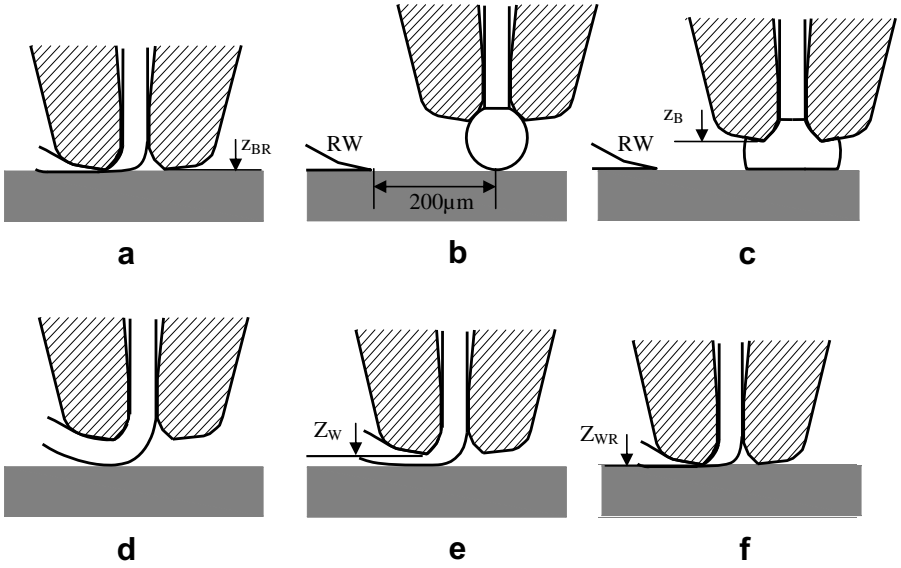

Fig. 2. Height measurement: (a) reference wedge bond (RW) with capillary touching the substrate surface, (b) FAB contacts the substrate without deformation, (c) FAB deformed under a predefined deforming force, (d) wire side contacts the substrate without deformation, (e) wireside deformed under a predefined deforming force, and (f) ultrasonic wedge bond with capillary touching the substrate surface for reference.