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Development of capillaries for wire bonding of low-*k* ultra-fine-pitch devices

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Abstract

Although wire bonding has been a well-established technology for many years, the bonding tool design becomes more complex and the process is very sensitive for wire bonding of low-*k* ultra-fine-pitch microelectronics devices. In this study, two different types of external transition profile were considered in order to use lower ultrasonic-generator power for preventing pad damage. The ultrasonic vibration displacements of the capillaries were measured using a laser interferometer. The measurement results revealed that the amplification factor (the ratio of the vibration displacement at the capillary tip to that at the transducer point) of a capillary with a small radius transition between the bottleneck angle and the main taper angle was 37% higher than that of a capillary with a sharp transition, and this led to satisfactory results in terms of ball size, ball height, ball shear and stitch pull. To solve the ball lift problem for wire bonding of low-*k* ultra-fine-pitch devices, optimization of the capillary internal profile was attempted to improve bondability. Actual bonding responses were tested. Compared to a standard design, a capillary with a smaller chamfer angle, a larger inner chamfer and a larger chamfer diameter could increase the percentage of the intermetallic compound in the bond interface. Metal pad peeling and ball lift failures were not observed after an aging test.

Keywords: Microelectronics packaging; Low-*k* devices; Ultra-fine pitch; Wire bond; Capillary; Ultrasonic vibration

1. Introduction

The demands for high electrical performance and pin count have resulted in significant advances in integrated circuit (IC) fabrication and microelectronics packaging [1–6]. Processing of silicon wafers also plays an enhanced role in microelectronics and microelectro-mechanical systems [7].

Wire bonding is a mature technology with a huge installed base of users. Wire bonding is the most widely used technology in the microelectronics industry [8]. For peripheral array chips, wire bonding is cheaper than flip chip [9,10] if the chip size and the pad pitch are very large [11]. Today's demands for speed, accuracy and reliability are fulfilled with modern cameras and intelligent algorithms [12].

Microelectronics packaging has sparked intensive interest in ultra-thin packages [13]. The bond loop height is one of the dominating parameters in reducing the thickness of ultra-thin packages [14]. Besides the most commonly used gold wires, Al–Si wires are also used for microelectronics packaging [15]. To improve the performance of advanced ICs, a transition from Al to Cu metallization is in progress [16].

High quality of bonds is vital to the performance of an IC chip. Therefore, a proper bonding quality control system is desirable [17]. Parameter settings for successful wire bonding depend on many factors, requiring expert knowledge to optimize critical process characteristics [18]. The principal parameters such as bonding time, normal force and ultrasonic power can affect wire-bonding quality [19].

Ultrasonic technology can be used for many applications [20,21]. In ultrasonic metal welding, the use of ultrasounds allows metals to be cold-welded [22]. A decisive factor affecting electrical and mechanical proprieties of

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the wire bond is the vibration behaviour of the capillary [23]. Ultra-fine-pitch wire bonding [24] requires higher stability and robustness of ultrasonic vibrations [25].

A dielectric constant $k < 3$ is a challenging demand for dielectrics in conventional multilevel metallization schemes of modern IC technology [26]. Novel IC devices based on the structure of low-k material/Cu have been proposed recently [27]. The requirements for future high-end complimentary metal-oxide semiconductor (CMOS) logic technologies can only be achieved by using ultra low-k materials ($k \sim 2.3$ or lower) [28].

A polymer-induced bonding problem occurs when the bond pad is small. If the polymer is soft or it is heated above its T_g during thermosonic bonding, the small bond pad can partially sink into the polymer during application of bonding force. This lowers the effective bond force after the capillary contacts the pad, and therefore higher ultrasonic energy is required. Cupping or sinking can damage low-k diffusion barriers and result in failure [29].

The biggest problem with low-k device bonding is ball bond reliability. The process for low-k device bonding is very sensitive especially for ultra-fine-pitch bonding. During such bonding, relatively high reject rates caused by metal pad peeling were observed. One solution to the problem was parameter optimization and ultra-fine height control of the wire bonder to reduce the damage to the underneath layers during impact. However, the demand for low-k device bonding ranges from fine pitch to ultra-fine pitch below 50-μm bond pad pitch. As the bond pad pitch becomes smaller, ball bond becomes a major issue as we are operating within the range of non-sticking on pad and peeling, i.e., lower parameter settings result in non-sticking and higher parameter settings cause metal pad peeling. The process window is narrow. The effects of ultrasonic energy and dynamic force also become more critical.

Although wire bonding has been a well-established technology for many years, the bonding tool design becomes more complex and the process is very sensitive for wire bonding of low-k ultra-fine-pitch devices. In this study, two different types of external transition profile were considered in order to use lower ultrasonic-generator power for preventing pad damage. The ultrasonic vibration displacements of the capillaries were measured using a laser interferometer. To solve the ball lift (non-sticking) problem for wire bonding of low-k ultra-fine-pitch devices, optimization of the capillary internal profile was attempted to improve bondability and increase the percentage of the intermetallic compound in the bond interface. Actual wire bonding experiments were also conducted to test the capillary designs.

2. Capillary design to improve ultrasonic transfer

For wire bonding of low-k ultra-fine-pitch devices, lower ultrasonic-generator power is needed to prevent pad damage. Optimization of the external profile of a capillary can make the capillary more efficient to transfer ultrasonic vibrations in the preferred direction with lower ultrasonic-generator power.

A capillary is a tiny hollow tube used to guide the wire and create ball and stitch bonds. Capillaries with ‘‘bottlenecks’’ are used in fine and ultra-fine-pitch bonding because their slim profile near the tip prevents contact with adjacent wires. The overall cone angle is referred to as the main taper angle. The minimum bottleneck angle is set to avoid contact with adjacent wires.

Two different types of transition profile were considered, as shown in Figs. 1 and 2. The difference between the two capillaries is the transition between the bottleneck angle and the main taper angle. All other dimensions of Capillaries A and B are the same except for the transition. Capillary A has a sharp transition between the main taper angle and the bottleneck angle, while Capillary B has a small radius transition.

In wire bonding, it is important to achieve a robust process within the defined operating window. Currently, the

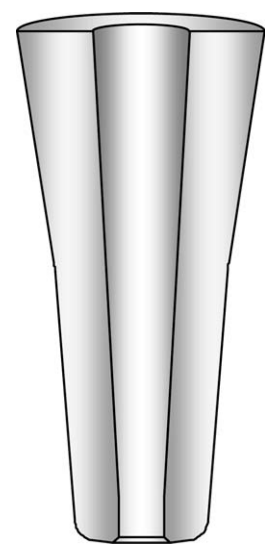

Fig. 1. Capillary A has a sharp transition.

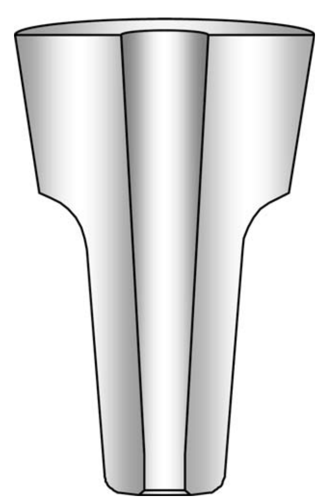

Fig. 2. Capillary B has a small radius transition.