OPTIMIZATION AND INVESTIGATION OF THE FREE AIR BALL FORMATION OF THE GOLD WIRE BOND

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Abstract: This paper deals with Free air ball (FAB) formation and its optimization. It is part of the thermocompression of the thermosonic wire bonding process. This paper consists of a theoretical introduction to the topic and specific technological steps that is crucial for correct FAB formation. Technological parameters that can have an impact on the FAB formation process were analyzed. These are for example power of the electric discharge, length of the wire tail or protective atmosphere in the case of corrosive materials of the wire. The impact of these parameters on the quality of the reliability of the FAB and the wire-bonded joint were evaluated. At the end of this paper is a recommendation for the optimization of the wire bonding process for the small amount of the semiconductor chips.

Keywords: Free air ball, optimization, gold, silver, wire tail, discharge

1 INTRODUCTION

The wire bonding technology is the commonly used first-level technology for connecting semiconductor chips with a lead frame of the components or other substrates Three basic processes can be used for this technology. It can be used thermocompress wire bonding or the wire bonding by ultrasonic energy. Another option is to use the thermosonic process, which combines the two previous ones. A joint is made due to the combination of a pressing force, ultrasound energy, and temperature, for a defined time. [1].

The FAB formation is the first technological step for the thermosonic or thermocompress bonding process. For this process is a real condition where the FAB has variable sizes, is not consistent or is off-centered. Mentioned problems can depend on the length of the wire used for the formation of the sphere or on the shape and size of the bonding tool. A result of the mentioned process is important for wire bonding of joint, for the correct wire bonding process of an entire chip and reliability of the entire device [1],[2],[3].

2 MOTIVATION

In an industry scale, billions to tens of billions of joints are made by wire bonding technology [1]. For these purposes are used specialized industrial machines. However, for small volumes of wire bonding joints or experimental samples, wire bonding by industrial machines is not suitable. Usually, compact semiautomatic devices, where the process is operated by an operator or a trained person, are used [4]. For the success of the entire process and its long-term reliability, it's necessary to optimize this process. Specific parameters of the wire bonding process are selected according to the type of semiconductor chip for wire bonding. We are interested mainly in the material of the wire bonding pad and its thickness [5]. We are interested in the same details for the second pad also [1]. The next important thing is the purpose of using the mentioned application. It is possible to choose different wire materials or his diameter according to the application of a chip. The most commonly used material for wire bonding with the thermosonic process is gold [1]. The first step of this process is the formation of the FAB (Figure 1). This is performed by using electrical electronic flame off (EFO) discharge [1],[2],[3].

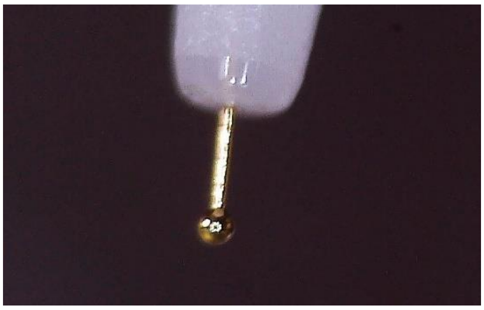


Figure 1: Gold Free Air Ball

3 EXPERIMENT

This experiment has two main parts. The first part contains the preparation of the samples. These samples were prepared on the semiautomatic wire bonding machine. After this preparation were the samples observed and evaluated. Based on this evaluation was technological wire bonding process designed. At the end of this experiment was performed wire bonding on the semiconductor chip. The results of this process were evaluated again.

3.1 FAB FORMATION

The entire experiment was performed on the HB16 wire bonding device equipped with a capillary tool [4]. First, a golden wire was manually pulled out of the tool. The pulling out to a specific length process was done by the device's console. After launching of a panel, the wire is ejected via clamps. [4]. The motion of the clamps causes insignificant mechanical damage to the bonding wire (Figure 2). This damage is not critical for bonding in these technological conditions.

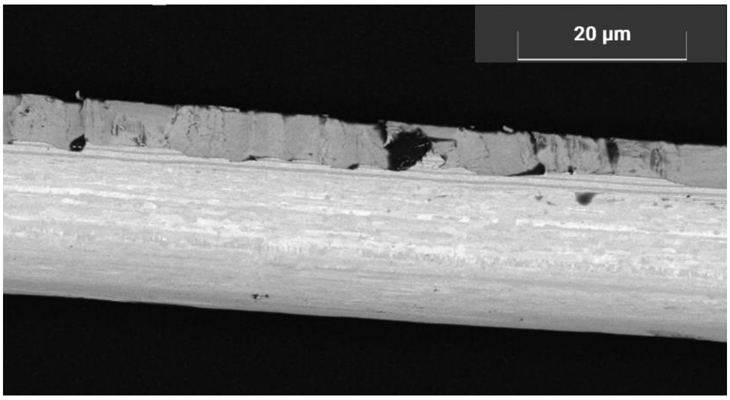


Figure 2: Damage of the wire caused by the clamps

A tail of the wire was manually ejected to lengths 100, 250 a and 500 µm. After that, a formation FAB was done via the EFO system with a negative discharge. The negative EFO system was used intentionally. In a case of the discharge with opposite polarity (a positive one), the material of the wire is blasted off. This material clings to the bonding tip and can cause problems during the process of wire bonding. The electrical current and duration of the discharge have a significant impact on the size and shape of FAB [2],[3]. In this case, the discharge had constant parameters. After the discharge, FAB with various diameters was formed.

3.2 THERMOSONIC WIRE BONDING PROCESS

The tail length of 250 µm was selected for the wire bonding of the semiconductor chip. The FAB for this solution was approximately 60 µm in diameter. Generally, it is considered optimal when the

FAB has a 2 – 5x of wire size in diameter. For wire bonding experiment was selected LM124 semiconductor chip with aluminum bonding pads (Figure 3). All these bonds were performed in the same process setting. However various results were achieved. The diameter of the ball bond and its deformation was various.

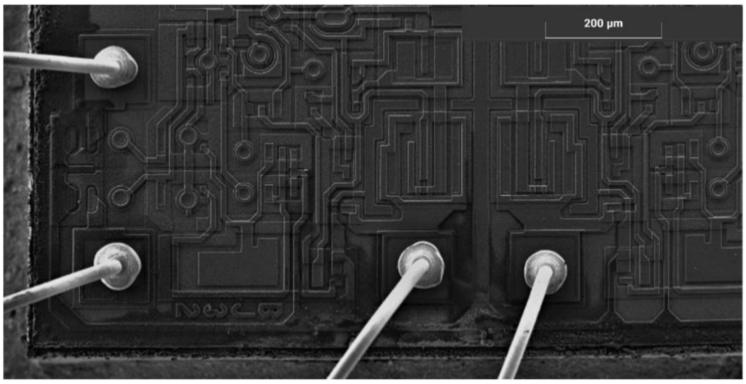


Figure 3: Surface of the bonded chip

4 RESULTS

4.1 RESULTS OF THE FAB FORMATION

With constant energy of the negative discharge (recommended by the manufacturer: V_{dis}= 2 kV; t_{dis}, I_{dis}=100% of the adjustable range), a ball of various sizes was formed by using different tail lengths of the wire (Figure 4). Direct proportion is observed here - with lengthening of wire's tail, the FAB gains in volume.

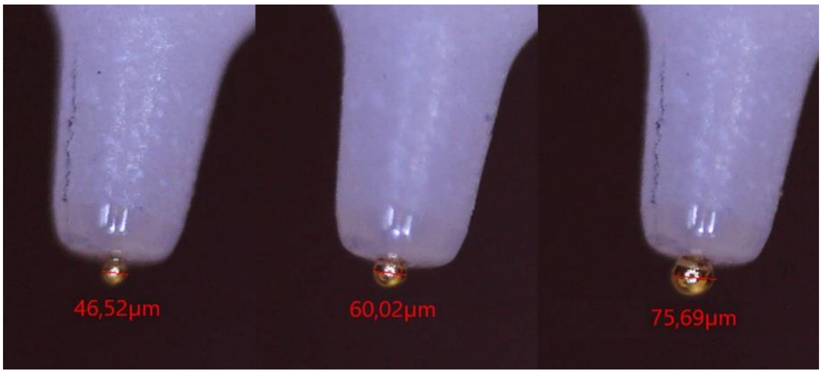


Figure 4: Comparison of the dimensions of FAB for 100, 250 and 500 µm

After FAB inspection by the scanning electron microscope, it is possible to say that for all chosen tail lengths was made FAB which was centered and had a consistent spherical shape (Figure 5).

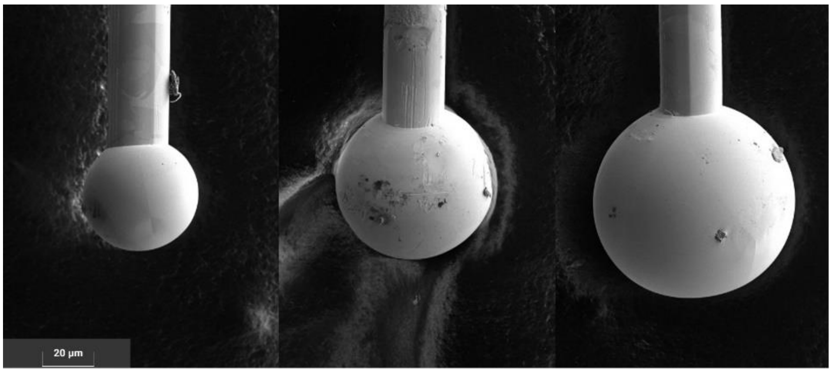


Figure 5: Detail of FAB for 100, 250 and 500 µm

In the case of FAB with 60 µm in diameter, it is possible to observe the ripples (Figure 6). These ripples are typical for FAB made of copper wire. In the case of gold wire is this phenomenon unusual [3].

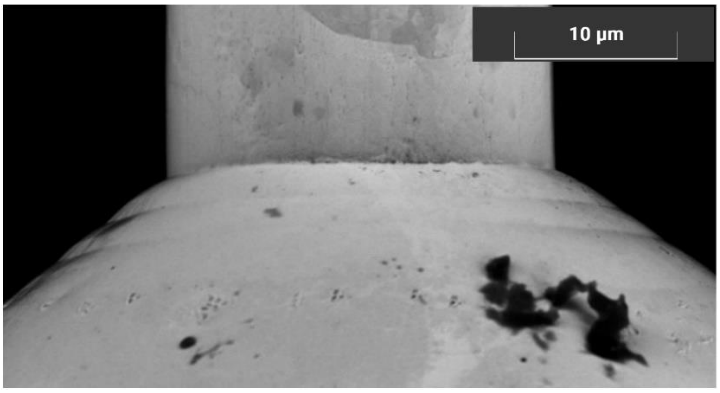
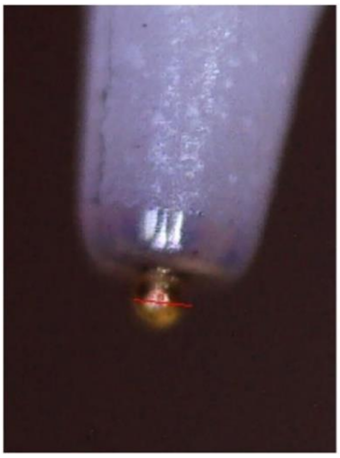


Figure 6: Detail of FAB Ripples

For all mentioned cases was used the negative EFO discharge. With positive polarisation (recommended by the manufacturer: V_{dis}= 2 kV; t_{dis}, I_{dis}=25% of the adjustable range), the wire material is blasted off and lands on the tool. This can lead to higher adhesion of the wire ball to the bonding tool. This change adversely affects the shape and centering of FAB. During the experiment, a visible change was observed on the surface of the bonding tools, whereas created FAB wasn't centered and was deformed because of clinging to the bonding tool (Figure 7, 8). This solution was evaluated as unsuitable.



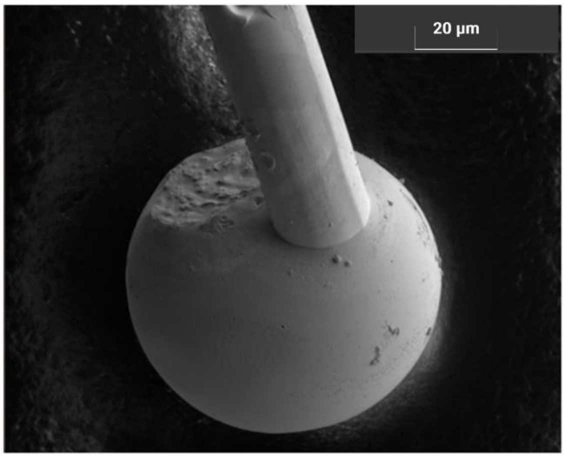


Figure 7 (left): Consequences of the positive EFO for the bonding tip
Figure 8 (right): Off-centered and damaged FAB

4.2 RESULTS OF THE SEMICONDUCTOR CHIP BONDING

After the optical inspection was observed various degrees of deformation on performed ball bonds. This difference is caused by different lengths of the tail during the bonding process. Shorter tail creates a smaller ball. With constant parameters, specifically constant pressing force, more deformation is inflicted on the FAB that is smaller. In the case of a bigger ball, the pressing force impacts a bigger surface and the spatial deformation of the FAB is smaller (Figure 9). In the case of too small FAB (smaller than 2 times the diameter of the wire), there is a risk of jamming the ball in the bonding tool. This could lead to the stopping of the process and a forced change of the tool.

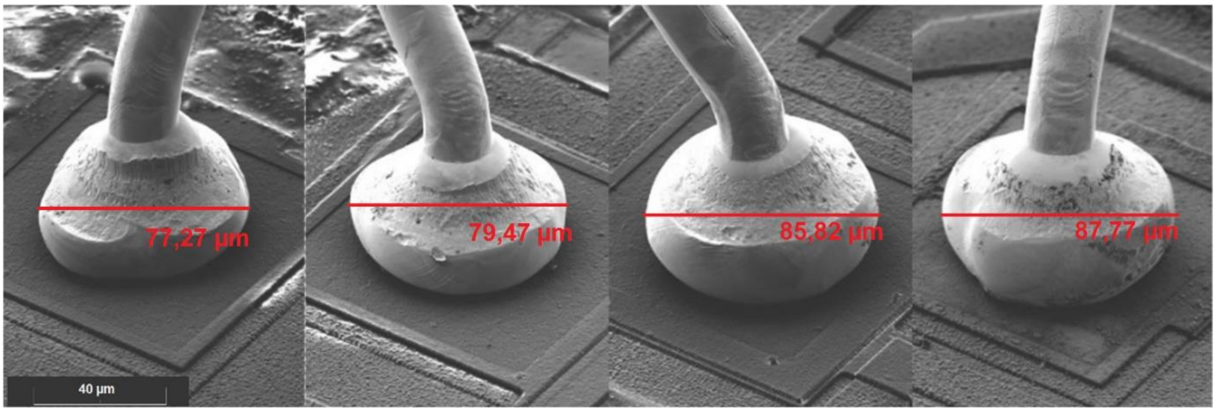


Figure 9: Different bonding result with constant bonding parameters

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