Characteristics of copper wire wedge bonding

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Abstract:

Copper wire bonding is an alternative interconnection technology that serves as a viable and cost saving alternative to gold wire bonding. In this paper, ultrasonic wedge bonding with 25 μm copper wire on Au/Ni/Cu metallization of a PCB substrate was performed at ambient temperature. The central composite design of experiment (DOE) approach was applied to optimize the copper wire wedge bonding process parameters. After that, pull test of the wedge bond was performed to study the bond strength and to find the optimum bonding parameters. SEM was used to observe the cross section of the wedge bond. The pull test results show good performance of the wedge bond. Additionally, DOE results gave the optimized parameter for both the first bond and the second bond. Cross section analysis shows a continuous interconnection between the copper wire and Au/Ni/Cu metallization. The diffusion of Cu into the Au layer was also observed.

1. Introduction

Nowadays, copper wire has attracted more and more attention in wire bonding technology due to its better electrical performances in comparison with aluminum[1]. Therefore, many studies on the copper wire bonding are being in progress [2-4]. Copper wires provide many advantages that are superior to gold wires. The advantages of copper wire are as follows:

First, copper wire is 3 to 10 times lower in cost compared to gold wire. Second, copper wire shows superior mechanical and electrical properties to gold and aluminum wires. Excellent electrical conductivity and small amount of heat generation allow copper wire to be used not only for power management devices but also for thinner diameter wires to accommodate small pad sizes. The high rigidity of copper wires is considered more compatible to the fine pitch bonding than gold wires. Third, slower intermetallic compound (IMC) growth between copper wires and aluminum pads results in lower contact electrical resistance and better reliability in comparison to gold wires and aluminum pads.

2. Experimental procedure

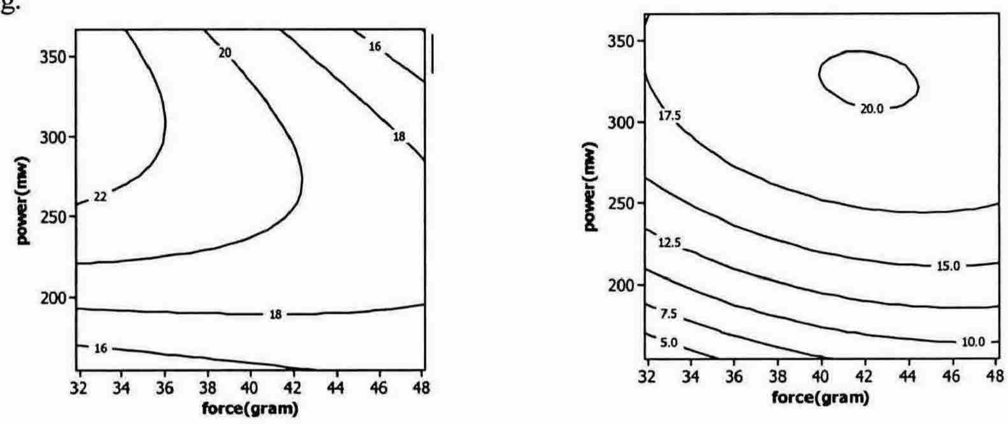
Copper wire bonding was performed on Au/Ni/Cu metallization using copper wire of 99.99% purity provided by MK Electronics Co. The bonding machine used was a commercial semi-automatic wedge bonder.

The central composite design of experiment (DOE) approach was chosen for parameters optimization for both the first bond and the second bond. When the second parameters were studied, the first bond parameters were fixed, and vice versa. There are 20 runs in total, and for each set of parametric conditions 20 bonds were made. After wedge bonding, the pull test was carried out on DAGE 4000 for pull force of the wedge bond.

The cross section samples were observed under a scanning electron microscope (SEM). Energy dispersive X-ray (EDX) was used to study the chemical composition.

3. Results

During the pull test procedure, there are two failure modes, one is lift off mode of the wedge bond, the other is the neck break on copper wire. If the wire was not deformed too much by high power and large force, usually the pull force of the wedge bond failed at neck position is higher than the wedge bond lifted off from the interface. Fig.1 shows the contour plot of the pull force results under the DOE design parameter settings when the bonding time is 30ms. It could be found that the highest pull force of the first bond was achieved when the power is high while the bonding force is low. However, for the second bond, to get higher pull force of the wedge bond, both high power and high force were needed. This might because during the wedge bonding process, after the second bond has been made, a wire clamp closes and pulls back on the wire to break it at the heel of the bond. However, there is no pulling force of the clamp on the first bond. So the higher force and power were needed to make a strong second bond. Fig.2 show the wedge bond when the Run order is 9, that is, the power is 260mW, time is 30ms, and bonding force is 40g.



(a) (b)

Fig. 1 Contour Plot of pull force vs bonding power and bonding force when bonding time is 30ms (a) the 1st bond and (b) the 2nd bond

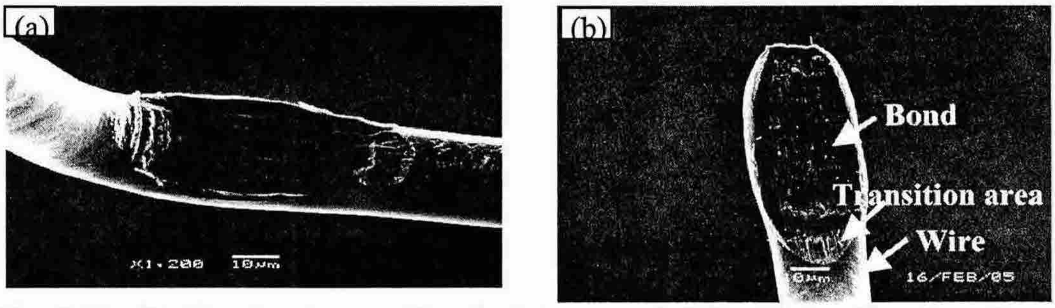


Fig. 2 The first bond and second bond when power is 260mW, bonding force is 40g, and bonding time is 30ms

The possibility of using Cu wires bonded to Au/Ni/Cu metallization has led to interest in the reliability of this metallurgical system. Fig.2 show the cross section of the wedge bond when the bonding power is 260mW and 390mW respectively. It could be found that with the bonding power increasing, the thickness of the gold layer in the Au/Ni/Cu metallization decreased, as shown in Fig.2 (b). Line scan on the cross section showed the diffusion of Cu element into the Au layer, seen from Fig.3. EDX analysis on several positions of the interface also show that Cu diffuse into the Au layer. With the power increasing, the content of the Cu and the distance of diffusion increase, which could be found from the Table 3 and 4. It was reported that Cu could move rapidly through the Au film by boundary diffusion at temperatures in the 100~300°C range and in times of an hour or so. This indicates that Cu-Au intermetallic can occur very rapidly and at low temperatures. The diffusion coefficient for Cu through Au was $D=1.64\times10^{-20}cm^2/s$ at 200°C [5], and the other data could be found from Table. 5. It could be found that the diffusion of Cu through the Au is faster than the Au through the Cu, because the atom size of the Cu is smaller than the Au.

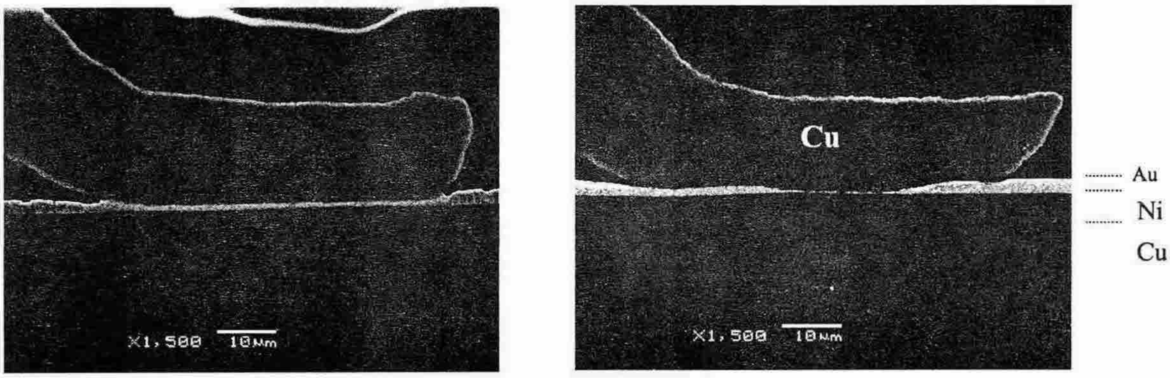


Fig.2 Cross section of the second bond (a) power is 260mW; (b) power is 390mw

Summary

Copper wire bonding at ambient temperature was achieved, and the bonding parameters for both first bond and second bond were optimized by Design of Experiment method. It is confirmed that to get the stronger pull force of the wedge bond, the higher power and bonding force were needed for the second bond than that for the first bond. Cross section analysis showed that the continuous connection between the copper wire and metallization when the appropriate bonding parameters were chosen. During the wedge bonding process, diffusion of copper in to the gold layer was also observed. When a higher bonding power was used, the thickness of the gold layer in the metallization decreased.

Reference

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