Interface mechanical behavior of gold alloy wire bonding

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Abstract. The connection between the internal chip and external pins of the semiconductor package and the connection between the chip play an important role in establishing the electrical connection between the chip and the outside and ensuring the input/output between the chip and the outside. It is the key to the entire subsequent packaging process. Wire bonding has a dominant position in connection methods due to its simple process, low cost, and application of a variety of packaging forms. In high-reliability fields such as military and aerospace applications, bonding wires are usually used as chip interconnect materials. The bonding wires have good electrical conductivity, thermal conductivity, and oxidation resistance, but there are some reliability problems in bonding due to the production of Au-Al compounds. In this paper, Al element is used to modify the bonding alloy wire innovatively, the mechanical properties of Au-Al and Au-Pd system bonding points and the growth and evolution of IMC are studied, and the influence of Al and Pd elements on the reliability of bonding points is evaluated.

1. Introduction
Bonding wire is one of the basic materials in the IC packaging material market. It is an inner lead material with excellent electrical, thermal conductivity, mechanical properties and excellent chemical stability. It is an important structural material for the manufacture of integrated circuits and discrete devices. Currently, the commonly used bonding wires on the market are gold, aluminum, silver, and copper. Among them, the bonding alloy wire is widely used in high-reliability fields such as military aerospace applications due to its excellent electrical conductivity, thermal conductivity, and oxidation resistance. With the development of integrated circuit packaging in the direction of miniaturization, high density, and high reliability, there are higher requirements for the arc, hardness, wire diameter, and high temperature performance of the bonding wire, and the reliability of the bonding device is also stricter. The harsh challenge is to drive the alloying research of the key alloy wire.

At present, a lot of research results have been made in the field of gold wire bonding failure mechanism and alloying research. H. Xu[1] focused on the growth mechanism of bonding interface compounds and the theory of cavity growth, suggesting that under the combined effect of the kirkendall effect, IMC oxidation and volume shrinkage, voids grow along with the evolution of the interface compounds, of which Kirkendall effect is the main influencing factor. Adding trace elements is an effective way to increase the strength of gold wire and reduce the wire diameter. Zhu Jianguo have investigated the development of bond alloy wires and found that Ca and Be in alkaline earth elements are beneficial to increase the tensile strength of gold wires. Rare earth elements help to increase the strength of the bond alloy wire, improve processing performance and use reliability, and there is a compound synergistic effect between different added elements. H. J. Kim[2-4] studied the effects on Au-1wt%Pd bonding wires and Al pad interfacial reactions, and fitted the curve of the thickness of interfacial compound at high temperature for thermal aging. It is concluded that Au-1wt%Pd wire can
reduce the growth rate of IMC by two orders of magnitude. However, the research object of H. J. Kim et al. is the gold stud bump, and the bonding device is not evaluated. S. A. Gam[5] performed 150°C high temperature storage tests on 4N gold and Au-1wt% Pd wire and Au-1wt% Cu wire bonded devices to analyze the pull-off data and the growth mechanism of the bonded interfacial compound and found that both Cu and Pd can improve the mechanical properties of the bonding site and both can form atomic buildup to inhibit IMC growth. Among them, the improvement effect of Cu is better than Pd. However, S. A. Gam performed the assessment in a high temperature environment of 150°C, and the experimental results may not be suitable for the assessment requirements of high-reliability applications.

This paper intends to investigate the effect of different elemental doping on the reliability of the bonding interface under high temperature storage by adding the same content of Al, Pd and other alloying elements for the characteristics of high purity gold wires.

2. Test method and material preparation

2.1. Material preparation
This experiment is based on 99.999wt% Au wire, adding the same content of aluminum and palladium, the content of these elements is 1%, and the undoped high-purity gold wire is the control group. The wire diameter is 25μm; the product chip is selected, and the chip pad material is Al with a thickness of 1μm. The capping is completed by a parallel seam welding process.

2.2. Test method
The Au-Pd alloy wire adopts the ball bonding process, and the Au-Al alloy wire adopts the wedge bonding process. The two processes are used to bond the gold wire as a comparison. The bonding parameters of the two gold alloy wires were debugged, and qualified bonding points with similar appearances were obtained. High temperature storage (temperature of 150°C, annealing of 0h, 100h, 300h, 500h, and 1000h) and process assessment (temperature of 300°C, storage time of 0h, 2h, 12h, 24h, respectively) And 48h). After the test is completed, use the pull-off tester to test the pull-off strength of the bumps; use the scanning electron microscope to observe the microstructure and IMC morphology of the bumps; use the photoshop software to extract the thickness of the IMC and analyze the growth of the IMC. Through the above methods, the influence of trace element doping on the reliability of bonding points is analyzed.

3. Result of test

3.1. The fracture morphology of the bonding point
Figure 1 shows the pull-off fracture morphology of the bonding point after bonded of Au wire and Au-Pd and Au-Al alloy wire.. The bond point can be seen that the fracture locations are the neck of the spherical solder joint and the root of the wedge solder joint. They are both located in the deformation zone of the bonding point. Obvious ductile fracture characteristics can be observed at the fracture position. This indicates that the bonding wire and the aluminum pad have formed a good welding. The changing trend of the bond point pull-off strength value at this time is related to the nature of the bonding wire itself.
3.2. Mechanical properties of bonding points

The pull-off force value after bonding is closely related to the bonding process parameters, the properties of the bonding wire itself, and the bonding strength of the bonding interface. Bonding strength is one of the important technical indicators for judging bonding quality. The rate of change that bonding strength after annealing of high temperature reflects the heat resistance of the bonding wire. Figure 2.a shows the change trend of pull-off strength of samples with qualified Au-Pd wire and gold wire bonding after being subjected to a high temperature storage test at 150°C. It can be seen from the figure that the pull-off strength of the two bonding points is showing a declining trend, which is much higher than the internal control standard of 3g; the bonding strength of Au-Pd alloy wire is higher than that of Au wire at different time nodes; Au- The bonding force of the Pd alloy wire decreases greatly in the early stage of the assessment, and tends to be stable in the later stage, and the overall decrease is relatively large.

Figure 2. Trend of pull-off strength of spherical bond after annealing at 150℃ and 300℃

Figure 2.b shows the change trend of the pull-off strength of Au-Pd wire and gold wire bonded samples after process assessment at 300°C. Figure 3 shows the fracture morphology of the bond point after process assessment. It can be seen from the figure that the bonding strength of the two bonding wires is basically the same as that at 150°C. After 12 hours of annealing, although the pull-off force meets the requirements, the pull-off failure mode is fracture from the pad. After 24 hours of annealing, the bonding point is obviously invalid. From the surface of the pad after annealing at 300°C for 24 hours, it can be seen that the gold-aluminum compound has almost diffused to the entire surface of the pad, while the gold-palladium bonding point has only diffused two-thirds of the pad.
Figure 3. The fracture morphology of the point after process assessment

Figure 4.a shows the change trend of the pull-off strength of samples qualified for Au-Al wire and gold wire bonding after the annealing at 150°C. It can be seen from the figure that the pull-off strength of the two bonding points shows a continuous downward trend. Both are much higher than the standard of 3g; the bonding strength of Au-Al alloy wire is lower than that of Au wire in the first and mid-term of the test, but the bonding strength of Au-Al alloy wire tends to be stable after 500h.

Figure 4. Trend of pull-off strength of wedge-shaped bonding point after annealing at 150°C and 300°C

Figure 5 shows the change trend of the pull-off strength of the Au-Al wire and gold wire bonded samples after the process assessment at 300°C. Figure 5 shows the fracture morphology of the bond point after Au-Pd wire and gold wire process assessment. It can be seen from the figure that the bonding strength of the two bonding wires is basically the same as that at 150°C; after 24 hours of annealing, the intermetallic compound of Au wire bonding interface diffuses to the pad, and it diffuses faster in the vertical direction at Au-Al wire bonding interface., spreading in the vertical direction is obvious.

Figure 5. Bonding point morphology after annealing for 24h: a) Au wire; b) Au-Al alloy wire

The addition of Pd enhances the mechanical strength of the bonding wire. It can inhibit the growth of IMC due to Pd accumulation at the bonding interface; the addition of Al will reduce the spheronization
of the bonding wire, but it can promote the reaction of Au and the internal Al and slow down the diffusion of IMC at the interface. From the perspective of the mechanical properties of the bonding wire, Au-Pd alloy wire is the best, followed by Au wire, and Au-Al wire is slightly inferior. However, Al wire is not suitable for ball bonding process. From the point of view of the heat resistance of the bonding wire, Au-Al alloy wire is the best, followed by Au wire, and Au-Pd wire is slightly inferior.

We can conclude that the formation of bonding interface compounds will seriously harm reliability; the higher the ambient temperature, the faster the growth rate of interface compounds; because Au-Pd binary alloys can form infinite mutual solutions, the addition of Pd elements will increase the strength of the bond alloy wire, but the heat resistance will be reduced, and the effect of thermal stress is more obvious; Au-Pd alloy wire can effectively inhibit the growth of Au-Al compounds, which is consistent with the article of S. A. Gam.

4. Conclusion
This paper mainly studies the mechanical properties of Au-Pd and Au-Al alloy wires after annealing. By analyzing the pull-off force of the bonding point and the interface morphology, the conclusions are as follows:

1. The formation of bonding interface compounds will seriously harm reliability. The higher the annealing temperature, the faster the growth of IMC; the longer the annealing time, the thicker the IMC, the worse the reliability.

2. Au-Pd alloy wire has better bonding strength, but weakens the heat resistance of the bonding wire; Au-Al alloy wire has better long-term reliability, but the bonding strength declines faster in the initial annealing stage. In addition, the process is difficult in craftsmanship.

3. The addition of Pd and Al elements can inhibit the growth of bonding interface compounds, but their mechanism of action is different. Pd doping can form a barrier layer at the bonding interface, while Al doping promotes the equilibrium of the diffusion rate of gold and aluminum atoms at the bonding interface.

References
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