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Micro-Structural Observation of the Bonding Interface between Au Wire and a Platinum Electrode †

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Abstract

The Au wire/Pt bonding pad interface mechanism using ultrasonic bonding was studied in this paper. Following experiments were investigated ; After the bonding process or thermal aging test at 235 ℃ for 300 h, the Au-Pt interface was observed by UHR-SEM, TEM and electron diffraction. Intermetallic compound layer was not formed. Even under thermal aging less than 235 ℃, Au-Pt interface keeps the same structure. These results show that Au-Pt bonding has strong thermal stability.

KEY WORDS: (Interface), (Wire bonding), (Interfacial reaction), (Pt bonding pad), (Au wire)

1. Introduction

The technique of wire bonding is widely used as a means for connecting (means for wiring) a semiconductor device such as an IC, a LSI, or a LED, to a lead frame. In general, in a process for wiring and packaging an IC or a LSI, pairs of Au wire/Al bonding pad are commonly used. In addition, since the cost of gold has been rising recently, Cu wire has been used so as to decrease the production cost[1]. Each of the pairs of Au/Al and the pairs of Cu/Al are connected by forming an intermetallic compound layer at the bonding interface[2),3)]. However, due to the heat generated during the operation of a device, the intermetallic compounds grow by the Kirkendall effect and cause generation of voids, and mechanical characteristics are degraded by corrosion. Therefore, the reliability of the bonding portion is still low.

On the other hand, a technique of wire bonding using homogeneous metals is also used. For example, pairs of Au wire/Au bonding pad are used for connecting a LED, and pairs of Al wire/Al bonding pad are used for connecting a power device such as an IGBT. Specifically, since the pairs of Au/Au are not easily oxidized and are not greatly deteriorated by heat, the pairs of Au/Au are widely known as pairs that provide highly-reliable bonding portions[4]. Power devices for automobiles and SiC devices, which are expected to be commercialized in the near future, are required to be usable at higher temperatures. Accordingly, in the technique of the wire bonding, it is extremely important to provide high bonding reliability at high temperatures.

In view of the reliability (stability) at high temperatures, the pairs of Au/Au can be selected from the above described pairs for wire bonding. In this case, since Au has a high degree of reactivity to Si, an intermetallic compound layer of Au-Si system may be generated, and Au may have a negative influence on a device[5]. On the contrary, pairs of Au wire/Pt bonding pad may have a low degree of reactivity to Si, superior adherability of the Pt bonding pad to the Au wire, and high stability at high temperatures. Thus, it is assumed that it is important to evaluate the joining interface in the pairs of Au wire/Pt bonding pads.

In this paper, a fundamental study was performed on the bonding condition of the interface of an Au wire/Pt bonding pad. Specifically, shear strength of the Au-Pt bonding portion was evaluated. Moreover, a microscopic interface structure and crystal grain boundaries of the Au-Pt bonding portion were observed and were analyzed by UHR-FE-SEM (Ultra High Resolution Field Emission Scanning Electron Microscope) and TEM (Transmission Electron Microscope). The structure of the bonding portion of Au-Pt will be described hereinafter.

2. Experimental

2.1 Test material

Specifications of test chips used in the experiment are shown in **Table 1**. A schematic drawing of an outline and a cross section of a bump is shown in **Figure 1**.

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The entire surface of a Si chip with 1.3 square meters was coated with a SiO_2 film as a passivation film. In addition, Pt was used on the Si chip as a bonding pad for connecting a wire. By using a wire of Au with a purity of 99.99 % having a diameter of 30 μm, an Au bump was formed so as to have a diameter of 140 μm by the ultrasonic bonding method.

Table 1 Specification of test chip

Item	Specifications	
Chip	Size	1.3 mm ×1.3 mm
	Thickness	0.4 mm
	Passivation film	SiO_2
Bump	Material	Au 99.99 %
	Diameter	140 μm

2.2 Conditions of thermal aging test

In a bonding interface of the Au wire and the Pt bonding pad, in order to research temporal change of the bonding characteristics under high temperature, two kinds of heat treatments were performed in this work as follows. First, a heat treatment was performed on samples at a temperature of 150 °C for 15, 30, 60, and 120 h. These samples were evaluated by a strength test. Moreover, in order to research an interface structure, another heat treatment was performed. The recrystallizing temperature of a metal is approximately 1/3 of the melting point, and the recrystallizing temperature of Au is assumed to be from 220 °C to 230 °C. Therefore, this heat treatment was performed on samples at 235 °C for 300 h.

2.3 Strength test method

The strength test was performed by using a BT2400PC manufactured by Dage. The test speed was 3 mm/min and a height of the tool from the electrode surface (shear height) was 5 μm.

2.4 Method for evaluation of the interface structure

In the samples before and after heat treatment, the structure of the bonding interface was observed in detail from a cross-section direction. Cross-sectional specimens of the sample were formed by the CP method and were analyzed by FE-SEM observation. Cross-sectional specimens of the sample were formed by FIB method and were analyzed by TEM observation.

3. Results

3.1 Bonding strength

The bonding strength of the Au wire and the Pt bonding pad was studied. A relationship between shear strength and heat treatment was evaluated by using four samples (N = 4) having an Au bump form shown in **Figure 2**. The result is shown in **Figure 3**. The bonding portion of the Au bump and Pt showed bonding strength of approximately 50 gf without heat treatment. The bonding strength was stabilized by the heat treatment and was not greatly decreased. From this result, it is expected that the Au-Pt bonding portion may have high thermal stability.

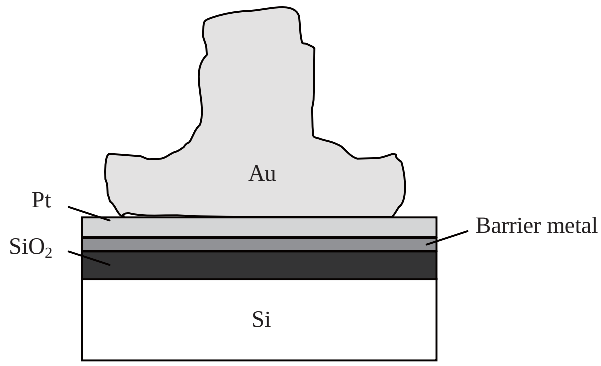


Fig. 1 Drawing of a cross-section of Au-Pt bonding.

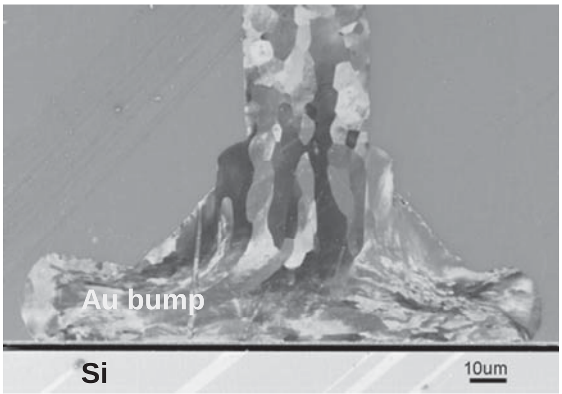


Fig. 2 Observation of Au bump form.

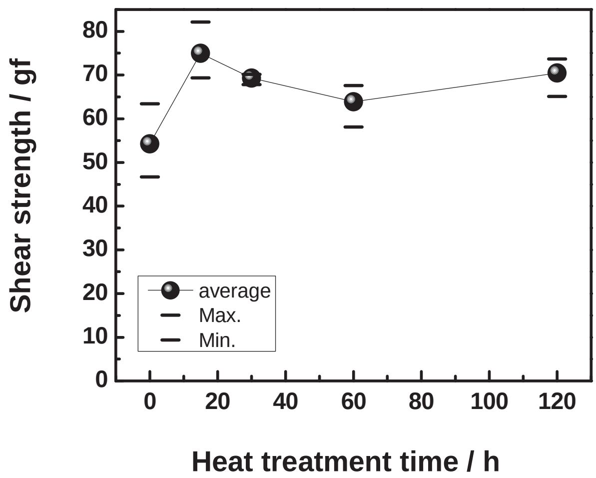
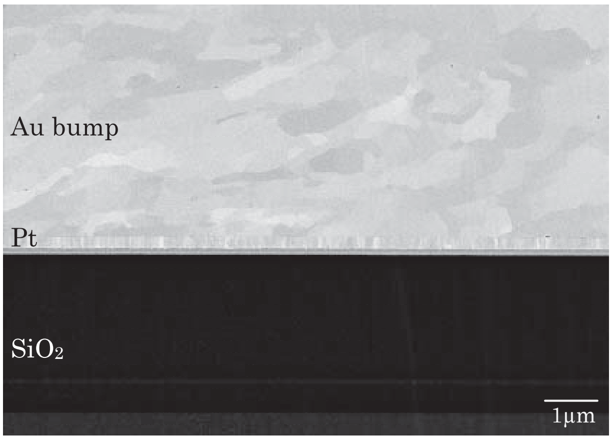
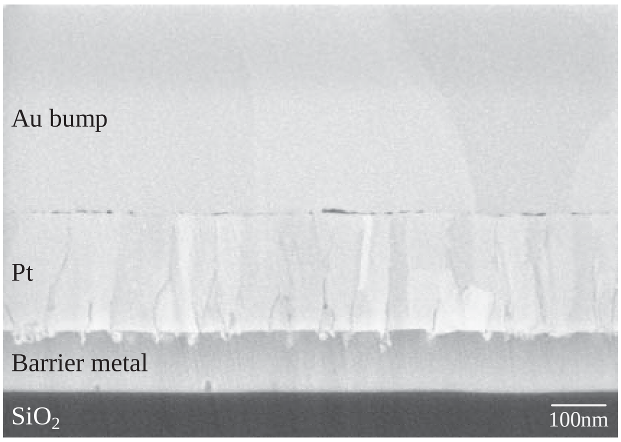


Fig. 3 Relation between heat treatment time and shear strength of the Au bump.

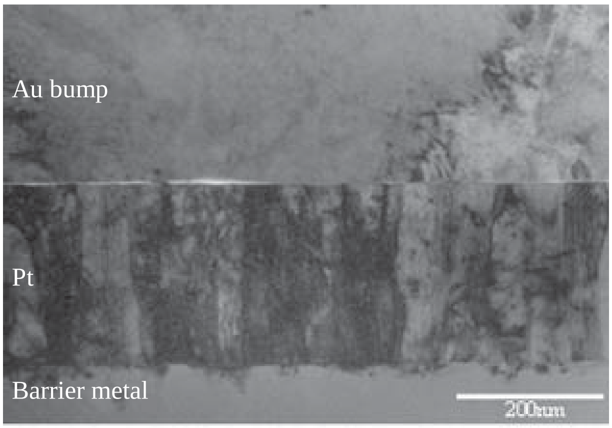


(a) Lower magnification

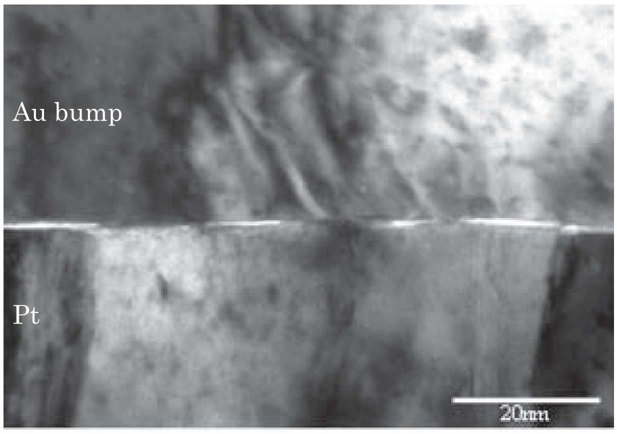


(b) Higher magnification

Fig. 4 SEM images of Au-Pt interface.



(a) Lower magnification



(b) Higher magnification

Fig. 5 TEM images of Au-Pt interface.

3.2 Evaluation of the interface structure without heat treatment

3.2.1 Evaluation of the interface structure by SEM

In order to investigate the bonding condition of Au and Pt, cross-section observation was performed by SEM as shown in **Figure 4**. As shown in **Fig. 4(a)**, the bonding portion had a bonding interface which was very similar to those of the pairs of Au/Au[4], and the Au-Pt interface was intermittently connected. **Fig. 4(b)** shows a cross section of the bonding portion observed at a higher magnification by SEM. As shown in **Fig. 4(b)**, in the Au-Pt interface, an intermetallic compound layer due to alloying reaction was not observed, and crystal grains due to recrystallization were not observed.

The crystal structure of the Au bump side was extremely different from the crystal structure of the Pt bonding pad side. That is, the interface of the Au bump side was mainly made of granular crystal grains having a size of submicrometers to several micrometers. On the other hand, the Pt bonding pad was a polycrystalline film and was made of columnar crystals. In the Au-Pt interface, crystal grains due to recrystallization of the both metals were not observed. From these result, the Au-Pt bonding was not a local fusion bonding and was not a diffusion bonding. That is, it is expected that the Au bump and the Pt bonding pad were adhesively bonded with each other.

3.2.2 Evaluation of the interface structure by TEM

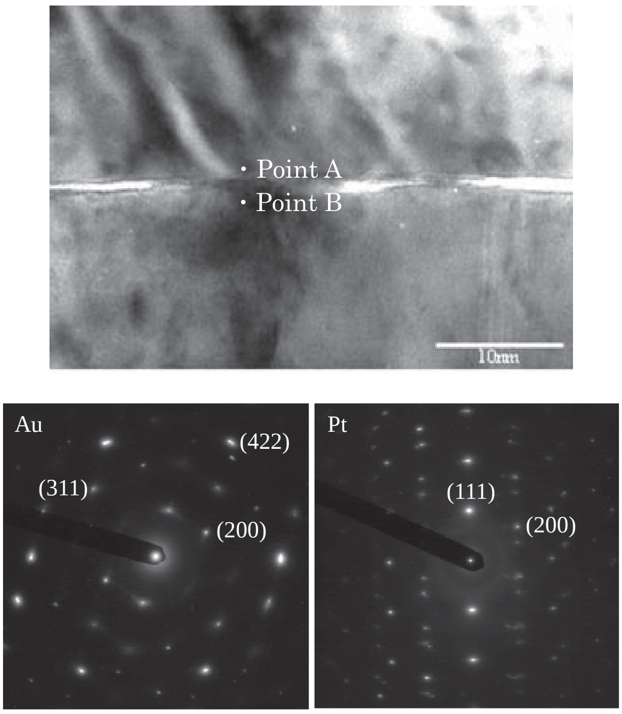
Figure 5 shows an image of an Au-Pt bonding interface that was observed at a relatively low magnification by TEM. The Au-Pt bonding interface was sharply defined. Specifically, a great amount of voids (unbonded areas) were observed at the interface, whereas the voids were not clearly observed by SEM. Moreover, a fine subgrain structure was clearly observed in the crystal grain which was previously observed by SEM.

We focused on two crystal grains that were bonded with each other and had an interface between them. The two crystal grains were analyzed by electron beam diffraction, and the result is shown in **Figure 6**. As shown in **Fig. 6**, diffraction patterns of two measuring points (A, B) were different from each other. In this case, the measuring point A had lattice constants corresponding exactly to the lattice constants of Au, which is 2.04 Å (200), 1.23 Å (311), and 0.83 Å (422). The measuring point B had lattice constants corresponding exactly to the lattice constants of Pt, which is 2.27Å (111) and 1.96 Å (200). Accordingly, an alloying reaction due to diffusion did not occur at the Au-Pt bonding interface.

As shown in **Fig. 5(b)**, crystal grains specific for Au and Pt were observed in the vicinity of the interface and crystal grains due to recrystallization were not observed. Accordingly, it is expected that the Au wire and the Pt bonding pad were adhesively bonded with each other, and the Au atoms and the Pt atoms directly contacted with each other. In this case, crystal structures were not observed at white contrast portions in the vicinity of the bonding interface, and therefore, the white contrast portions were unbonded portions. The area of the white contrast portions was large.

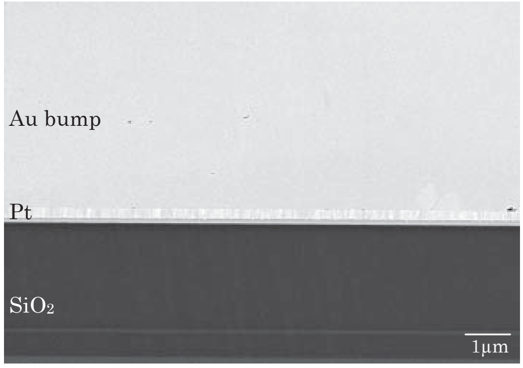
3.3 Influence of the thermal aging test on the Au-Pt bonding interface

Figure 7 shows the SEM images of an Au-Pt interface after the thermal aging test and **Figure 8** shows the TEM images of an Au-Pt interface after the thermal aging test. As shown in **Fig. 7** and **Fig. 8**, the structure of

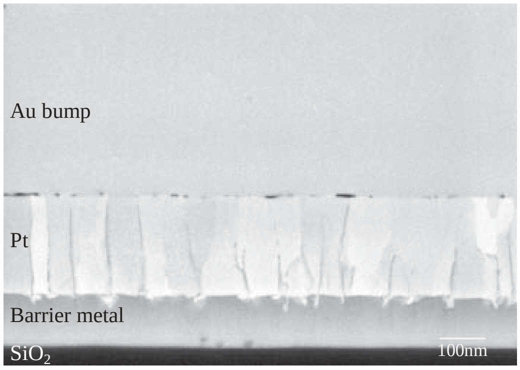


Point A Point B

Fig. 6 TEM images of Au-Pt interface and diffraction pattern.

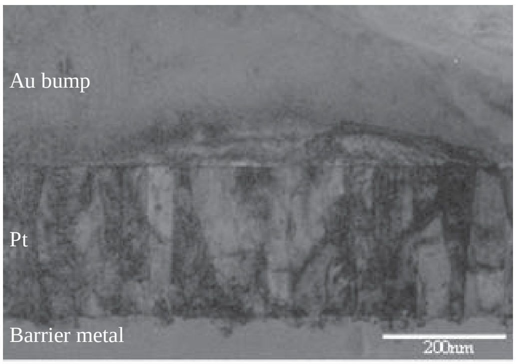


(a) Lower magnification

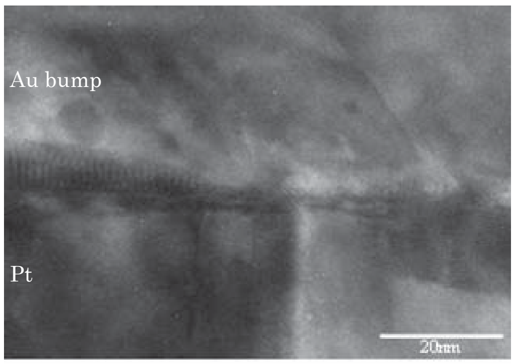


(b) Higher magnification

Fig. 7 SEM images of Au-Pt interface after thermal aging test.



(a) Lower magnification



(b) Higher magnification

Fig. 8 TEM images of Au-Pt interface after thermal aging test.

the Au-Pt interface was not greatly changed before and after the thermal aging test, and bonding areas were intermittently observed. Specifically, in the inside of the Au wire, coarsened crystal grains of Au were clearly observed as shown in **Fig. 4(a)** and **Fig. 7(a)**.

Recrystallization of Au was caused by the heat of the thermal aging test. According to this finding, it is expected that interface strength may be decreased by the coarsening of the crystal grains of Au. However, since the structure of the Au-Pt interface was not greatly changed before and after the thermal aging test, the strength is not greatly affected by heat as described in the discussion of the shear strength.

4. Conclusions

The structure of ultrasonic bonding of an Au wire and a Pt bonding interface was evaluated in detail by electron microscope observation (SEM,TEM). As a result, we found that the thermal stability of the Au-Pt interface can be improved. In addition, a great amount of the unbonded portions was observed in the samples. Accordingly, there is still a problem that the bonding defects need to be removed. The findings in this paper are shown as follows.

(1) The shear strength of the Au bump was not greatly changed by heat regardless of the heat treatment time, and the shear strength was stable with respect to the heat treatment.

(2) According to the observations of the bonding interface by SEM and TEM, the Au wire and the Pt bonding pad were adhesively bonded with each other, and the Au atoms and the Pt atoms directly contacted with each other.

(3) According to the observations of the Au-Pt bonding interface by SEM and TEM after the thermal aging test, the crystal grains of Au were coarsened in the Au-Pt bonding interface in the adhesively bonded condition. However, the interface structure was not greatly changed even when the heat energy of approximately 235 °C was used. Consequently, according to the condition of the interface, the strength of the bonding interface is not greatly affected by heat.

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