Reliability of silver wedge bonding for power devices

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Abstract
Recently there is a trend toward to use SiC instead of Si in power devices since SiC can withstand higher temperature (above 300℃) and higher voltage with less power loss than Si. So there is a great interest to improve interconnection technique for power devices package. In this study, Ag wire with diameter of 200 µm was bonded on Al pad, after annealing at 200℃ and 300℃, intermetallic compounds (IMC) were investigated by energy dispersive X-ray spectroscopy (EDS). The results show that, when annealed in air, two kinds of IMC Ag_2Al and Ag_3Al formed and no voids or cracks were observed; but when annealed with epoxy molded IC package, voids were observed, and between Ag wire and IMC there was a corrosion layer.

Key words
Wedge Bonding, Silver Wire, Intermetallic Compounds, Power Devices

I. Introduction

Wire bonding is a primary interconnection technique between an integrated circuit (IC) and a metal lead frame in an IC package. Wire bonding can be classified into two types：ball-wedge bonding and wedge-wedge bonding [1]. For high power device packages, wedge-wedge bonding with large-diameter Al wire has been used. However, with the requirement of withstanding higher temperature (the melting point of Al is about 660℃), there is a trend to investigate for replacing bonding wires.

Cu wire is proposed as an alternative bonding wire because of the low cost and good electrical properties. But because of the hardness of Cu wire, it has the problem of under pad damage. Ag wire is another possible alternative, but the reliability of Ag and Al is not so clear. In this paper, we studied the reliability of Ag wire bonded on Al pad and annealed under different conditions.

II. Experimental Procedure

A. Bonding materials

In this experiment, pure Ag wire (>99.9%) of 200 µm in diameter was bonded on Al pad by ultrasonic wedge bonder. The mechanical properties of Ag bonding wire are shown in Table 1.

Table 1. Mechanical properties of Ag bonding wire

Breaking Load [gf]	Elongation [%]
572	45.7

Fig. 1 shows the structure of bonding pad, the top one is Al pad and the thickness of Al is 4 µm; the bottom one is Cu substrate with Ag plating to prevent oxidation. And the Si chip was die bonded on Cu substrate using Ag paste.

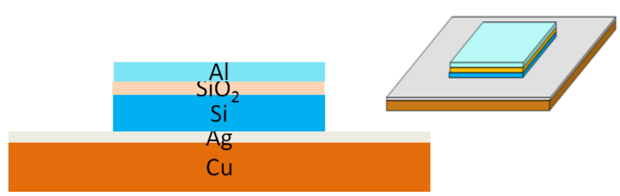


Fig 1. The structure of bonding pad

B. Bonding conditions

Wedge-wedge bonder (F&S DELVOTEC MODEL 5350) was used, and the first bond was on Al pad, the second bond was on Cu substrate. The bonding conditions are shown in Table 2.

Table 2. Ag wedge bonding conditions

	First Bonding	Second Bonding
Bonding Force	700 g/cN	700 g/cN
US Power	65	65
US Time	100 ms	100 ms
TD Steps	100 μm	100 μm
Temperature	Room temperature	

C. Annealing conditions

All the samples were divided into two groups and annealed at 200℃ and 300℃. The first group was annealed in air. And the second group was annealed in an aluminum box where molded IC package were separately placed (shown in Fig. 2) to test the effect of chemical reaction with molded resin.

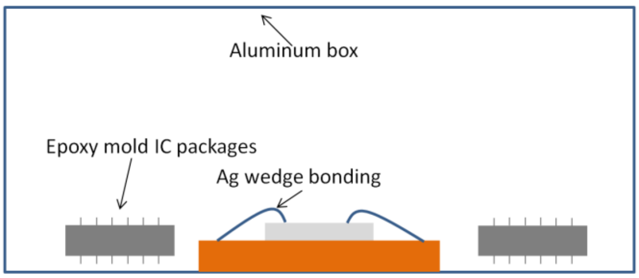


Fig. 2 The structure of Ag wedge bonding annealing with epoxy molded IC packages

D. Shear test conditions

To test the reliability of Ag wedge bonding, shear tester (Nordson Dage 4000 Plus) was used and the shear test parameters are shown below:

Test Group Parameters
Cartridge: S5Kg
Range: 2.00Kg
Shear Height: 20 μm
Test Speed: 200 μm/s

III. Results and Discussion

A. Shear test result

To investigate the reliability of Ag wedge bonding, shear test was done after annealing at 200 ℃ and 300℃ in air, and 300℃ with molded IC packages.

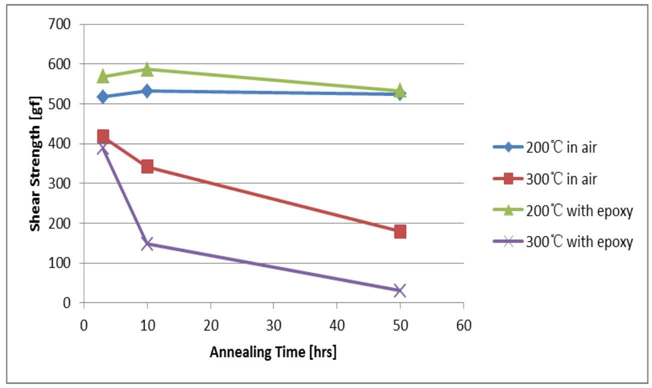


Fig. 3 Shear test of Ag wedge bonding

Figure 3 shows the shear test results of Ag wedge bonding after annealing. The shear strength didn't decrease after annealing at 200℃ both in air and with molded IC packages. But with higher temperature 300℃, after 10 hrs, the shear strength decreased substantially. And it decreased more rapidly with molded IC packages compared with annealing in air. After 50 hrs, the samples annealing with molded IC packages at 300℃ has the problem of bonds-lift.

The elements mapping of pad surface was done by EDS after shear test shown in Fig. 4. Initially, Si element was observed on both sides. When annealed at 200℃, Si intensity increased with time but didn't link together. On the other hand, when annealed at 300℃, after 10 hrs, a large area of Si was observed, also the shear strength decreased [2].

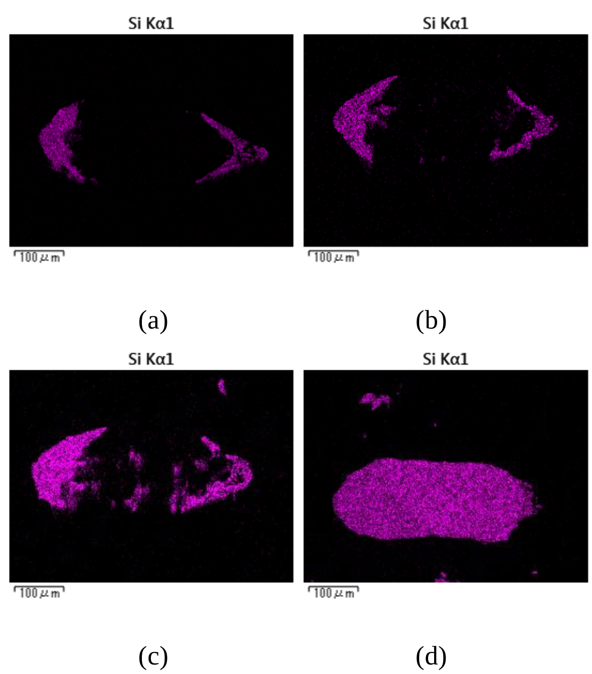
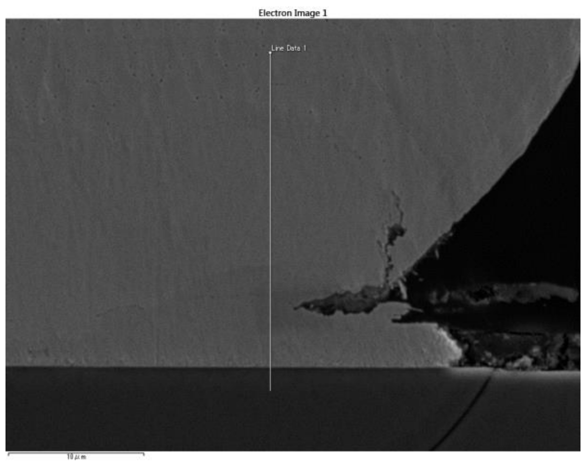


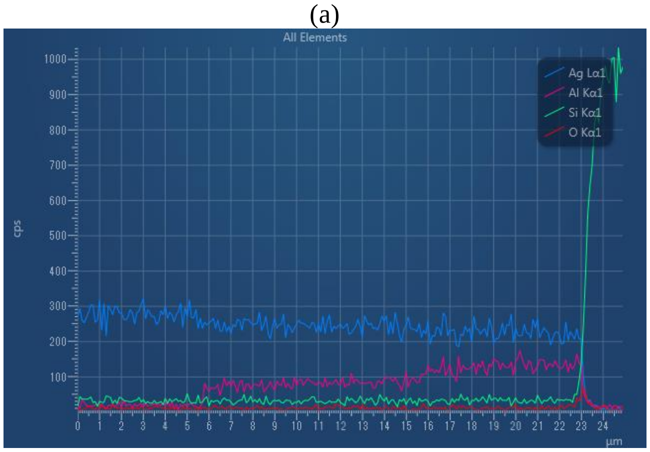
Fig. 4 Si mapping of pad surface after shear test
(a) Before annealing (b) 200℃ for 10 hrs (c) 200℃ for 50 hrs (d) 300℃ for 100 hrs

B. Ag wedge bonding annealing in air

To investigate the IMC of Ag and Al, the cross-section of all samples were prepared by mechanically lapped and then polished by an ion milling machine (Hitachi IM 4000 Plus). After that, optical microscope, scanning electron microscope (SEM) and EDS were used to do the cross-section analysis. Fig. 5 (a) shows the cross-sectional SEM view of Ag wedge bonding annealed at 300℃ for 50 hrs in air. Fig. 5 (b) shows the EDS line analysis, and two layers of IMCs were observed.



(a)



(b)

Fig. 5 Ag wedge bonding annealed at 300℃ for 50 hrs in air (a) SEM view (b) EDS line analysis

Fig. 6 shows the Ag-Al binary alloy phase diagram. There are the "μ" phase with 20~25 At.% of Al and the "δ" phase with 34~39 At.% of Al [3], [4]. References [5]-[7] show the IMCs are Ag_3Al in "μ" phase and Ag_2Al in "δ" phase.

In case of Ag-Al wedge bonding samples annealed at 300℃ for 50 hrs, two kinds of IMCs are observed. It is considered that the upper layer is Ag_3Al and the lower layer is Ag_2Al. And from all the samples that annealing in air, no voids were observed.

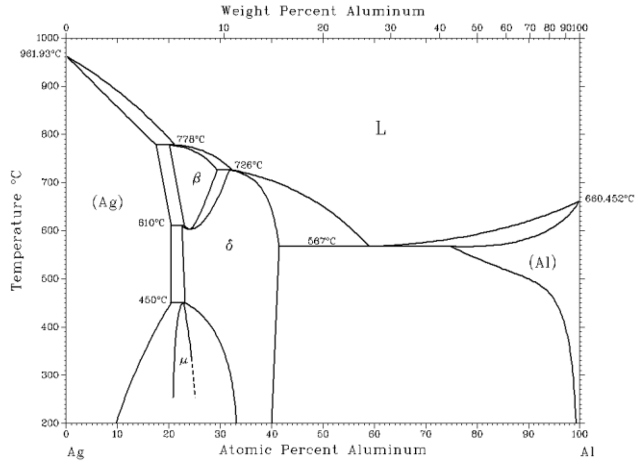
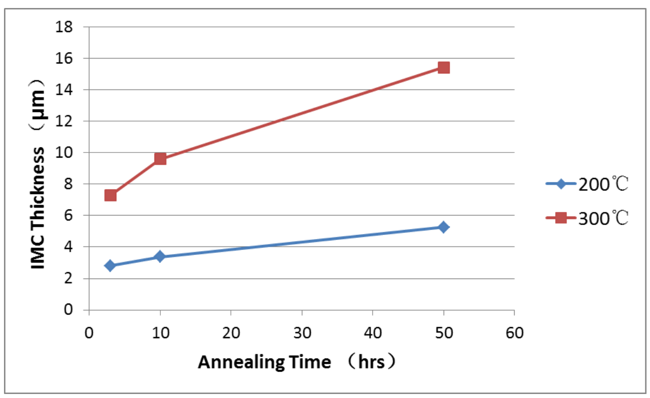
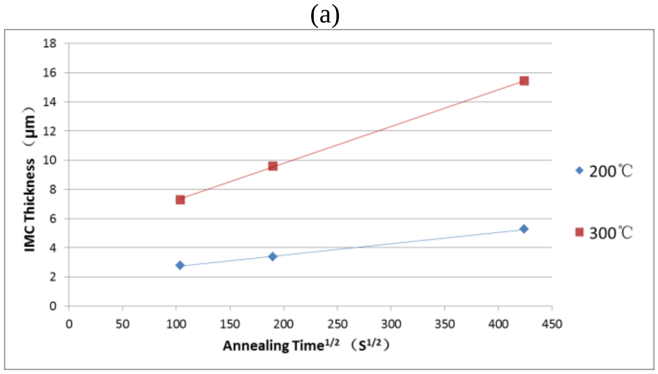


Fig. 6 Ag-Al binary alloy phase diagram

The growth of Ag-Al IMC was determined by measuring the thickness of diffusion layers after annealing. Fig. 7 (a) shows the growth behavior of IMC. At the beginning of annealing, IMC thickness grew fast. However as annealing times increased, the IMC growth rate decreased. And the IMC growth significantly depended on annealing temperatures. Fig 7 (b) shows the IMC thickness linear growth with annealing time$^{1/2}$.



(a)

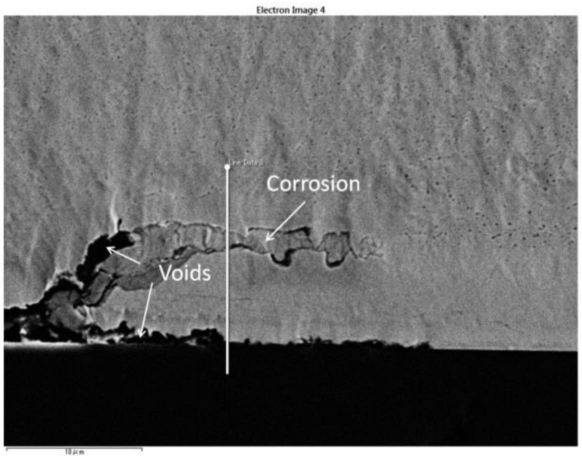


(b)

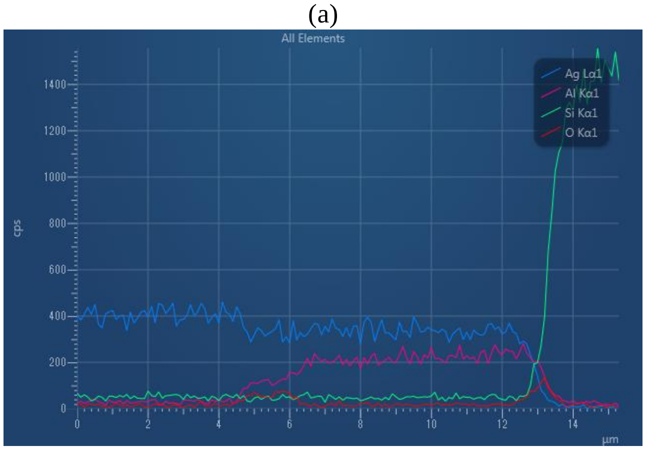
Fig. 7 (a) IMC thickness versus annealing time (b) IMC thickness versus annealig time$^{1/2}$

C. Ag wedge bonding annealing with molded IC packages

In this experiment, Ag wedge bonding was put in an aluminum box with some molded IC packages and then annealed at 300℃. Fig. 8 (a) shows the cross-sectional view of Ag wedge bonding annealed for 3 hrs, and some voids were observed. Fig. 8 (b) shows the EDS line analysis, there is a layer of corrosion between IMC and Ag wire as a peak of element O was detected.



(a)



(b)

Fig. 8 Ag wedge bonding annealed in 300℃ for 3 hrs with molded IC packages (a) SEM view (b) EDS line analysis

Fig. 9 shows the cross-sectional SEM view of Ag wedge bonding annealed in 300℃ for 50 hrs with molded IC packages. And cracks were observed. The crack leads failure and there is nearly no shear strength.

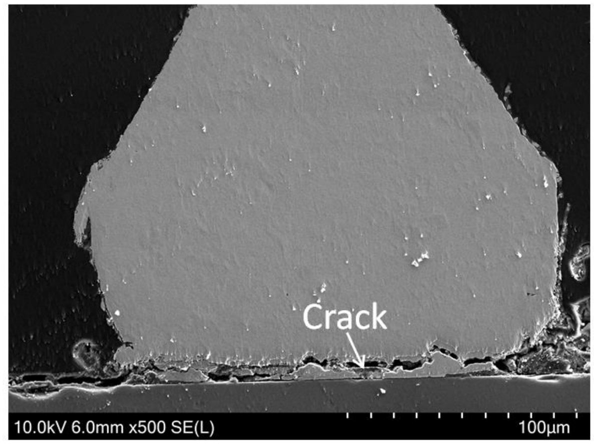


Fig. 9 Ag wedge bonding annealed in 300℃ for 50 hrs with molded IC packages

IV. Conclusions

To investigate the reliability of Ag and Al, ultrasonic wedge bonds were made on Al pad with Ag wire and annealed at 200℃ and 300℃ in air and with molded IC packages. The major findings from this study are summarized as follows:

(1) Two kinds of IMC layers in the bond-interface were observed after annealing. It is considered to be Ag_3Al in "μ" phase and Ag_2Al in "δ" phase.
(2) The thickness of IMC grows linear with annealing time$^{1/2}$. And the IMC growth significantly depended on annealing temperatures.
(3) Ag wedge bonding annealing in air, no voids and no corrosion layers were observed. At 200℃, the shear strength didn't decrease; at 300℃, the shear strength decreased after 10 hrs.
(4) Ag wedge bonding annealing with molded IC packages, the corrosion layer between IMC and Ag was observed, also many voids and cracks were formed and it would lead the reliability problem.

Acknowledgment

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References

[1] Preeti S. Chauhan, Anupam Choubey, ZhaoWei Zhong, Michael G.Pecht, "Copper Wire Bonding" Spring Science+Business Media New York 2014, pp. 1-9

[2] Xing Wei, Zhou YU, Wanmeng Xu, Tomonori Iizuka, Kohei Tatsumi, "Reliability study of Ag wire bonding for power devices" Microelectronics Sympsium, 2015, pp. 87-90

[3] Kyung-Ah Yoo, Chul Uhm, Tae-Jin Kwon, Jong-Soo Ch, e-Tak Moon, "Reliability Study of Low Cost Alterative Ag Bonding Wire with Various Bond Pad Materials" 11th Electronics Packaging Technology Conference, 2009, pp. 851-857

[4] Seizou Nagasaki, Makoto Hirabayashi, "Binary Alloy Phase Diarams" Agune Technology Center, 2001, pp. 1

[5] Yuki Antoku, Satoshi Teshima, Jun Chiba, Kauhko Ysuhara, "Bond reliability of Ag wire" Microelectronics Sympsium, 2012, pp. 39-42

[6] Santosh Kumar, Hoontae Kwon, Young IL Heo, Seung Hyun Kim, June Sub Hwang, Jeong Tak Moon, "Thermosonic Ball Bonding Behavior o Ag-Au-Pd Alloy Wire" IEEE 15th Electronics Packaging Technology Conference, 2013, pp. 15-20

[7] Liao Jun Kai, Liang Yi Hung, Li Wei Wu, Men Yeh Chiang, Don Son Jiang, C.M. Huang, Yu Po Wang "Silver Alloy Wire Bonding" IEEE, 2012, pp. 1163-1168