

New Methodology for Enhancing Electrical Conductivity and Strength of Copper Alloy Using Combined Structure

Hyo-Soo Lee^{1,*}, Hai-Joong Lee¹, Hyuk-Chon Kwon¹

¹Korea Institute of Industrial Technology, 7-47, Songdo-Dong, Yeonsu-Gu, Incheon 406-840, South Korea

*E-mail : todd3367@kitech.re.kr, Tel : +82-32-850-0492, Fax : +82-32-850-0241

Abstract

Copper alloy has been used as interconnection materials for various electronic applications due to their intrinsic properties of high conductivity and pertinent strength. The required properties of copper alloy have been intensified to let higher performance of final products possible. That is to say, the copper alloy featuring both high conductivity and high strength has recently been needed. However, the both properties are generally known as an inverse relationship each other.

We suggested new methodology for enhancing electrical conductivity and strength of copper alloy using the combined structure, which consists of a strengthened bulk with discretely thin-layered copper embedded by silver. It was expected that the combined structure consisting of copper and silver would show higher performance than the conventional copper when applied into the high frequency products, because the silver was embedded on the surface of copper. The embedded layer, conduction path, having a 100um width was formed by photo resist coating, UV exposure/development, chemical etching and plating, which is similar to the conventional semiconductor process.

From these works, copper alloy with the 40%IACS conductivity and 600MPa strength showed the improved properties of 60%IACS and 600MPa, respectively, which was 50% higher conductivity than the conventional copper alloy and was similar strength. The simultaneous properties of conductivity and copper alloy were possibly obtained by the combined structure.

Introduction

It is easily expected that the electronic devices related with network, multimedia and various digital contents are developed to be user-friendly, easy operation and handling [1-3]. Therefore, the electronic devices have been focused on the adaptation of high frequency with GHz such as return loss and insertion loss. High electrical conductivity of copper material is required for these needs.

We are to develop the new copper materials with, possibly, 80%IACS-800MPa by combining the copper alloy with high strength and the silver with high conductivity in this study. The conventional copper alloy shows maximally 60%IACS and 700MPa.

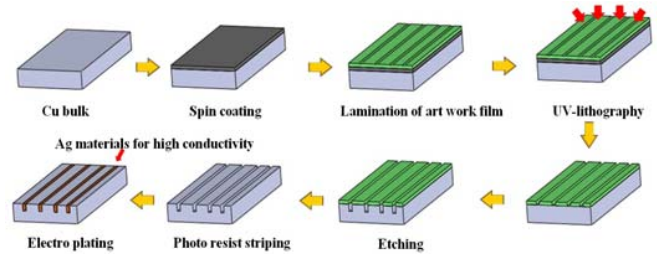


Figure 1. Fabrication process of the combined structure

Figure 1 showed the fabrication process of the combined structure in this study. The copper alloys having tensile strengths ranged 561~592MPa were spin-coated with photo-resist ink. The photo-resist layer on copper alloys were opened with ultra violet lithography process and followed by chemical etching.

It was expected from this study that the copper alloys with high electrical conductivity and high mechanical strength would be obtained simultaneously by the combined structure, and also could be implemented into the various electronics for GHz frequency.

Experimental procedure

Table 1. Composition of Cu-Fe-P alloys

Alloy No.	Fe	P	C
1	2.5	0.1	N/A
2	2.5	0.1	N/A
3	4.0	0.1	N/A

Table 2. Mechanical properties of Cu-Fe-P alloys

Alloy No.	Hardness(Hv)	Conductivity (%IACS)	UTS (MPa)
1	141	49.6	561
2	138	50.6	572
3	153	40.1	592

The Cu-Fe-P alloys with tensile strength ranged 561~592MPa and electrical conductivity ranged 40~51%IACS were used in this study, which were also named as alloy number 1, 2 and 3, respectively, as shown in Table 1 and Table 2. The Cu-Fe-P alloys were recently developed and supplied by Korea Institute of Materials Science.

The Cu-Fe-P alloys were cut with 30mm × 30mm and their surfaces were cleaned with ethanol. The cleaned surfaces were spin-coated with photo-resist ink by 5μm in the condition of 5000rpm speed for 20 seconds. The lithography process was carried out by ultra-violet ray with 900mJ for 60 seconds and by FeCl₃ etching solution for 60 seconds. And also, the plating process was carried out by 2A under 3V and for 30min using silver. From this process, the conduction paths of silver on the Cu-Fe-P alloys were formed in a row with thickness of 20μm, width of 100μm and space of 30μm. The electrical conductivities and the mechanical properties were characterized by 4-point probe and nano-indentation, respectively.

Results and Discussion

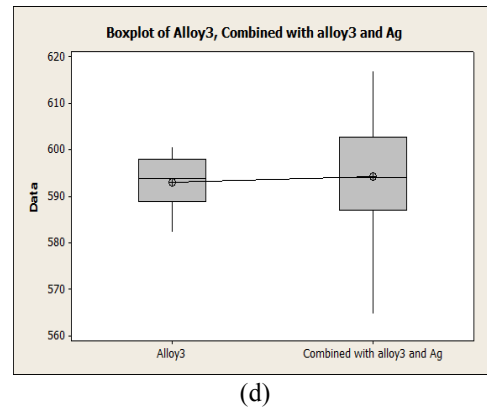
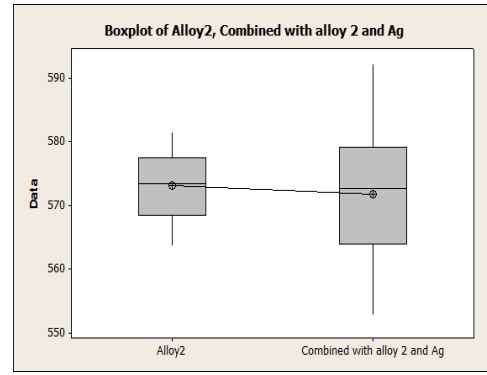
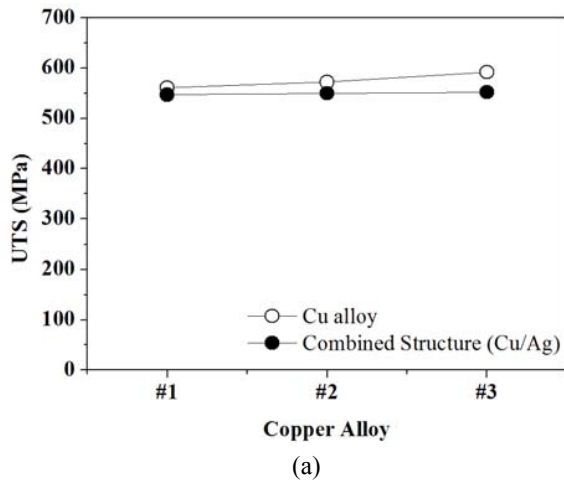


Figure 2. Mechanical properties of Cu-Fe-P alloys and their combined structure. (a) Tensile strengths, (b) analysis of 2-sample t on alloy 1 and their combined structure (P-value:0.612), (c) alloy 2 and their comined(P-value:0.530), (d) alloy 3 and their combined(P-value:0.638).

The tensile strengths of Cu-Fe-P alloys were measured as 561, 572 and 592MPa with their compositions, respectively. When the conduction path was formed on those alloys by silver, the tensile strengths were similar to each other, which could be proven by statistical analysis, 2-sample t. If the P-value is larger than 0.05 during the statistical analysis, there is no difference significantly between two samples within 95% confidential interval. Therefore, even though the tolerance of tensile strengths of the combined structure is a little larger than that of Cu-Fe-P alloys, it could be understood that the tensile strengths between Cu-Fe-P alloys and their combined structure were nearly the same, which results strongly induce that the tensile strength of the combined structure is dependent on their matrix.

$$K_{\text{combined}} = 2K_{\text{Cu}} \cdot \left(1 - \frac{\kappa\alpha}{1+2\kappa}\right) \quad (1)$$

K_{combined} : electrical conductivity of the combined structure

K_{Cu} : electrical conductivity of copper alloy

κ : ratio of electrical conductivity, silver/copper alloy

α : ratio of area, silver/combined structure

On the other hand, it was expected that the electrical conductivity of combined structure formed from Cu-Fe-P alloys would be enhanced because the silver with higher conductivity was embedded on the surface of Cu-Fe-P alloys. From the simple calculation as equation (1), the conductivity of combined structure was influenced by the conductivity of embedded materials and dimension. Therefore, the conduction paths embedded by silver would be given to the good conductivity of Cu-Fe-P alloys if the volume of paths were large.

Figure 3(a) and 3(b) showed cross sections of the combined structure before and after silver plating, respectively.

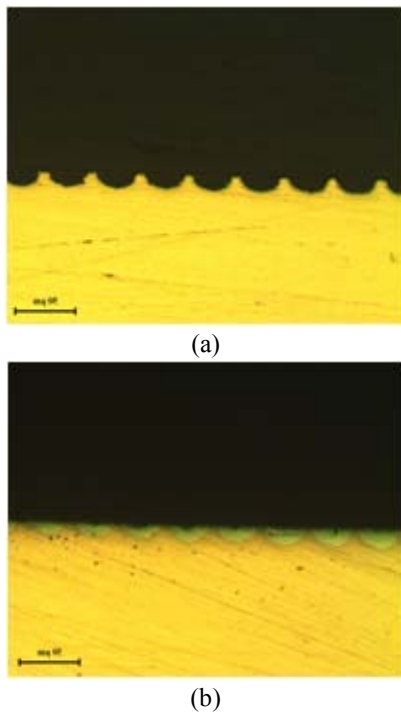
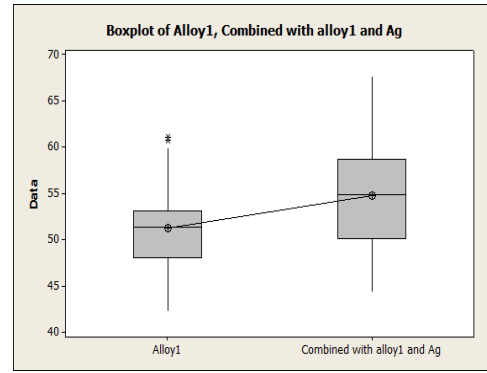
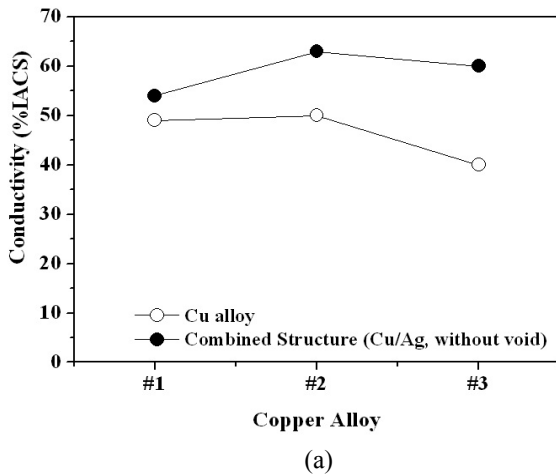
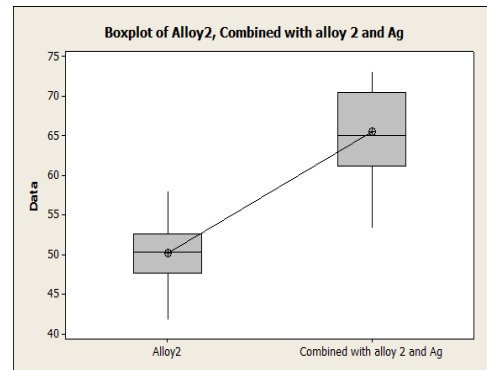


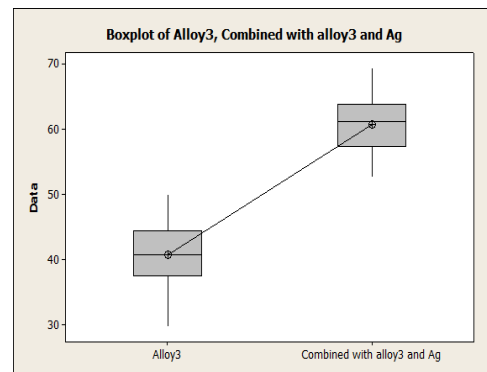
Figure 3. Cross sections of the combined structure. (a) Before silver plating, (b) after silver plating.



(b)



(c)



(d)

Figure 4. Electrical conductivity of Cu-Fe-P alloys and their combined structure. (a) Electrical conductivity, (b) analysis of 2-sample t on alloy 1 and their combined structure (P-value:0.01), (c) alloy 2 and their comined(P-value:0.00), (d) alloy 3 and their combined(P-value:0.00)

As shown in Figure 4, the electrical conductivity of combined structure was higher than that of Cu-Fe-P alloy due to the silver conduction path embedded on the copper alloy. The average values were measured as 54, 63 and 60% IACS with the sample number, respectively, which were increased by 30~40% comparing with the Cu-Fe-P alloys. These results were also coincided by the statistical analysis, where the P-value of all samples were lower than 0.05. Therefore, We can know obviously that the electrical conductivity of the

combined structure is increased by the silver path on copper alloys. If the silver paths were formed largely on the highly strengthened copper alloy, the conductivity and strength would be increased simultaneously as displayed from these results.

In order to spin-off our results, we applied the conduction paths of silver into several copper alloys such as copper thin foil (18 μ m), C7025 and C5210R. The 18 μ m copper thin foil was used generally as raw materials for printed circuit boards, And also, the C7025 and C5210R were used as raw materials for lead frame. As previous results on electrical conductivity, the combined structure of several copper alloys showed the increased values as shown in Figure 5, where the conductivity of copper thin foil was increased very highly by 80% through forming the conduction path of silver. Whereas, the tensile strength of each combined sample was very similar to their matrix, namely, also considered to be dependent on the tensile strength of their matrix.

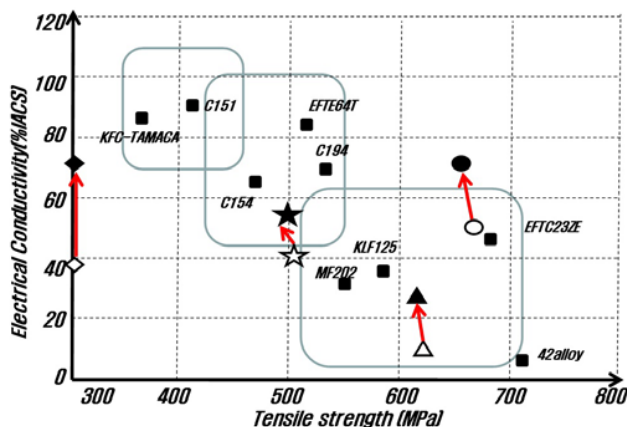


Figure 5. Property positioning of the combined structure. (◇ : Copper foil, ◆ : combined copper foil, ☆ : Cu-Fe-P alloy, ★ : combined Cu-Fe-P alloy, △ : C5210R, ▲ : combined C5210R-Ag, ○ : C7025, ● : combined C7025-Ag)

Conclusion.

It was suggested successfully by the combined structure that electrical conductivity and tensile strength were simultaneously increased.

The combined structure of copper alloy was formed by embedding silver into the surface of copper alloy, which was likely as the semiconductor process.

The embedded silver layer played a role of the conduction path of electrical current without any changes of tensile strength because the conduction paths were formed with a thickness of 20 μ m. Therefore, the tensile strengths of all combined samples were very similar to their matrix alloy, whereas, the electrical conductivity of the combined samples were increased by 20% comparing with the Cu-Fe-P alloy. The variation of conductivity and strength of the combined structure formed from copper foil and commercial copper alloys were also the same, where the conductivity of copper foil was increased by 80% through combining the silver on foil. It was obvious from this study that the higher

conductivity and strength could be obtained at once by the combined structure, and also was expected that the simultaneous properties were designable by controlling a volume of silver on copper alloy.

Acknowledgments

This study was supported by a Grant-in-Aid (Project title : Multi function realizing technology by quasi-state control, Project No. K0001337) from the Fundamental R&D Program for the Core Technology of Materials funded by the Ministry of Knowledge Economy, Republic of Korea.

References

1. Copper and Copper alloys, ASM Specialty Handbook, ASM International (2001).
2. Hyo-Soo Lee, Min-Su Yi (2007) Fabrication process and CTQ analysis of organic solderability preservatives finish on Copper pad for SMT. Journal of the Microelectronics & Packaging Society, 13: 43-49.
3. D. Edelstein J. Heidenreich, R. Goldblatt, W. Cote, C. Uzoh, N. Lustig, P. Roper, T. McDevitt, W. Motsifft, A. Simon, J. Dukovic, R. Wachnik, H. Rathore, R. Schulz, L. Su, S. Lucet and J. Slattery, Proc. IEEE-IEDM Conf., p.773 (1997).