Enhanced Adhesion of Copper Thin Film on Aluminum Oxide by Ion-Beam Mixing

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1. Introduction

Recently, aluminum base metal PCB is drawing interest with the development of high power light emitting diode (LED). The thermal dissipation property of PCB is crucial for stable operation and prevention of degradation of LED. In this work we have applied direct formation of the oxide layer on the metallic substrate followed by the conductive layer coating. This epoxy-free PCB structure is expected to show a higher thermal dissipation property. However, Van der Waals forces between atoms of metal film and non-reacting ceramic substrate can provide only extremely weak adhesion [1-3].

We utilize the ion beam mixing (IBM) method for the enhancement of the adhesion at metal-ceramic interfaces. The variables of the IBM process consist of the film thickness, the ion energy, the mass of the incident ions, the irradiation temperature, and the ion dose.

2. Experiments and Results

In this section some of the experiments are described and the relevant results are presented.

2.1 Experiments

Aluminum oxide layer, as the electric insulating layer of metal PCB was formed on the aluminum alloy (A5052) sheet by anodizing in 15% sulfuric acid up to the thickness of 20 µm. For better insulation, the porous oxide layer was sealed in hot water.

Onto the aluminum oxide layer, we deposited 500nm thin copper film as the seed layer. Then, an additional copper layer is to be coated to the designed thickness by an electroplating method, which will work as the electric conducting layer of PCB. The 500 nm seed layer deposition was carried out by e-beam evaporation with an assistance of an ion beam irradiation. The seed layer formation consists mainly of three steps; a thin copper film deposition, N-ion bombardment, and additional deposition of copper layer. To determine the thickness of the first thin copper layer, SRIM [4] software was employed. So we deposited the first thin copper layer for IBM to 80nm. Prior to the initial copper deposition, aluminum oxide surface was irradiated with 10 keV-N atoms at the incidence of 45° for 30 minutes to remove the surface contaminants and activate the surface layer. The deposition and ion irradiation were conducted in the same work chamber.

For the deposition of copper film, electric power of 1.4kW was used. During the film deposition process, the work vacuum pressure was about 1.0×10^{-5} Torr and the vacuum pressure during 70keV N ion bombardment was about 5.0×10^{-5} Torr. The specimen was heated to 120 ℃ during the coating and ion bombardment by halogen lamps. Following 80 nm ion-beam mixed deposition of copper, 420 nm copper film was deposited additionally. Post deposition heat treatment of the sample was done in the work chamber at 200℃ for 1 hour.

The surface of anodic oxide and cross-section of copper/oxide interface were analyzed with SEM images obtained by a JEOL model JSM 6300 system. The adhesion property was tested by an adhesive taping test and the Cu/alumina interface was also analyzed by Auger depth profiling.

2.2 Results and Discussion

SEM images of the anodic oxide surface before and after the sealing are shown in Fig. 1(a) and (b) respectively. The insulation of this sealed anodic oxide shows the breakdown voltage of about 1,000VDC and the thermal conductivity is about 30 W/m·K, which is higher than that of ceramic power mixed epoxy bond.

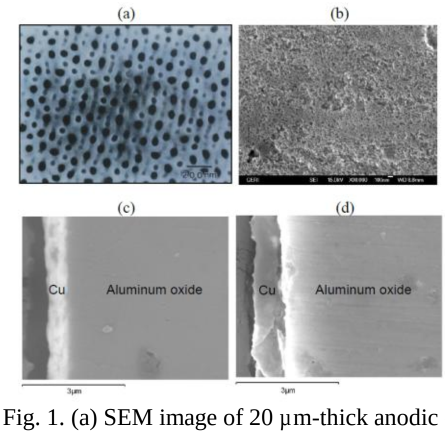

Fig. 1. (a) SEM image of 20 µm-thick anodic oxide surface shows pores before sealing. (b) Pores disappeared on the anodic oxide surface by sealing. (c) Cross sectional SEM of Cu film on oxide substrate deposited with IBM. (d) IBM deposited and heat-treated Cu film on oxide substrate exhibits similar color on both side.

As shown in Fig. 1, the cross-section of the 500 nm copper thin film deposited on anodic oxide without IBM shows a clear interface and the color is apparently different across the interface. Brighter color of left side of interface indicates the deposited copper film [Figure 1(c)]. However, the IBM treated and annealed sample shows a darker color on the film area and the element analysis by EDS revealed that lots of Al and O atoms diffused into the copper film. EDS result also shows few Cu atoms diffused into aluminum oxide layer on the contrary to the copper film side. It seems that chemical bonds between Al and O are broken by ion bombardment and mixed with the deposited Cu atoms. The heat treatment during and after the ion irradiation may have assisted the diffusion of Al and O atoms.

Adhesion of the Cu/oxide interface was tested by the adhesive tape peel test method in which the film surface was scratched by 10x10 grids in the area of 2cm x 2cm and pasting the adhesive tape on it, then pulling the tape out. As shown in Figure 2(a), Cu film deposited on the anodic oxide without IBM was peeled off easily however IBM and heat-treated film was never dethatched from the oxide layer [Figure 2 (b)] and the adhesion was strong enough for the PCB application. This adhesive tape test is simple but widely accepted method in the industrial sector.

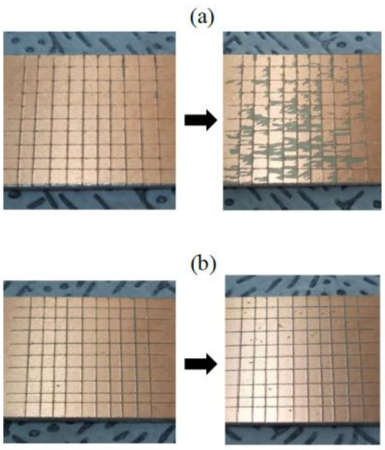

Fig. 2. Adhesion test of Cu films: (a) Cu film without IBM is delaminated easily by adhesive tape test (b) Cu film deposited by IBM and heat-treated exhibits no delamination and tiny spots on the tested surface is remaining glue of adhesive tape after the test.

Figure 3 is Auger depth profiling of the samples of Cu sole deposition, Cu IBM deposition and IBM deposition with post-deposition heat treatment. Figure 3 shows elemental distribution of Cu, Al and O atoms near the interface of Cu/Oxide. The intersecting points between the Cu and Al lines in the profiles can be the references of the interfacial broadening since the sputter etching rate was constant for all the samples. Obviously, the intersecting point of the Auger lines in the non-IBM sample is formed at the larger sputtering depth than samples with IBM. The sample with IBM followed by heat treatment shows the broadest interfacial region because the intersecting point is not reached at the given sputtering cycle. In general, the ion mixing can be used as a tool in fastening a thin film to a substrate. However, the thermodynamic compatibility is important. Evidences suggest that ion mixing can be employed to the Cu/Al_2O_3 couples since the sample with IBM and heat treatment shows the best adhesion property.

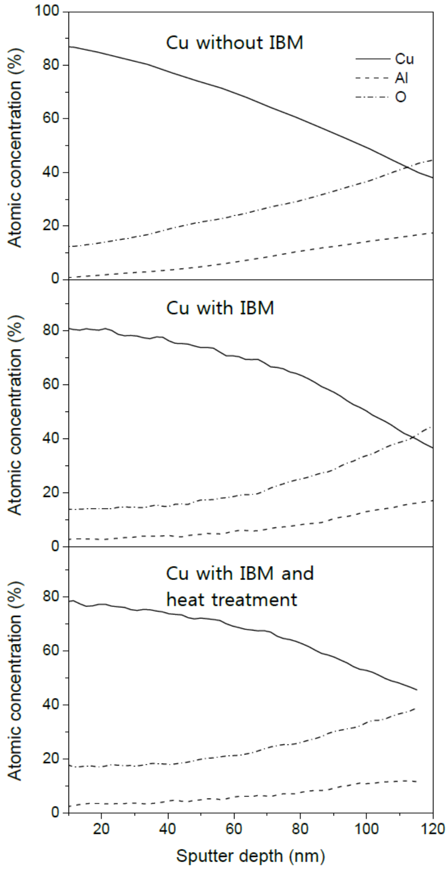

Fig. 3. Auger depth profiling of Cu/oxide interfaces without IBM, IBM only and with IBM and heat-treatment.

3. Conclusions

We demonstrated a possible way of a direct Cu metallization on anodized aluminum with the assistance of ion beam mixing to enhance the adhesion. The adhesion properties were investigated with Auger depth profiling and the adhesive tape test. The ion beam mixed sample shows a distinctive adhesion and a further increase in the adhesion was achieved after the post IBM annealing.

REFERENCES

[1] J. E. E. Baglin, Nucl. Instr. and Meth. B56, 119, 1992.
[2] P. Alemany, R. S. Boorse, J. M. Burlitch, and R. offmann, J. Phys. Chem. 97, 8475, 1993.
[3] T. Hong, J. R. Smith, and D. J. Srolovitz, Acta metall. Mater. 43, 2721, 1995.
[4] J. F. Ziegler, J. P. Biersack and U. Littmark, The Stopping Range of Ion in Solids, Pergamon, New York, 1985.