Adhesion Mechanism of Ni-Au and Cu layer in Electro-less Nickel Immersion Gold Process for Chip on Glass MLED Backplane

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Abstract

Researching on mechanism of insufficient adhesion between Ni-Au and Cu layer was using for improving product yield and reliability for chip on glass (COG) MLED backplane. The main factors are the Cu surface cleanliness before electro-less nickel immersion gold process (ENIG) and the Cu/Ni interface voids influence during the ENIG process. Therefore, the adhesion problem can be solved completely by adjusting the backplane process.

Keywords

COG; MLED backplane; ENIG; Ni-Au/Cu adhesion; Cu surface cleanliness; Interface Voids; Activation; Pd^{2+}

1. Introduction

Recently, MLED display technology (Mini/Micro-LED) has become a hot spot. MLED is a mass transfer technology where LED or IC chips are transferred to the driver backplane. The COG (chip on glass) solution has several advantages: better heat dissipation, low warping, semiconductor processing ability, high contrast, ultra-thin design, seamless splice, high flatness and high reliability compared to PCB in the MLED backplane.

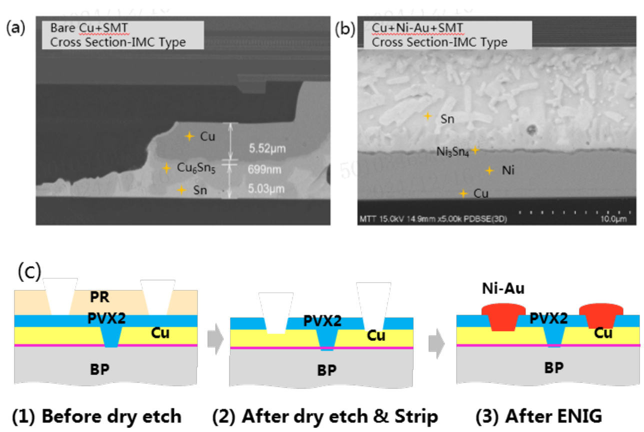

Figure 1. (a) IMC FIB-bare Cu(0.9um)directly with chip after SMT; **(b)** IMC FIB- Cu layer(0.9um)adding Ni-Au layer with chip after SMT**; (c)** stack layers schematic for before dry etch(left), after dry etch & strip(middle) and after ENIG(right)

As shown in Figure1 a-c, the Cu process is used in MLED wiring for low impedance requirements. However, if the chips are directly welded on the bare Cu which thickness below 2um, it can be completely reacted with Sn, leading to Cu_6Sn_5 IMC, which cannot meet the requirements of the SMT process (surface mounting technology). Adding the Ni-Au layer on bare Cu surface during ENIG (electro-less nickel immersion gold) process, Ni_3Sn_4 IMC is mainly generated after SMT, and the welding layer is even and has good wettability, which can meet the requirements of COG MLED SMT technology [1].

Therefore, the ENIG Ni-Au layer is necessary for the backplane with Cu process because of the rework and reliability requirements for COG SMT welding. This paper mainly studied the influence factors of adhesion between Ni-Au and Cu interface, which directly affected the product yield and reliability [2]. Figure2 shows main Ni-Au process, namely activation, Ni/P deposition, Au replacement and corresponding reaction mechanism in ENIG [3].

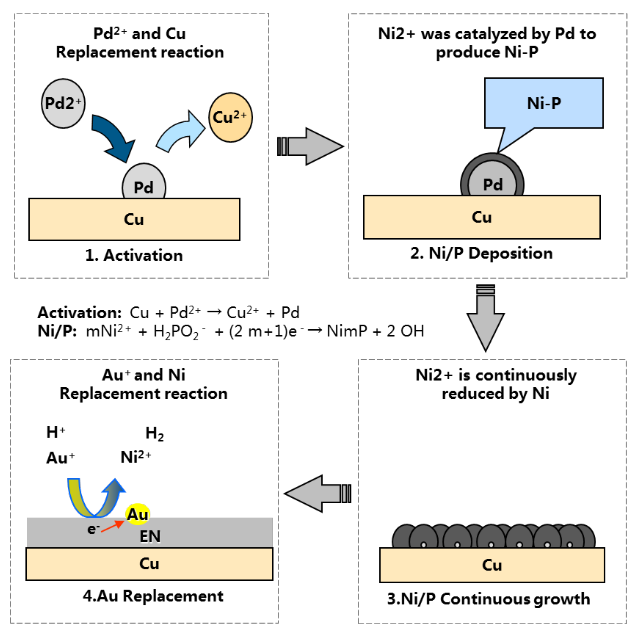

Figure 2. Main Ni-Au process flow and corresponding reaction mechanism in ENIG

The adhesion test of the Ni-Au/Cu interface is conducted by using 3M tape in ENIG area. Figure3 shows that the Ni-Au layer is detached from the Cu layer after the adhesion test through FIB analysis. The nickel grows from the Cu surface with a thickness of 2.95um.The Au layer generates Au through a displacement

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reaction on the surface of the Ni layer and it is very thin, designed to be about 40nm.

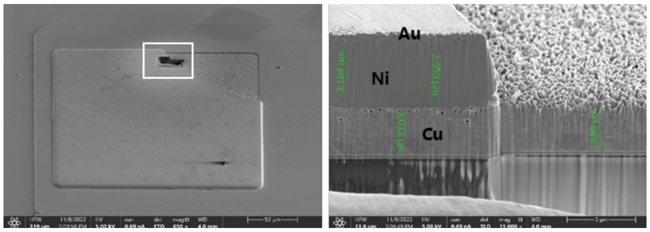


Figure 3. Top pad area of ENIG sample after 3M tape test, and the image of the peeling region by FIB analysis

2. Experiment and analysis

The binding force of the Ni-Au and Cu interface investigated has two main factors: firstly, the cleanliness level of the Cu surface exposed before the gold-plating process, which is mainly affected by the adsorption residues of by-products in the dry-etching Chamber, and secondly, the effect of the ENIG process on the Cu surface.

2.1 Effect of Cu surface cleanliness on Ni-Au peeling

In backplane process, PVX is a SiNx film deposited by CVD process, containing Si-H bond, which is easy to adsorb organic matter. Due to the influence of dry atmosphere (CF4/O2), the dry process is prone to produce organic by-products (C/Si/O groups) in the areas would be connected to the chips, as shown in Figure 4. The cleanliness of Cu interface is affected by two factors. Firstly, the by-products produced in PVX dry etching process are not completely pulled out by vacuum pump and are absorbed on the SiNx surface due to the presence of Si-H. Furthermore, when Cu is exposed along with PVX etched, Cu acts as a catalyst, and the interface has a carbon deposition effect, which affects the cleanliness of Cu surface. Therefore, we focused on studying the effects of D/H value (ratio of dummy area to hole area) and oxygen content of the dry etching process on by-products to optimize the dry etching process design.

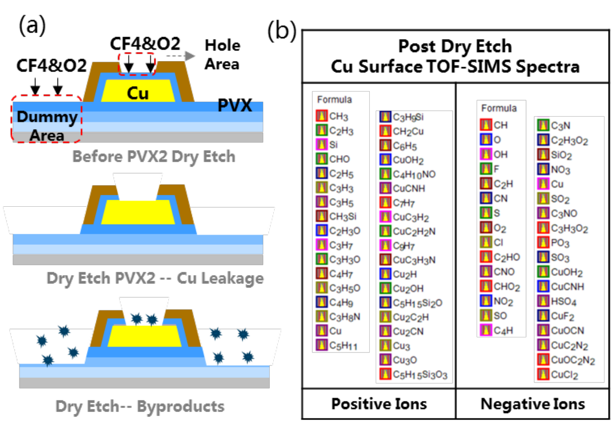
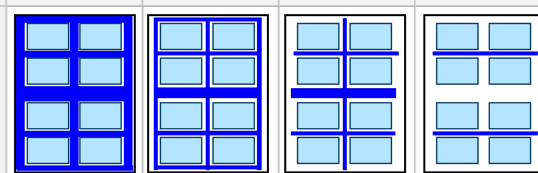


Figure 4. (a) Schematic diagram of the formation mechanism of dry etching byproducts; **(b)** The distribution of bonding groups of positive and negative ions on Cu surface measured by Tof-SIMS analysis after dry etching

2.1.1 Effect of Dry etching D/H value on Ni-Au peeling

The ENIG process design mainly studied the influence of different D/H values and oxygen content on Ni-Au peeling. The experiment for different D/H values design was conducted on the 55″ backplane, and the same ENIG condition was realized through graphical design adjustment. In table1, the results showed that 100% panel peeling occurred when D/H ratio was more than 21.8. At the D/H ratio of 5.8, the defect ratio of Ni-Au peeling was reduced to less than 10%. Figure 5(a) shows the microscope and FIB images of Ni-Au peeling at D/H ratio 21.8. Figure 5(b) shows microscope images of Ni-Au peeling at D/H ratio 5.8, and FIB analysis shows that Ni-Au layer is not uniform, and the degree of defects was significantly improved. Therefore, the optimized cleanliness of the Cu surface and uniform dry etching area (D/H ratio less than 5.8) are the most important factors. The subsequent ENIG experiments followed the baseline.

Table1 Experimental design of different D/H values and corresponding adhesion ability

Item	Different D/H Ratio of 55″ Product			
	Case 1	Case 2	Case 3	Case 4
Dummy Dry zone **Blue Colour**				
Cu hole Area/Glass	0.3567%	←	←	←
Dummy Area/Glass	22.0005%	11.5446%	7.7765%	2.09%
D/H Ratio	61.68	32.37	21.80	5.80
Peeling Test	NG Peeling Severe	NG Peeling Severe	Spec OK Peeling Little	Spec OK Peeling Little
Occurrence Rate	100%	100%	＜10%	＜10%
Remark	• Case 1/2/3/4, adjusted by patterning design adjustment			

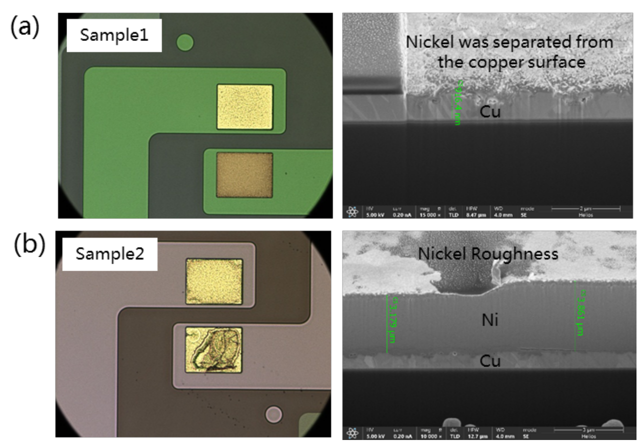


Figure 5. (a) Sample1 at D/H value=21.8，FIB image of Ni-Au peeling defect; **(b)** Sample2 at D/H value=5.8, FIB image of uneven Ni-Au deposition, look like Ni-Au peeling by OMM.

2.1.2 Effect of dry etching O2 content on Ni Au Peeling

In the dry atmosphere (CF4/O2), the higher is the O2 content, the faster is dry etching rate, such as PR or organic films. By-products were easy to adsorb on the surface of copper pad especially in lower exhaust inside the chamber. The experiment was designed to research Ni-Au peeling with different oxygen contents in dry etching atmosphere, including O2 reduce 0%, 10%, 25% and 40%. As shown in Figure 6, when the O2 reduce more than 25%, the ratio of Ni-Au peeling were all 0%. In the dry etching atmosphere of BP process, the surface-clean copper layer was produced when the CF4/O2 content ratio ≥ 1.33 (O2 reduce more than 25%). Therefore, the cleanliness of Cu layer is relatively good, which can meet the ENIG requirements.

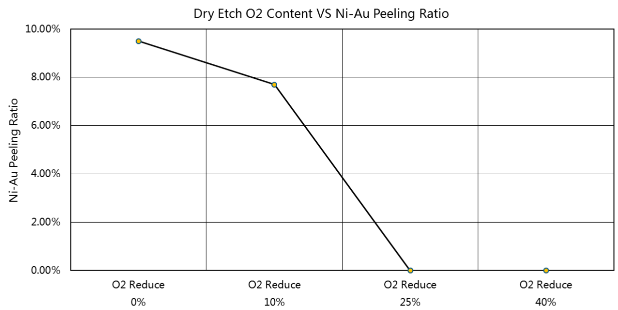


Figure 6. the curve of Ni-Au peeling ratio correlated with dry etching atmosphere for different O2 content（baseline, D/H 5.8）

2.2 Effects of ENIG Process on Ni/Au Peeling

Before ENIG process, based on the surface-clean copper layer, we have defined design and process specifications of dry etching. Furthermore, the ENIG process can also affect the adhesion of the each film layer. One factor related to production environment of ENIG is that the reaction between Ni solution and the copper layer can be prevented if the copper surface was contaminated and formed Cu-S bonds before Ni deposition. Another factor is about insufficient process margin, the contact issue will be magnified at the Ni-Cu interface.

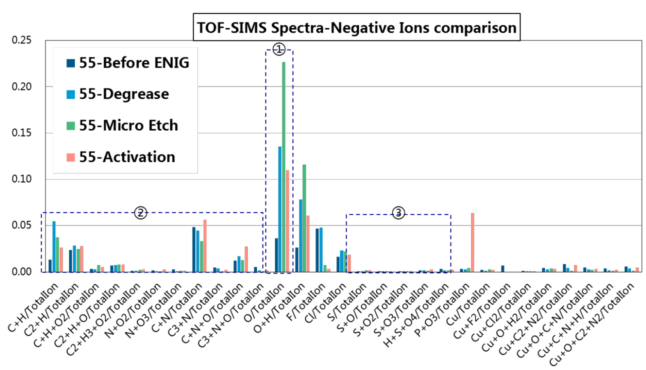


Figure 7. Tof-SIMS analysis for negative ion groups at different stages of ENIG process

2.2.1 Analysis of Cu surface composition

According to Tof-SIMS analysis on the Cu surface before and after the ENIG process, we confirmed whether Cu-S bonding existing or not. As shown in Figure 7, the samples collected include before ENIG process, after the degrease process, after the micro-etching process, and after the activation process. The results are as follows: ①The content of O-element increased after the micro etching process; ②A large number of C-element groups were contained on the copper's surface before ENIG process. The C-element groups didn't decrease significantly after the degrease process (C-H bonds increased significantly); ③At different stages of the ENIG process, the content of the S-element unchanged and the copper surface had no CuS bonding. Therefore, there is no Cu-S bonding formation in the backplane and ENIG process, and the adhesion had nothing to do with this.

2.2.2 Correlation between Cu/Ni interface voids and adhesion

As shown in Figure 8, there are many voids at the Cu-Ni interface in the cross-section of peeling-NG sample1 by FIB analysis. For peeling-OK Sample2, there are few voids at the Cu Ni interface in the cross-section. Therefore, based on mechanistic analysis, reducing the formation of voids can enhance Cu/Ni interface adhesion.

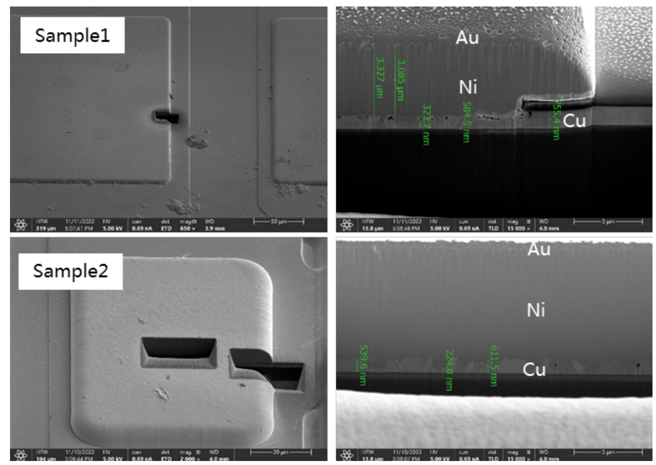
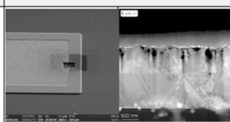
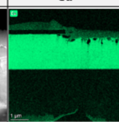
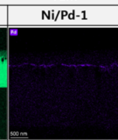
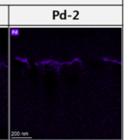
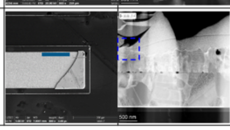
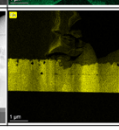
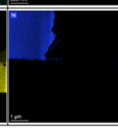
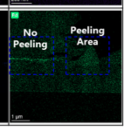


Figure 8. The FIB image of peeling-NG sample1 and peeling-OK sample2 about Cu/Ni interface

2.2.3 The mechanism of interface voids and improvements

At the end of the ENIG solution life time, TEM interface analysis was performed after the activation and Au process in ENIG, as shown in Table2. Sample1 shows the voids contain palladium (Pd) elements and the voids are formed because of Pd^{2+} replace Cu. Sample2 shows the Pd distribution was obviously enriched in Ni-Cu interface area, and it can be inferred that interface adhesion is related to the Pd layer. The Pd element normally acts as a catalyst in the substitution reaction, and the content proportion is small. According to the sample2, the more Pd quantities were distributed, the faster exchange rate was caused between Pd and Cu ions. Many factors affected Cu interface voids, including activation time, the oxidation degree of Cu surface, activation acidity and Pd^{2+} concentration. The effect of activation time on the Cu surface is shown in Figure 9 a-b. Serious oxidation occurs on the Cu surface when the activation time is from 180s to 360s. According to Table3, Pd as a product of substitution reaction, longer soaking time, more depth of the Cu micro-etch lead to more serious the copper oxidation. According to the effect of acid concentration, Pd and Cu are connected together with a potential difference, resulting in a galvanic cell effect, in which H^+ plays an electrolyte role. The higher concentration leads to the faster reaction. The higher acid concentration, the bigger the amount of copper was replaced. According to the effect of Pd concentration, the higher the Pd^{2+} concentration leads to the faster deposition rate. The larger the Pd adsorption capacity result in the more amount of replaced copper.

Table 2. FIB and TEM interface analysis. Sample1 Voids and Pd elements distribution after activation process; Sample2 Ni-Au peeling and interface elements distribution after ENIG process

Sample	FIB	TEM		
		Cu	Ni/Pd-1	Pd-2
Sample1 Post Activation				
Sample2 Ni-Au Peeling				

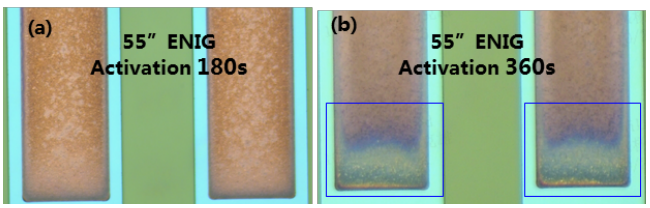
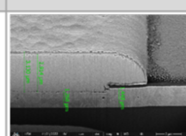
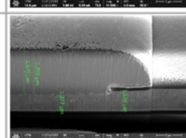
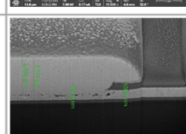
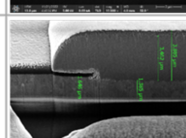
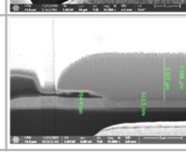


Figure 9. (a) the normal Cu surface with activation 180s; **(b)** The serious oxidation Cu surface with activation 360s

Table 3. The effect of acidity, Pd^{2+} concentration and time on the Cu interface voids

DOE	Acidity	Pd²⁺	Time	FIB	Void Level
Acidity↓	21ml/L	16ppm	360s		Severe
	11ml/L	16ppm	360s		Slight
Pd^{2+}↓	11ml/L	18ppm	360s		Severe
	11ml/L	12ppm	360s		Slight
Time↓	11ml/L	18ppm	120s		Slight

The formation mechanism of the activated voids is shown in Figure 10. Firstly, the drip water from the transported or washed process after micro-etch causes oxidation of the copper surface. Secondly, the longer the activation time, the more serious the oxidation caused by the copper in the gap position being continuously micro-etch. Thirdly, the drip water of transported or washed process after activation causes the copper to continue oxidize in the air. Finally, the oxidized copper on the surface does not react with Pd^{2+}, resulting in voids between nickel and copper.

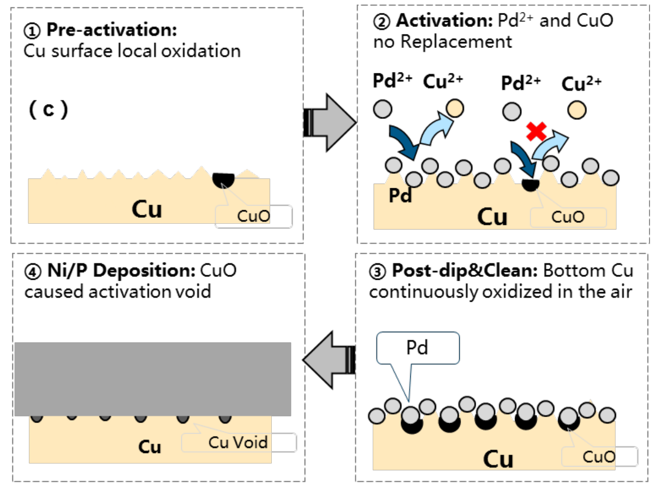


Figure 10. The formation mechanism of the activated voids

3. Conclusion

In this paper, the cleanliness of Cu surface was improved by optimizing dry etch D/H parameters of PVX patterning and reducing the dry etch oxygen content. It was found that the mechanism analysis of poor adhesion is related to the Cu/Ni interface voids. By reducing the acidity, Pd^{2+} concentration and process time in the activation process of ENIG, the adhesion problem between the Ni-Au layer and Cu interface is completely solved, and the product yield and reliability are greatly improved.

4. References

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