

The Effects of Zincation Process on Aluminum Bond Pad Surfaces for Electroless Nickel Immersion Gold (ENIG) Deposition

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Abstract. This paper reports the number of experiments that were designed to study the effects of aluminum bond pad surfaces prior to electroless nickel immersion gold (ENIG). During this process, called as zincation, an oxide layer of aluminum will be replaced with a thin layer of zinc metal through the reduction and oxidation process. Zincation process is very important process to provide trustworthy interconnection of under bump metallurgy in advanced packaging. The study was carried out to determine the best conditions, through the various zincation exposure times and multiple zincation process to the surface topographic and morphology. In addition, for further understanding the effect of zincation process, the study includes of investigating aluminum dissolution rate and ball shear strength between eutectic Pb/Sn solder ball and under bump metallurgy (UBM) interfaces. Scanning Electron Microscope (SEM), Atomic Force Microscopy (AFM), Focus Ion Beam (FIB) and Intellectest STORM series FA1500 were used as analytical tools in this study. The result suggests, the triple zincation process consistently produces a smooth surface of ENIG UBM and

consequently a better shear strength with only minimum aluminum dissolved.

I. INTRODUCTION

Electroless nickel Immersion Gold (ENIG) as under bump metallurgy (UBM) of the bond pads silicon wafer is gaining interest in flip chip packaging application because of it relatively low cost and simple process. Electroless refers to the autocatalytic or chemical reduction of metal ions plated to a base substrate from an aqueous solution [1]. The depositions are very uniform because no external current is required and deposition rate is not influenced by current distribution in the plating cell. The deposition is very selective, only occurred on the exposed bond pad metallization.

Aluminum is the dominant material for Integrated Circuit (IC) bond pad metallization since the introduction to semiconductor world. Aluminum and aluminum alloys quickly form a tenacious, refractory oxide layer on the surface that requires special technique to remove and achieve successful soldering. Special treatment required to ensure an oxide layer of aluminum is removed by pre-plating procedure called

zincation prior to electroless nickel immersion gold (ENIG). In this process the oxide film of aluminum are replaced with a thin layer of zinc metal. The zinc protects the aluminum from re-oxidized until it ready to be plated.

Zincation rely on the electrochemical exchange reaction between zinc ion in solution and aluminum metal to deposit zinc metal at the expense of aluminum dissolution (etching) [2]. Zincation is currently one of the most suitable processes to activate the aluminum surface for electroless technique [3]. Once this process is performed, aluminum coated with zinc then can be electroless plated by nickel followed by immersion gold. Nevertheless, a multiple immersion zincation operation is necessary for achieving better adhesion strength of the zinc layer. However, common practicing of double zincation process is more preferable by industry [3-7]. It is generally necessary to etch the zinc deposited with a suitable acid solution between the consecutive zincation steps in order to successfully carry out the multiple zincation operation.

Previous studies have shown that the zincation process have significant impact on the resultant zinc layer morphology, which in-turn directly correlates with the ENIG bump quality and its shear strength to solder ball interface [2]. Thus, the series of systematic experiments were carried out in this study in order to get better understanding of the surface topographic and morphology at each of different period of first zincation, multiple zincation process and aluminum dissolution rate during these zincation processes. The correlation between the surface appearance of nickel and gold to the solder ball shear strength also being studied. The information presented may be useful in providing better condition of zincation process to produce a reliable under bump metallurgy (UBM) in electroless nickel immersion gold (ENIG) technique.

II. EXPERIMENTAL

The 6" wafer with bond pads composition of Al with 1%wtSi and 0.5%wtCu was used in this experiment. The bond pads thickness is 2 μm with opening of 320 μm and

the rest of the metals were passivated with 0.9 μm thickness of silicon nitride.

The chemical used is newly prepared solution. Experiments were carried out in laboratory scale using small beakers and heating plate that was equipped with fuzzy contact thermocouple. The system was used to heat and agitate the plating solution. A microcontroller pH digital meter was used to obtain pH measurement. Two point calibrations were performed using standard pH solution before start of use for optimum accuracy.

Prior to the deposition of electroless nickel, the back side of the wafer was covered with high temperature polymer tape to prevent deposition of nickel at the wafer backside and subsequently prolong the life cycle of chemical solution. The wafer was then cleaned in weak alkaline solution at 70°C for seven minutes. Then, the cleaned aluminum pads were activated through the wet-etching to remove the oxide layer of aluminum on the surface using phosphoric acids solution.

Following next is the zincation process, consists of first, second and third zincation. However, an acidic etches using nitric acid solutions were performed between the consecutive zincation for 10 s at room temperature. Different exposure times of first zincation (30 s, 60 s, 120 s and 300 s) and multiple zincation exposure times (30 s and 60 s of first, second and third zincation process) were used as variable parameter for this experiment.

Once the aluminum surfaces coated with zinc, some of the sample preparation was then proceeds to electroless nickel (EN) deposition for 25 minutes at 85°C. The nickel plated surfaces were then immersed in gold plating solution for 10 minutes at 85°C to have a thin layer of gold on the surface. Each process steps were rinsed with de-ionized-water to avoid chemical mixture to the subsequent process.

Scanning Electron Microscopy (SEM) and Atomic Force Microscopy (AFM) were used for surface morphology and surface topographic. Focus Ion Beam (FIB) was used for precise cross-section followed by aluminum thickness measurement through the image on the computer screen. This was done on the samples after each

zincation process and compared with initial bond pad.

Ball shear strength was evaluated using shear test machine from Intellectest STORM series FA1500. Eutectic Pb/Sn solder ball with diameter of 300 μm was used in this study. The shear force was set at 500 gram and the back-off height is 30 μm . The ball shear strength was evaluated for different multiple zincation exposure times.

III. RESULT AND DISCUSSION

1. *Effects of Zincation Process on Aluminum Bond Pad Surfaces*

Figure 1 and 2 shows the effects of multiple zincation process on surface topographic and surface morphology. It clearly reflects that the multiple zincation process produces better smooth surface. The first zincation process produces a rough surface of zinc deposition and it preserved the contour of initial bond pad with agglomerates bump exist on the surface. The effects of second zincation process can be observed from the appearance of the surface of which to be quite uniform in size and shape. The contour of the surface also preserved the contour of initial bond pads but with the agglomerates bumps are getting fine and smaller. The surface from third zincation process becomes a

continuous zinc deposition that form together like an isolated island. Quantitatively, as a result of multiple number of zincation, the surface roughness is improved and getting smoother.

During the multiple zincation process, zinc removal has been carried and surface topographic and morphology are shown in figure 1 (c), 1(e), 2(c) and 2(e). The zinc removal or chemical etching process that was performed in between of zincation process (first and second, second and third) will dissolve the zinc deposition into zinc removal solution. Fresh zinc will deposit during the next zincation step resulted a fine and uniform zinc deposition. Therefore, the above-mentioned experimental results evidently revealed that the multiple zincation process will provide uniform and smooth surface of zinc deposition.

Then, some of the samples of first zincation were subjected to dipping times of 30 s, 60 s, 120 s and 300 seconds to study the effect of times. Figure 3 shows the effects of dipping times upon surface morphology of the bond pad. The surface morphology clearly shows that longer dipping time will cause rougher surface as shown in figure 3(a) to 3(d). This result shows that longer zincation times will cause continuous chemical reaction of the zinc deposited to keep growing, resulting thick and dense population of zinc that roughens the surface appearance.

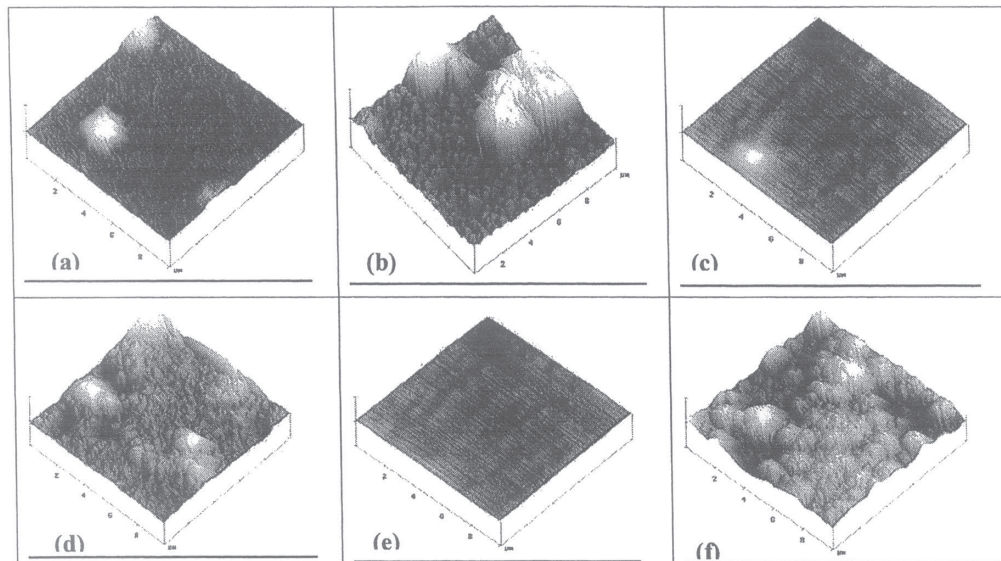


Figure 1: Surface topographic images of (a)Initial bond pad surface, (b) first zincation (c) first zinc removal (d) second zincation (e) second zinc removal (f)third zincation

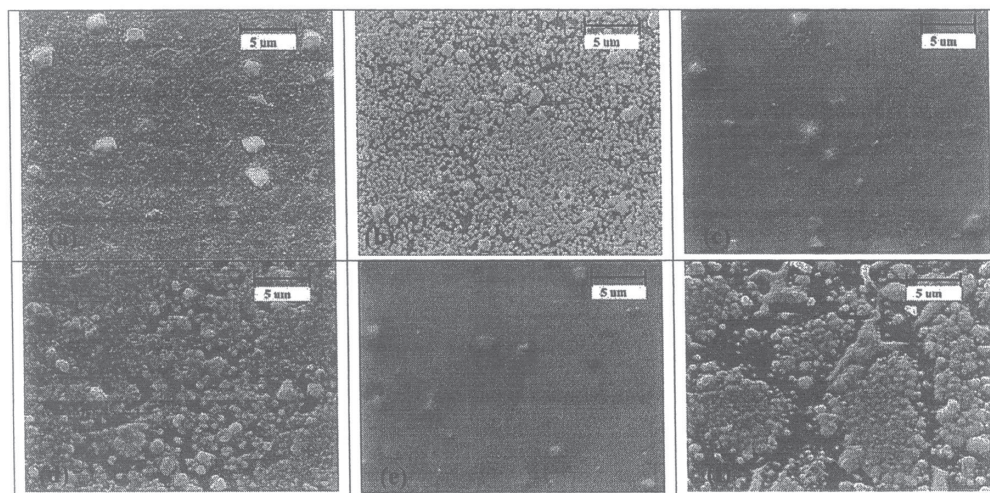
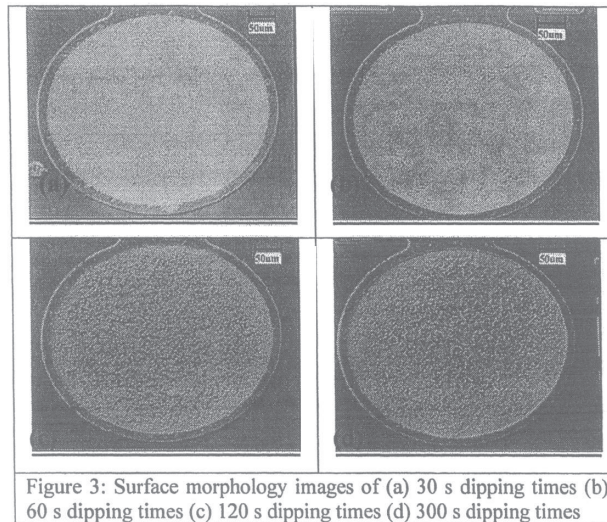


Figure 2: Surface morphology images of (a) Initial bond pad (b) First zincation (c) First zinc removal (d) Second zincation (e) Second zinc removal (f)Third zincation



2. Effects of multiple zincation and exposure times to Nickel and Gold Surface Morphology

Furthermore, the samples that were treated with multiple zincation exposure times were subjected to electroless nickel immersion gold. Figure 4 shows the surface morphology of nickel and gold. Third zincation process produces smooth and homogeneous nickel and gold surface but not significantly different if compared with double zincation as shown in figure 4 (b), (c) and figure 4(e), (f) regardless of exposure time. However this result clearly reflects that differently zinc surface deposition will be unavoidably being transferred to nickel and gold surface surfaces appearance.

As shown in figure 4(a) and (d), for sample treated with first zincation process, the surface appearance shows a rough surface with agglomerate bumps distributed on the surface. This was due to the first zincation process was not able to refine the existence of agglomerates at initial bond pads surface as shown in figure 1(a) and 2(a). For this reason, it's a good advantage to have the initial bond pads surface free from agglomerates bumps with smooth bond pad surface is most preferred. This yield a surface

treatment process simple with less number of zincation to produces a smooth and homogeneous nickel and gold surfaces.

Basically the zincation process involved of the oxidation and reduction reaction. The reaction will start with oxidation of aluminum surface, thus releasing electrons to reduce the zinc ions from solution to form zinc metal. This reaction will cause detrimental of aluminum thickness, therefore it is necessary to determine the aluminum dissolution rate while depositing zinc [9, 10]. The samples were then proceeds with FIB for precise cross-section on the bond pad and followed by aluminum bond pad thickness measurement directly from the screen over the selected area with the aid of cursor. Figure 5 shows the results of aluminum thickness for differently zincated compared with initial surface. The 30 s exposure times shows slightly less aluminum dissolution as compared to 60 seconds, but not significantly. Typically, third zincation with 30 s should provide minimum attacks on aluminum compared to double zincation with 60 s exposure times. This is because third zincation with 30 seconds treatment times will bring the total about 90 s as compared with total of 120 s for double zincation with 60 s exposure times.

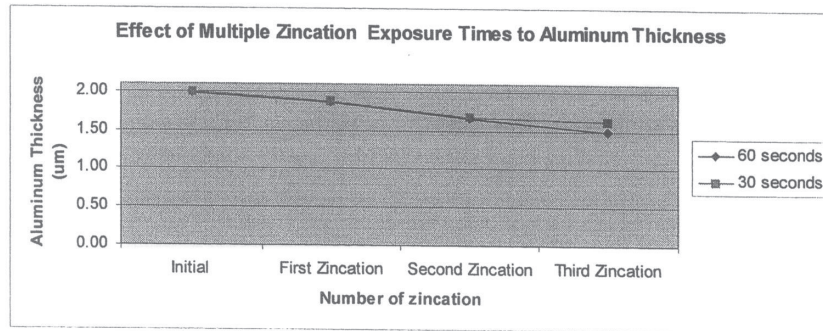
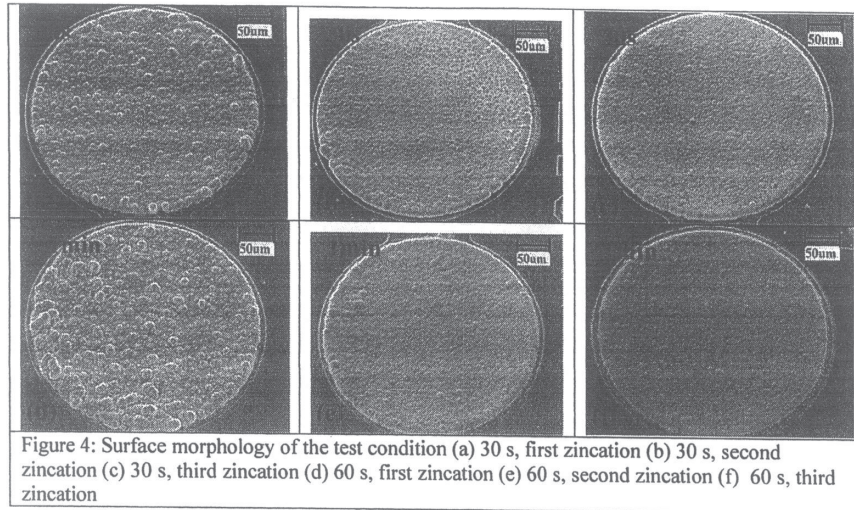


Figure 5: Influence of zincation to aluminum thickness

3. Shear Strength Test

Ball shear test was conducted to perceive the correlation between UBM surface roughness and morphology to the ball shear strength. Figure 6 shows third zincation produces better shear strength regardless of zincation exposure times (either 60 s or 30 s). This shows that smooth and homogeneous of

nickel and gold surface provides good adhesion between UBM and solder ball interface. This result with an agreement with other people study, where by the rough and coarse surface adversely affects the ball shear force [5, 8]. The detrimental ball shear result was suspected due to the formation of high stress points in the rough and coarse grain size of UBM surfaces.

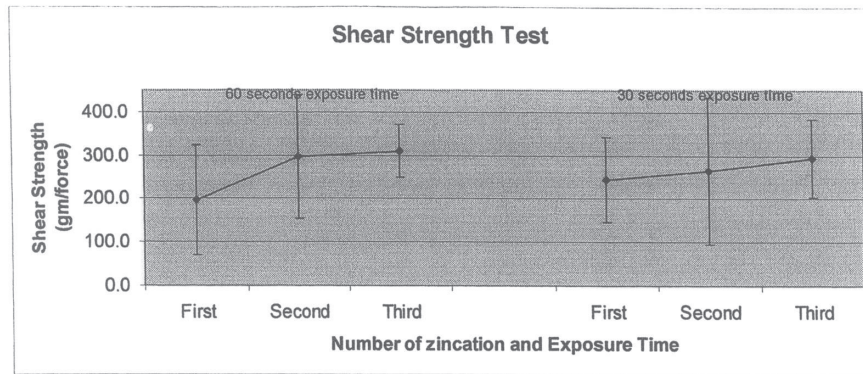


Figure 6: Shear strength results of electroless nickel immersion gold

IV. CONCLUSION

Longer zincation times will produce thick and high population density of zinc seed that caused roughens surface appearance. Third zincation process consistently produces smooth and continuous zinc film on the surface regardless of exposure time and consecutively transfers to nickel surface appearance. Ball shear test also shows third zincation provide better adhesion between UBM and solder ball interfaces. However, third zincation will cause some deterioration in aluminum thickness that may lead to reliability failure.

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REFERENCES

- [1] J.Simon, E.Zakel and H.Reichl "Electroless Deposition of Bumps for TAB Technology" Electronic Components and Technology Conference, 1990, Proceeding 40th, 20-24 May 1990.
- [2] G.Qi, X.Chen, Z. Shao "Influence of Bath Chemistry on Zincate Morphology on Aluminum Bond Pad" Thin Solid Films, Volume 406, Issues 1-2, March 2002.
- [3] Kwang-Lun Lin, Shiuh-Yun Chang "The Morphologies and the Chemical States of the Multiple Zincating Deposits on the Al Pads of Si Chips" Thin Solid Films, Volume 288, Issues 1-2, November 1996.
- [4] Guojun Qi, Lambertus G.J Fokkink, Kee Heng Chew "Zincating Morphology of Aluminum Bond Pad: Its Influence on Quality of Electroless Nickel Bumping" Thin Solid Films, Volume 406, Issues 1-2, March 2002.
- [5] Esther Wai ChingYau, Jing Feng Gong, Philip Chan, "Al Pad Surface Morphology Effect on Flip-Chip Solder Bump Shear Strength" Microelectronics Reliability, Volume 44, Issue 2, Feb 2003.
- [6] Sung-Ki Lee, Jeong-Gi Jin, Young-Ho Kim, Jae-Ho Lee "A Study on the Nucleation Behavior of Zinc Particles on Aluminum Substrate", International Symposium on Electronics Material and Packaging, EMAP 2001, 19-22 Nov 2001.
- [7] Ng Wei-Chin, Ko Tze-Man, William Chen, Qi Guo-Jun, "The Effect of Immersion Zincation to the Electroless Nickel Under-Bump Materials in Microelectronics Packaging" Electronics Packaging Technology Conference, 1998. Proceedings of 2nd, 8-10 Dec, 1998.
- [8] David A.Hutt, Changqing Liu, Paul P. Conway, David C. Whalley, Samjid H. Mannan, "Electroless Nickel Bumping of Aluminum Bond Pads-Part I: Surface Pretreatment and Activation" Electronic Components and Packaging Technologies, Vol. 25, Issue 1, March 2002.
- [9] Andrew J.G Strandford, Scott Popelar, Chrsitine Jauerning, "Interconnecting to Aluminum- and Copper-based Semiconductor (Electroless-Nickel/Gold for Solder Bumping and Wire Bonding" Microelectronic Reliability, Volume 42, Issue 2, Feb 2002.
- [10] A.Ostman, J.simon and H.Reichl "The Pretreatment of Aluminum Bond Pads for Electroless Nickel Bumping" Multi-chip Module Conference, Proceeding IEEE, 15-18 March 1993.