QUALITY AND YIELD IMPROVEMENT OF BARREL TIN PLATING PROCESS FOR SMX SEMICONDUCTOR PACKAGES

M.M.D. Kanan[1], M. Zaimi[2], M.E.A. Manaf[2] and N.M. Pham[1]

[1]Plating Department, ON Semiconductor,
Bien Hoa, Dong Nai Province, Vietnam.

[2]Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia.

Corresponding Author's Email: [1]m.misri@onsemi.com

Article History: Received 16 August 2017; Revised 25 October 2017; Accepted 10 December 2017

ABSTRACT: Most of semiconductor solderability improvement is done using tin. The tin plating can be done in lead frame or barrel. Barrel tin electroplating process for Surface Mount X (SMX) semiconductor packages has a distinct advantage: the ability to finish a greater volume of work for a specified time period. However, as the SMX packages are applied in critical automotive and medical fields, barrel tin plating also faces yield and quality challenges. This work discusses the common rejects and some solutions to improve the quality and yield of barrel tin plating process for SubMinitature version B (SMB) semiconductor packages. Among the common rejects are missing plating, burn mark, unit coupling, lead discoloration and crack package. The improvement efforts are the introduction of metal ballast to improve conductivity and reduce missing plating, improvement of solution filtration to avoid discoloration, addition of 'Zig-zag balls' to reduce unit coupling, auto tracking of ampere spike that causes crack package and vision system to further screen out rejects. As a result, SMX barrel plating yield can be increased to more than 99.8% and there are continuous effort to further improve yield and quality.

KEYWORDS: *Barrel Plating; Plating Rejects; Yield; Crack Package*

1.0 INTRODUCTION

Electroplating is a process that uses electric current to reduce dissolved metal cations so that they form a coherent metal coating on an electrode [1]. Major components of electroplating are electrolyte, anode, cathode and power supply as in Figure 1. Most tin plating chemistry utilize methyl sulfonate acid (MSA) bath. Chemicals used are MSA, tin MSA and confidential additives [2].

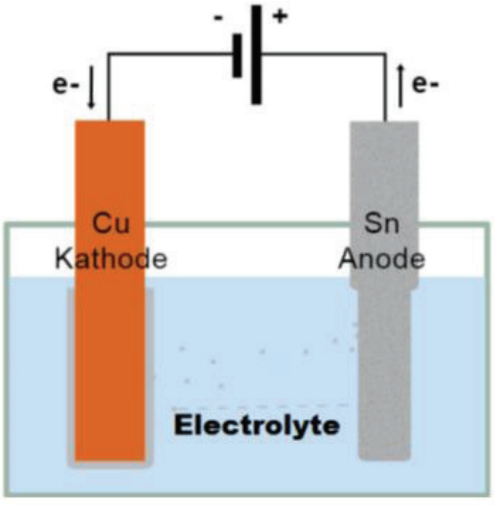

Figure 1: Basic Tin Electroplating concept

The electrochemical process that is taken place such as;

<u>At Anode</u>: Oxidation reaction taken place in plating tank with Anode or Tin Ball (Sn solid) become Sn^{2+} (metal tin cation) and releasing 2 electrons.

$$Sn \rightarrow Sn^{2+} + 2e^{-} \quad (1)$$

$$Sn^{2+} = \text{Tin cation}$$

<u>At Cathode</u>: Reduction reaction taken place inside barrel cylinder with contact dangler, SMB unit and ballast as a cathode. The primary reaction is. The Sn^{2+} cation gaining 2 electrons to form Sn or tin metal coating on to SMB units and ballast.

$$Sn^{2+} + 2e^{-} \rightarrow Sn \text{ (tin solid)} \quad (2)$$

In semiconductor industry, tin plating is applied to component leads to make them solderable to printed circuit board (PCB) [3]. There are a few types of plating machines, e.g., reel to reel, strip to strip, barrel and rack plating [4]. Barrel plating has a distinct advantage which is: the ability to finish a larger variety of work and produce a greater volume of work for a specified time period [5]. The barrel machine productivity can be further improved by using multiple barrel and process tanks. In this paper, we will discuss about barrel plating quality and yield improvement for SMX - semiconductor packages for surface mounted (Figure 2). SMX packages have two copper lead terminals as base metal prior to tin plating process. The SMX copper leads are connected to negative power supply to become cathode and the tin metal balls are connected to positive terminal to become anode. The tin (Sn^{2+}) cations are plated or coated to SMX copper leads [7].

Dimension (mm)	PACKAGE		
	SMA	SMB	SMC
A	2.10	2.30	2.13
D	2.60	3.56	5.84
E	4.32	4.32	6.86

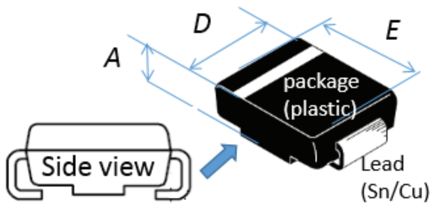

Figure 2: Nominal dimensions of SMX (SMA, SMB and SMC) surface mount device [6]

2.0 SMX BARREL TIN PLATING REJECTS

Despite its successful use for many years, barrel plating does have drawbacks, often stemming from poor electrolyte movement within the barrel. This can result in issues associated with poor mass transport, i.e. low limiting current and slow electroplating rates [8]. Tin barrel plating for semiconductor products faces further yield and quality challenges. In recent years, the use of electronic components in automotive and medical industry has changed the semiconductor landscape significantly and pushed the limits further on product reliability, which further challenges semiconductor industry to look beyond the conventional manufacturing process and controls [11]. Among the common rejects in SMX barrel tin plating process are missing plating, burn mark, unit coupling and lead discoloration [9].

Semiconductor parts are also sensitive to electrical surge as it would cause internal device failure and external crack package (Figure 3). As a containment action, SMX manufacturers are doing 100% product inspection after plating and automated vision system during product testing to ensure rejects are not going to customers. However, product inspection and vision system are costly and could not screen out all rejects which cause some escapees to reach customers.

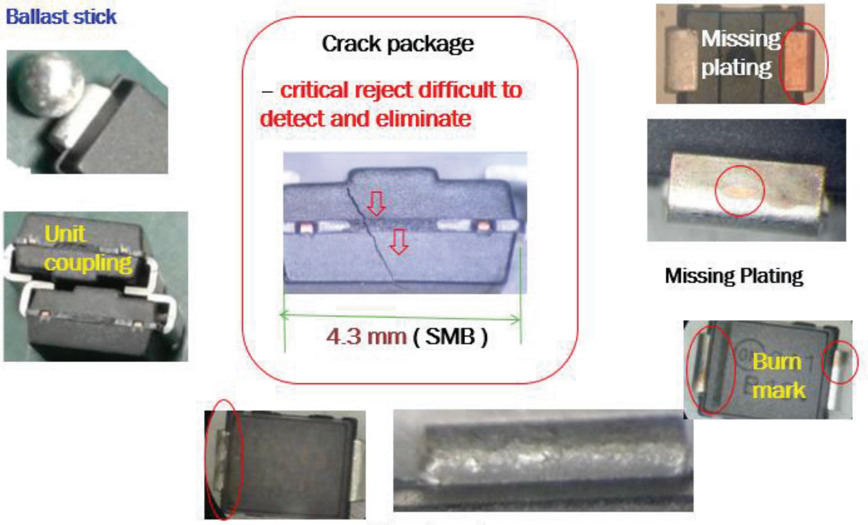

Figure 3: SMX barrel tin plating rejects (Note: The box size is about 1x1mm)

2.1 Missing Plating and Burn Mark

Missing plating and burn mark are common visual mechanical plating problem. Missing plating is a defect where the product leads are either partially or not plated at all. Sometimes, it is also called exposed copper or exposed base metal. Burn mark is a partial missing plating or thin plating layer with "burn mark" like dark grey color. Missing plating and burn mark could directly impact solderability performance [12]. Unlike standard plating for metal parts such as screw and nuts where the whole part is conductive metal and would be fully plated, semiconductor parts have both conductive metal and nonconductive plastic sections (Figure 2). Additional conductive media (ballast) need to be added to improve thickness distribution [13]. Various studies have been conducted to reduce missing plating and burn mark rejects. Missing plating or low plating thickness is caused by insufficient contact to plated surface. Some units could be accidently trapped at barrel door or any isolated locations. Some units can be also trapped by excessive plating bubbles that reduce plating efficiency.

The concentrations of methane sulfonic acid (MSA) [16], MSA tin and additive and other parameters such as temperature and flow rate can be optimized to eliminate missing plating and burn mark [14].

2.2 Unit Coupling

The unit coupling is the tendency of plated units and nickel ballast to stick to each (Figure 2). Unit coupling is related to plating solution surface tension and surface roughness. Higher surface tension and smoother surface contribute to more unit coupling. Plating additives with high surface tension help to improve throwing power [15] and better thickness distribution but it can contribute to more unit coupling reject. Some approaches for reducing unit coupling are by increasing barrel cylinder rotation and adding another media (such as Zig-zag balls in washing machine). These two strategies are focusing on reducing chance of product from sticking to each other. Plating voltage also plays a significant factor as unit coupling tend to occur at higher voltage [9].

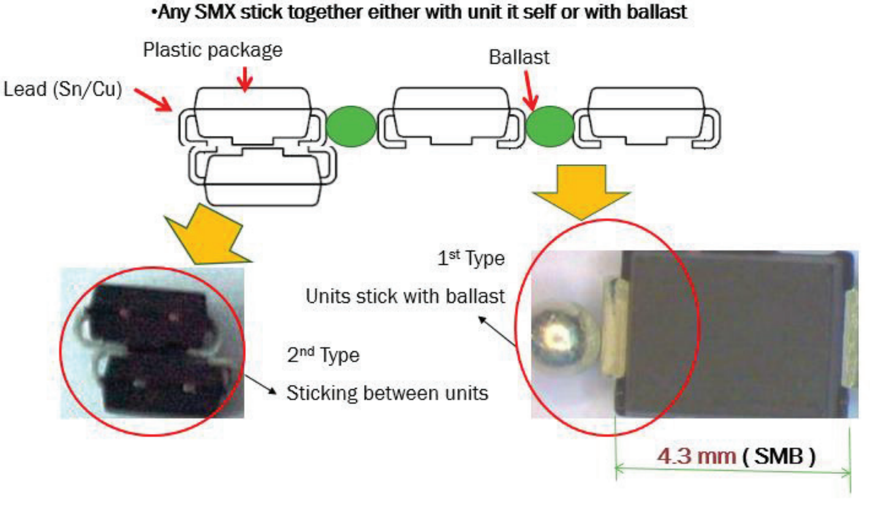

Figure 4: Unit coupling formation

2.3 Crack Package

Another critical reject for SMX barrel plating is crack package. External crack is normally caused by mechanical impact in previous process (moulding and trim-forming). Internal crack is due to excessive current. As electroplating is a process that uses electric current [1] it could affect sensitive semiconductor devices. High current inside the package causes ampere spike which melt the solder inside the package and micro crack outside the plastic package. The occurrence of crack package is noticed during the transition from tin-lead (Sn-Pb) plating to Pb-free or pure tin (Sn) plating. Pb-free plating requires higher plating thickness (and higher plating current) as part of tin whisker growth mitigation.

3.0 EXPERIMENTALS

Five steps of DMAIC method (Define, Measure, Analyze, Improve, Control) [10] approach were used to identify root cause of crack package due to high plating current. The preferred setting are tabulated in Table 1.

Table 1: Preferred barrel parameter setting to reduce plating rejects [a]

#	Type of Rejects	Cylinder (RPM)	Acid conc.	Tin conc.	Additive conc.	Solution turbidity	Zig -zag ball conc.
1	Missing plating/Burn mark	LOW	HIGH	HIGH	HIGH	LOW	LOW
2	Discoloration	NA	NA	HIGH	LOW	LOW	NA
3	Unit Coupling	HIGH	NA	LOW	LOW	HIGH	HIGH
4	Crack package	LOW	HIGH	HIGH	HIGH	NA	LOW

[a] *Expected setting. It shows that increasing one parameter may reduce certain rejects but increases other rejects. The setting needs further verification with process optimization.*

3.1 Transparent Cylinder Test

A special transparent tank with barrel cylinder assembly was fabricated to observe what happened inside the plating cylinder during plating process (Figures 5 - 7). To achieve this, simulations inside a transparent tank filled with water were performed using different settings (with/without Zig-zag ball, different speed (RPM) and different water level).

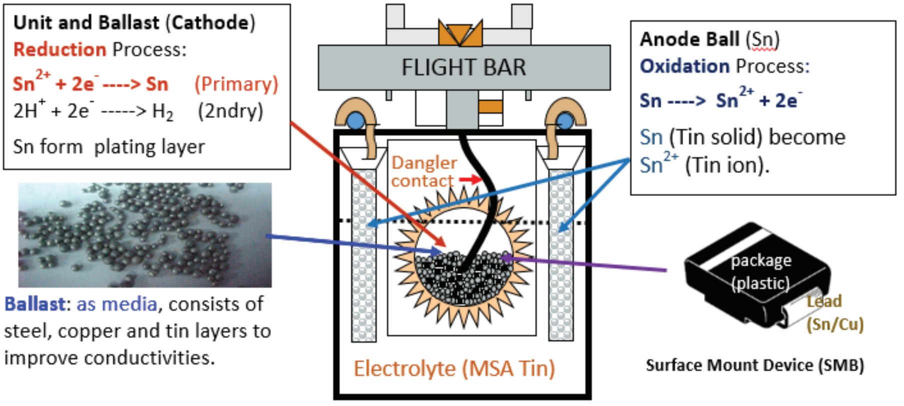

Figure 5: Mechanism of lead free barrel plating process (side view)

4.0 RESULTS AND DISCUSSION

4.1 Dangler Spike and Crack Package

Plating "current" can affect the SMX semiconductor device units (in term of short/crack package inside plating tank) (Figure 3). More than 50A current can create short and crack package. High current (forward bias) can flow through units only if the single units are connected to the dangler.

Figure 6: Mechanism of lead free barrel plating process (front view)

It was observed that the Zig-zag balls can push out the dangler to be over the ballast level and increase the possibility of current surge when only a very few units are connected to the dangler (Figure 7). Inside the ballast mixture, the current will be "diluted" causing only small current flow to each unit [17]. Without the Zig-zag balls, the dangler was consistently inside the ballast and unit mixture.

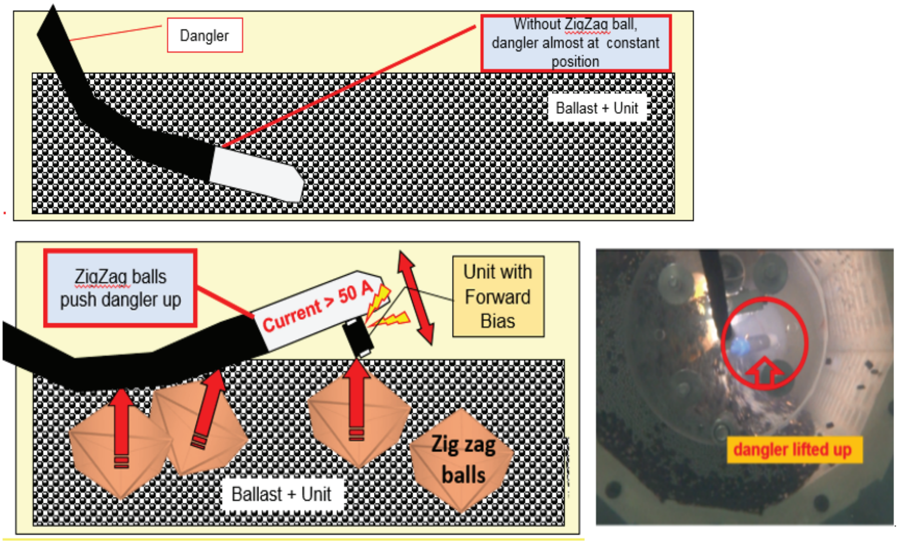

Figure 7: Dangler, ballast and unit movement can be seen through transparent cylinder (right) and this dangler is pushed up by the Zig-zag balls, creating short/over stress/crack package

4.2 Zig-Zag Ball: Crack Package vs Unit Coupling

The Zig-zag balls (Figures 6-7) were introduced in SMX barrel plating to reduce the occurrence of unit coupling (Figure 4), however the Zig-zag balls tend to push dangler up above the surface of bulk units and ballast mixture, causing ampere spike and resulting in crack package defect.

It is advisable to use smaller and heavier Zig-zag balls (Figure 8). The Barrel plating machine must also have the feature to detect ampere spike. The Zig-zag ball elimination proposal cannot be fully implemented as unit coupling reject will increase (Table 1). The ampere spike detection also has weaknesses as it can only detect severe ampere spike cases.

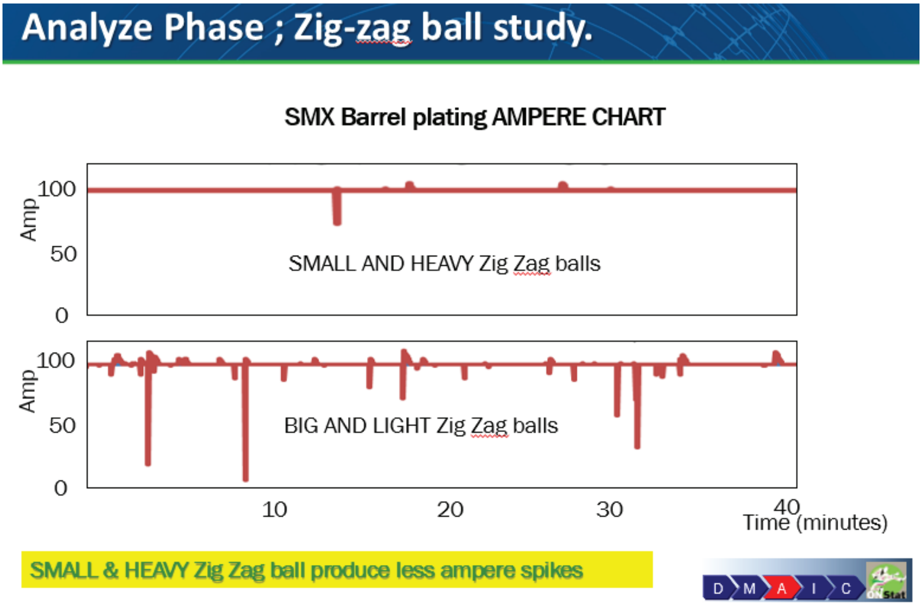

Figure 8: The effect Zig-zag ball type on the current surge occurrence

In conventional barrel plating, the parts to be plated are contacted either by a rod, dangler or metallic wall as they rotate inside the barrel. There are continuous efforts to modify barrel design such as changing the dangler contact with uniformly distributed contact tips at varying points on the periphery of the barrel [18].

4.3 The Chemical Source Factor in Missing Plating and Unit Coupling Rejects

There are several suppliers for the plating chemicals. Only the plating additive differentiates between them. There was a study to compare between the existing and new chemicals. The existing chemical has high unit coupling but very few missing plating. On the other hand, the new chemical produces very low unit coupling, but high missing plating rejects (Table 1). Missing plating is a reject that is more critical than unit coupling. The unit coupling defect could easily be screened out at various operations but missing plating could end up failing in customers' PCB.

There are a lot of efforts that have been done to improve SMX barrel plating yield and quality. The metal ballast was added to barrel cylinder to improve conductivity and reduce missing plating. The plating solution was filtered to maintain cleanliness to avoid discoloration. The Zig-zag balls were introduced to reduce unit coupling. The digital monitoring system (DMS) was implemented to track ampere spike that caused crack package. The automated vision system was also installed to screen out rejects. As a result, the SMX barrel plating yield showed an increase to more than 99.8% (Figure 9). However, manufacturer and customers expect better yield and quality especially on crack package and missing plating rejects.

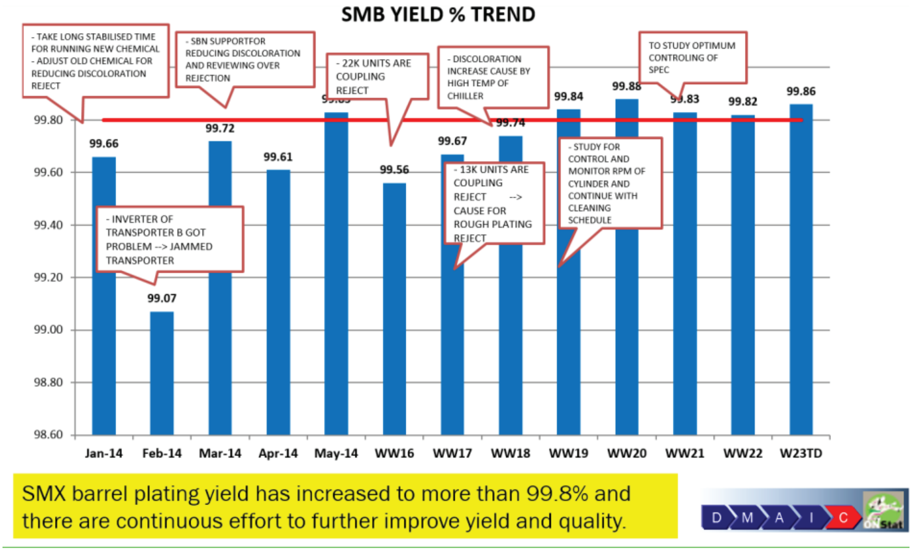

Figure 9: Continuous improvement trend for Tin SMX Barrel Plating Yield

5.0 CONCLUSION

The introduction of the metal ballast in the barrel plating improves the missing plating defect occurrence, nevertheless, causing unit coupling. The Zig-zag balls can reduce the occurrence of unit coupling, however, it also can push out the dangler to be over the packages and ballasts level, causing current surge resulting in crack package defect. Hence, the use smaller and heavy Zig-zag balls can decrease current surge occurrence. The DMS implementation can detects the current surge occurrence, thus, reduces the crack package defect occurrence. The automated vision system increases the yield above 99.8% by screening out the defected packages. The plating solution filtration has less effect on the discoloration defect since high temperature is the cause of the defect.

ACKNOWLEDGEMENT

The authors would like to thank ON Semiconductor Seremban and Vietnam especially to Mr. Sariman Tasmin and Mr. Mohd Kamal Bashah for their help in this study. The authors are also grateful to the Faculty of Manufacturing, UTeM for the technical supports. Lastly, the authors would like to acknowledge the Ministry of Education Malaysia for funding this publication under FRGS/2013/FKP/TK04/02/4/F00164.

REFERENCES

[1] J. Dufour, *An Introduction to Metallurgy, 4th Edition*. New York: Cameron, 2006.

[2] J. Horner, *Kirk-Othmer Encyclopedia of Chemical Technology, 4th Edition*. New York: John Wiley and Sons Inc. 2004.

[3] A. C. Tan, *Tin and Solder Plating in the Semiconductor Industry*: *A Technical Guide*. London: Chapman and Hall, 1993.

[4] J. G. Donaldson, "Continuous strip plating of electronic components", *Metal Finishing*, vol. 97, no. 1, pp. 642-655, 1999.

[5] R. Singleton, "Barrel plating", *Metal Finishing,* vol. 97, no. 1, pp. 346–367, 1999.

[6] S. M. Schottky. (2017). *SMB case 403a power rectifier* [Online]. Available: http://www.onsemi.com/pub/Collateral/MBRS140T3-D.PDF

[7] R. Singleton, and E. Singleton, "Fundamentals of barrel plating", *Metal Finishing*, vol. 8, no 109, pp. 14–22, 2011.

[8] A. J. Cobley, J. Halut and P. Negre, "Ultrasonic agitation in barrel electroplating: Field trial results", *The International Journal of Surface Engineering and Coatings*, vol. 93, no. 4, pp. 171-175, 2015.

[9] M. K. Basha and Y. H. Yeoh, *Reduction of SMB Pb-Free Units Coupling in Barrel Plating*. Seremban: ON Semiconductor, 2008.

[10] S. K. Land, D. B. Smith and J. W. Walz, *Practical Support for Lean Six Sigma Software Process Definition: Using IEEE Software Engineering Standards*. New Jersey: John Wiley & Sons.

[11] S. K. S. Nadarajan, "Effective maintenance strategy to improve performance through RCM concept", in 36th International Electronics Manufacturing Technology Conference, Johor Bahru, 2014, pp. 1–9.

[12] W. Cavanaugh and J. Langan, "Solderability of electrodeposits", *Plating*, vol. 57, pp. 45-47. 1970.

[13] F. Altmayer. (2004). *Barrel plating blues. products finishing* [Online]. Available: https://www.pfonline.com/articles/barrel-plating-blues

[14] E. Dunigan. (2012). *Troubleshooting guide for tin plating* [Online]. Available: http://www.thefinishingexperts.com/knowledgebase/troubleshooting-guide-for-tin-plating/

[15] D. Pletcher and F. C. Walsh, *Industrial Electrochemistry*. New York: Chapman and Hall, 1992.

[16] F. C. Walsh and C. Ponce de Leon, "Versatile electrochemical coatings and surface layers from aqueous methanesulfonic acid", *Surface & Coatings Technology*, vol. 259, pp. 676-697, 2014.

[17] G. Harsanyi. "Electrochemical processes resulting in migrated short failures in microcircuits", *IEEE Transactions on Components Packaging and Manufacturing Technology*, vol. 18, no.3, pp. 602–610, 1995.

[18] J. Rethinam, S. Sriveeraraghavan, S. Jayakrishnan, S. Sethumadhavan, S. Ramesh, V. Sriram and R. M. Krishnan, "Electroplating of nickel using a modified barrel design", *The International Journal of Surface Engineering and Coatings,* vol. 74, no. 5, pp. 179-181, 1996.