STUDY OF IMMERSION GOLD PROCESSES THAT MAY BE USED FOR BOTH ENIG AND ENEPIG

Don Gudeczauskas, Albin Gruenwald and George Milad
UIC Technical Center
Southington, CT, USA

ABSTRACT

The use of ENEPIG (Electroless Nickel / Electroless Palladium / Immersion Gold) has been steadily increasing the past several years and benefits of the finish have now become well known throughout the industry. The finish provides both reliable solder joints and wire bonds. In some Asian countries where mass production is performed at many facilities, dedicated production lines have been installed for plating of ENEPIG using an immersion gold optimized for ENEPIG but not for ENIG. In the North American market, however, many PWB facilities are producing both ENIG and ENEPIG finishes from the same plating line due to lower overall production volumes and desire to use the same immersion gold for both finishes. Most facilities have neither the room for two separate immersion golds nor the desire to tie up capital with the cost of gold for two separate immersion gold tanks. The challenge for North American manufacturers has been in choosing the proper immersion gold chemistry which can suitably deposit gold for ENIG and ENEPIG while providing a robust finish for soldering, wire bonding, and electrical contact with both finishes. This paper presents results of a comparative study for three types of immersion golds which could be used for both ENIG and ENEPIG deposits in the same production line: standard displacement immersion gold, high efficiency immersion gold which limits nickel dissolution, and a mixed reaction immersion gold which utilizes a mild reducing agent. Comparative results for solder wetting force, solder joint reliability and wire bonding will be presented for ENEPIG. Additionally, plated samples will be examined by SEM for evidence of nickel or palladium damage from the immersion gold plating operation.

INTRODUCTION

Recently, it is well-known that the electroless ENEPIG process has excellent solder joint reliability (SJR) and that it has the same wire bond reliability (WBR) compared to electroless Ni/Au with thicker Au (ENAG) process, even if the electroless Au thickness is between 0.1 to 0.2um. Past studies have examined the performance of ENEPIG [1,2]. The current IPC ENEPIG specification (IPC-4554 Amendment 1) calls for gold thicknesses between 1.2 minimum at 4 sigma below the mean and 2.8 microinches maximum and some specific customer requirements call for even thicker gold. It has been found that thicker deposits of immersion gold might lead to nickel corrosion with ENEPIG if the dwell time in the immersion gold solution dwell time is long.

The goal of this study was to examine the performance of ENEPIG using three different types of immersion gold: standard displacement immersion gold, high efficiency immersion gold, and reduction assisted immersion gold. The three types of immersion gold dissolve corresponding different amounts of nickel while the gold deposits as shown in Figure 1 using ENIG. The high efficiency immersion gold dissolves approximately half the amount of nickel from that of the standard displacement immersion gold while the reduction assisted gold dissolves approximately 60 percent of the nickel dissolved from the high efficiency immersion gold solution. Later studies will compare results for these immersion golds with ENIG only.

Examination methods in this study included solder wetting balance tests, gold sire bonding tests, cross section analysis for nickel corrosion examination and for intermetallic formation after solder testing.

EXPERIMENTAL AND RESULTS

The coupons used in this study consisted of a copper metallized and pattern plated (to 25um) test board which was subsequently coated with soldermask as shown in Figure 2. For wetting balance tests, standard wetting balance coupons with 36 mm wetting area were used. Specific BGA pads of 0.7 mm diameter connected to a ground plane were used for cross section examination of nickel corrosion. Two BGA pads in each array were connected to a ground plane containing 0.375 in^2 area giving a 629:1 area ratio which has been shown to help cause excess nickel corrosion in the past [3]. A wire bonding coupon was used for wire bonding tests. The test coupon is shown in Figure 1. This substrate was plated with ENEPIG by using plating chemicals commercially available from C. Uyemura & Co., Ltd. The ENEPIG plating process is shown in Table 1.

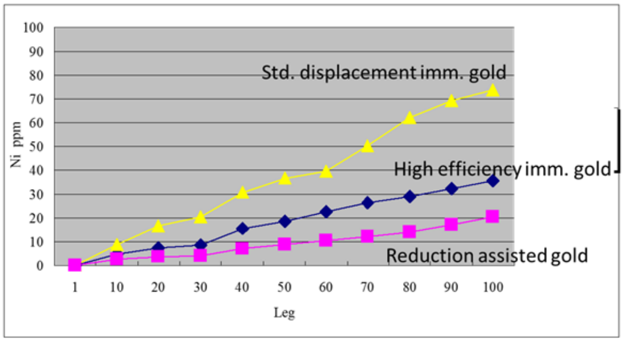


Figure 1. Depiction of nickel concentration in the

immersion gold solutions after approximately 0.25 MTO comparing the three different types of gold plating processes used with ENIG

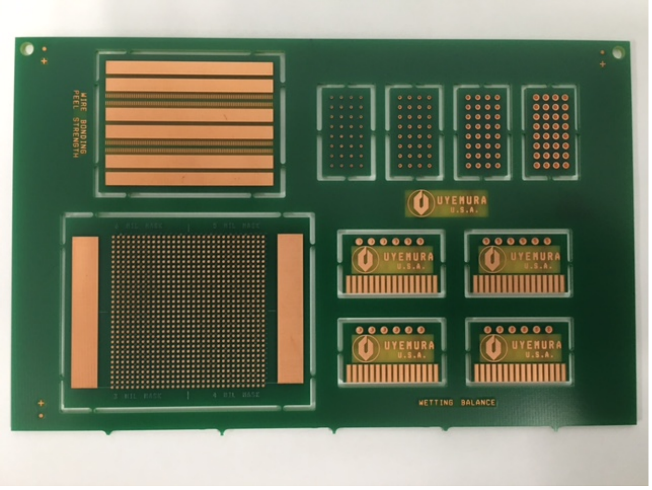


Figure 2. Test board showing wetting balance coupons, BGA array and wire bond array

Table 1. ENEPIG Plating Process

Process	Chemical	Temp	Time
Cleaner	Mild acid	40 deg. C	5 min.
Etching	Persulfate	25 deg. C	2 min.
Pre-Dipping	3% sulfuric acid	R.T.	1 min.
Activator	Palladium-type	30 deg. C	2 min.
Electroless Ni-P	Mid Ni-P	80 deg. C	25 min.
Electroless Pd-P	Pd-P (P=3%)	66 deg. C	6 - 9 min.
Immersion gold	Conventional Imm. Gold	85 deg. C	12 - 30 min.
Immersion gold	High Efficiency Imm. Gold	80 deg. C	15 - 45 min.
Immersion gold	Reduction assisted Imm. Gold	80 deg. C	5 - 13 min.

Thickness results were recorded using a Seiko SEA-5120 Element Monitor MX XRF. Gold deposit thicknesses were targeted for the lower and upper ranges of the IPC-4556 Amendment 1 specification. The cross section images of BGA pads were observed using a JEOL JSM-6010LA SEM. Wetting balance coupons were tested in an as-plated condition and after 3x reflow at 255 deg. C maximum temperature using a Heller 1088 reflow oven. Solder wetting balance testing was performed using a Metronelec Menisco ST 50 wetting balance with IPC test flux #1 using SAC305 solder at 255 deg. C. Wire bond coupons were first baked at 175 deg. C for 16 hours in a Fisher Isotemp 400 series oven. The wire bond coupons were subsequently argon plasma cleaned prior to wire bond tests. Wire bond testing was performed at Fast Semiconductor Packaging LLC (Anaheim, CA) using the equipment and conditions shown in Figure 3.

Equipment	**K&S 4524**	
	Bond 1	**Bond 2**
Temp. Setting	150	150
Temp Actual	150	150
Power (mW)	2.54	3.01
Time (ms)	3.0	3.0
Force (g)	3.0	3.5
wire size	**1 mil gold**	

Figure 3. Wire bond conditions

Measured thicknesses are shown in Table 2.

Table 2. Deposit thicknesses in microinches

	Sample	Avg. Au	Avg. Pd	Avg. Ni
Sample	Description	thk. u"	thk. u"	thk. u"
1	Red. assisted immersion gold	2.94	9.39	217
2	Red. assisted immersion gold	1.59	7.05	224
3	Std. displacement imm. gold	2.79	7.56	224
4	Std. displacement imm. gold	1.49	7.77	206
5	High efficiency imm. gold	2.98	4.82	204
6	High efficiency imm. gold	1.27	6.35	187

SOLDER WETTING BALANCE

Solder wetting balance test results are shown in Table 3.

Table 3. Solder wetting balance test results

		Gold	Solder wetting	Final wetting
Sample	Condition	thk. u"	time, sec.	Force mN/mm
1	High Eff. Gold as plated	2.94	0.31	0.25
1	High Eff. Gold - 3 reflows	2.94	0.20	0.25
2	High Eff. Gold as plated	1.59	0.27	0.23
2	High Eff. Gold - 3 reflows	1.59	0.26	0.23
3	Std. Displ. as plated	2.79	0.64	0.25
3	Std. Displ. - 3 reflows	2.79	0.42	0.25
4	Std. Displ. as plated	1.49	0.38	0.25
4	Std. Displ. - 3 reflows	1.49	0.36	0.23
5	High Eff. as plated	2.98	0.59	0.24
5	High Eff. - 3 reflows	2.98	0.25	0.26
6	High Eff. as plated	1.27	0.40	0.22
6	High Eff. - 3 reflows	1.27	0.32	0.22

Solder wetting curves were compared to the standard curves shown in Figure 4 while a typical curve from the testing (Sample 4, standard immersion gold at 1.49 u") is shown in Figure 5. Solder wetting times and final wetting forces were excellent for samples tested with good wetting observed as described in the depiction figure.. Interestingly, the wetting times decreased in all cases after the 3X reflow exposure. Final wetting forces were all above 0.20 mN/mm. The reduction assisted immersion gold samples showed some of the lowest wetting times while the standard immersion gold samples exhibited the longer wetting times.

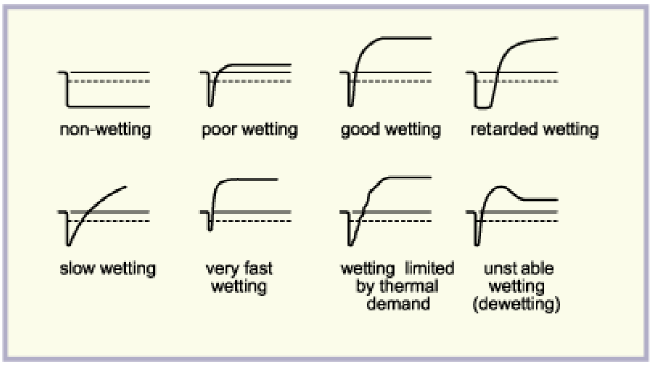


Figure 4. Wetting balance curve depictions

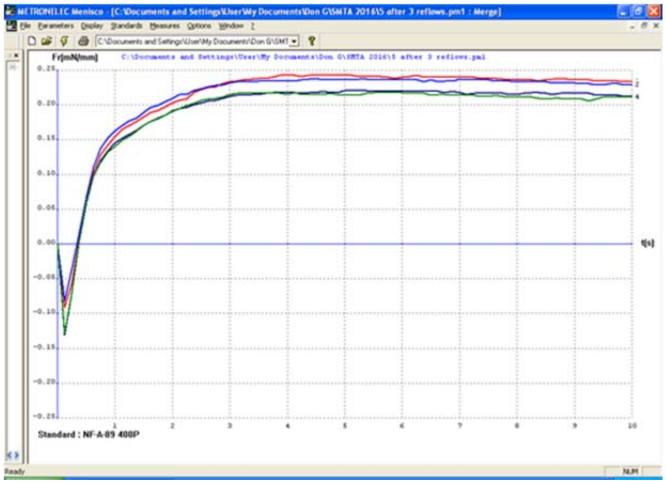


Figure 5. Wetting balance test results sample 4 after 3 reflows

WIRE BOND TESTING

Previous work performed by the IPC in the writing of IPC-4556 involved a large round robin test program whereby several ENEPIG deposits of varying gold thicknesses from various suppliers were wire bond tested. It is believed the samples for the IPC study were not baked to simulate die attach and this current study attempted to determine if any effects of baking at 175 deg. C for 16 hours were seen on gold wire bond results when using different types of immersion gold. A depiction of the typical wire break modes are shown in Figure 6. Ideally, wire breaks at locations B, C, and D are preferred. Wire breaks at position A and E would indicate a poor bond between wire and substrate. Results for the current study are shown in Table 4 and Figure 7 respectively. Despite heat aging, all results appeared acceptable, well above the 3 gram pull strength minimum. The standard displacement immersion gold sample with thick deposit showed lower minimum wire pull strength and higher variation in values when compared to the other samples.

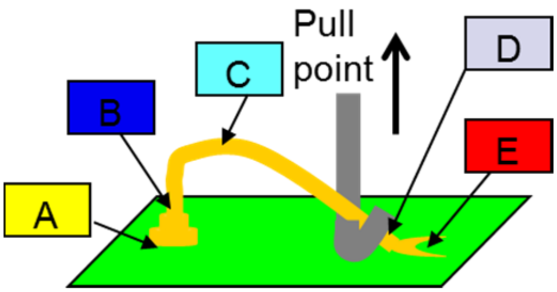


Figure 6. Wire break modes

Table 4. Wire bond test result data for the six samples

Sample	Mean	Min	Max	Std. dev.
1-Red. Assisted thick gold	10.3	9.4	11.2	0.48
2- Red. Assisted thin gold	9.9	7.9	10.8	0.78
3-Std. Disp. thick gold	10.2	7.2	11.7	1.07
4-Std. Disp. thin gold	10.3	9.5	11	0.47
5-High eff. thick gold	11.0	9.4	12	0.58
6-High eff. thin gold	10.7	9.9	11.9	0.44

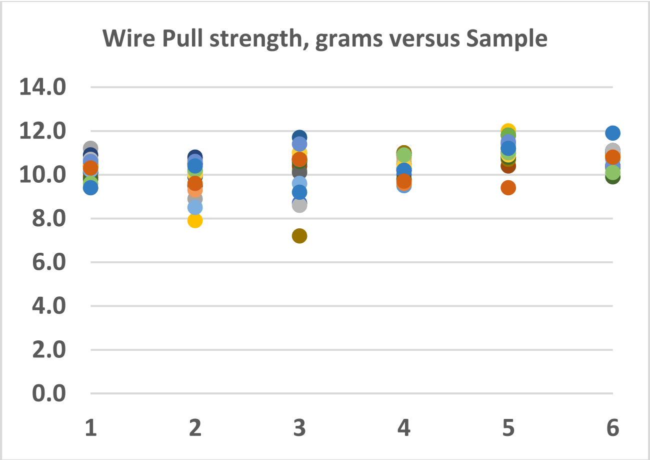


Figure 7. Wire bond data, 20 points per sample

Wire breaks in all tests were in the wire either just above the first bond or just above the second bond (modes B or D). No failures were seen at the wire / substrate interface (modes A or E).

SEM EXAMINATION OF THE DEPOSITS

Figure 8 shows the ENEPIG deposit top-down. In general, the palladium and gold uniformly coat the electroless nickel.

Past experience has shown that attempts at obtaining very thick gold with ENEPIG using a standard displacement immersion gold results in some damage in the electroless nickel layer below the electroless palladium deposit. Of the three deposited metals the electroless nickel is the least noble. Any access the immersion gold may find to the nickel will result in nickel dissolution in the immersion gold solution. Excess dwell time in the immersion gold solution may dissolve enough palladium which may allow a pathway for the gold to attack the nickel deposit. Lateral attack of the nickel underneath the palladium has been seen in some cases where the immersion gold layer has become very thick. The resultant lateral nickel attack in extreme cases may cause delamination between nickel and palladium especially after wire bonding. The delamination results in wire lifting and connection failure. Figure 9 shows the lateral corrosion from an ENEPIG deposit which contained 5.1 microinches of gold and 3.4 microinches of palladium. The gold used in this instance was the standard displacement process.

SEM cross section examination was performed for the three samples with thick gold in an attempt to detect any deposit damage from the immersion gold reaction.

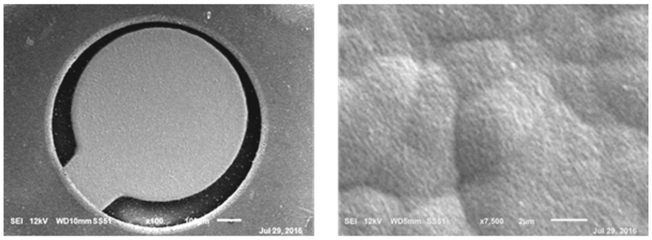


Figure 8. SEM images top-down of the ENEPIG deposit at 100x, 7500x

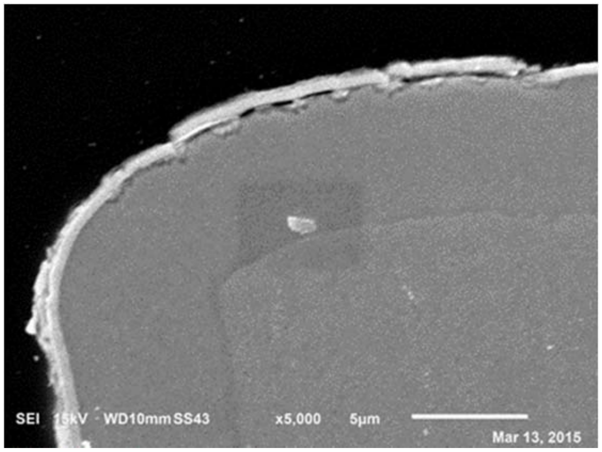
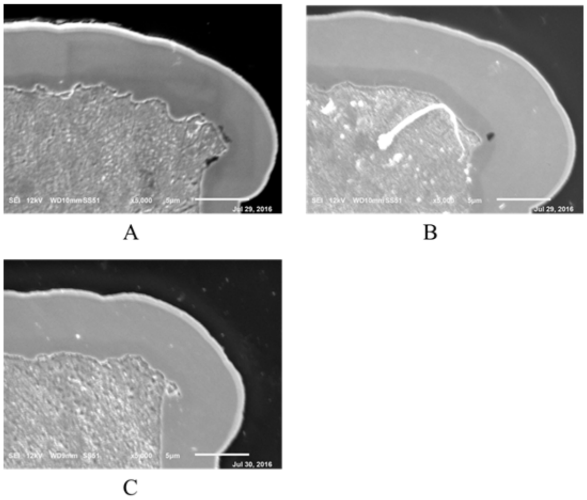


Figure 9. Example of ENEPIG corrosion under the gold and palladium deposit at 5000x

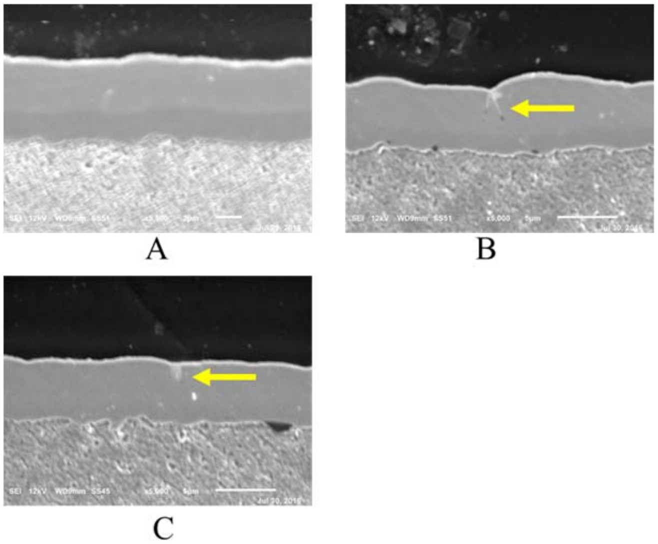
Figures 10 and 11 show cross section images from the different deposit at the BGA pad edge and pad center. The BGA pad was connected to the ground plane. In these three examples, the thicker gold deposit was examined for each of the three different types of immersion gold solutions. The BGA pad edges showed no nickel corrosion. The BGA pad center showed no corrosion for the reduction assisted immersion gold while small corrosion spikes were seen with both the standard immersion gold and high efficiency immersion old. The small corrosion spikes seen are not believed to be of consequence based on the wetting balance and wire bond data collected in this paper but can be considered a process indicator. No corrosion spikes were seen from any of the samples with thinner gold deposits.



A B

C

Figure 10. Cross section on BGA pad edge at 5000x
A - Reduction assisted thick immersion gold
B - Standard immersion thick immersion gold
C - High efficiency thick immersion gold

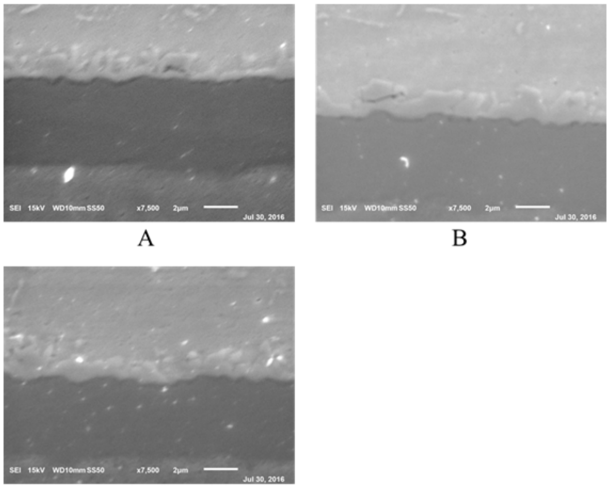


A B

C

Figure 11. Cross section on BGA pad centers at 5000x
A - Reduction assisted thick immersion gold
B - Standard displacement thick immersion gold
C - High efficiency thick immersion gold

While wetting balance testing showed excellent wetting time and wetting force, cross sections were performed on the solder samples from the three thick immersion gold deposits to examine the intermetallic formed. In all cases, a uniform, continuous intermetallic layer was observed as shown in Figure 12.



A B

C

Figure 12. Cross section examination of the intermetallic formed after wetting balance test, 7500x
A - Reduction assisted thick immersion gold
B - Standard immersion thick immersion gold
C - High efficiency thick immersion gold

CONCLUSIONS

Solder wetting balance tests showed that the reduction assisted immersion gold process yielded the fastest wetting times while the standard displacement immersion gold showed slightly lower wetting times. All final wetting forces were excellent regardless of heat exposure from 3X reflows.

Wire bond testing showed very good results from all six samples with higher standard deviation observed for the standard displacement immersion gold with thick deposit. Average wire bond values were well above the 3 gram minimum with average readings all above 9 grams.

Cross section analysis of the plated samples showed some small corrosion spikes in the standard displacement and high efficiency immersion gold with no such corrosion spikes seen in the reduction assisted gold deposit. It is thought that the corrosion spikes, if present in higher amounts, would affect solder wetting and wire bond results and could be used a process check for production considerations.

Future data presentations will include the performance of the three different immersion gold types with gold thicknesses at the high end of the new IPC ENIG specification. Solder testing and cross section analysis will be performed.

REFERENCES

1. Yukinori Oda, Masayuki Kiso, Akira Okada, Kota Kitajima, Shigeo Hashimoto, George Milad, Don Gudeczauskas, 41st International Symposium on Microelectronics, Providence, RI, Nov 2008
2. Donald Gudeczauskas et al, 39th International Symposium on Microelectronics, October 8-12, 2006, San Diego
3. Snugovsky, P., Arrowsmith, P. & Romansky, M. Journal of Electronic Materials (2001) 30: 1262. doi:10.1007/s11664-001-0159-z