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Reliability and Requirement of HDI Blind Hole

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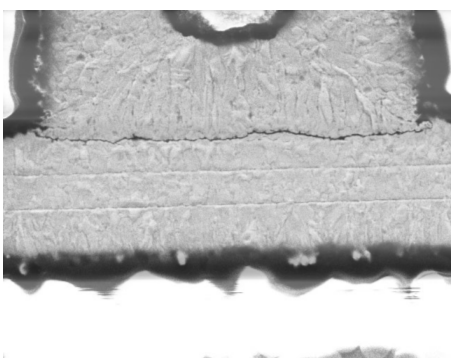
Abstract
Nowadays there are two major ways to achieve the conducting function of HDI Blind Hole One is to employ conducting metal paste to fill in the blind holes after laser drilling. The other is to fill those mechanical drill holes by means of conventional PTH technology. Referring to the second way, we discuss how to assess and assure the hole reliability in this article using several methods of research, we try to demonstrate the relation between the reliability and some requirement such as blind hole size, copper plating thickness, connecting area of pad in inner layer, under cut, and so on. We hope to provide sufficient information for the design of blind holes and a set of reasonable design and manufacturing requirements.

When you call your family or friend for an urgent issue using your cell phone outdoors, if your cell phone suddenly does not work suddenly, no voice, no signal, shut down automatically, and so on, it may cause you to hit the ceiling. This is particularly true if you try again and the problem is same. Of course, the cell phone maker would rather not leave any bad impressions in the eye of consumer, especially in the reliability of the phone's performance.

Why a cell phone does not work suddenly has many reasons. As to the PCB, it may have a circuit connection problem. This is particularly true in the case of blind holes for HDI that are not easy to find or test. In this article, we discuss the reliability of blind holes that are formed on the outer layers with HDI technology as well as for those mechanical drilled holes produced by means of conventional PTH technology. Applying several research techniques based on mass production conditions we will determine which factors impact reliability and determine what are the reliable design parameter for blind holes that can insure they can withstand a series of critical test conditions.

What is the Reliability of a Blind Hole?
Blind holes are used for connecting outer-layer to inner-layer whether the HDI type is 1+N+1or 2+N+2. The defects seen are usually opens, shorts, high continuity resistance and low insulation resistance. The Figures 1-10 are typical examples of conducting function failures of blind holes.



Figures 1 - Separation between PTH Layer and Target Land of Inner Layer

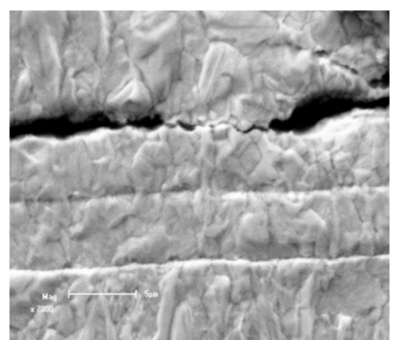


Figure 2 - Behave as Open or High Resistance

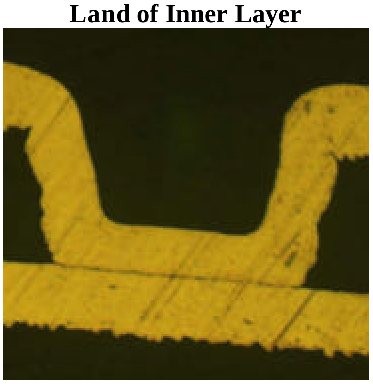


Figure 3 - Poor Desmear Before PTH

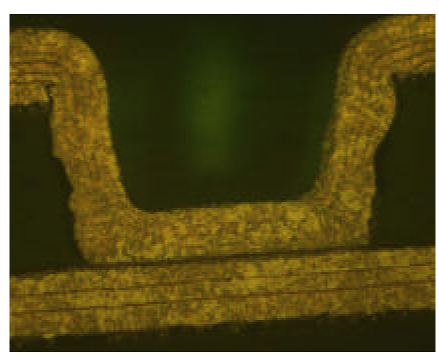


Figure 4 - Behave as Open or High Resistance

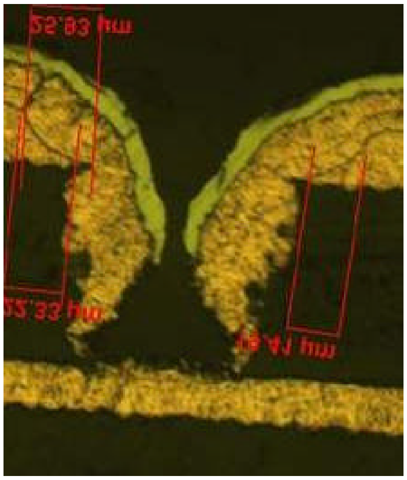


Figure 5 - Peel off PTH Layer

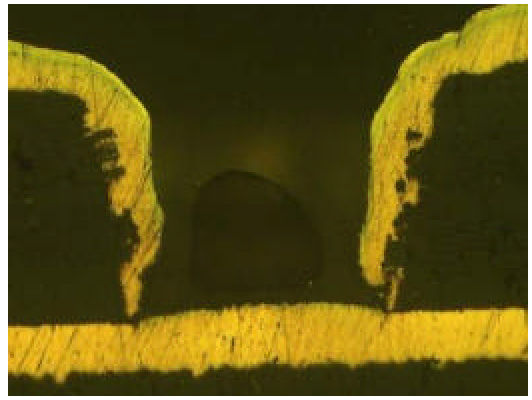
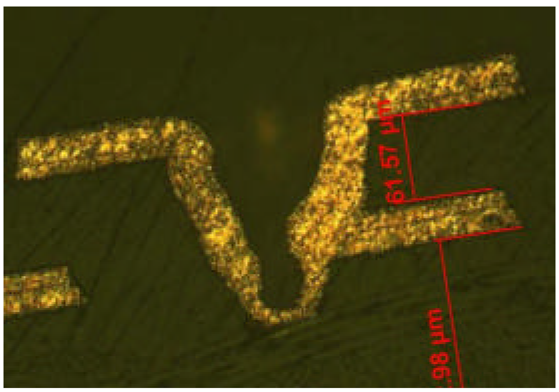
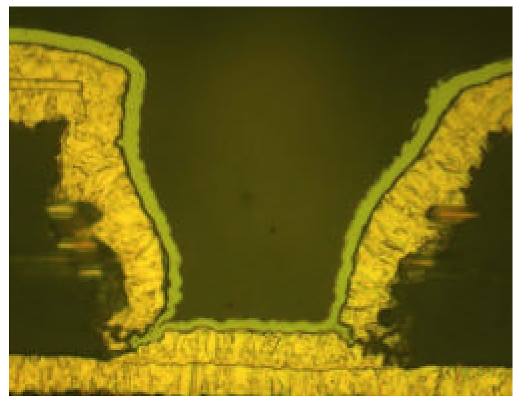


Figure 6 - Behave as Open



Picture 7 - Deviation of Laser Drilling



Picture 8 - Crack in PTH, Behave as High Resistance

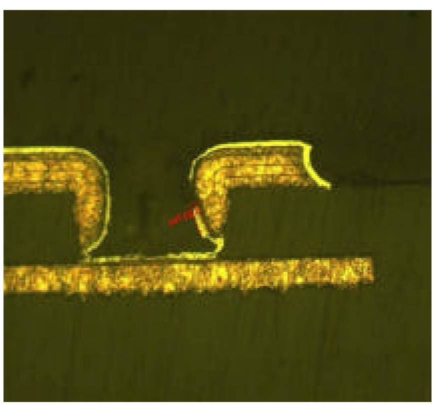


Figure 9 - Void in PTH Ayer

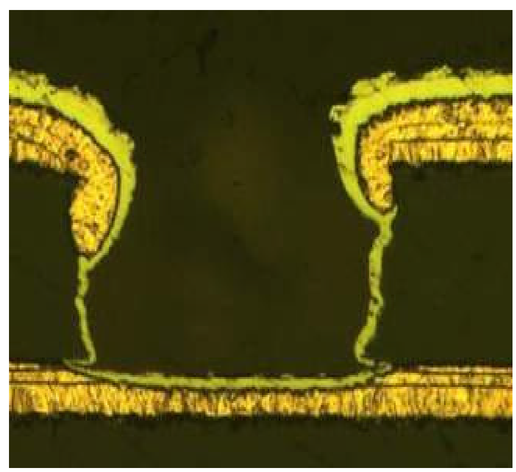


Figure 10 - Covered By Immersion Au/Ni

Reviewing most of the failure mechanisms it is seen that the conducting performance of the blind via is the major reliability problem of the HDI blind hole. Note that despite that the common conducting problem every kind of failure of conducting reliability has its own particular feature.

How to Test the Conducting Reliability of HDI Blind Hole

There was a time when people used to think that electrical test only could do the job of distinguishing the opens or shorts PCBs. However, electrical test can only judge an absolute open or short. So, as to conducting reliability of blind hole, we can only say that when the continuity resistance of the blind hole is only a little higher than usual, it's difficult to find out whether the problem is due only to the contact resistance of electrical test pin. Moreover, it's impossible to depend on electrical test to find such potential failures as plating voids, folds or cracks in the blind hole. This is especially true when the resistance is not significantly changed. There is no any other suitable way that can be employed to distinguish these defects with a 100% success rate unlike the inspection of dents or nicks of track that can be done via AOI technology.

So to assess and assure the conducting reliability means that not only should the blind hole pass the electrical test after finishing PCB manufacturing but that the blind hole must withstand the assembly conditions and working conditions. These conditions include such conditions as high temperature, long exposure times to direct sunlight or the low temperature of outdoor cold weather with little or no change in the conducting functions.

According to IPC-6016, blind holes should exhibit no or less than 10% change in resistance after thermal stress and thermal shock. But how many cycles of thermal stress should be appropriate are discussed and specified in the specification according to which kind of the products the PCB will be used for. However, any kind of test method is only suitable for sample test rather than 100% test since the specimens must be scraped after test.

Impact of Factors Relate to the Conducting Reliability of HDI Blind Hole
It's well known that PTH formation is dependent on the size of mechanical drilling hole. The smaller the hole the more difficult is the formation. In general, the factors that affect the reliability of HDI blind hole are as following:

Contact area of blind hole on target land of inner layer
- Size of laser drilling
- Thickness of dielectric such as RCC or LDP
- Shape of blind hole (or undercut of laser drilling)
- Copper thickness of PTH
- CTE

As for the test conditions, we have picked 3 major factors for the research test specimen:
1. Daisy Chain Net Test Coupon (736 blind holes per net) (Figure 11)

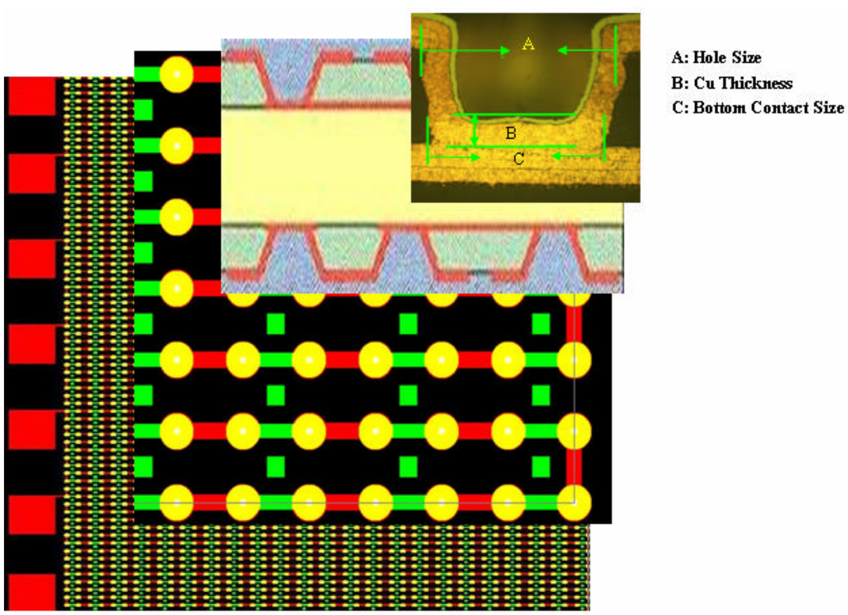


Figure 11 – Daisy Chain Net Test coupon

2. Design Parameters for the Test Specimen:
- Contact area of blind hole on target land of inner layer: 100% contact;
- Thickness of dielectric: select RCC, thickness around 3.5mil
- CTE: 60-70ppm/°C , same lot of RCC

- Hole size/Hole shape/Copper thickness:
  - Hole size: conformal mask, all kinds of the hole size were designed in same test panel
  - Hole shape: defined as C/A, determined by adjusting the energy of laser drilling, all kinds of the hole shape were designed in same test panel.
  - Copper thickness: ATO uni-plate PTH technology include equipments and chemicals, copper thickness were just determined by adjusting the convey speed rather than current density

The above three factor in design shown in Table 1.

Table 1 – Three Factors

Hole size (mil)	Hole shape (%)	Hole shape (%)	Hole shape (%)	Hole shape (%)	Hole shape (%)	Copper thickness (mil)	Copper thickness (mil)	Copper thickness (mil)	Copper thickness (mil)
3.5 (3.7)	40 (39)	50 (44)	70 (76)	90 (86)	100 (93)	0.40 (0.37)	0.60 (0.49)	0.80 (0.68)	1.00 (0.92)
4.0 (4.1)	40 (47)	50 (55)	70 (73)	90 (88)	100 (101)	0.40 (0.42)	0.60 (0.52)	0.80 (0.78)	1.00 (0.95)
4.5 (4.8)	40 (35)	50 (47)	70 (75)	90 (91)	100 (96)	0.40 (0.47)	0.60 (0.49)	0.80 (0.82)	1.00 (1.10)
5.0 (5.1)	40 (47)	50 (56)	70 (80)	90 (86)	100 (97)	0.40 (0.48)	0.60 (0.49)	0.80 (0.88)	1.00 (1.16)

Remarks: The value in the brackets are actual mean value that being measured via micro section.

3. The Specimen's Preparation and Test Procedure /Pre-Condition/Evaluation/Acceptable Level

Procedure was a follows: Core material preparation—inner layer —acid etch—brown oxide—RCC Lamination—hole pattern —acid etch—laser drill—desmear—PTH—Outer Layer pattern—acid etch—solder mask--measure resistance—5 cycles of Reflow—measure resistance--500 cycles of thermal shock-- measure resistance

Pre-Condition a Reflow

	Preheat1	Preheat2	Preheat3	Reflow	Cooling
Temperature ?	150	180	245	270	240
Dwell time (second)	100	80	70	70	15

Thermal shock (air to air)

	High Temperature	Transfer	Low Temperature
Temperature ?	125	20	-55
Dwell time (minute)	15	2	15

Evaluation: Measure resistance via ohm meter

For evaluation the resistance was done via an ohm meter. An acceptable test level was determined be no or less than 10% change in resistance and no cracks or separations.

4. Results of the testing:

(1) Hole size (See Tables 2 and 3; Figures 12 15)

Table 2 – Hole Size

Hole Size (mil)	Hole Shape (%)	Copper Thick -ness (mil)	Total pass nets	After 5cycles of reflow	After 500cycles of thermal shock				
				Pass nets	Fail nets	Fail rate (%)	Pass nets	Fail nets	Fail rate (%)
3.5	70%	1.0	55	34	21	38	25	9	26
4	70%	1.0	72	67	5	7	63	4	6
4.5	70%	1.0	96	95	1	1	92	3	3
5	70%	1.0	72	72	0	0	72	0	0

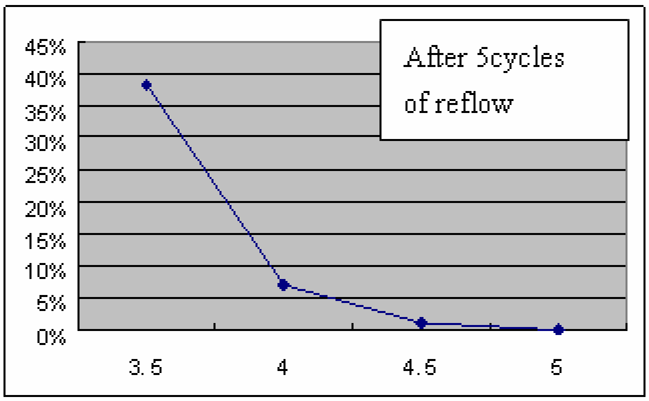


Figure 12 - Fail Rate Curve after 5cycles of Reflow

(Actually, after first cycle of reflow, about 5% of 3.5mil hole size of nets and 3%of 4mil hole size of nets had already failed.)

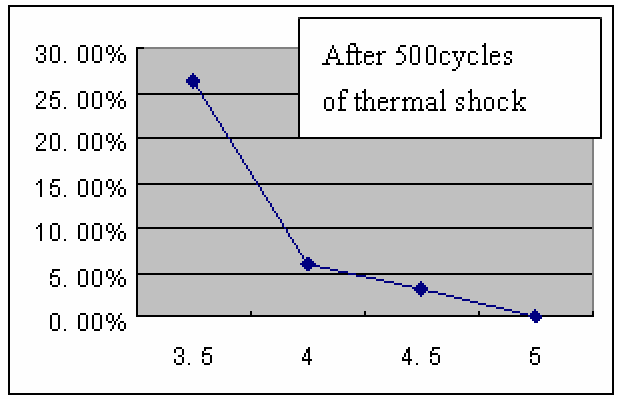


Figure 13 - Fail Rate Curve after 500 Cycles Thermal Shock

(Actually, after first 100 cycles of thermal shock, about 12% of 3.5mil hole size of nets and 1.5% of 4mil hole size of nets had already failed.)

Table 3 – Hole Size

Hole Size (mil)	Hole Shape (%)	Copper Thick -ness (mil)	Total pass nets	After 5cycles of reflow			After 500cycles thermal shock		
				Pass nets	Fail nets	Fail rate (%)	Pass nets	Fail nets	Fail rate (%)
3.5	90%	0.8	4	3	1	25	2	1	33
4	90%	0.8	47	46	1	2	45	1	2
4.5	90%	0.8	48	48	0	0	48	0	0
5	90%	0.8	48	48	0	0	48	0	0

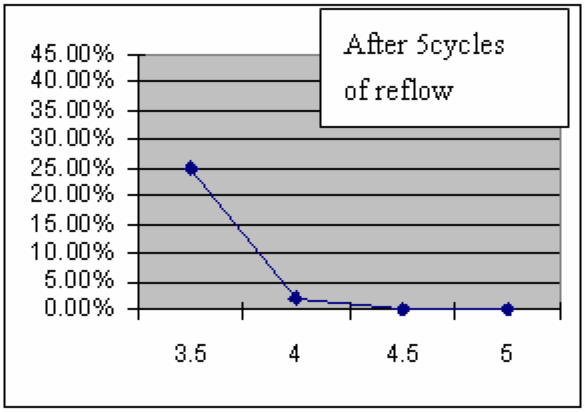


Figure 14 - Fail rate Curve after 5 Cycles of Reflow

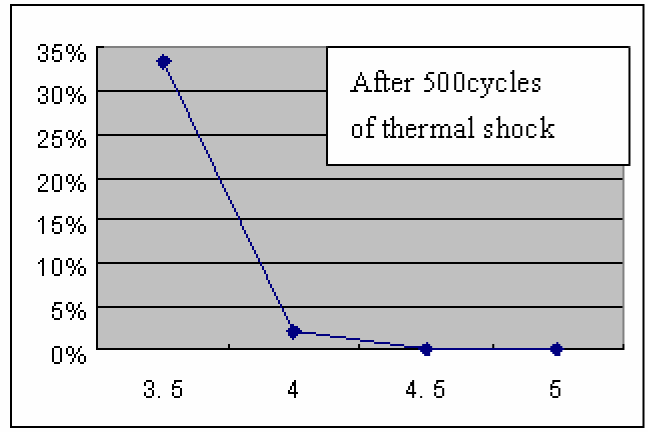


Figure 15 – Fail Rate curve after 500 Cycles of Thermal Shock

(2) Hole shape (See Tables 4 and 5; Figures 16-19.)

Table 4 – Hole Shape

Hole Size (mil)	Hole Shape (%)	Copper Thick-ness (mil)	Total pass nets	After 5cycles of reflow			After 500cycles of thermal shock		
				Pass nets	Fail nets	Fail rate (%)	Pass nets	Fail nets	Fail rate (%)
5	40	0.8	18	6	12	67	5	1	17
5	50	0.8	47	44	3	6	43	1	2
5	70	0.8	96	96	0	0	96	0	0
5	90	0.8	48	48	0	0	48	0	0
5	100	0.8	48	48	0	0	47	1	2

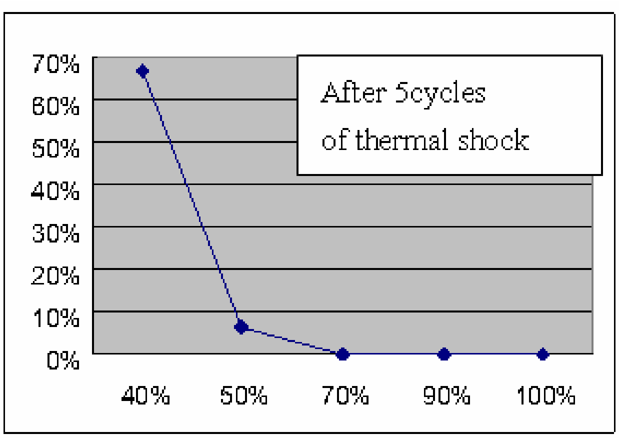


Figure 16: Fail Rate Curve after 5 Cycles of Reflow
(Actually, after first cycle of reflow, about 67% of nets of 40% hole shape and 4% of nets of 50% hole shape had already failed.)

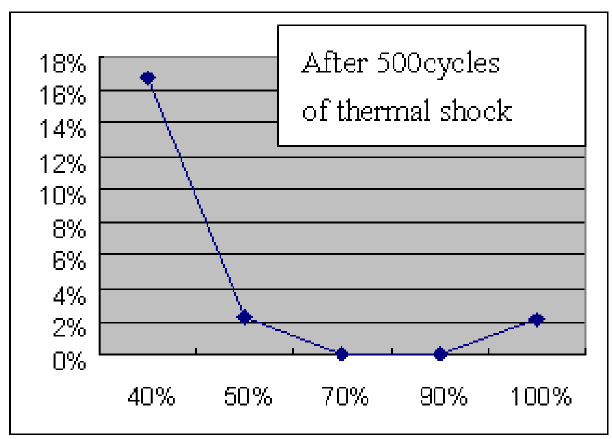


Figure 17 - Fail Rate Curve after 500 Cycles of Thermal Shock

Table 5 – Hole Shape

Hole Size (mil)	Hole Shape (%)	Copper Thick-ness (mil)	Total pass nets	After 5cycles of reflow			After 500cycles of thermal shock		
				Pass nets	Fail nets	Fail rate (%)	Pass nets	Fail nets	Fail rate (%)
4	40	1.0	12	1	11	92	1	0	0
4	50	1.0	30	13	17	57	10	3	23
4	70	1.0	72	67	5	7	63	4	6
4	90	1.0	35	34	1	3	33	1	3
4	100	1.0	35	34	1	3	33	1	3

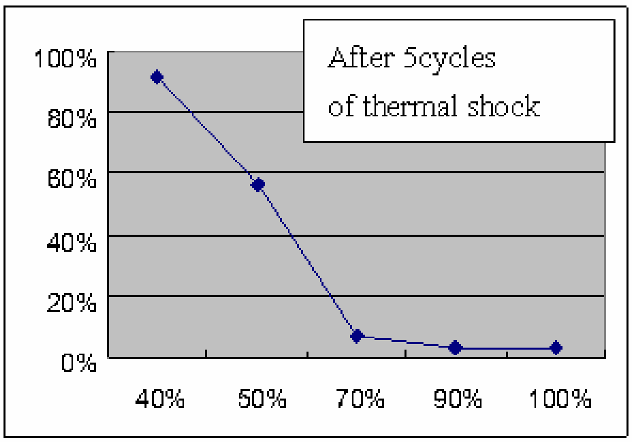


Figure 18 - Fail Rate Curve after 5 Cycles of Reflow, as to 40% Hole Shape, 42% of Nets had already been Fail after First Cycle of Reflow

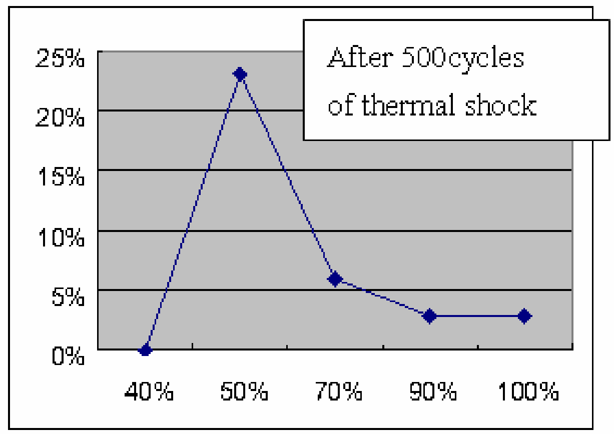


Figure 19 - Fail Rate Curve after 500 Cycles Thermal Shock

(3) Copper thickness (See Tables 6 and 7; Figures 20-23)

Table 6 – Copper Thickness

Hole Size (mil)	Hole Shape (%)	Copper Thick-ness (mil)	Total pass nets	After 5cycles of reflow			After 500cycles of thermal shock		
				Pass nets	Fail nets	Fail rate (%)	Pass nets	Fail nets	Fail rate (%)
5	70	0.4	48	48	0	0	47	1	2
5	70	0.6	48	48	0	0	48	0	0
5	70	0.8	36	36	0	0	36	0	0
5	70	1.0	48	48	0	0	48	0	0

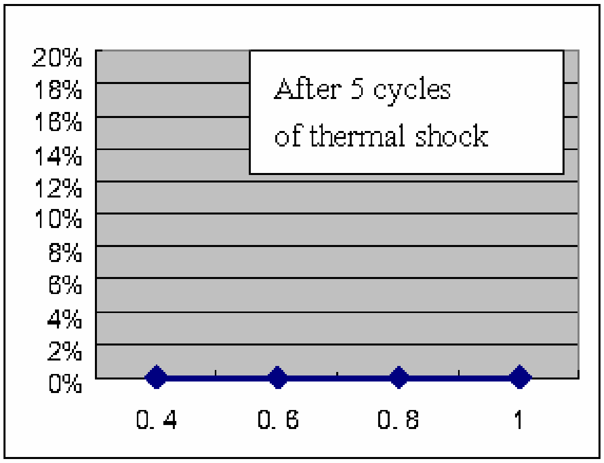


Figure 20 – Fail Rate Curve after 5 Cycles of Reflow

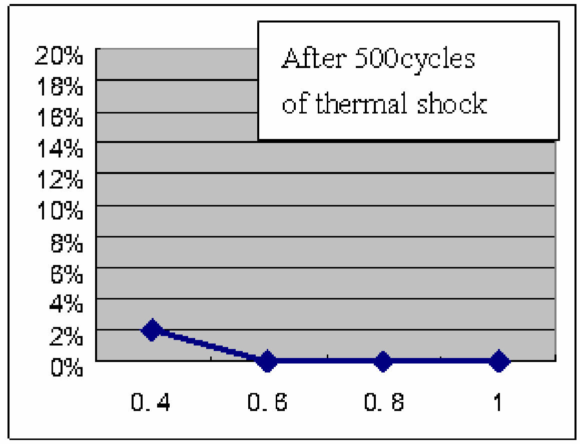


Figure 21 – Fail Rate Curve after 500 cycles of Thermal Shock

Table 7 – Copper Thickness

Hole Size (mil)	Hole Shape (%)	Copper Thick -ness (mil)	Total nets	After 5cycles of reflow			After 500cycles of thermal shock		
				Pass nets	Fail nets	Fail rate (%)	Pas s nets	Fail nets	Fail rate (%)
4	90	0.4	48	47	1	2	45	2	4
4	90	0.6	48	47	1	2	44	3	6
4	90	0.8	35	33	2	6	33	0	0
4	90	1.0	48	48	1	2	44	3	6

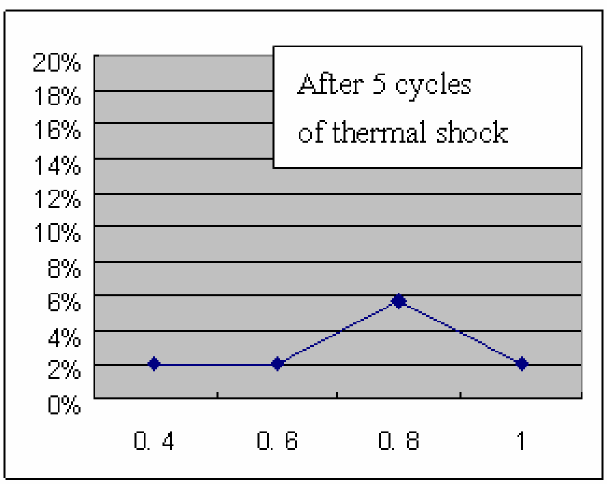


Figure 22 - Fail Rate Curve after 5 Cycles of Reflow

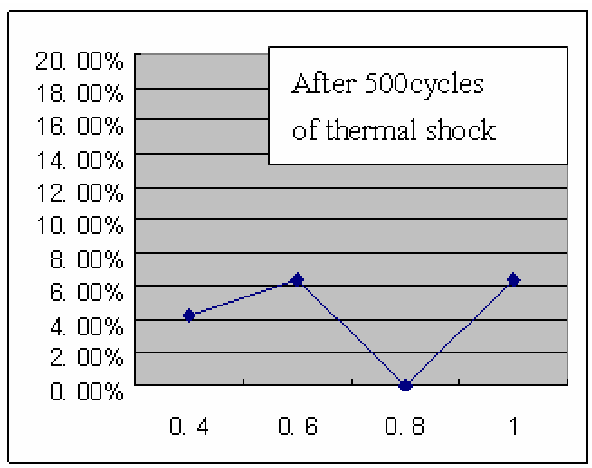


Figure 23 - Fail Rate Curve after 500 Cycles of Thermal Shock

(4) Typical failure

Almost all the failures can be divided into two types. See Figures 24 and 25.

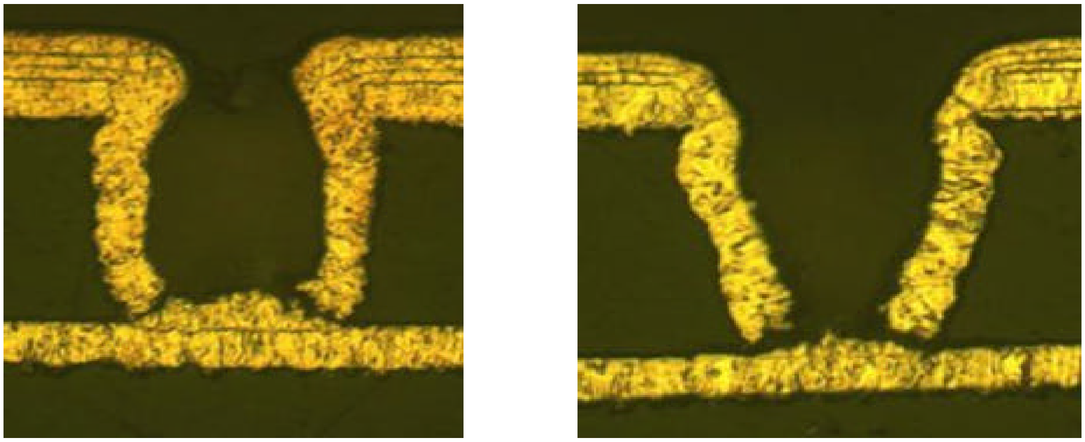


Figure 24 - Crack in the Corner of Blind Hole after Reflow

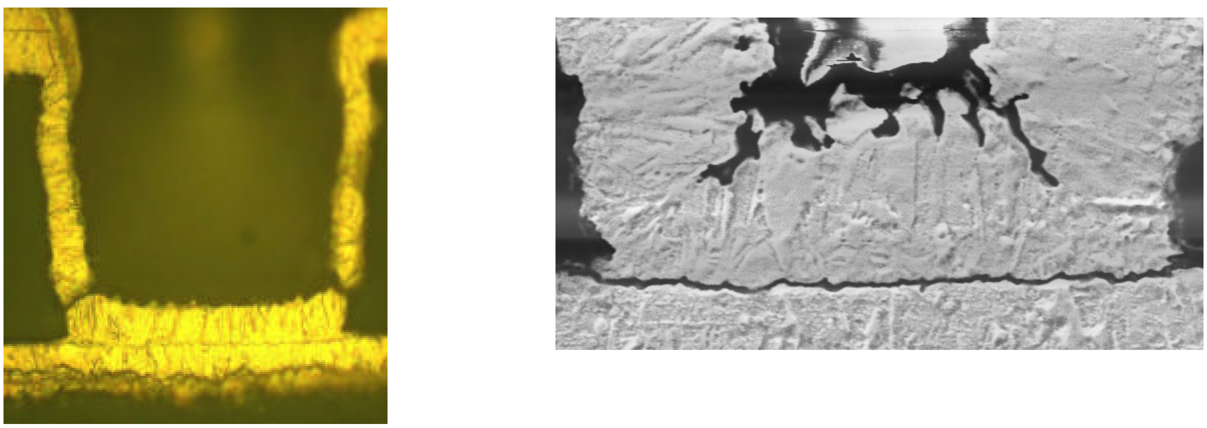


Figure 25 – Cracks in the Corner Blind Hole or Separation between the PTH Layer and the Surface of the Target Land after Thermal Shock

Summary

Considering the above results, where the thickness of RCC and the CTE were the same and the same laser drilling with CO2 and conformal mask was done for all samples and 100% contact area of blind hole on target land of inner layer was maintained for a constant PTH process, we could summarize the results as follows:

- The most important factor is hole size, the larger the hole size, the more reliable conducting function. For mass production, a reliable design target is a 5mil minimum hole size.
- Hole shape is an important factor, with the best ratio of axes being between 70% and 90%.
- Copper thickness is most important factor. If it is too thin the tensile strength of hole copper wall will not be enough to counteract the expansion of dielectric layers. If the copper is too thick than the plating of the space in blind hole may become a reverse taper that can cause a blow hole during assembly. The mean copper thickness of the hole wall is recommended to be maintained between 0.6-1.0mil.

Conclusion

Reliability of HDI blind hole is major factor in marinating the conducting functions of the PWB. The conducting function is determined by it's the PWB formation process including the factors of laser drilling and desmear during PTH formation. The process capability of the PTH formation is related to the hole size, hole shape and copper thickness within the PTH. For reliable mass production process capability, design requirements must state that the hole size is larger than 5mil for conformal processes, the hole shape is kept between 70%-90%, the copper thickness is held between 0.6-1.0mil, and the contact area on the target land of inner layer is held at 100%. It is recommended that the HDI PCB manufacturer monitor and evaluate the reliability of HDI blind hole daily via a Daisy Chain Test Coupon that is then subjected to the appropriate test conditions. However, the first and foremost requirement for any manufacturer is always to maintain and assure the daily related PWB processes in good condition.

Reference

IPC-6016 Qualification and Performance Specification for High Density Interconnect (HDI) Layers or Boards

Reliability & requirement of HDI blind hole

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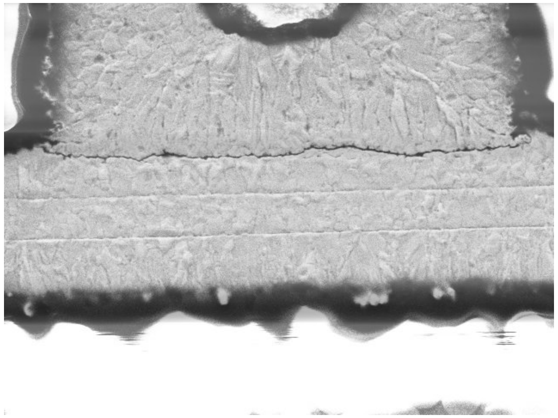
Shantou, Guangdong , China

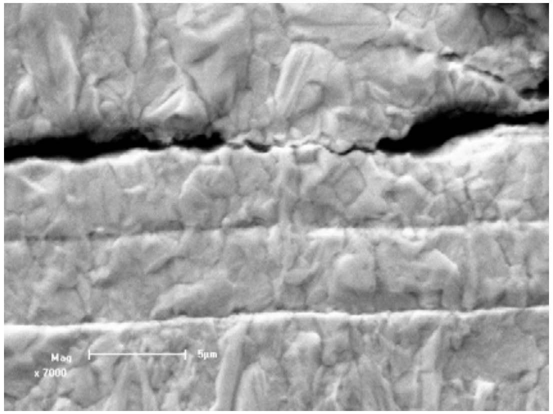
Two major ways in PCB manufacturing for conducting function of HDI blind hole:

- Employ conducting metal paste to fill in blind holes after laser drilling ;
- Via conventional PTH technology as well as for those mechanical drill holes

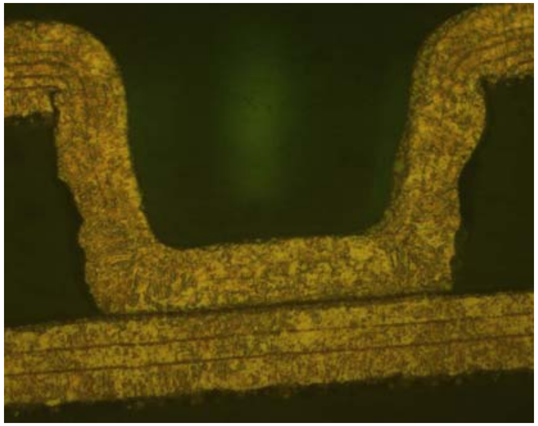
1.Typical failures of blind hole with conventional PTH technology



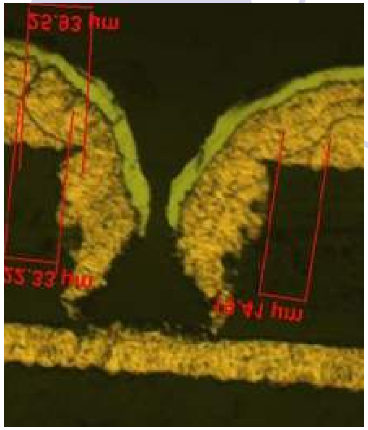
Separation of PTH,
Behave as open



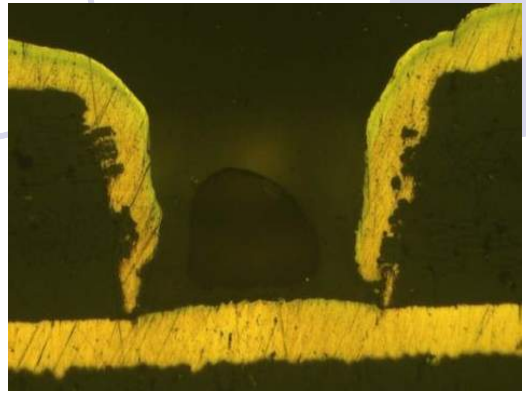
contamination of inner
layer, high resistance



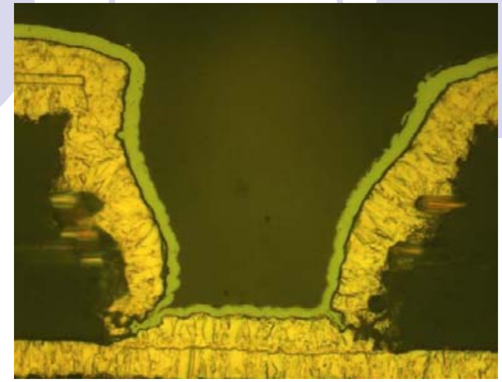
Poor desmear
before PTH, open



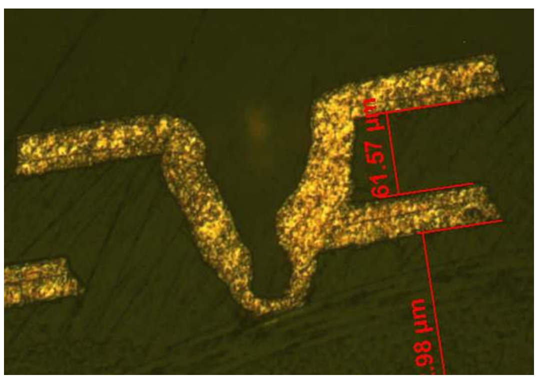
Peel off in corner, open



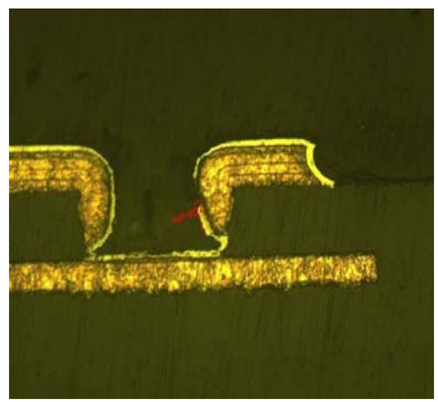
Peel off in corner, open



Crack in corner, high resistance



Misregistration of Laser drilling



Void in PTH, covered by Au/Ni

Large area of void in PTH

2.How to test the conducting reliability of HDI blind hole for mass production

- Difficult to rely on E-test that can only assure to judge the absolute open or short;
- Impossible to count on AOI technology that can only distinguish the visual defects;
- No any other suitable way that can distinguish the conducting reliability of HDI blind hole by 100% as far as concerned

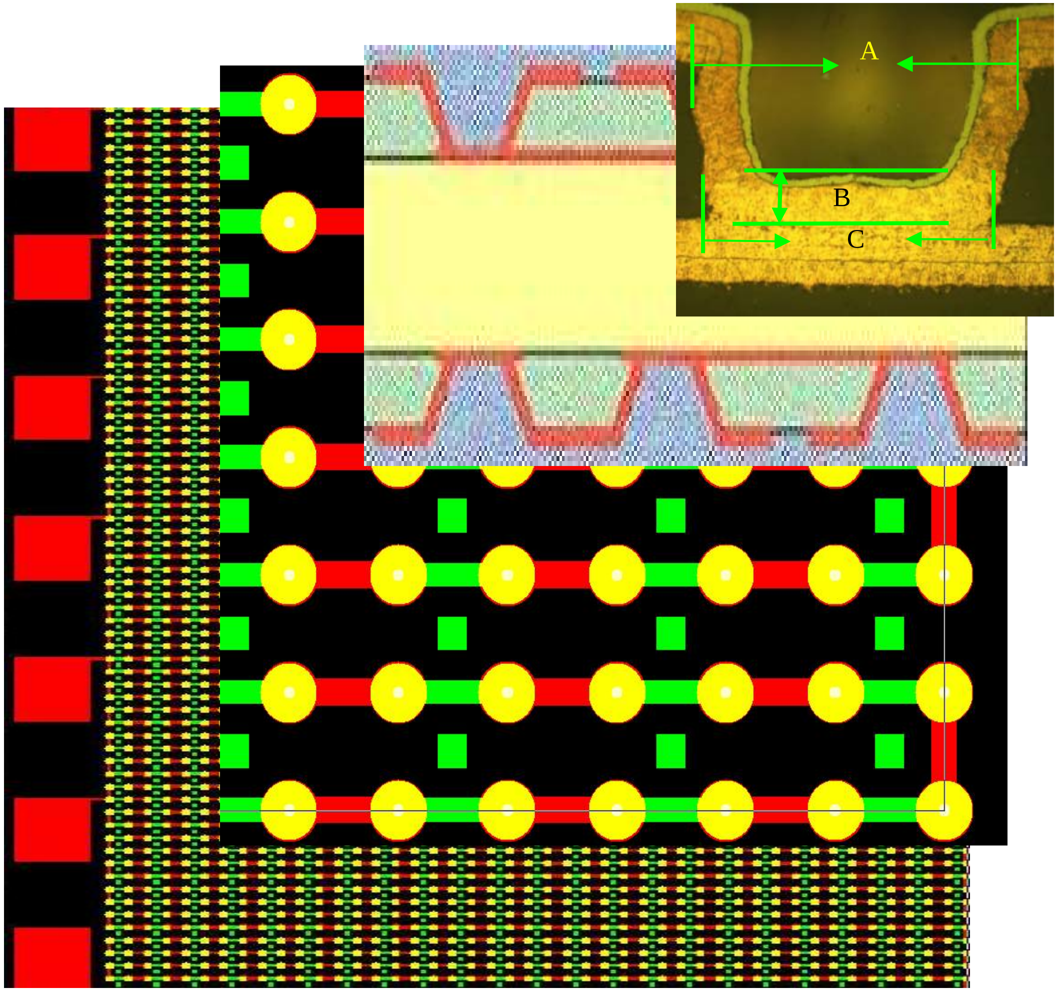
  So far, IST, thermal shock & stress test are always available test method, but just suitable for sample test since the specimens must be scraped after test

3. Impact of factors relate to the conducting reliability of HDI blind hole

- Contact area of blind hole on target land of inner layer
- Size of laser drilling
- Thickness of dielectric such as RCC or LDP
- Shape of blind hole (or undercut of laser drilling)
- Copper thickness of PTH
- CTE

Research of major factors

①Daisy Chain Net test coupon



Note:736 blind hole
Per net
A: Hole size
B: Cu thickness
C: Bottom contact
Size

②Design parameter

- Contact area of blind hole on target land of inner layer: 100% contact;
- Thickness of dielectric: select RCC, thickness around 3.5mil
- CTE: 60-70ppm/℃ , same lot of RCC
- Hole size/Hole shape/Copper thickness:

Hole size: conformal process, all kinds of the hole size were designed in same test panel

Hole shape: defined as C/A, determined by adjusting the energy of laser drilling, all kinds of the hole shape were designed in same test panel

Copper thickness: ATO uni-plate PTH technology include equipments and chemicals, copper thickness were just determined by adjusting the convey speed rather than current density

Hole size (mil)	Hole shape (%)	Hole shape (%)	Hole shape (%)	Hole shape (%)	Hole shape (%)	Copper thickness (mil)	Copper thickness (mil)	Copper thickness (mil)	Copper thickness (mil)
3.5 (3.7)	40 (39)	50 (44)	70 (76)	90 (86)	100 (93)	0.40 (0.37)	0.60 (0.49)	0.80 (0.68)	1.00 (0.92)
4.0 (4.1)	40 (47)	50 (55)	70 (73)	90 (88)	100 (101)	0.40 (0.42)	0.60 (0.52)	0.80 (0.78)	1.00 (0.95)
4.5 (4.8)	40 (35)	50 (47)	70 (75)	90 (91)	100 (96)	0.40 (0.47)	0.60 (0.49)	0.80 (0.82)	1.00 (1.10)
5.0 (5.1)	40 (47)	50 (56)	70 (80)	90 (86)	100 (97)	0.40 (0.48)	0.60 (0.49)	0.80 (0.88)	1.00 (1.16)

Remarks: The value in the brackets are actual mean value that being measured via microsection

③Specimens preparation and test procedure /Pre-condition/Evaluation/Acceptable level

- Procedure: Core material preparation—inner layer —acid etch—brown oxide—RCC -- lamination —Hole pattern —acid etch—laser drill—Desmear—PTH—outer layer pattern—acid etch—solder mask--measure resistance—5 cycles of reflow—measure resistance--500 cycles of thermal shock– measure resistance

- Pre-condition:

a. Reflow:

	Preheat1	Preheat2	Preheat3	reflow	Cooling
Temperature ℃	150	180	245	270	240
Time (second)	100	80	70	70	15

b. Thermal shock (air to air):

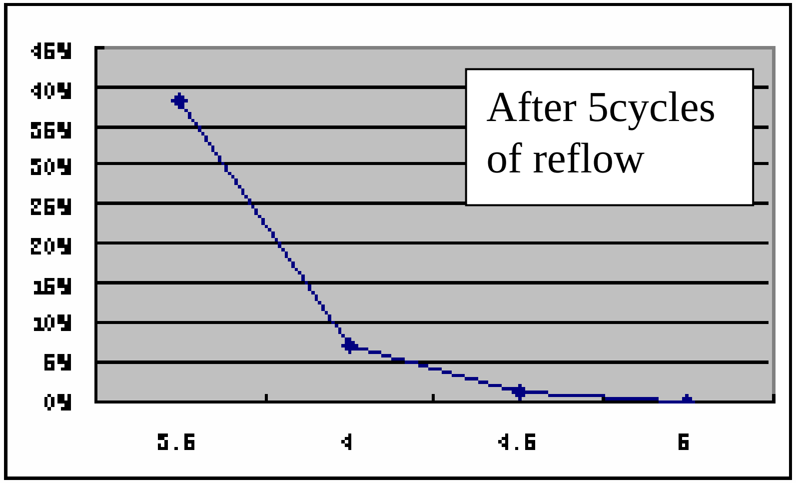
	High temperature	Transfer	low temperature
Temperature ℃	125	20	-55
Time (minute)	15	2	15

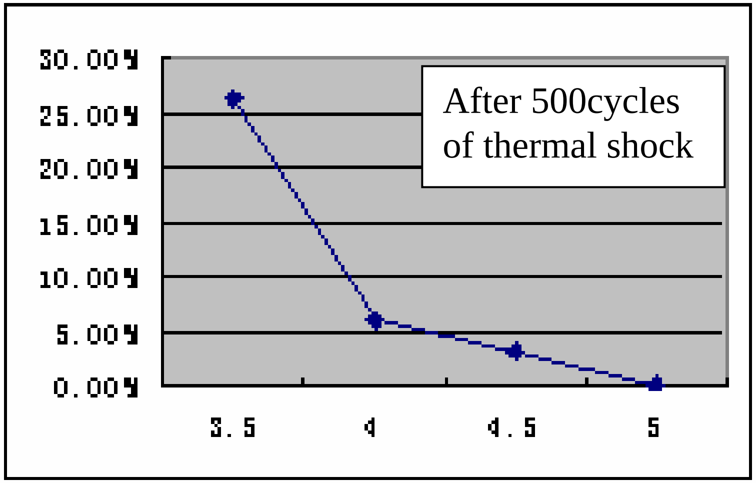
- Evaluation: Measure resistance via ohm meter
- Acceptable level: No change or less 10% change in resistance , no crack or separation

④Results

- Hole size

Hole shape/Copper thickness:70%/1.0mil

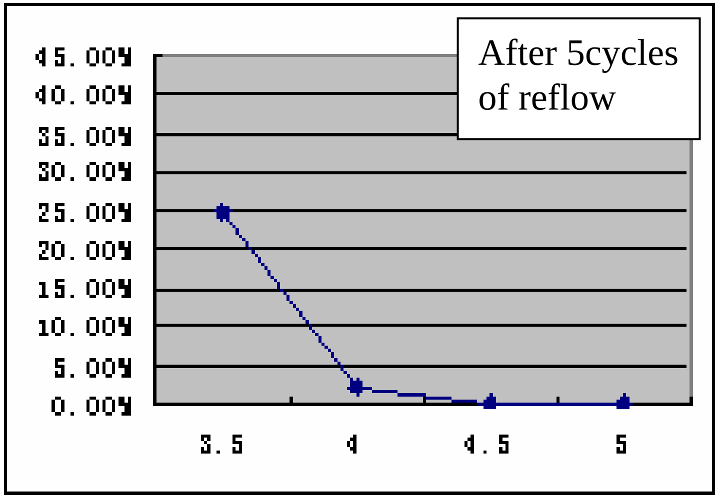


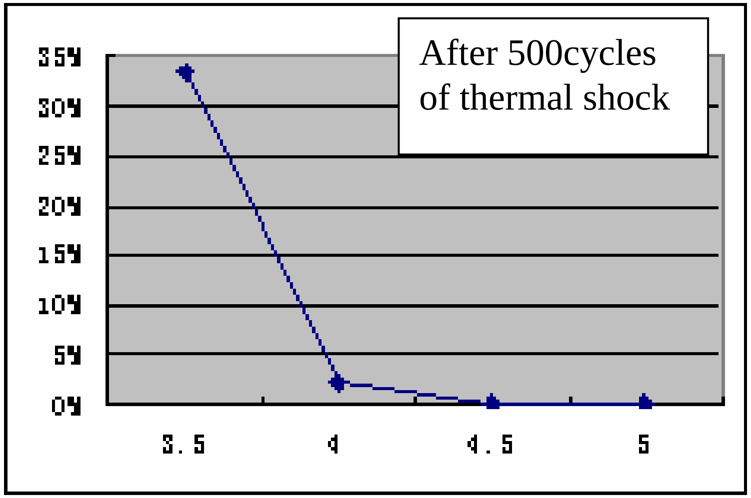


Fail rate curve after 5cycles of reflow. Actually, after first cycle of reflow, about 5% of 3.5mil hole size of nets and 3%of 4mil hole size of nets had already been fail.

Fail rate curve after 500cycles thermal shock. Actually, after first 100 cycles of thermal shock, about12% of 3.5mil hole size of nets and 1.5% of 4mil hole size of nets had already been fail

Hole shape/Copper thickness:90%/0.8mil



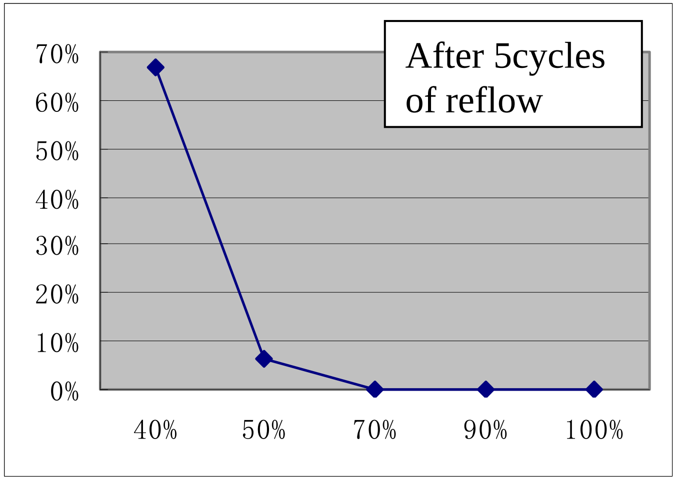


Fail rate curve after 5cycles of reflow

Fail rate curve after 500 cycles of thermal shock

- # Hole shape

Hole size/copper thickness:5mil/0.8mil



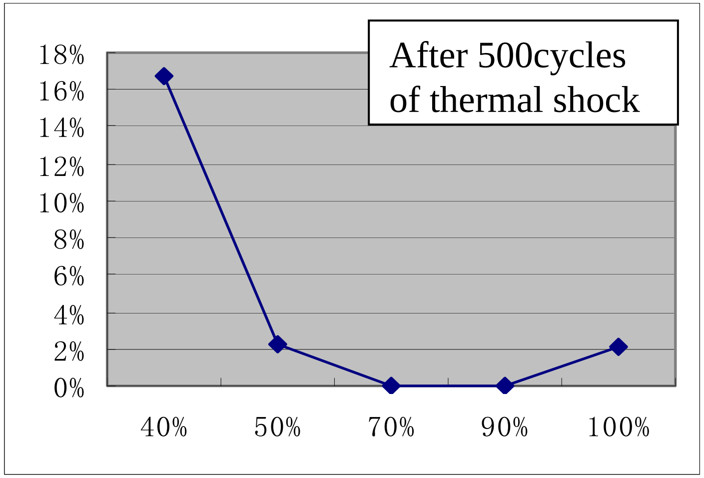
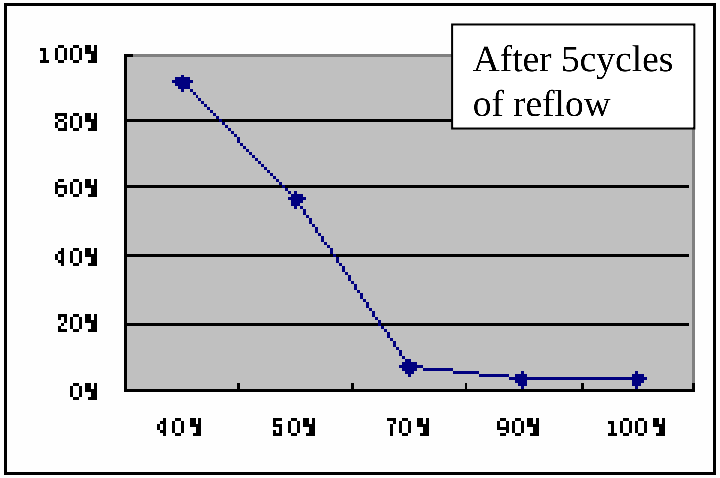


Figure5: Fail rate curve after 5cycles of reflow. Actually, after first cycle of reflow, about 67% of nets of 40% hole shape and 4% of nets of 50% hole shape had already been fail

Figure6: Fail rate curve after 500 cycles of thermal shock

Hole size/copper thickness:4mil/1.0mil



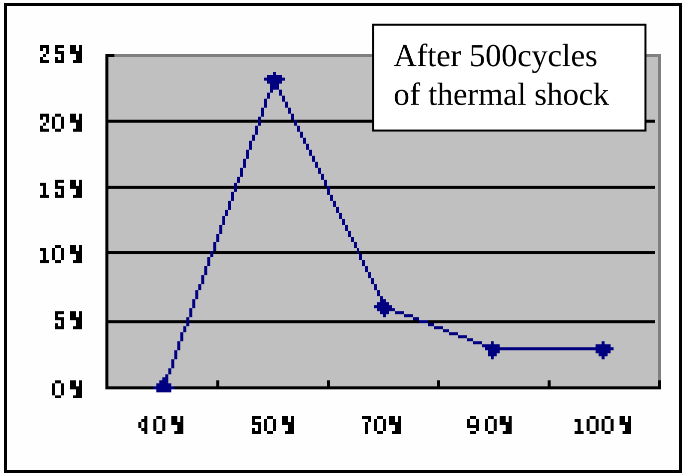
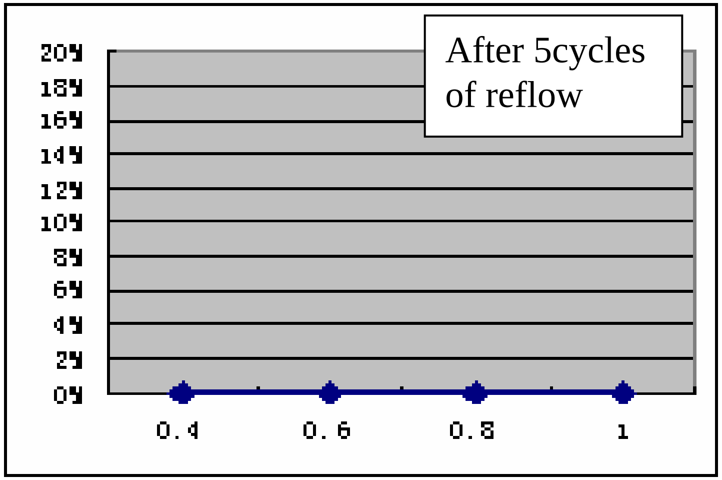


Figure7: Fail rate curve after 5cycles of reflow , as to 40% hole shape, 42% of nets had already been fail after first cycle of reflow

Figure8: Fail rate curve after 500 cycles thermal shock

- Copper thickness

Hole size/hole shape:5mil/70%



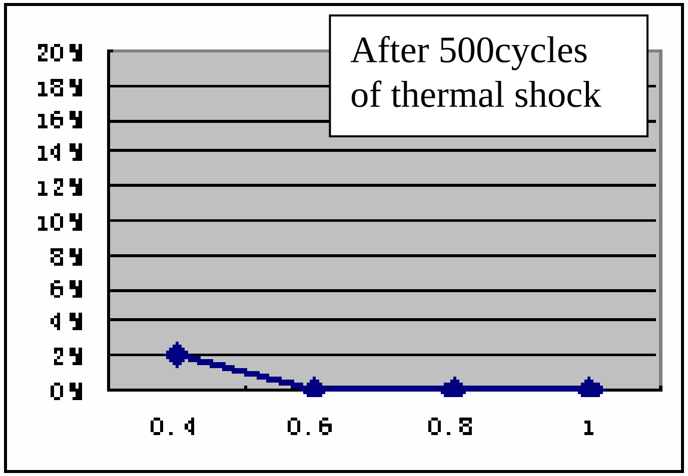
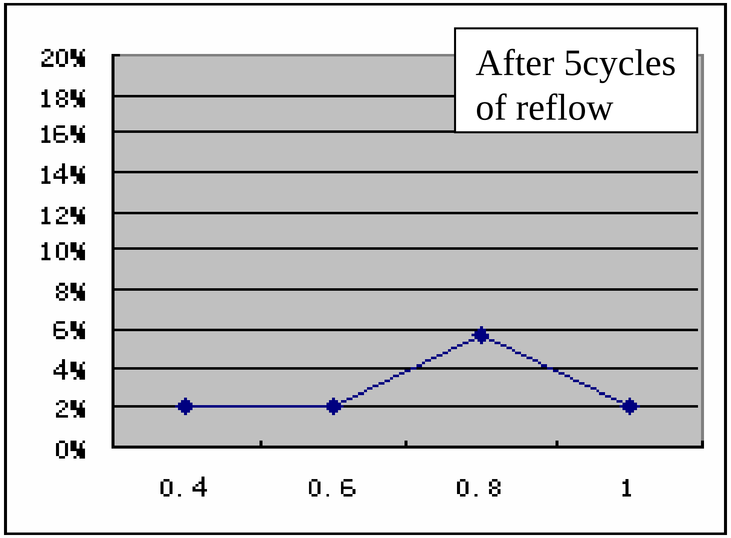


Figure9: Fail rate curve after 5cycles 5 cycles of reflow

Figure10: Fail rate curve after 500 cycles of thermal shock

Hole size/hole shape:4mil/90%



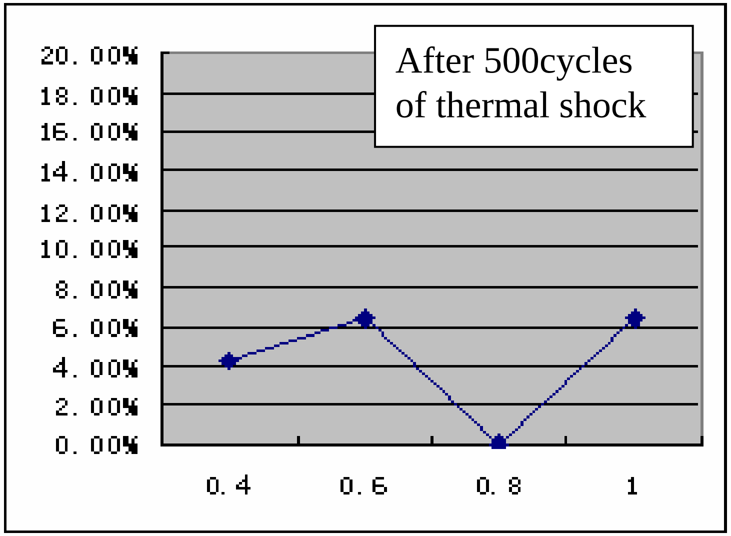


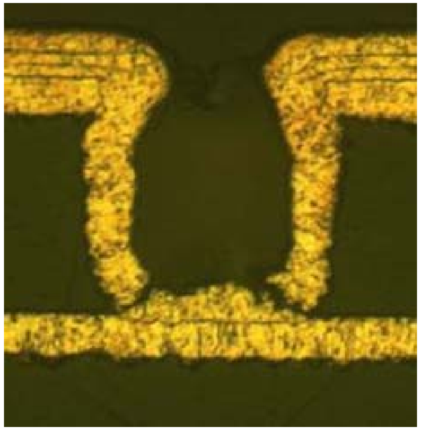
Figure11: Fail rate curve after 5cycles of reflow

Figure12: Fail rate curve after 500 cycles of thermal shock

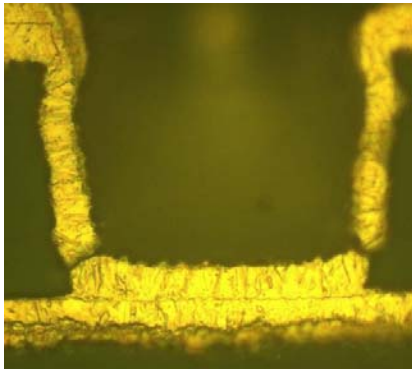
⑤Typical failure

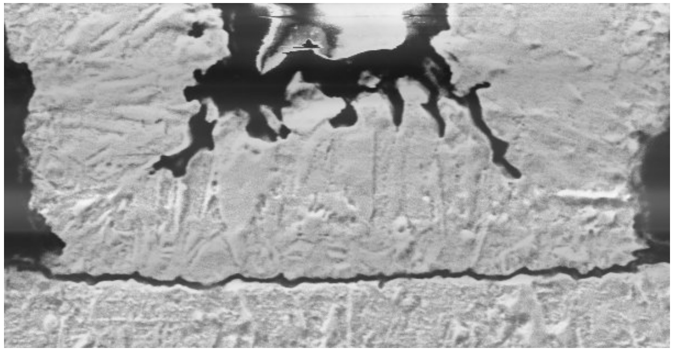
Almost all of the failure can be divided into two types:

a. Crack in the corner of blind hole after reflow as following pictures:



b. **Crack in the corner of blind hole or separation between the PTH layer and the surface of the target land after thermal shock as following pictures:**





⑥ Summary of above results

- The most important factor is hole size, the larger the hole size, the more reliable conducting function; Refer to mass production, it’s reliable design base on 5mil of minimum hole size;
- Hole shape is another important factor, it would be better that the ratio is between 70% and 90%;
- Copper thickness is basic factor, it is neither too thin as the tensile strength of hole copper wall is not enough to anti the expansion of dielectric layer, nor too thick that may plate the space of blind hole into reverse taper that may cause blow hole during assembly. The mean copper thickness of hole wall is recommended to maintained between 0.6-1.0mil.

4.Conclusion

- Reliability of HDI blind hole is major in conducting function
- The conducting function is determined by its formation process include laser drilling, desmear, PTH
- The process capability is related to the hole size, hole shape and copper thickness of PTH
- Reliable design & requirement:

  minimum hole size: 5mil

  Hole shape: between 70%-90%

  Copper thickness: 0.6-1.0mil
- Recommend to HDI PCB manufacturer to monitor and evaluate the reliability of HDI blind hole daily via Daisy Chain Coupon