Hybrid ALD/CVD as a Low-cost Alternative Protective Coating To Poly-para-xylylene and Traditional Liquid Conformal Coatings

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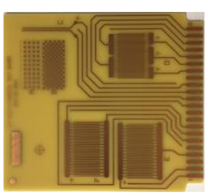
Abstract
A new hybrid ALD/CVD protective coating is being considered as a low-cost alternative to poly-para-xylylene and traditional liquid conformal coatings. All of the typical conformal coatings protect the printed circuit boards. This relatively new process is a hybrid atomic layer deposition (ALD) / chemical vapor deposition (CVD) process that produces a unique and very uniform thin film coating. This film offers improved protective properties compared to the other materials such as poly-para-xylylene and the liquid coatings. Plus, the material may have the added improvement that the costly process of masking components is normally not required. The hybrid coating process is carried out in a small-footprint platform and can process PCBs in a large batch. Results will be shown that demonstrate excellent performance results as tested to standard IPC-TM-650 testing protocols, and an opportunity for a new technology that represents an improvement over traditional conformal coatings and poly-para-xylylene.

Introduction
Printed circuit boards continue to evolve into increasingly complex assemblies. Components continue to shrink and PCB profiles continue to become thinner, especially when using surface mount components. As a consequence of the tight spaces on the PCB, it has become more of a challenge to integrate poly-para-xylylene and traditional protective coatings. In some cases, coatings are made thicker to ensure full encapsulation, but this can lead to higher cost and reliability issues. With a new hybrid ALD/CVD coating, 100% conformal coating is easily achieved using an ultra-thin film (approx. 0.1µm thick, which is 10-100 times less than Poly-para-xylylene). The ultra-thin film has the advantage to produce no lux loss for PCB's that employ LEDs. The new technique includes a design strategy that permits highly efficient utilization of chemicals, which keeps application cost relatively low. The coating equipment employs a design that permits reaction and deposition of vapor in a vacuum chamber. ALD and CVD deposition technology is described in Figure 1 and a coating example is shown in Figure 2. Minimal chemical usage is achieved by employing molar delivery of chemical and reacting vapor in an isolated vacuum chamber. In addition to the IPC standard test results, a real-world product evaluation result will be shown.

Method
Experiments were performed using ALD/CVD coating equipment. Two different PCB designs were tested for salt solution resistance, moisture and thermal resistance as described in Table 1. The samples were tested by the end user.

Table 1 - Test Methods

#	Board Type	Salt Test	Moisture and Temperature Test	Other Tests
1	IPC-B-25A (Standard Test board) 	Spray @ 1ml/hr/80cm^2 ASTM-B117-16 (35°C, 5% conc., pH=6.7, 48 hrs; with visual corrosion check)	IPC-TM-650 # 2.6.3.4 (25°C to 65°C, 85% RH, multiple thermal cycles with check for MIR-Moisture and Insulation Resistance)	Solderability through coating Breakdown voltage
2	LED Circuit Board (Street Light) 	Salt water soak test (25% conc., 17 hrs; with check for Lux and electrical performance)	Heated water soak test (0°C to 70°C, 6 hrs in DI water; with check for Lux and electrical performance)	Solderability through coating

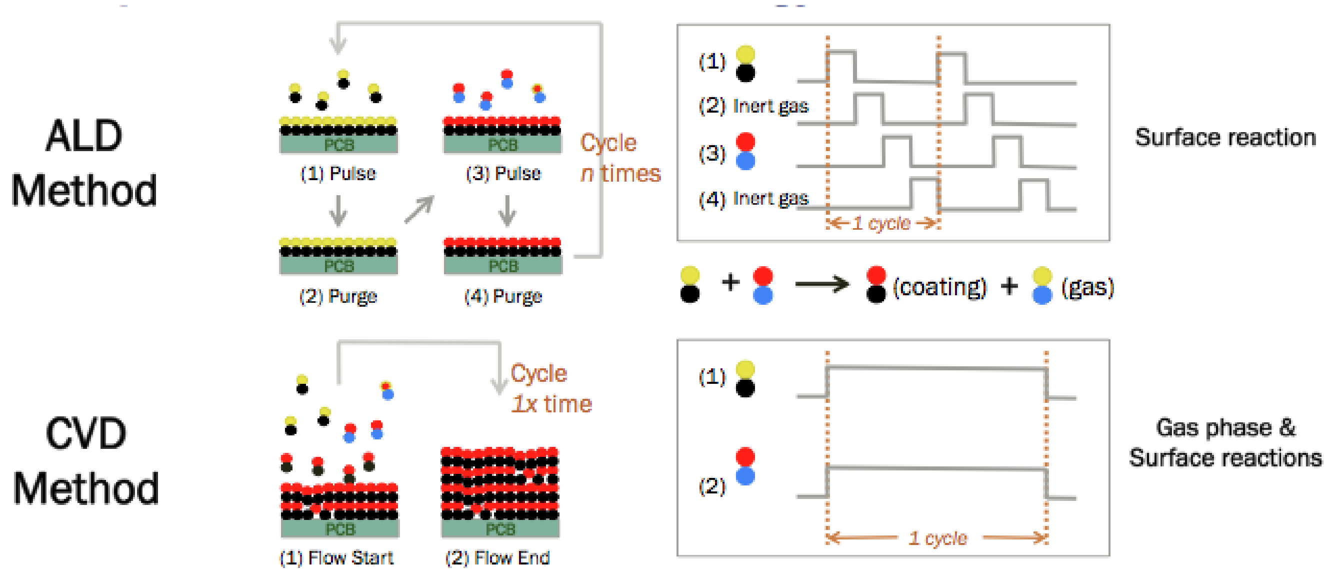
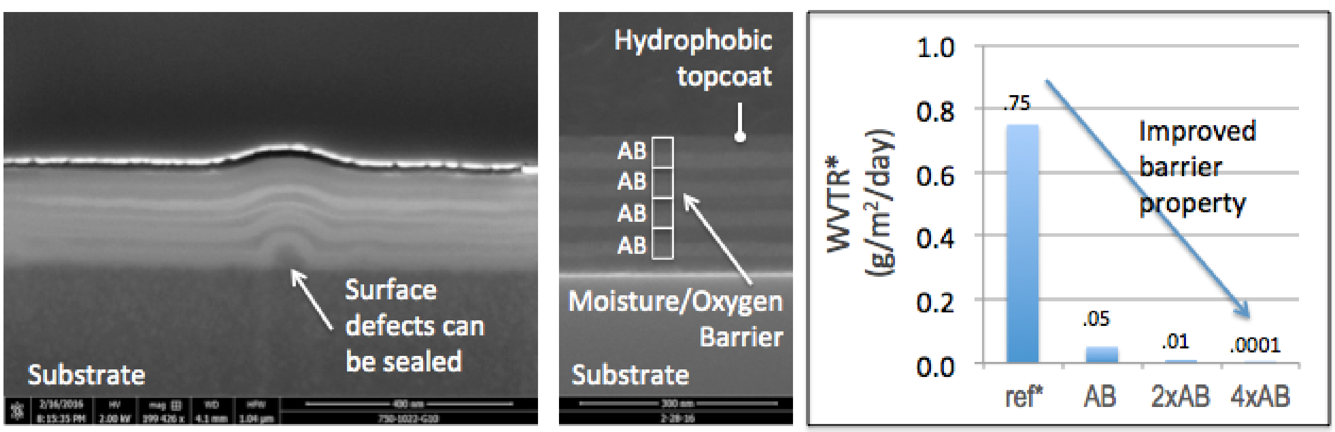


Figure 1 – Description of ALD and CVD Technology



*Typical Poly-para-xylylene coating

Protective Coating:

- Multilayer coating. Layer A deposited by ALD. Layer B deposited by CVD.
- Increased number of AB layers lowers water vapor ingress
- Hydrophobic topcoat to repel liquid water

*WVTR = Water Vapor Transmission Rate measured in grams of water (vapor) passing through a square meter of coating per day

Figure 2 – Protective Coating Description

Results

1. <u>IPC-B-25A Testing</u>
   a) Salt Spray testing: The PCB with coating after salt spray exposure appears similar to a new board. The PCB without coating shows copper traces severely corroded after salt spray exposure. (Figure 3 – Salt Spray Results)

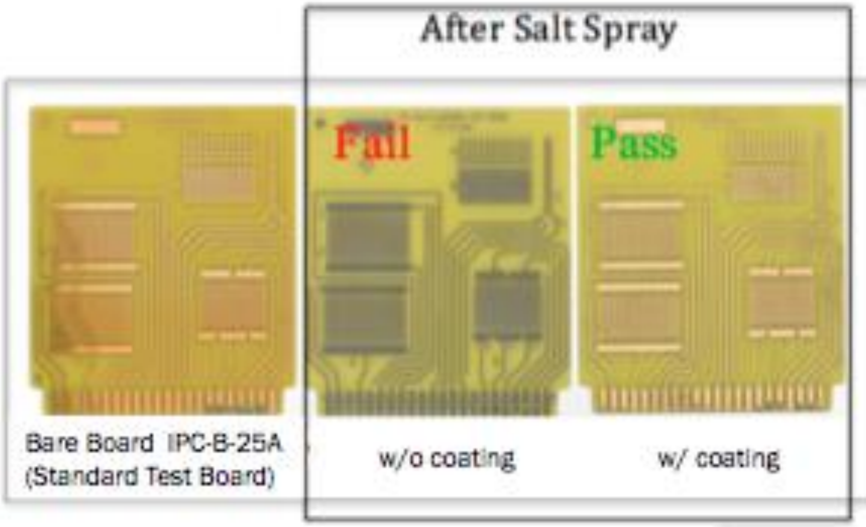


Figure 3 – Salt Spray Results

   b) Moisture and Temperature testing: Moisture and Insulation Resistance (MIR) tests passed IPC specifications by 2 orders of magnitude compared to the poly-para-xylylene coating requirement (Figure 4 – MIR results)

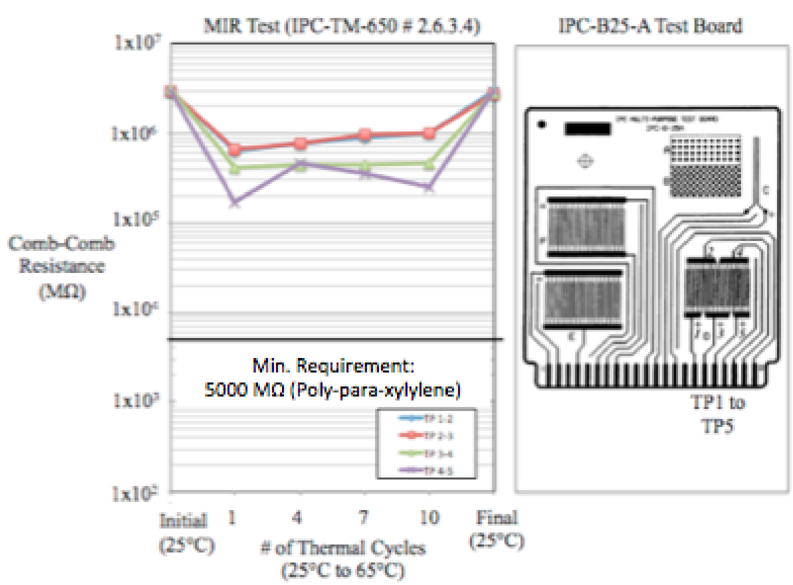


Figure 4 – MIR Results

c) AC Breakdown (arcing) voltage on the coated board was 1.07 kVAC. The breakdown voltage of an uncoated board was also 1.0 kVAC.

2. LED Circuit Board Testing (Street Lighting)

Table 2 describes results of testing of a LED street light circuit board. The manufacturer of the LED circuit board provided the authors with a board without a protective coating. A protective coating was subsequently applied and the coated assembly was exposed to various environmental stresses described in Table 2.

Table 2 – LED Street Light Circuit Board Results

Test Name	Test Description	Power	Current	Lux	Visual Observation*
Before coating	Initial check before coating	21 Watts	94 mA	720 lumens	Normal
Pre-stress Test	Initial check after coating	Pass	Pass	Pass	Pass
Water Test	After 12 hour dip in DI water	Pass	Pass	Pass	Pass
Corrosion Test	After 17 hour dip in salt water	Pass	Pass	Pass	Pass
Thermal Test	After two 6-hour cycles in water ramped from room temperature to 70°C	Pass	Pass	Pass	Pass

* Visual observation involves examination for scratches, smudges, and any mechanical degradation. Pass = No Change.

Discussion

PCBs coated with a new hybrid ALD/CVD thin film went through preliminary evaluation by exposing the coated PCBs to typical environmental stresses. The coated PCBs were functionally tested at elevated humidity and temperature, including vapor and soak testing in both water and salt water. The coating included a hydrophobic top layer that contributes to moisture ingress resistance. The environmental stresses did not degrade the electrical or physical performance of the PCB. The board testing for electrical breakdown demonstrated that the coating maintained the original breakdown performance. In addition, the use of this thin film coating maintains LED light output performance. The cost of this coating can be kept very low due to the small quantities and efficient utilization of the coating chemical and the ability to coat in large batches. In addition, deposition time is approximately 8 hours, so the use of processing in a large batch will help to keep costs low. It is expected that this ultra-thin coating does not require masking of connectors and is resistant to ultraviolet light (sunlight), which will be the result of ongoing tests.

Table 3 – Comparison of Properties

Property	Poly-para-xylylene	ALD/CVD Coating
Hardness	Soft	Hard
Wear resistance/Handling Ease	Poor	Excellent
Water Vapor Transmission Rate	Good	Excellent
Temperature Resistance (extended time)	100°C	350°C
Color	Gray/white	Clear
Adhesion to various materials	Poor*	Excellent
Scalable to large production	Poor	Excellent
Process Time	8 - 12 hrs	8 – 12 hrs
Hydrophobicity	Good	Good - Excellent
Cost	High	Low - Med

*Good adhesion requires silane pre-treatment

Conclusions

The Hybrid ALD/CVD thin film passed all spray and soak functional testing requirements. The thin film acts as an excellent barrier to both liquid water and water vapor, including salt water up to 25% concentration, while maintaining LED light output. Since these key performance indicators have passed testing, the next steps for further work involves testing these coatings on PCBs populated with more complex electrical components and testing powered devices while soaked in water and salt water.

Acknowledgements

The authors would like to thank National Technical Systems in Anaheim, California for testing of the IPC test boards.

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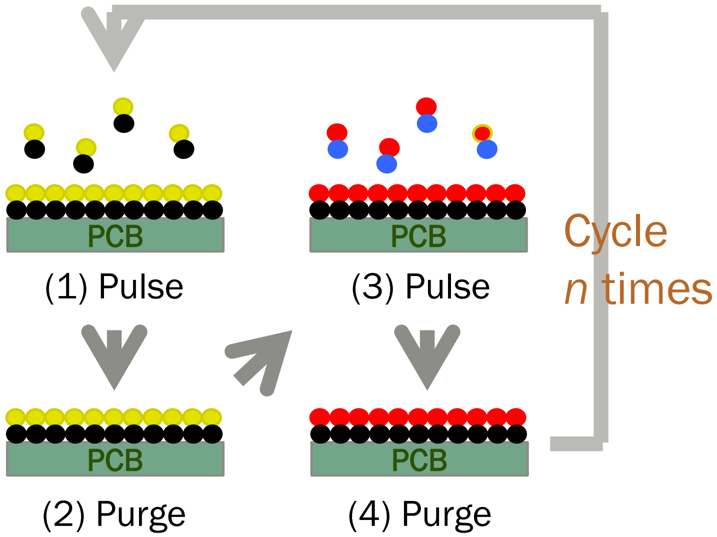
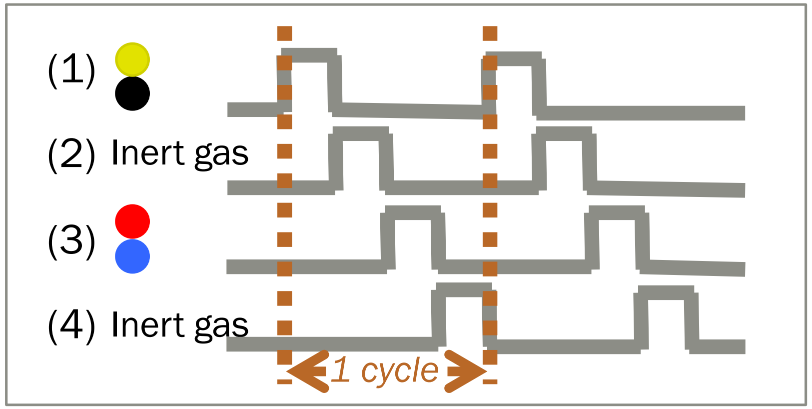
Introduction

- Printed Circuit Boards continue to shrink and component density is increasing due to the use of surface mount components, creating greater challenges for standard protective coating techniques such as liquid dip, liquid spray, and Poly-para-xylylene. In many cases, the standard coating techniques are not feasible due to lack of sufficient protection or high cost.
- Tighter spaces require even better conformal deposition techniques with a goal to provide 100% coverage at a reasonable cost.
- The use of a protective coating deposited using a hybrid ALD/CVD technique will be shown as a solution to these challenges.
- The ALD/CVD coating is hydrophobic.
- For the specific application of LED circuit boards, this ALD/CVD coating will be shown to be uniquely qualified to protect the PCB while preserving LED Lux.

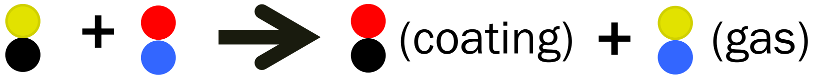
Description of ALD and CVD Technology

ALD Method

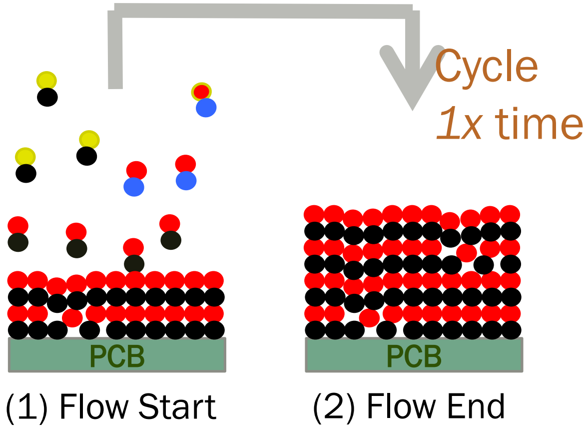


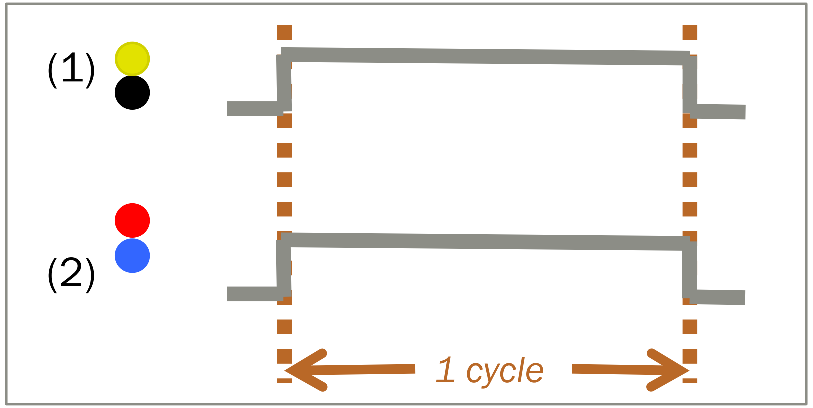


Surface reaction

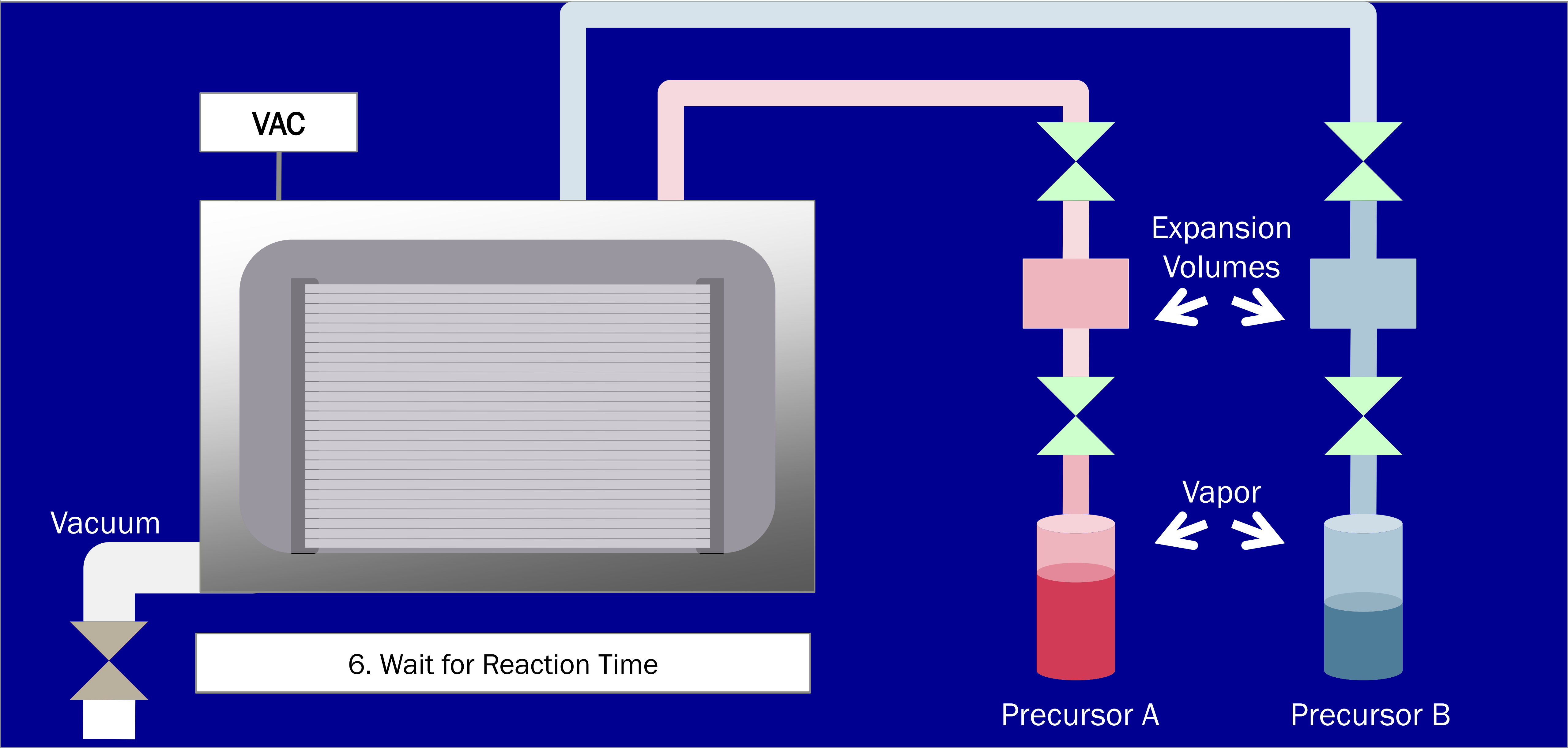


CVD Method



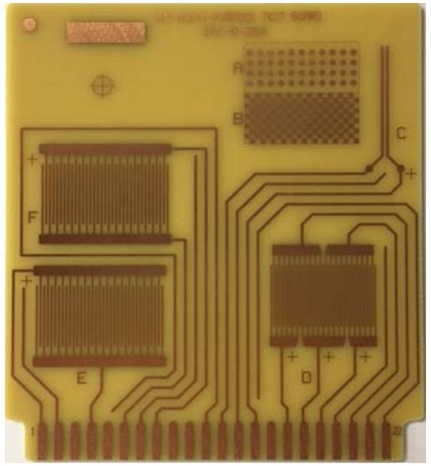


Gas phase & Surface reactions

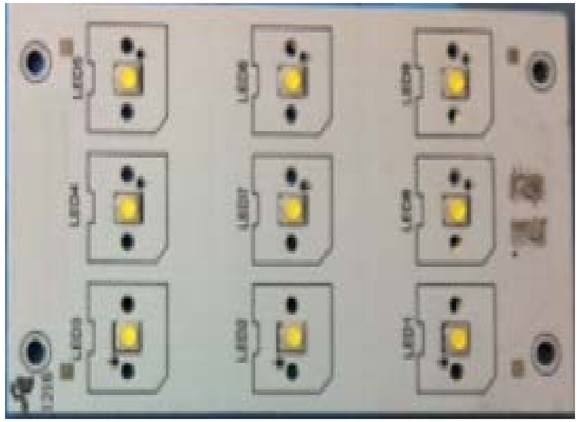

VAC
Expansion Volumes
Vapor
Vacuum
6. Wait for Reaction Time
Precursor A
Precursor B

Method

- Two different PCB designs were coated and tested for resistance against:
  - Salt
  - Moisture
  - Temperature



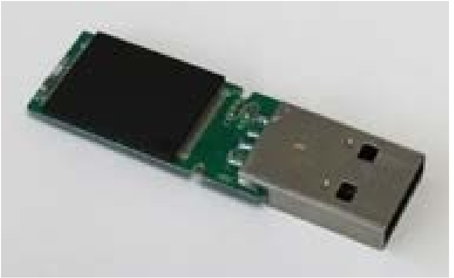
IPC-B-25-A PCB



LED Street Light

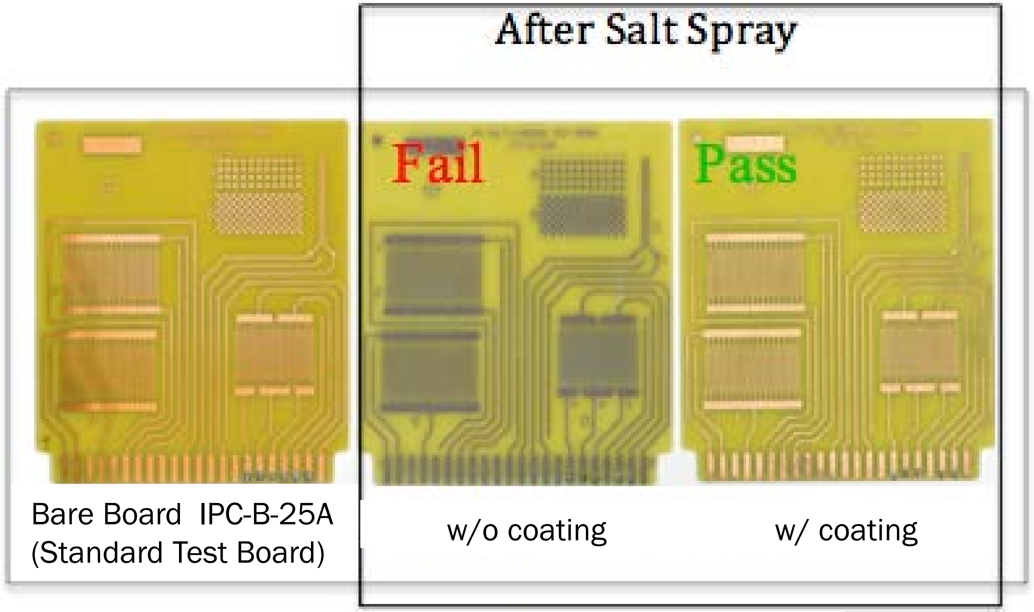
- Two different parts were coated without masking and tested for:
  - Connection integrity

SVGA cable

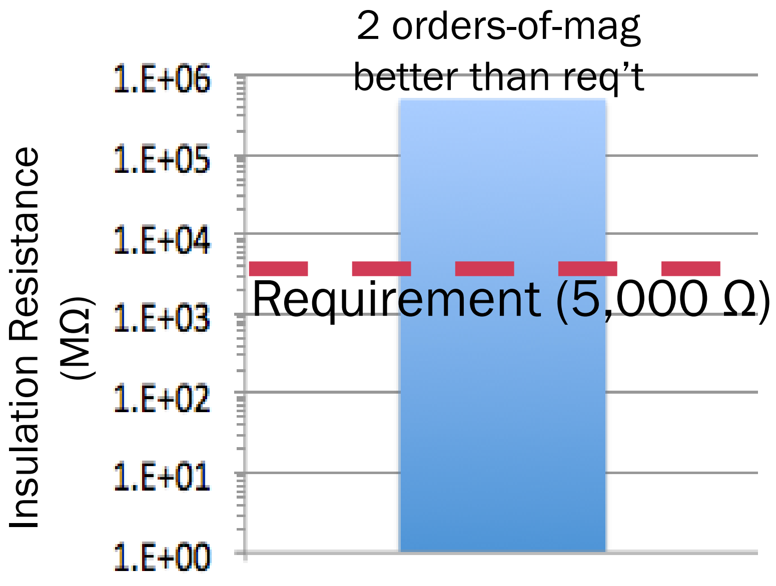


USB

Results



Salt Spray Results



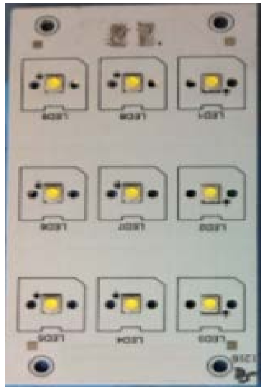
Item #2: Moisture and Insulation Resistance Results (after 7 days)

Item #	Standard #	Description	Status
1	ASTM-B117	Salt Fog/Spray, 5% solution, 48 hrs	Passed
2	IPC-TM-650 Method 2.6.3.4	MIR. Moisture and Insulation Resistance, 7 days w/ temperature ramp 10 times from 25°C to 65°C	Passed

Results

Item #	Test Description	Change in Current Draw	Change in Lux	Change in Appearance	Status
1	Initial Check* after coating	0	0	none	Pass
2	After DI water dip, 12 hrs.	0	0	none	Pass
3	After 25% conc. salt water dip, 17 hrs.	0	0	none	Pass
4	After 2x 6-hr cycles in water ramped from room temperature to 70°C	0	0	none	Pass

*Before coating: @ 21 Watts, Current Draw = 94mA, Lux = 720 lumens



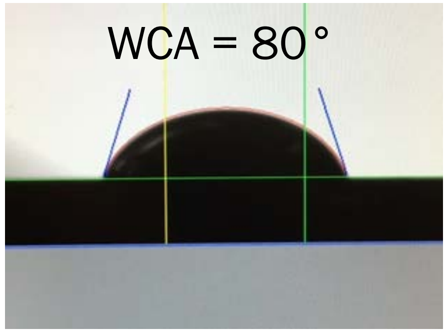
LED Lighting Board

Results

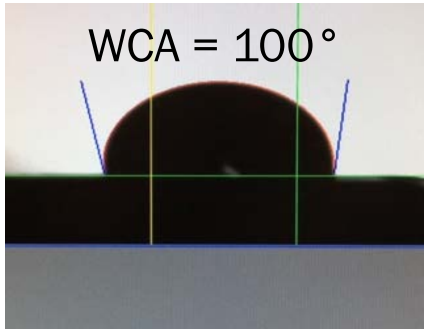
Item	Test Description <u>After Coating</u>	Test Result
SVGA Cable (as-is) 	Connect between computer and screen and check for normal operation	Passed
USB (casing removed) 	Install in computer USB port and perform read and write functions	Passed

Proof of Coating:

Water Contact Angle (WCA) measured in circled area



Before coating



After coating

Different and higher WCA on part After coating indicates that coating physically exists

Cost Reduction Approach

Poly-para-xylylene

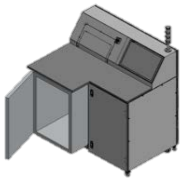



A

Wet Clean & Bake → Mask → Silane Initiation & Poly-para-xylylene Deposition → Unmask → Ship

Hybrid ALD/CVD

Cost of B < Cost of A



B


Wet Clean & Bake → ALD/CVD Deposition → Ship

Hybrid ALD/CVD vs Poly-para-xylylene

Property	Poly-para-xylylene	ALD/CVD Coating
Hardness	Soft	Hard
Wear resistance/Handling Ease	Poor	Excellent
Water Vapor Transmission Rate	Good	Excellent
Temperature Resistance (extended time)	100°C	350°C
Color	Gray/white	Clear
Adhesion to various materials	Poor*	Excellent
Scalable to large production	Poor	Excellent
Process Time	8 - 12 hrs	8 – 12 hrs
Hydrophobicity	Good	Good - Excellent
Cost	High	Low - Med

*Good adhesion requires silane pre-treatment

Summary and Conclusion

- The Hybrid ALD/CVD coating passed standard IPC tests (Salt Fog, MIR)
- Masking was not needed for good connection integrity or soldering
- Further coating optimization is on-going to test low power devices when soaked in tap water or ocean water.