ATMOSPHERIC PLASMA TREATMENT PRIOR TO SELECTIVE CONFORMAL COATING

Brian Stumm

ANDA Technologies USA, Inc.

Fremont, CA USA

BStumm@ANDA.us

ABSTRACT

One of the most common causes of defects in the conformal coating process is contamination of the printed circuit assembly resulting in bubbles, dewetting or delamination of the cured coating material. The image below (Figure 1) illustrates this contamination related defect.

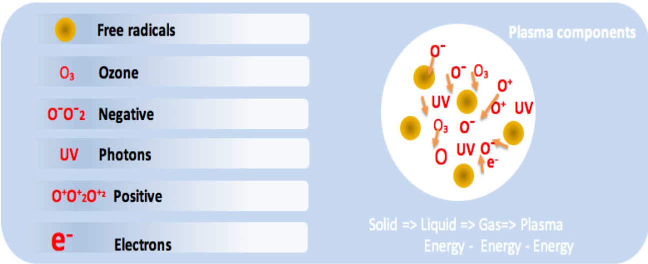
Figure 1: Conformal Coating Dewetting

Plasma Treatment removes contaminants and increases surface energy, thus offering a potential solution to these common failures.

Plasma Treatment is a form of surface modification. It is used in the pretreatment of material surfaces prior to gluing, bonding, painting, dispensing, or coating and can be used on virtually any material surface including those of textiles, metals, plastics, glass, etc.

Plasma is generated by combining a gas with an increased amount of energy where the gas becomes electronically charged with freely moving electrons in both the negative and positive state (Figure 2). This cocktail of neutral gas atoms, positive ions, UV light along with other excited gas molecules and atoms is packed with loads of internal energy. Plasma treatment is initiated when this energy comes into contact with the surface of a substrate.

Figure 2: The 4th State Of Matter



There are two common forms of plasma treatment Low Pressure Plasma (Vacuum Plasma) and Atmospheric Plasma that are used for surface modifications of substrates. Vacuum Plasma is created using a vacuum pump in which most of the air is removed from a sealed chamber. With enough air removed, the chamber low-pressure reaches adequate levels for ionizing the remaining air or gases with a strong electrical field producing plasma. All surfaces of a material are treated at the same time using Vacuum Plasma. Atmospheric Plasma on the other hand requires no closed chamber, it is produced by electrically energizing air or gases as they pass through a nozzle at surrounding atmosphere or normal pressure using a pulsed electric arc generated by high voltage discharge.

The effects of plasma treatment are short lived, typically allowing less than one hour to apply coatings or adhesives. Atmospheric Plasma Treatment allows for in-line processing, eliminating the time constraint and the need for labor intensive, batch processing.

The purpose of this study is to confirm the feasibility of in-line, atmospheric plasma treatment prior to automated, selective conformal coating of printed circuit boards.

Keywords: Atmospheric Plasma Treatment, Conformal Coating, Dewetting, Delamination, Cleanliness

INTRODUCTION

In printed circuit assembly, it is often required to protect the assembly from environmental conditions through the application of conformal coating.

Conformal coating is a thin, protective film which conforms to the three dimensional shape of the electronic assembly. Conformal coatings are applied to electronics in order to protect against vibration, dust, moisture, chemicals and temperature extremes [1].

Two of the most common issues associated with conformal coating are Dewetting and Delamination, both of which are caused primarily by contamination of the printed circuit board assembly.

Contaminates include residues from board manufacturing, component residues like mold release agents, flux residues from the soldering process and oils from the skin (handling by manufacturing line operators) [2].

Dewetting, Delamination and Bubbles can also happen when the surface energy of the PCBA are lower than the surface tension of the conformal coating material [3].

Plasma cleaning is the removal of impurities and contaminants from surfaces through the use of energetic plasma or dielectric barrier discharge (DBD) plasma created from gaseous species [4].

Plasma surface treatment is a process that raises the surface energy of many materials so as to improve the bonding characteristics [5].

Atmospheric-pressure plasmas have prominent technical significance because in contrast with low-pressure plasma or high-pressure plasma no reaction vessel is needed to ensure the maintenance of a pressure level differing from atmospheric pressure. Accordingly, depending on the principle of generation, these plasmas can be employed directly in the production line. The need for cost-intensive chambers for producing a partial vacuum as used in low-pressure plasma technology is eliminated [6].

Based on these advantages, atmospheric plasma treatment before application of conformal coating was chosen to be studied, with focus on reduction or elimination of defects related to contamination and/or surface energy to surface tension mismatch.

TEST VEHICLE

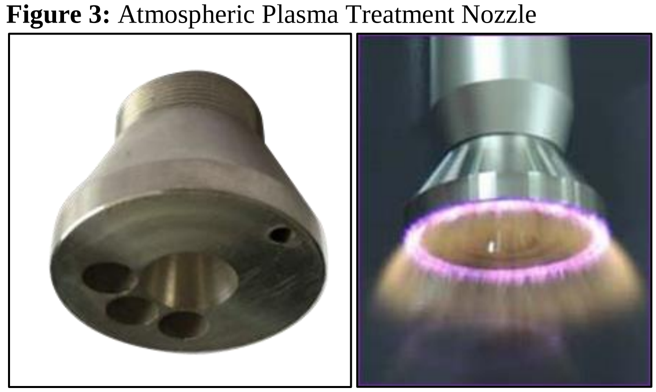
The test vehicle utilized was an inline workcell with a conveyor and 3 axis (X, Y, Z) gantry robot.

The plasma generator had a fixed power level of 500 Watts, the gas medium used was factory supplied clean, dry, compressed air. The nozzle tip (Figure 3) was a rotational type nozzle with 50mm diameter.

The system allowed for custom process settings such as nozzle height above substrate, processing movement speed and selective treatment path creation.

With the exception of the plasma nozzle end-effector, the gantry robot workcell used was very similar to commonly available automated, selective conformal coating gantry robot workcells.

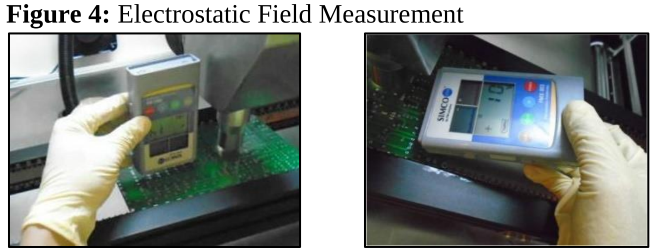
Figure 3: Atmospheric Plasma Treatment Nozzle



ELECTRICAL DISCHARGE

Since Plasma is produced under under high voltage discharge and the sensitive nature of electronic assemblies, it was also necessary to ensure that the plasma beam will not damage ESD sensitive components. Testing was conducted using a Electrostatic Field Meter. Testing (Figure 4) showed no ESD concern.

Figure 4: Electrostatic Field Measurement



DYNE MARKER TESTING

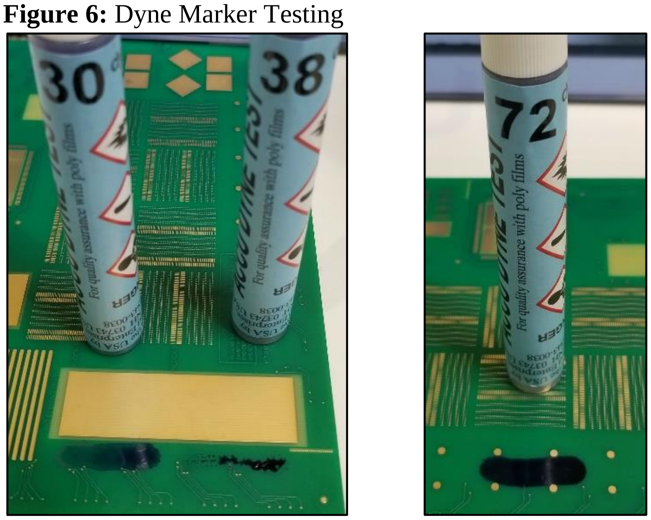
For adequate wetting and adhesion, most conformal coating manufacturers indicate that the minimum required substrate surface energy is 35 ~ 38 dyne/cm [7,8].

Dyne Markers or Pens (Figure 5) are a relatively inexpensive tool that can be used to test the surface tension of a substrate. Each Dyne Marker has a different surface tension rating which can be used to get an approximation of surface energy. Using a Dyne Marker is as simple as drawing a line on the substrate you wish to test. If the ink pools or puddles the surface energy is less than the indicated dyne/cm. If the ink forms a smooth line the surface energy is higher than the indicated dyne/cm.

Figure 5: Dyne Marker Test Pens

The images below (Figure 6) represent a random sample, bare PCB. Initial Testing indicates surface energy greater than 30 dyne/cm but less than 38 dyne/cm (left). Following atmospheric plasma treatment, surface energy increased to greater than 72 dyne/cm (right).

Figure 6: Dyne Marker Testing



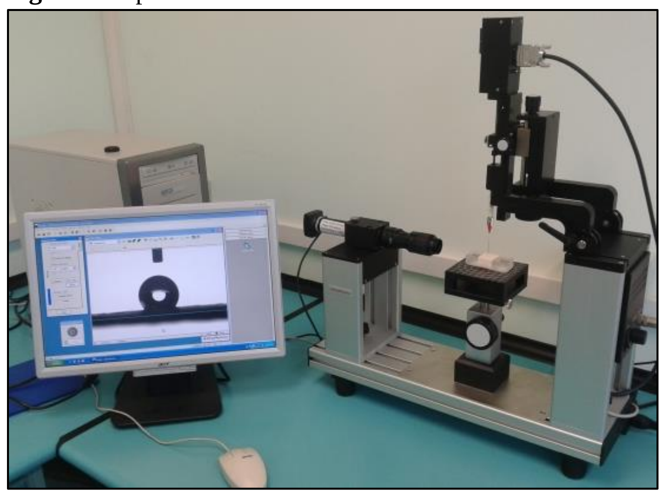
Before Plasma Treatment After Plasma Treatment

CONTACT ANGLE TESTING

Another method for determining wettability and adhesion is contact angle measurement.

Using an Optical Tensiometer or Contact Angle Goniometer (Figure 7), a droplet of water is placed on the test substrate, an image at high magnification is captured and finally and sophisticated software routines then fit the theoretical Young-Laplace equation to the liquid drop profile. The angle of contact between the water droplet and substrate can then be calculated.

Figure 7: Optical Tensiometer

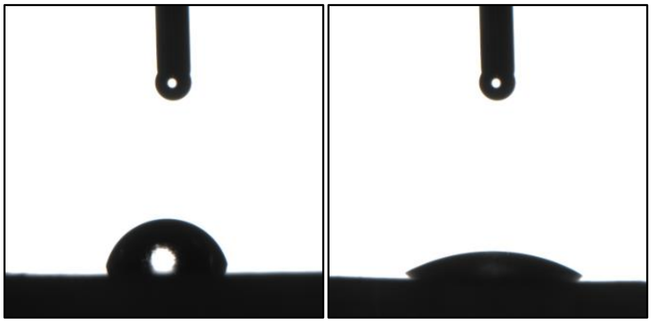


The contact angle is the angle, conventionally measured through the liquid, where a liquid–vapor interface meets a solid surface. It quantifies the wettability of a solid surface by a liquid via the Young equation [9].

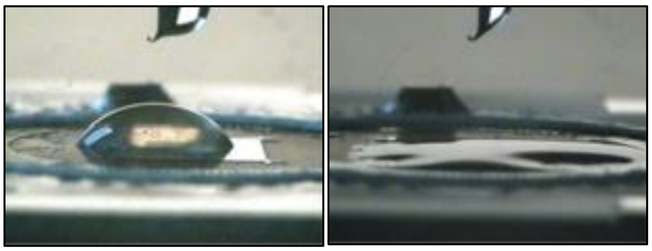
A high contact angle indicates the substrate is hydrophobic while a low contact angle indicates the substrate is hydrophiling. For strong adhesion of conformal coatings and other adhesives, a low contact angle is desired. Opposite of dyne marker testing where a higher number is desired.

The images found in figure 7 represent a random sample, unpopulated printed circuit board. Initial Testing indicates contact angle greater than 80 degrees (left). The substrate was spot treated for 2 seconds. Following atmospheric plasma treatment, contact angle decreased to less than 15 degrees (right).

Figure 8: Contact Angle Images



Before Plasma Treatment After Plasma Treatment



Before Plasma Treatment After Plasma Treatment

TEST PROCEEDURE AND RESULTS

Treatment analysis was conducted to determine the optimal atmospheric plasma treatment processing speed. Static parameters included processing distance (10mm above the substrate). This height was chosen based on the maximum component height of approximately 7mm for the populated printed circuit assemblies used in other testing. Using the same 50mm, rotating plasma nozzle, both dyne and contact angle measurement were conducted before and after plasma treatment. All samples failed 38 dyne/cm testing but passed 30 dyne/cm prior to plasma treatment. The chart below (Figure 9) illustrates these test results.

Figure 9: Determining Treatment Speed

Speed	Temperature	dyne/cm			Contact Angle	
		34	38	72	Before	After
50mm/s	93C	Pass	Pass	Pass	82.7	6.65
100mm/s	72C	Pass	Pass	Pass	84.2	8.64
150mm/s	60C	Pass	Pass	Fail*	81.6	20.94

*Passed at 68 dyne/cm

Based on preliminary testing, a processing speed of 100mm/second was determined to be optimal because of the recorded temperature, dyne marker results and and contact angle measured. 150mm/second processing speed would likely provide adequate surface modification and a lower temperature but for the purpose of this testing, the goal is to achieve greater than 72 dyne/cm and less than 15 degree contact angle.

Since the effects of Plasma Treatment (both low pressure and atmospheric pressure) are shorted lived, it is necessary to determine the process window available between plasma treatment and automated, selective conformal coating (or other glue/adhesive dispensing and post processing steps).

Given enough time, typically three to seven hours, the surface energy (and resulting wettability) of the treated substrate will return to it's untreated state. Because of this, it was decided to perform additional testing to determine the time limit for next step processing.

With processing parameters decided, additional testing was conducted. Ten samples were treated with Atmospheric Plasma with post-treatment results recorded almost immediately after treatment, as well as at twenty and forty minutes intervals post-treatment. The results of this testing (Figure 10) are shown in the table below.

Figure 10: Contact Angle Measurement

	~2 minutes	~20 minutes	~40 minutes
Sample 1	7.516	12.824	20.486
Sample 2	8.468	16.682	28.519
Sample 3	13.341	15.951	22.498
Sample 4	10.797	13.326	18.04
Sample 5	8.063	14.817	23.118
Sample 6	6.928	13.081	20.486
Sample 7	7.946	17.294	29.179
Sample 8	8.085	17.008	27.547
Sample 9	6.803	13.065	29.135
Sample 10	7.503	14.487	23.686
Average	**8.545**	**14.854**	**24.269**

Based on these results, one can conclude that secondary processing should be conducted as soon after atmospheric plasma treatment as possible, preferably not more than twenty minutes later.

Typical tact times in an automated conformal coating process line are short, often measured in seconds rather than minutes. Even when processing complex assemblies, time between atmospheric plasma treatment and conformal coating can be maintained to far less than twenty minutes.

CONCLUSION

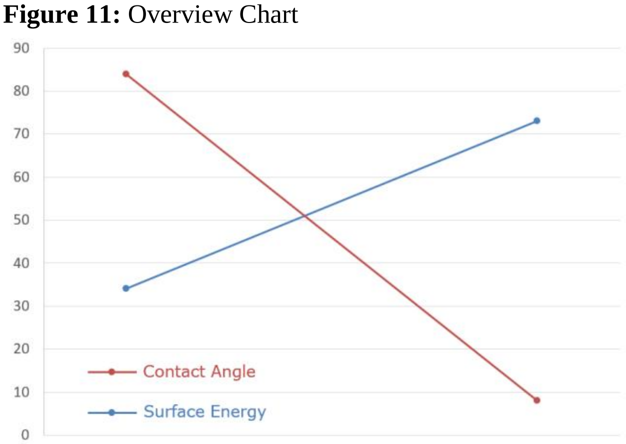
As a processing step that can be inserted in-line into an existing automated, selective conformal coating process line, atmospheric plasma treatment shows definite promise.

Significant improvements are shown in both contact angle and surface energy, a direct correlation to the bond strength of any given adhesive.

Surface energy ranges from high to low. To illustrate the concept of surface energy, think of water on the unwaxed hood of a car. The unwaxed hood has high surface energy and water on the hood flows into puddles. In comparison, a waxed hood has low surface energy and the water beads up rather than flows out. Similar to water, adhesive on a high surface energy surface flows and “wets out” the surface. “Wetting out” is required to form a strong bond. As a rule of thumb, the higher the surface energy, the greater the strength of adhesion [10].

To recap, the chart below (Figure 11) shows the surface energy (dyne.cm) and contact angle (degrees) both before and after atmospheric plasma treatment. The resulting change in surface energy is an increase of approximately 40 dyne/cm and a decrease in contact angle of more than 70 degrees.

Figure 11: Overview Chart



Before Plasma Treatment After Plasma Treatment

Atmospheric plasma treatment allows for a next-step process window of up to 20 minutes and with large area, high speed processing it certainly should keep up with the tact time of the rest of the automated coating line.

The increase in Surface Energy and reduction in contact angle are known to promote wettability and as such make in-line, atmospheric plasma treatment an excellent candidate for insertion into the conformal coating process.

FUTURE WORK

Future work will require additional testing to include visual inspection, automated optical inspection and adhesion testing of the applied conformal coating.

Analyzing adhesion strength of different coatings such as Silicones, Acrylics and Urethanes.

Examining the feasibility of atmospheric plasma treatment on real world printed circuit assemblies, particularly those with component heights that exceed the effective reach of the plasma nozzle.

ACKNOWLEDGEMENTS

The Author would like to give thanks to LiYaoYong of Dongguan ANDA Automatic Equipment Co. Ltd, Jacky So of ANDA Automation (Hong Kong) Limited and Anderson Arvelo of ANDA Technologies Mexico for the time and effort spent on running equipment and gathering data for this report.

REFERENCES

[1] “What is Conformal Coating?” https://www.electrolube.com/products/what-is-conformal-coating.html. Retrieved 9 March, 2019.

[2] “How to Identify and Cure the Top 7 Conformal Coating Defects”, https://www.techspray.com/how-to-identify-and-cure-the-top-7-conformal-coating-defects Retrieved 10 March, 2019.

[3] “Simple Steps to Resolve Conformal Coating Wetting Problems”, http://blog.humiseal.com/simple-steps-to-resolve-conformal-coating-wetting-problems Retrieved 11 March, 2019.

[4] “Plasma Cleaning”, https://en.wikipedia.org/wiki/Plasma_cleaning Retrieved 11 March, 2019.

[5] B. Welt (2009) “Technical Synopsis of Plasma Surface Treatments”, University of Florida

[6] “Atmospheric-pressure plasma”, https://en.wikipedia.org/wiki/Atmospheric-pressure_plasma Retrieved 12 March, 2019.

[7] “Simple Steps to Ensure Proper Wetting & Good Adhesion”, blog.humiseal.com/simple-steps-to-assure-proper-wetting-good-adhesion Retrieved 18 March, 2019.

[8] C. Peterson “ULTRAVIOLET CONFORMAL COATING PROCESS DEVELOPMENT”, www.circuitinsight.com/pdf/uv_conformal_coating_smta.pdf Retrieved 18 March, 2019.

[9] “Contact Angle”, https://en.wikipedia.org/wiki/Contact_angle Retrieved 3 April, 2019

[10] “Substrates and Adhesion”, https://www.3m.com/3M/en_US/bonding-and-assembly-us/resources/full-story/?storyid=1d2481ca-5c8c-455d-952d-5ed90e04e8a7 Retrieved 4 April, 2019