THE BENEFITS OF PLASMA TREATMENT IN ELECTRONICS MANUFACTURING

Brian Stumm
ANDA Technologies USA, Inc.
Fremont, CA USA
BStumm@ANDA.us

Anderson Arvelo
Anda Technologies México, SA DE CV.
Guadalajara, México
AArvelo@ANDAMexico.com

ABSTRACT

Plasma treatment is a fast and environmentally friendly process for fine cleaning and surface modification in preparation for other applications. Plasma Treatment offers the following benefits:

- Surface Modification: Surface Energy is increased, surface tension is decreased, wettability and adhesion are improved.
- Micro-sandblasting: The surface is removed by ion bombardment.
- Chemical reaction: Chemical reaction of the ionized gas with the surface.
- UV radiation: UV radiation breaks down long-chain carbon compounds.

The effect of plasma treatment changes based on the process parameters utilized such as power level, air or vacuum pressure, treatment time, gas flow and gas type. Several effects can therefore be achieved with a single plasma treatment method.

Plasma removes release agents (including silicone and oil) from the surface. These are chemically attacked by e.g. oxygen and converted into volatile compounds. The release agents, or their residues, partially evaporate due to the vacuum and the surface heating and modification. The release agent molecules are broken into smaller molecular fragments by the energetic particles in the plasma and can therefore be extracted. In addition, a "micro-blast effect" is created on an atomic level which makes the targeted surface more subjective to bonding.

On PCBs and other electronic assemblies, there are usually invisible deposits such as grease, oil, silicones, fine dust, moisture and oxidation layers. Plasma treatment eliminates these contaminates which would likely affect the flow of coatings or solder, or affect the bond strength of adhesives.

In this study, the benefits of plasma treatment are discussed and the various types of plasma treatment are introduced along with the most effective plasma treatment parameters for electronic manufacturing.

Keywords: Plasma Treatment, Surface Treatment, Cleaning, Oxide Removal, Adhesion, Wettability,

INTRODUCTION

What Is Plasma?

Plasmas are the fourth state of matter and believed to be the most common state of matter in the universe (Figure 1). In simple terms, plasma is an ionized gas into which enough energy is provided to free electrons from atoms or molecules and coexist in both the negative and positive state [1].

Solid + Enough Energy = Liquid

Liquid + Enough Energy = Gas

Gas + Enough Energy = Plasma

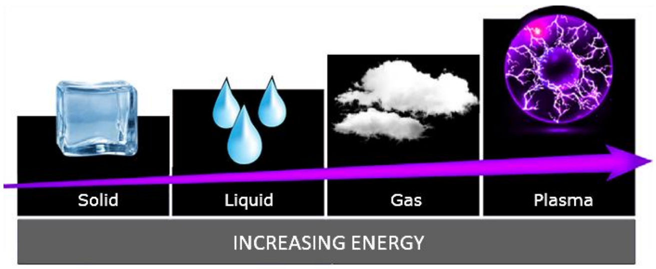


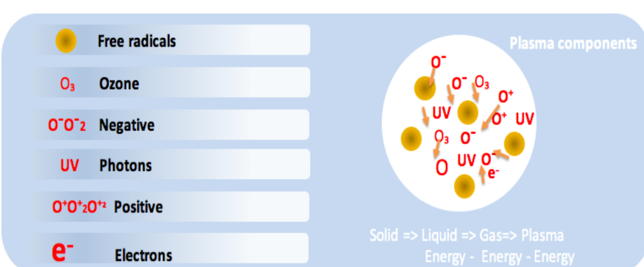
Figure 1: The 4 states of matter

What Is Plasma Treatment?

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. It is used to raise the surface energy, or wettability, of the substrate. It can also be used to remove fine contaminates or even remove oxidation.

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. 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 (figure 2). Plasma treatment is initiated when this energy comes into contact with the surface of a substrate.

Figure 2: The composition of plasma



Plasma treatment modifies the surface of a material by increasing its surface energy. It's like sanding a surface with a microscopic fine abrasion. The treatment increases the surface energy but also generates an increased amount of surface area as a result of the surface modification. This allows for better wettability and flow to occur within the treated area. The outcome produces better coverage and allows adhesion to take place on materials where never before possible.

Plasma is proven to significantly increase surface area and to create polar groups on the surface of polymers so that strong covalent bonding between the substrate and its interface (i.e., inks, coatings, and adhesives) takes place [2].

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 does not require a closed chamber. This atmospheric process allows for a selective treatment. With this method plasma 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.

Why Use Plasma Treatment?

Plasma treatment can be used on any surface. One of those surfaces is a printed circuit board. A printed circuit board or PCB, as it is commonly referred to in the electronics manufacturing industry, holds together electrical components which are connected using conductive tracks navigating between sheet layers of a non-conductive substrate. Components are generally soldered onto the PCB to both electrically connect and mechanically fasten them to it.

The surface of a PCB is one of the most common surfaces Plasma treatment is used on. One of the benefits of plasma treatment can be found in the conformal coating process. The Conformal Coating process was designed to protect electronic boards or assemblies (PCBs) from damage caused by exposure to the environment. In this process the PCB is coated with a protective barrier in the form of Acrylic, Urethane, Silicone, Epoxy and others. This protection extends the life of the electronic assemblies, facilitating the assurance and guarantee of the functionality of the product and minimizing costly repairs once the product is in service. There are many methods of applying Conformal Coating. The most sophisticated and effective method is a Cartesian robot with three or more axis with a spray gun that applies the material with high precision. No matter how precise conformal coating is applied there are challenges that can not be overcome with high accuracy. One of those challenges is surface contamination.

During the manufacturing process of electronic assemblies, the surface accumulates impurities and electronic charges that act as a repellent, causing the conformal coating material not to cover the entire surface. This phenomenon is known in the electronics manufacturing industry as dewetting (figure 3) The solution to this phenomenon in many cases is plasma treatment on the surface of the electronic assembly.

Figure 3: Dewetting

Plasma treatment strengthens the bonds between surfaces, it improves the ability for coatings to adhere to surfaces, and allows for adhesion to occur on surfaces where previously impossible. When surfaces are plasma treated prior to coating, painting, or bonding; the risk of adhesion failure is substantially reduced.

This improvement is achieved by removing contaminants e.g. oils, glues, silicones, oxide, and other organic and inorganic compounds without damaging the substrate. Surfaces also stand to benefit from improved wettability, it raises the surface energy and lowers surface tension to improve flow and wetting.

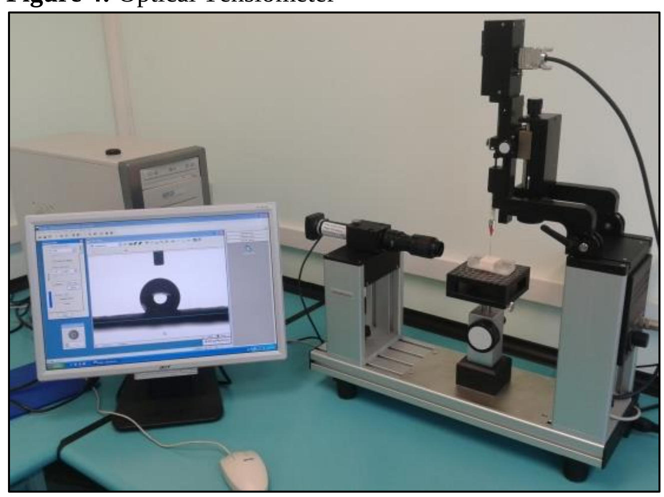
There are numerous applications in almost any industry where some form of plasma treatment can be of benefit. Almost all international automotive manufacturers have used plasma treatments for bonding headlight housings, seats, and even windshields since 1995. Modern aircraft construction even utilizes plasma treatment before any paint is applied to ensure it is of the highest quality. Not to mention all of the instrument displays have a plasma coating to prevent reflection [3].

METHODOLOGY

For this study, testing was conducted using both vacuum plasma treatment and atmospheric plasma treatment. Contact Angle Measurement was used to evaluate surface tension prior to treatment as well as after treatment.

Using an Optical Tensiometer or Contact Angle Goniometer (Figure 4), a droplet of water is placed on the test substrate, an image at high magnification is captured and a sophisticated software routines evaluates the image using the theoretical Young-Laplace equation to the liquid drop profile. The angle of contact between the water droplet and substrate can then be calculated.

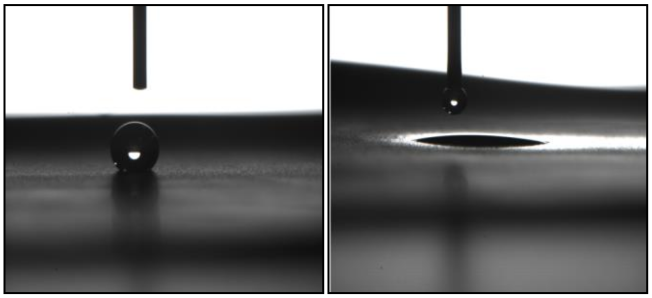
Figure 4: Optical Tensiometer



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-Laplace equation [4].

A high contact angle indicates the substrate is hydrophobic while a low contact angle indicates the substrate is hydrophiling. The images found in figure 5 represent a random sample. Initial testing indicates contact angle greater than 100 degrees (left). Following atmospheric plasma treatment, contact angle decreased to less than 10 degrees (right).

Figure 5: Contact Angle Images



A variety of materials were tested for this study. The materials included:

- Silicone Rubber Sheet (50 Shore A)
- Bare Printed Circuit Board (PCB)
- Aluminum (6061 -T651)
- Hard Anodized Aluminum (6061-T651)
- Steatite Ceramic
- Tempered Glass
- Polyimide Flex Circuit Material
- Polyoxymethylene (Acetal Plastic)
- Gold Plating over Copper

Vacuum Plasma

Vacuum Plasma Treatment requires a sealed, vacuum chamber which typically means an off-line or batch process. Figure 6 represents the 400mm X 400mm X 400mm vacuum chamber used in this study.

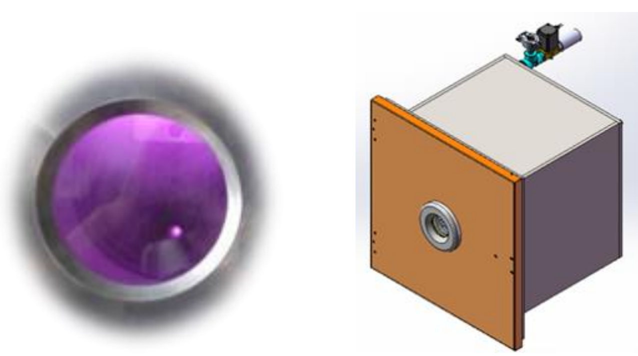


Figure 6: Vacuum Plasma Chamber, 0.064 Cubic Meters

Figure 7 illustrates the testing results of vacuum plasma treatment on various different material types, using different gas combinations and varying treatment times. The plasma treatment power level used for each of these tests was 500 Watts. Treatment time does not include the time required to draw the vacuum (approximately 2 to 3 minutes).

Material	Gas	Treatment Time	Before Treatment			After Treatment		
			1	2	3	1	2	3
Silicone	O2: 10ml, Ar: 40ml	30s	119.3	120.6	123.1	5.6	5.2	6.1
	N2: 40ml, Ar: 40ml		122.6	122.9	124.2	9.1	10.2	9.5
PCB (FR4)	O2: 10ml, Ar: 40ml	30s	74.5	76.1	74.6	9.5	9.6	9.9
	N2: 40ml, Ar: 40ml		76.7	72.9	75.3	8.3	8.1	8.5
Aluminum	N2: 40ml, Ar: 40ml	30s	96.1	95.7	99.4	33.2	35.2	34.6
		60s	95.2	97.2	98.2	20.7	20.2	21.2
		180s	93.6	94.1	96.7	12.4	11.6	12.8
		300s	96.4	95.9	98.7	6.4	6.2	6.7
Anodized Aluminum	N2: 40ml, Ar: 40ml	180s	93.6	94.1	96.7	12.4	11.6	12.8
		300s	96.4	95.9	98.7	6.4	6.2	6.7
Ceramic	N2: 40ml, Ar: 40ml	30s	36.2	35.4	36.9	13.3	13.8	12.9
		60s	37.1	36.4	35.7	9.1	8.7	8.3
Glass	N2: 40ml, Ar: 40ml	30s	39.6	39.1	39.9	8.6	7.9	8.2
		60s	37.2	38.3	38.7	3.5	4.2	4.7
Polyimide (Kapton)	O2: 10ml, Ar: 40ml	30s	67.8	66.4	64.2	8.2	9.2	8.7
	N2: 40ml, Ar: 40ml		64.2	65.2	63.5	11.3	10.6	11.7
Polyoxymethylene (Acetal)	O2: 10ml, Ar: 40ml	180s	77.1	74.5	76.4	49.3	50.4	50.9
	N2: 40ml, Ar: 40ml	300s	79.8	77.3	78.4	46.3	47.1	46.8
Gold Plating	O2: 10ml, Ar: 40ml	25s	102.1	102.9	102.3	20.8	21.5	21.1
		60s	99.6	101.4	104.7	14.9	14.7	16.1

Figure 7: Vacuum Plasma Test Results

Atmospheric Plasma

Atmospheric Plasma is created as compressed air or gas passes through a nozzle and by a high frequency, high voltage, electrical arc. The resulting plasma is then emitted from the tip of the nozzle with an approximate effective range of 15 millimeters. The test vehicle used in this study was an enclosed work cell with 3 axis (X, Y, Z) movement. The test vehicle offered two nozzle types: a 50mm rotation nozzle and a 6mm spear tip nozzle. Figure 8 below represents the two plasma nozzles used in this study.

Figure 8: 50mm Rotation Nozzle (left) and 6mm Spear Nozzle (right)

Figures 9 illustrates the testing results of atmospheric plasma treatment on various material types with different parameters using a 50mm rotational plasma nozzle. The nozzle distance to substrate was 7mm.

Material	Gas	Power	Treatment Speed	Before Treatment			After Treatment		
				1	2	3	1	2	3
Silicone	CDA	500W	50mm/sec	133.5	125.9	129.6	11.5	12.6	10.9
			100mm/sec	125.6	127.1	126.5	17.6	19.2	19.4
	N2		50mm/sec	130.1	127.1	128	10.2	10.5	9.8
			100mm/sec	128.3	128.6	128.1	15.6	16.4	15.1
	CDA	1000W	50mm/sec	126.7	124.7	125.6	8.6	8.4	8.8
			100mm/sec	125.3	124.1	129.5	12.5	12.7	13.1
	N2		50mm/sec	129.1	126.6	129.8	6.5	5.9	6.4
			100mm/sec	125.8	126.6	128.4	10.9	11.4	11.1
PCB (FR4)	CDA	500W	50mm/sec	75.3	76.5	74.1	24.6	25.3	23.5
			100mm/sec	77.3	79.2	76.3	29.8	28.6	29.7
	N2		50mm/sec	75.3	78.4	78.9	22.8	22.2	21.6
			100mm/sec	74.1	78.6	79.3	24.1	24.1	25.4
	CDA	1000W	50mm/sec	71.9	74.1	76.8	18.5	18.5	17.3
			100mm/sec	75.6	74.1	73.5	22.3	24.1	23.2
	N2		50mm/sec	74.1	76.5	79.8	15.2	16.2	15.7
			100mm/sec	75.3	72.5	76.4	20.6	20.3	21.5
Aluminum	CDA	500W	50mm/sec	94.2	94.1	99.1	29.7	30.1	31.2
			100mm/sec	95.3	96.3	94.6	39.6	39.7	38.6
	N2		50mm/sec	96.8	94.1	95.2	26.3	25.8	27.4
			100mm/sec	98.1	95.2	94.6	35.9	36.4	35.6
	CDA	1000W	50mm/sec	98.6	97.3	97.3	25.1	24.5	26.7
			100mm/sec	95.6	94.2	94.2	33.2	32.6	33.1
	N2		50mm/sec	92.8	96.4	91.5	23.5	24.1	24.6
			100mm/sec	94.6	95.2	95.6	30.1	31.5	29.3
Anodize Aluminum	CDA	500W	50mm/sec	108.3	105.3	107	11.1	12.5	11.2
			100mm/sec	106.2	108.4	103.8	17.8	18.3	18.7
	N2		50mm/sec	104.9	105.1	101.3	7.6	7.8	8.1
			100mm/sec	103.8	107.5	103.9	14.9	14.2	15.8
Ceramic	CDA	500W	50mm/sec	34.8	35.6	36.5	21.3	20.5	20.3
			100mm/sec	39.6	37.5	35.4	25.3	24.6	25.8
	N2		50mm/sec	37.4	39.5	38.3	19.4	20.1	19.8
			100mm/sec	36.4	38.2	35.2	23.7	24.1	23.6
	CDA	1000W	50mm/sec	37.5	36.3	38.6	20.6	20.9	21.4
			100mm/sec	36.7	34.9	37.1	22.8	22.3	23.1
	N2		50mm/sec	37.8	35.5	39.2	17.6	18.2	17.9
			100mm/sec	36.2	38.3	37.3	20.5	20.8	21.8
Glass	CDA	500W	50mm/sec	39.2	38.8	39.4	6.3	6.1	6.9
			100mm/sec	38.5	38.6	38.3	8.9	8.5	9.2
	N2		50mm/sec	38.5	39.4	37.9	5.1	5.5	6.1
			100mm/sec	39.4	38.1	39.6	7.6	8.3	7.9
Polyimide (Kapton)	CDA	500W	50mm/sec	66.9	69.4	65.2	19.2	18.6	18.2
			100mm/sec	62.5	61.2	63.2	23.5	22.6	22.8
	N2		50mm/sec	61.9	62.5	63.5	17.5	17.4	16.9
			100mm/sec	63.5	64.3	66.2	21.3	20.9	21.4
	CDA	1000W	50mm/sec	61.2	61.5	63.8	14.2	14.1	14.6
			100mm/sec	62.5	63.8	66.7	19.1	18.5	19.8
	N2		50mm/sec	63.5	63.5	65.1	12.3	13.5	12.9
			100mm/sec	68.3	65.2	61.5	15.6	16.1	15.7
Polyoxymethylene (Acetal)	CDA	500W	50mm/sec	78.6	73.5	76.2	55.3	53.6	54.6
			100mm/sec	75.4	73.8	74.2	56.1	55.7	56.4
	N2		50mm/sec	76.1	74.5	72.5	52.1	52.6	53.1
			100mm/sec	77.2	74.1	79.5	54.3	54.8	54.1
	CDA	1000W	50mm/sec	78.4	79.4	73.5	52.4	52.9	52.4
			100mm/sec	74.2	73.4	79.4	53.8	54.3	54.1
	N2		50mm/sec	76.8	76.8	74.2	50.1	52.3	50.2
			100mm/sec	71.5	75.5	73.5	53.4	53.6	52.8
Gold Plating	CDA	500W	50mm/sec	101.7	102.3	106.7	33.7	32.6	34.1
			100mm/sec	103.2	104.6	104.2	40.2	39.7	39.9
	N2		50mm/sec	109.7	103.3	105.9	31.5	29.6	30.2
			100mm/sec	105.8	104.9	106.1	37.3	36.8	36.4
	CDA	1000W	50mm/sec	106.4	102.7	107.6	29.4	28.4	28.9
			100mm/sec	102.4	106.4	105.8	33.2	33.5	34.1
	N2		50mm/sec	103.7	103.9	104.4	23.6	24.5	25.1
			100mm/sec	105.8	105.4	106.3	30.5	29.7	29.3
Polyoxymethylene (Acetal)	CDA	500W	50mm/sec	78.6	73.5	76.2	55.3	53.6	54.6
			100mm/sec	75.4	73.8	74.2	56.1	55.7	56.4
	N2		50mm/sec	76.1	74.5	72.5	52.1	52.6	53.1
			100mm/sec	77.2	74.1	79.5	54.3	54.8	54.1
	CDA	1000W	50mm/sec	78.4	79.4	73.5	52.4	52.9	52.4
			100mm/sec	74.2	73.4	79.4	53.8	54.3	54.1
	N2		50mm/sec	76.8	76.8	74.2	50.1	52.3	50.2
			100mm/sec	71.5	75.5	73.5	53.4	53.6	52.8
Gold Plating	CDA	500W	50mm/sec	101.7	102.3	106.7	33.7	32.6	34.1
			100mm/sec	103.2	104.6	104.2	40.2	39.7	39.9
	N2		50mm/sec	109.7	103.3	105.9	31.5	29.6	30.2
			100mm/sec	105.8	104.9	106.1	37.3	36.8	36.4
	CDA	1000W	50mm/sec	106.4	102.7	107.6	29.4	28.4	28.9
			100mm/sec	102.4	106.4	105.8	33.2	33.5	34.1
	N2		50mm/sec	103.7	103.9	104.4	23.6	24.5	25.1
			100mm/sec	105.8	105.4	106.3	30.5	29.7	29.3

Figure 9: 50mm Rotation, Atmospheric Plasma Test Results

Test Results Summarized

Vacuum Plasma Treatment and Atmospheric Plasma Treatment both provided similar reduction in contact angle. For Vacuum Plasma, different gas mediums offered better results for different materials. For example, Oxygen & Argon provided the lowest contact angle for plastic materials while Nitrogen and Argon provided the best result for metal substrates. For Atmospheric Plasma, results were similar using Nitrogen compared to Clean Dry Air (CDA).

CONCLUSION

Plasma Treatment shows a great deal of promise for various electronics manufacturing applications and processes. Coating and bonding applications would benefit from increased pull and shear strength. Coating applications should see a decrease in dewetting and delamination. Oxide removal would benefit soldering applications. Some of the potential applications for plasma treatment are listed below:

Plasma Treatment Applications:

- Cleaning and Surface Modification prior to Wire or Die Bonding
- Remove oxidation prior to applying solder paste
- Fine Cleaning and Surface Modification prior to Conformal Coating
- Cleaning and Surface Modification prior to edge bonding, BGA underfill and other surface mount adhesive applications
- Prior to potting or encapsulation
- Touch Panel Assembly
- Prior to Painting or Inkjet Printing
- Post SMT Assembly Packaging

FUTURE WORK

Future work will require numerous and extensive tests which involve varying the process parameters such as power level, gas medium, treatment time or speed, etc. With regard to Vacuum Plasma Treatment, this study has illustrated that different gases, or combinations of gases, offer different treatment results. Further studies will target which gas mediums work best for different material types.

Further studies are also required for specific processes as they apply to electronics manufacturing. One particular application that sticks out is plasma treatment prior to conformal coating. At the time of submission of this study, additional studies have already begun on this topic.

ACKNOWLEDGEMENTS

The Authors would like to give thanks to LiYaoYong of Dongguan ANDA Automatic Equipment Co. Ltd, Dave Law and Jacky So of ANDA Automation (Hong Kong) Limited, Alok Sahu of ANDA Technologies USA, Inc. along with Julio Pacheco and Cesar Cota of ANDA Technologies Mexico for the time and effort spent on running equipment and gathering data for this report.

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