THE BENEFITS OF PLASMA TREATMENT IN ELECTRONICS MANUFACTURING

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Objective

To educate the audience on:

THE BENEFITS OF PLASMA TREATMENT IN ELECTRONICS MANUFACTURING

Summary

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**: Cleans and etches surface by ion bombardment.
- **Chemical Reaction**: Chemical reaction of the ionized gas with the surface.
- **UV Radiation**: UV radiation breaks down long-chain carbon compounds.

Introduction: What is Plasma?

Plasma is the forth state of matter (substance that occupies physical space):

1. **Solid**
2. **Liquid**
3. **Gas**
4. **Plasma**

Introduction: What is Plasma?

Solid + Enough Energy = Liquid
Liquid + Enough Energy = Gas
Gas + Enough Energy = Plasma

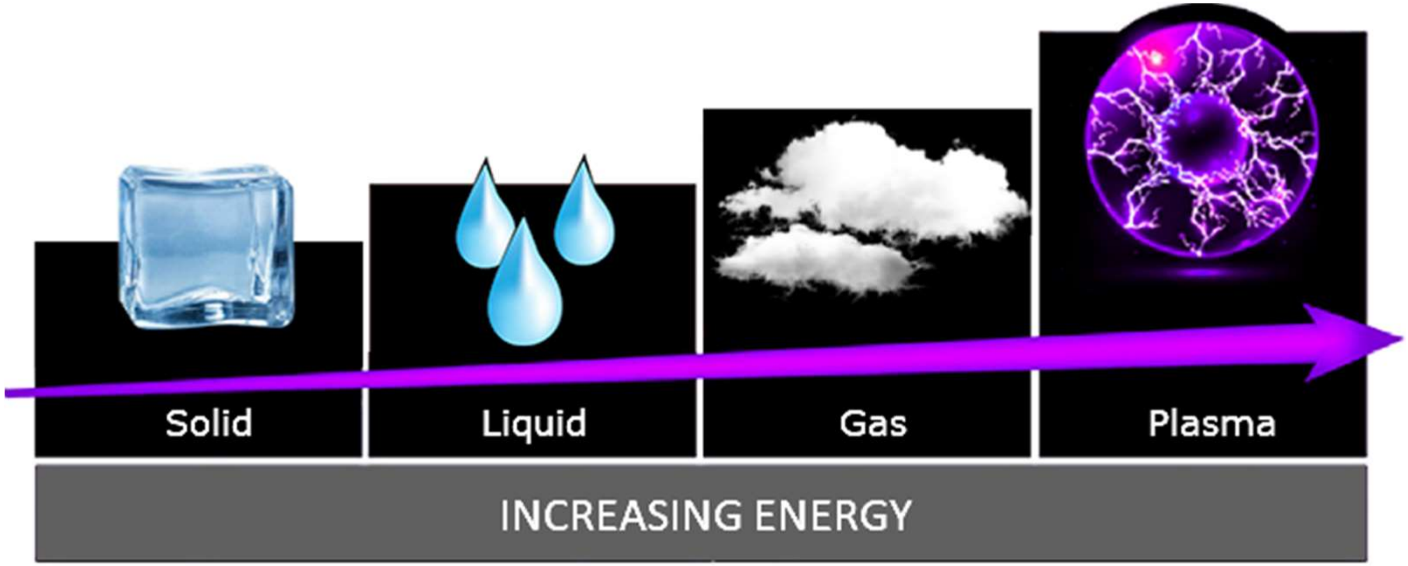

Figure 1: The 4 states of matter

Introduction: What is Plasma Treatment

1. *Plasma treatment is achieved by combining a gas with an increased amount of energy.*
2. *Gas becomes electronically charged.*
3. *Electronically charged gas is directed at the substrate.*

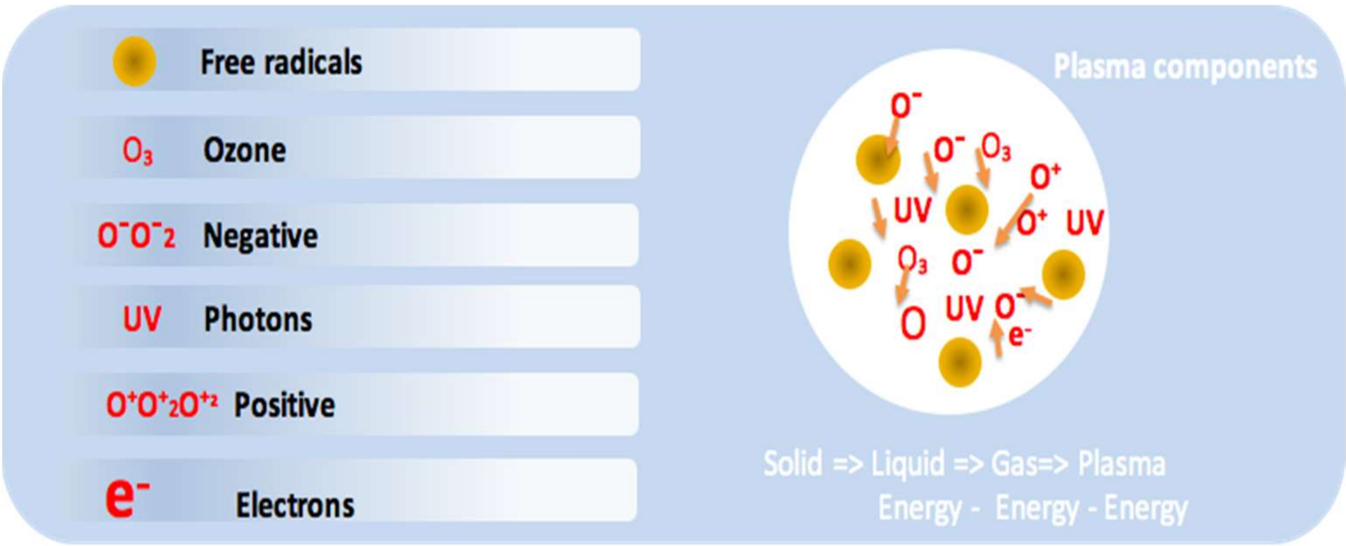

Figure 2: The composition of plasma

Introduction: Vacuum Plasma Treatment

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.

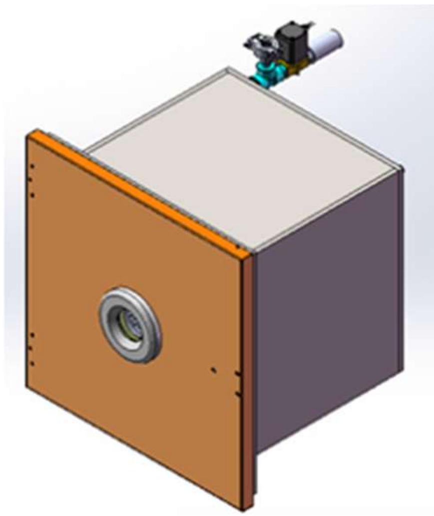

Figure 6: Vacuum Plasma Chamber, 0.064 Cubic Meters

Introduction: Atmospheric Plasma Treatment

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 onto the surface of the substrate.

Introduction: Atmospheric Plasma Treatment

1. *Plasma treatment is achieved by combining a gas with an increased amount of energy.*
2. *Gas becomes electronically charged.*
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Introduction: Why Use Plasma Treatment?

- *Improves adhesion*
- *Improves wettability*
- *Cleans surface*
- *Etches surface*
- *Increase surface energy*

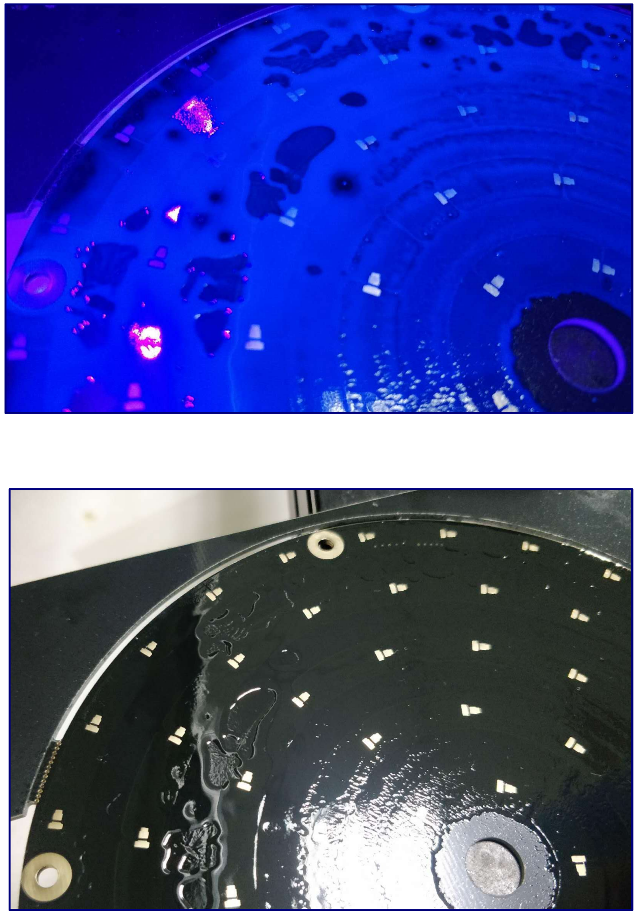


Figure 3: Dewetting

Introduction: Why use Plasma Treatment?

Industries where plasma treatment is useful:

Automotive

Aerospace

Medical

Electronics

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.

- Analyze Surface Energy of Substrates prior to treatment
- Perform Vacuum Plasma Treatment to test group A
- Perform Atmospheric Plasma Treatment to test group B
- Analyze Surface Energy of Substrates post-treatment
- Record Results

Methodology

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 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.

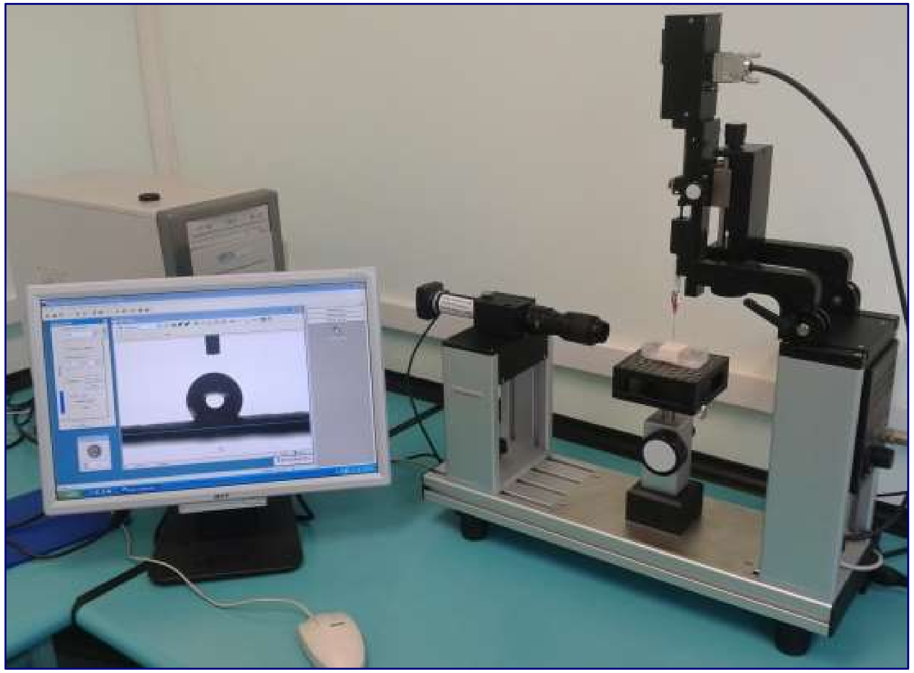
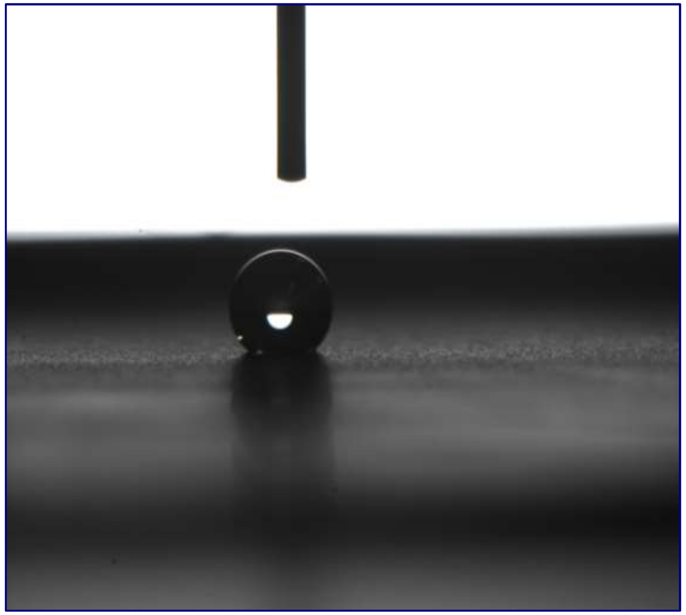


Figure 4: Optical Tensiometer

Methodology

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).



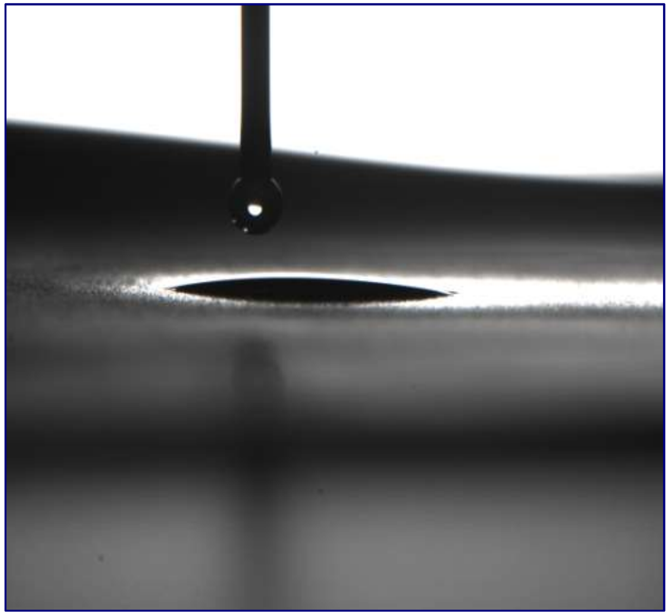


Figure 5: Contact Angle Images

Methodology

A variety of materials were tested for this study. 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

Methodology: 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

Methodology: Vacuum Plasma Testing

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

Methodology: 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)

Methodology: Atmospheric Plasma Testing

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

Figure 9: Atmospheric Plasma Test Results

Methodology: Atmospheric Plasma Testing

Material	Gas	Power	Treatment Speed	Before Treatment			After Treatment		
				1	2	3	1	2	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

Figure 9: Atmospheric Plasma Test Results

Methodology: Atmospheric Plasma Testing

Material	Gas	Power	Treatment Speed	Before Treatment 1	Before Treatment 2	Before Treatment 3	After Treatment 1	After Treatment 2	After Treatment 3
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

Figure 9: Atmospheric Plasma Test Results

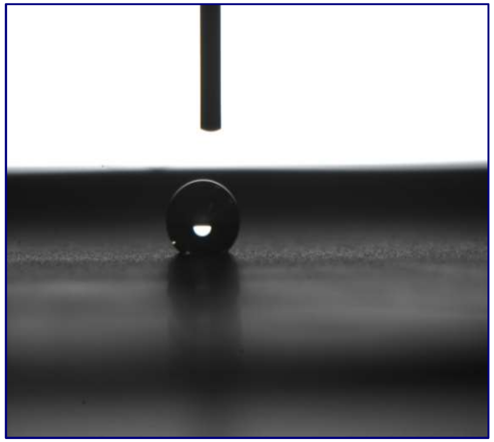
Methodology: Atmospheric Plasma Testing

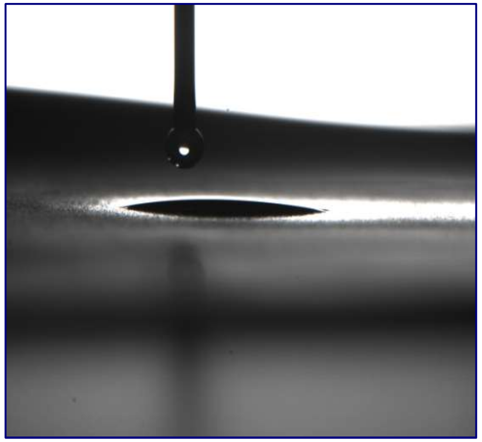
Material	Gas	Power	Treatment Speed	Before Treatment			After Treatment		
				1	2	3	1	2	3
Polyoxymethylene (Acetal)	CDA	500W	50mm/sec	78.6	73.5	76.2	55.3	53.6	54.6
			100mm/sec	75.4	73.8	74.2	56.1	55.7	56.4
	N2		50mm/sec	76.1	74.5	72.5	52.1	52.6	53.1
			100mm/sec	77.2	74.1	79.5	54.3	54.8	54.1
	CDA	1000W	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: Atmospheric Plasma Test Results

Methodology: 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.

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.

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