Overcoming the Challenges Presented with Automated Selective Conformal Coating of Advanced Electronic Assemblies by Employing Plasma Treatment Technology

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ABSTRACT

The reliability and performance of modern advanced electronic assemblies is steadily increasing to meet market requirements and demands. Contemporaneously, demands are such that material choices become as environmentally friendly as possible. Such constraints have presented the electronics industry with unforeseen challenges caused by certain limitations of legacy materials. For example, RoHS requirements have driven printed circuit board assembly materials to ever higher temperature capabilities. The High Tg materials are designed to withstand the higher reflow temperatures of lead free solders but present their own set of problems down the line in subsequent manufacturing steps. In particular the adhesion of existing conformal coatings to advanced materials has presented significant challenges. Either advanced conformal coatings can be applied to overcome the adhesion issues or an alternative is necessary.

In addition to RoHS materials posing challenges for conformal coating adhesion high performance materials also present challenges. System performance is being driven to ever higher levels to take advantage of higher frequency bands for telecommunications and military applications. Higher frequency applications require low dielectric constant (DK) materials to minimize cross talk and signal losses. Typically these materials consist of PTFE which inherently has poor adhesion to most materials. Not only is conformal coating adhesion a challenge but delamination is a fundamental issue during the board manufacturing process.

Additional challenges for conformal coating adhesion are contaminants such as mold release compounds and residual flux. The effects of residual mold release on various surface mount components, quad flat packs, dip packages and the like. Visually these devices appear to be clean and void of contaminants and although the packages have passed various levels of outgoing QC metrics as well as incoming inspection metrics, they often times display the effects of residual mold release when conformal coating is applied via select coating equipment. To a similar extent, manufacturers of printed circuit board assemblies have dealt with excess flux residues, both traditional and no-clean chemistries. With high lead count devices, minimal lead spacing, thus correspondingly high aspect ratios, often time’s residual flux can be left behind even after extensive aqueous cleaning and/or not sufficiently consumed in either the soldering or reflow processes. Given this reality, often selectively applied conformal coatings can be inhibited from sufficiently adhering to the critical junction points at the device body to lead and lead to pad.

Key words: Plasma surface treatment, conformal coating adhesion, plasma surface cleaning

INTRODUCTION

Plasmas can be considered the fourth state of matter following solid→liquid→gas and then plasma. These state transformations occur via the input of energy typically in the form of heat. In the case of radio frequency (RF) plasma the input energy is in the form of a rapidly oscillating electromagnetic field between parallel electrode plates. The RF energy is applied to the powered plate while the opposite plate is typically tied to ground (Figure 1).

![Figure 1. Typical Parallel Plate RF Configuration](https://example.com/figure1.png)
Any free electron within the field will follow the oscillations and collide with any matter that crosses its path. In the case of a gas plasma system the collision of energetic electrons with gas particles can result in a number of outcomes. The gas particle can become ionized either by the addition of the electron to the gas particle or more likely via the removal of an electron from the outer orbital of the particle. The collisions can crack molecules apart into reactive radicals or bump low energy orbital electrons into higher energy orbitals creating an excited gas particle. Once this out of place, high energy electron returns back to its lower energy state a photon of light is emitted to compensate for the energy loss. The conversion efficiency to these excited states is on the order of 1.0% or less so the overwhelming species within the plasma is the source species.

The relative ratios of active species along with the relative energies of those species can be manipulated by the input power from the RF generator, the pressure of the gas in the chamber and the position in the system relative to the electrodes. The input power drives current flow which produces the electron collisions that generate the plasma. Higher power yields more current which yields higher densities of active species. The gas pressure in the plasma system determines the mean free path of collisions within the plasma. Higher pressures result in more collisions but the mean free path is short so the collisions are not so energetic. At lower pressures the mean free path is long and the collision energies are much higher resulting in higher energy species. The position in the reactor determines how energetic the plasma species is due to self-induced biases resulting from the plasma itself. Electrons build up on the powered electrode as the RF energy is capacitively coupled to the electrode which eliminates any DC ground path. There is also a slight buildup of electrons on the ground surfaces. The sea of the plasma becomes slightly positive in nature to balance the potentials. These potential differences result in ion bombardment as the negative charge on the surfaces attract the positive ions from the sea of the plasma. The greater the potential difference the higher the ion energy becomes upon impact. Taking advantage of these characteristics of plasmas enables the user to properly treat, clean, or etch the surface of their material.

Plasma interacts with a surface in two distinct ways, physically and chemically. The physical interaction is via ion bombardment of the surface. Energetic ions will impact the surface and can dislodge material from the surface. This is a form of sputtering and is typically performed using an inert gas like argon. Chemical interaction with the surface takes advantage of active species created within the plasma such as oxygen radicals that are very reactive with organic materials. It is likely both mechanisms are present during a plasma treatment and the dominant mechanism can be controlled via the previously mentioned process parameters of pressure, power, location as well as chemistry.

A plasma treated surface normally will result in high energy surface states due to surface activation of the clean. High energy surface states are preferred for enhanced bonding whether it is adhesive bonding, wire bonding or lamination bonding. Untreated (Low surface energy) surfaces typical demonstrate hydrophobic characteristics while plasma treated surfaces typically are hydrophilic. The wettability of these surfaces can be quantified using dyne solutions or simply by measuring the contact angle of a water droplet on the surface. Low energy surfaces will have high contact angles while high energy surfaces will have low contact angles. Figure 2 shows the water drop contact angle of a polymer before and after plasma treatment.

![Figure 2. Contact angle before and after plasma treatment](image-url)
EXPERIMENTAL

Samples of high performance PCB materials were evaluated for surface energy modification and adhesion enhancement using plasma. Table 1 in the Appendix summarizes the results of plasma treatment of many typically used printed circuit board materials. Each material was processed using a Nordson MARCH AP-600 vacuum plasma reactor. The contact angles were measured using the ChemInstruments Tantec Cam-Plus contact angle measuring goniometer. The contact angles of each material were measured prior to plasma treatment. Plasma treatments using oxygen chemistry was performed and argon chemistry was also performed. The contact angles were measured following the plasma treatment for each condition.

Samples determined to be difficult to treat with oxygen or argon were treated with nitrogen, helium and an 80:20 mixture of hydrogen and nitrogen. These are gases that have been used in the past for difficult to treat materials like PTFE. Again, contact angles were measured before and after each plasma treatment.

Conformal coatings are applied to coupons of PCB materials using the Nordson ASYMTEK SL-940E selective coating dispenser and either heat cured or UV cured depending on the manufacturers recommendations. Plasma treated samples were compared to untreated samples and a Scotch Tape adhesion test was performed following cure (Figure 2.)

Enthane SR1000 solder mask coupons were plasma treated at various times and power levels to determine the sensitivity to plasma flux for conformal coating adhesion. Figure 3 shows the adhesion of an untreated sample (a) versus a well treated sample (b).

Figure 4 shows the effects of plasma processing time on the adhesion of conformal coating to solder mask coupons. All process plasma conditions remained constant with the plasma exposure time adjusted.
Figure 5 shows the effect of plasma power on adhesion of conformal coating to solder mask coupons. All plasma process conditions remained constant with the plasma RF power input adjusted.

**Figure 5.**

Plasma is excellent for improving adhesion by increasing the surface energy of materials like the preceding solder mask examples. Plasma is also very useful for cleaning contaminants that can adversely affect the adhesion of conformal coatings.2 Figure 6 shows the effect of plasma clean time on adhesion of conformal coatings to mold release compound contaminated substrates. The substrates were cleaned using oxygen or argon and both chemistries can successfully clean the mold release compound from the surface. The oxygen process is more efficient because it is cleaning both physically and chemically while the argon process can only remove the contaminant physically via ion bombardment.

Copper clad high performance materials were gathered from users and manufacturers. The copper was removed chemically and the materials were evaluated for wettability enhancement following plasma treatment. Contact angle data is summarized in Table 1. The samples were then evaluated for conformal coating adhesion with no plasma treatment. Both acrylic (Humiseal 1B73) and Polyurethane (Humiseal UV40) conformal coatings were evaluated. In general the epoxy based materials performed well for adhesion without the plasma treatment. The glass filled PTFE containing substrates (Rogers 5870) demonstrated more difficulty for adhesion and required more exotic plasma chemistries to improve adhesion. One polyimide (Dupont Pyralux AP-TK) material had poor adhesion with no plasma treatment and Taiyo solder mask demonstrated similar adhesive properties to the Enthone solder mask.

The glass filled PTFE samples were plasma treated one day and flown across country for conformal coating and cure. The delay time was on the order of twenty four hours which may have contributed noise to the data. The H₂/N₂ treated sample had the lowest contact angle of the pre-treatments yet the helium treated sample yielded the best adhesion. Figure 7 compares the H₂/N₂ treated adhesion (a) to the helium treated adhesion (b).

**Figure 6.**

**Figure 7.**
Figure 8 shows the Taiyo solder mask sample without plasma treatment. The surface wettability is very poor and the adhesion is poor as well. Any form of plasma treatment resolves the poor wettability and improves the adhesion.

![Figure 8](image)

Figure 9 shows effects of plasma treatment on the adhesion of conformal coating to polyimide. The untreated sample (a) has total adhesive failure while the plasma treated sample (b) has excellent adhesion.

![Figure 9](image)

CONCLUSIONS

Conformal coatings for advanced electronic assemblies are presented with a number of challenges affecting the performance. Conformal coatings previously had only been required for military and harsh environment applications. Today more assemblies require conformal coating as electronics have invaded the consumer handheld space and the challenging environments that result. In addition higher performance materials are necessary that enable higher frequency applications as well as meet strict environmental requirements such as RoHS.

Plasma surface treatment has been demonstrated to overcome conformal coating adhesion challenges due to these constraints. The enhanced surface wettability that results from plasma treatment results in improved adhesion of conformal coating to high performance solder mask materials and other difficult to adhere to substrates. PTFE based substrates can also be made more conducive to adhesion when tailoring the plasma chemistry.

Contaminants on the printed circuit that inhibit conformal coating adhesion board can also be removed using plasma processing. By optimizing the physical and chemical components of the plasma process the contaminants are removed without any damage to the substrate and conformal coating adhesion is enabled.

ACKNOWLEDGEMENTS

I would like to thank Carla Loeffler of Nordson MARCH for her assistance procuring the PCB materials and Gheorghe Pascu of Nordson ASYMTEK for use of his lab and operating the conformal coater.

REFERENCES
