

## 3rd Annual Semiconductor Packaging Symposium

# SEMICON® West 2000

Technical  
programs for  
the semiconductor  
and flat panel display  
equipment and  
materials industries.

# The Application of Atmospheric Pressure Plasma to Various Steps in Integrated Circuit Packaging

Jason Uner, Martin Theriault, Claude Carsac  
Air Liquide  
Countryside, IL

Thierry Sindzingre  
AcXys  
Grenoble, France

## **Abstract:**

In the process of integrated circuit (IC) packaging, a series of steps must be performed to properly connect the IC to the package. During these steps, surfaces are often cleaned prior to bonding or joining to improve yields and enhance reliability. Specifically, steps such as die attach and wire bond benefit from having a surface treatment before processing. This treatment step usually comes in the form of a flux or a plasma application.

The purpose of using a flux or a plasma is typically to remove oxides, in the case of metals, or organic impurities, in the case of plastics. Fluxes can be effective, but often come with several major drawbacks such as residues or the potential for voiding during soldering if flux gets trapped. Plasma has proved to be a more effective approach, but also has some drawbacks. The main drawbacks with plasma being that it can only be done at low pressures and in a batch process approach. To improve on this, experiments were done to create and test a plasma that can operate at atmospheric pressure.

## **Introduction**

The technology within the area of IC packaging has been rapidly growing in complexity and depth in recent years. This trend will continue as more functionality from both the package and the PCB is expected due to the increased functionality and reduced size of the IC itself. In addition, reliability and yields will continue to play an important part in allowing companies to keep expenses low and be competitive as products mature and pressure is placed on the price of electrical components and the finished product.

As the package becomes smaller and more complex, new materials, both metals and plastics, are being introduced. Along with these foundations, solders and underfills are also evolving and becoming more refined. However, one of the challenges in working with these new materials is to insure that they are used effectively and efficiently. Often times, issues can arise when materials are physically introduced to each other with the idea being to permanently bond or seal some aspect of the package to the IC. It is in these situations that additional steps are

needed to ensure that the bonding or encapsulating process is done reliably.

The materials used in packaging can vary between each process. Several different metals can be involved which can include gold, copper, aluminum, and eutectic mixtures such as solder. In addition, plastic materials such as epoxy, bismaleimide-triazine (BT) resin, polyimide, and others are used as substrates or encapsulants.

Currently, there are a few different steps that can be put into a packaging process line in order to improve reliability and increase the overall yield of the process. In certain situations, a chemical flux is used to remove oxides or impurities from various metal or plastic surfaces. However, fluxes leave residues that can inhibit the next process steps and cause problems. In addition, fluxes are acidic chemicals which can lead to unexpected corrosion leaving ionic by-products which are conductive. This can threaten the reliability of the end product.

Another alternative to fluxes is the use of plasma. Current plasma methods typically come in two forms, chemical and physical. Most, if not all, existing plasma methods involve the use of a vacuum in order to achieve the necessary low pressure required for the system to be effective. The need for a vacuum can cause a bottleneck in certain process lines and requires vacuum equipment.

Other alternatives can include coating interconnects with antioxidants. However, instead of using such a coating, the plasma could be used to treat the surfaces prior to bonding. The

ability to remove this step from the overall process may be beneficial.

After looking at existing technologies, a new process has been developed. It is a chemical plasma that allows for highly active gas while still operating at room temperature and pressure. It can be used to treat surfaces, both metal and plastic, for the purpose of removing oxides, organics, and other reducible compounds prior to any step in a packaging process.

### **Description of System**

The plasma technology that has been developed is essentially a chemical plasma that uses gas mixtures containing either  $N_2 + \%H_2$  or  $N_2 + ppmO_2$ . Other gases have been added in trace amounts in order to improve the overall efficiency of the system. This is something that can be done to optimize certain effects. The flow rates can vary depending on the application, however pilot scale flow rates were  $15-20m^3/hr$  total gas flow to treat an area  $\sim 200mm$  wide. Smaller areas would use proportionately less gas.

The system works by directing the gas mixture through a small inlet and into a discharge chamber. Within the discharge chamber is an electrode placed in a concentric manner within an outer wall that represents the second electrode (see figure 1). A dielectric barrier discharge approach is used to activate the gas and form the plasma.

Plasma is basically an ionized gas with equal number of free positive and negative charges [1]. The gas becomes ionized by passing it through an electrical discharge, thus breaking it into many free radicals that are very reactive. These species will stay reactive, even at

low temperatures, for a period of time. When treating, the free radicals are immediately introduced onto a surface by the convection from the gas flow. It is important to note that the radicals produced contain no electrical charge. However, they are extremely reactive and will attempt to react with compounds on the first surface that they come into contact with.

In a common example, treatment of a metal oxide layer, the radicals formed in the gas plasma mixture, which can include excited atoms such as  $H^*$  and  $N^*$ , will react with the oxygen atom in the  $MO_x$  compounds that have formed on the metal surface. The primary products of this reaction would be water vapor,  $NO_x$ , and pure metal. In the case of organic contaminants, the resulting products would be water vapor,  $NO_x$ ,  $CO_x$ , and pure metal. The metal surface that is left behind will be clean and actively open to new chemical reactions. Introducing an underfill or second metallurgy at this time to the active surface will result in a much stronger bond than if the surface were untreated. This improved bonding will allow for improved reliability of the process step.

Below is a basic diagram outlining the key components of the atmospheric plasma system [2,3]. The power generator is fabricated to supply a signal in the kHz range and of several kW in magnitude. This is the energy required to create the plasma gas mixture. A water cooling system is used to dissipate some of the excess energy that is not used while forming the plasma. Lastly, a gas panel is set-up in order to blend the gases to the proper mixture prior to

introducing them into the plasma chamber.

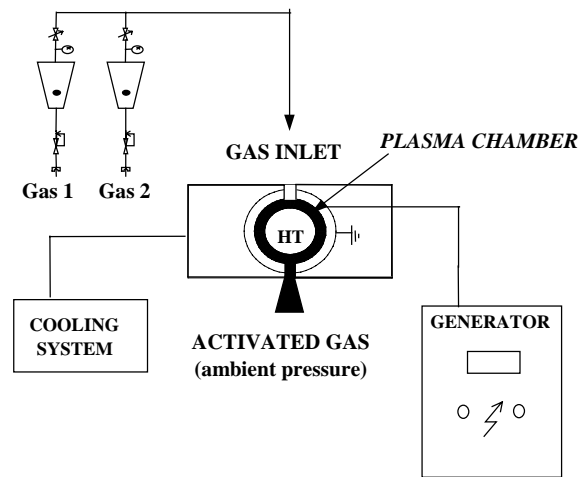


FIGURE 1a - Basic Schematic of System

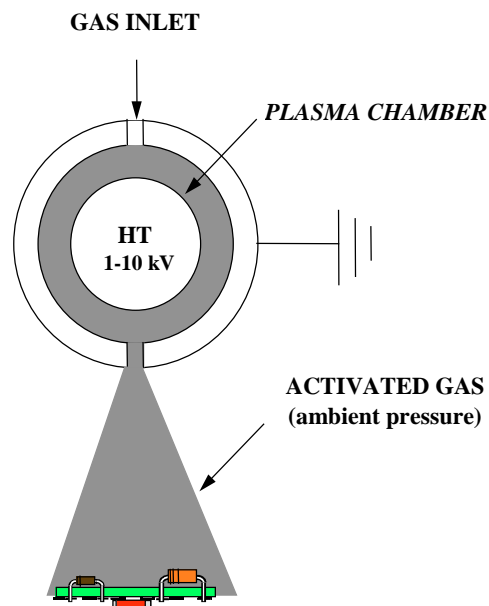


FIGURE 1b - Picture of Plasma Head

The plasma itself projects out in a cloud 0.1m to 0.2m deep using normal gas flow rates. The process can be further optimized for increasing the plasma reaction zone by adjusting the flow rate and power supplied to the electrode. In addition, since the system is a chemical (not physical) plasma, the sample being

treated does not need to be directly in the line of sight of the plasma head. The gas will treat a larger area through natural diffusion. In order to promote this, a nitrogen atmosphere is maintained in the area of the treatment. Allowing just air to be present would reduce the effect of the plasma to some degree.

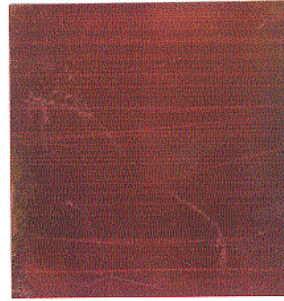
## Experimental Results

### Qualitative Data

In order to validate the use of the atmospheric plasma system in packaging applications, a series of experiments were done on various materials within a lab scale set-up. The types of substrates and surfaces tested were intended to relate to some of the common choices for materials in packaging. The first series of tests involved treating a surface and noting two aspects. The first one is the color change. Removing an oxide layer from a metal surface will result in a drastic change in the luster of the substrate. The second qualitative test is for wettability. A water-based ink is applied before and after treatment.

In the first example, a copper surface was treated with the plasma in order to show the color change just mentioned. In the set of pictures below (figure 2), the lower right corner of the sample was masked so as to show the difference in luster between the treated and non-treated copper. The left picture shows the untreated sample with a copper oxide layer present, while the right picture shows the treated, oxide-free copper.

**FIGURE 2 – Copper Color Change**



**(a) - Before Plasma Treatment**



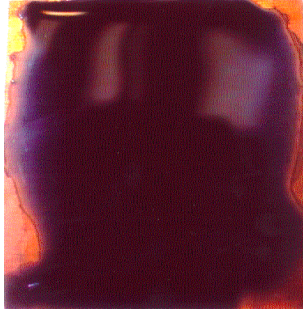
**(b) - After Plasma Treatment**

In the second example (figure 3), a great difference can be seen between the ‘before’ and ‘after’ pictures when placing a water based ink on the surface of the metal. The left picture shows the sample before treatment and the right picture shows the sample after treatment. The contact angle is greatly reduced after treatment, and the ink spreads freely over the clean, active surface.

**FIGURE 3 – Copper Wettability Change**



**(a) - Before Plasma Treatment**



**(b) - After Plasma Treatment**

This same wetting effect is also evident when applying the plasma to plastic surfaces such as FR4 used for PCB's (figure 4). In this case, a mixture of N<sub>2</sub> + ppm O<sub>2</sub> was used in order to treat the surface and remove any organic oils or reducible compounds that may be present on this type of material. Upon completion of the treatment, the ink readily spreads on the surface indicating a clean, active substrate.



**FIGURE 4 - Before/After Plasma Treatment on FR4**

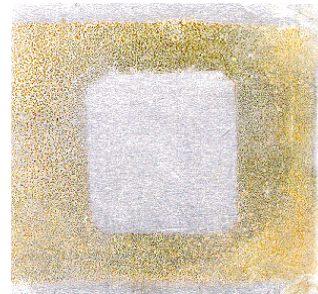
Lastly, a final test was done (figure 5) to demonstrate how the plasma activates the surface it treats. Activation is the term used for cleaning the surface such that there are many open sites available for bonding with the next material they come into contact with. This material can be a solder, underfill, ink, or even oxides from the air if the sample is not handled carefully. In the example below,

a piece of steel is exposed for 20 minutes to water vapor in the form of steam from boiling water. No significant change occurs. In the second photo, the sample is treated in plasma, around a masked area, just prior to being exposed to water vapor for roughly 2 minutes. Note the significant amount of metal oxide that quickly forms in the area that was treated with plasma. This shows the highly active metal atoms that are open to bonding, in this case with the oxygen atoms present in the water vapor.

**FIGURE 5 – Oxidation of Steel**



**(a) - Before Plasma Treatment**



**(b) - After Plasma Treatment and Moisture Exposure**

### **Quantitative Data**

One way to determine the relative cleanliness of a surface is to look at the wettability of a material on that surface. This property can be derived experimentally and give a good indication of how well a solder, metal, ink, or other material will spread on and bond to a surface [4]. To quantify this, a series of tests were done on copper,

aluminum, and epoxy before and after exposure to the plasma. Based on experience, different gas mixtures were used for metals and plastics, and the temperature was kept at 70C during treatment. Water was placed on the surface and the contact angle was measured. A low contact angle indicates that the spreading and wettability are good.

	Before Treatment	After Treatment
Copper	88.4	31.7
Aluminum	64.5	32.0
Epoxy	85.0	22.0

**TABLE 1 - Contact Angles (in degrees) using water before/after plasma treatment**

From the data we can see a significant effect on the wettability for each of the surfaces treated. For metal surfaces a gas mixture of N<sub>2</sub>, %H<sub>2</sub>, and a third gas was used. This was chosen since the key impurities typically found on metal are oxides. Including H<sub>2</sub> in the mixture improves the reducing capabilities of the plasma for metal oxides. A trace amount of a third gas was added to optimize the overall effect of the plasma. This was discovered through experimentation.

For the treatment of the epoxy a gas mixture of N<sub>2</sub> and ppm levels of O<sub>2</sub> was used. This was chosen since the impurities typically found on epoxy are oils and other organic compounds. Having O<sub>2</sub> in the mixture allows the plasma to break the organic molecules and form other volatile compounds such as CO or CO<sub>2</sub>. A trace amount of O<sub>3</sub> is also formed, but this is easily removed from the atmosphere downstream.

All experiments were carried out in a nitrogen atmosphere with ~30ppm O<sub>2</sub> present. While the plasma does run at atmospheric pressure, there are benefits to having a N<sub>2</sub> atmosphere at the point of treatment so that the plasma maintains its effectiveness. The sample exposure time was roughly a few seconds.

**Conclusions:**

The purpose of the experiments conducted in this study was to validate the potential of an atmospheric pressure plasma technology that was created with the idea to displace the use of fluxes and vacuum plasma when appropriate in packaging processes. The data shown allows for a good general conclusion about the effect of the plasma on two key metals and on a plastic. Both the qualitative and quantitative study gave some basis of demonstrating that the technology is both effective and unique in its approach. The system allows for an alternative method for treating surfaces. Treatment with atmospheric pressure plasma may prove to be an effective tool for packaging processes.

**References:**

1. Manos, D., Flamm, D., "Plasma Etching: An Introduction," Academic Press Inc., San Diego, CA 1989
2. US Patent No. 5,722,581
3. Potier, N., Sindzingre, T., Rabia, S., "Fluxless Soldering Under Activated Atmosphere at Ambient Pressure," Proceedings Surface Mount International 1995
4. Comyn, J., "Contact angles and adhesive bonding," International Journal of Adhesion and Adhesives, Vol. 12, No. 3, July 1992, p.145-148