

Plasma Processes for Printed Circuit Board Manufacturing

By Lou Fierro and James D. Getty



Accelerating performance requirements are driving the demand for high-speed, multilayer PCBs. Traditional manufacturing methods for laminating these layered boards and removing residue from the vias are no longer effective. The use of radio frequency driven, low-pressure plasma provides an efficient, cost-effective and environmentally friendly method for surface treatment and cleaning of the boards. Specific applications of plasma technology to PCB manufacturing, critical parameters, and process examples will be discussed.

Innovations in PCB material technology and the use of smaller geometries have led to an increased requirement for plasma processing at multiple steps in the manufacturing cycle. Multilayer PCBs with high-density interconnects require designs with finer pitch, smaller vias, and the use of new material technologies with high glass transition temperatures and low loss factors. While these materials solve coefficient of thermal expansion (CTE) and speed issues, difficulties arise during board manufacturing where the use of traditional processes is limited.

Chemical processing with permanganate chemistry is limited due to the inability of the fluid to penetrate the small vias found in multilayer PCBs. In addition, permanganate does not effectively clean the very small via holes that are usually located at the inner layer level of laser-drilled via holes. Other wet chemistries, such as acid etch, have difficulties etching polyimide dielectric materials.

Plasma processing overcomes these limitations due to the inherent penetrating nature of plasma and the ability to precisely control the process. Plasma can etch high-aspect ratio vias, and is environmentally benign with a low cost of ownership.

Complex and sophisticated boards with ever increasing layer counts and circuit densities need the benefits of plasma for descum, desmear/carbon removal, etchback, Teflon® activation, and surface preparation. Examples include: multilayer boards with 6 to 64 or more inner layers; boards with high-aspect ratio holes; PCBs with microvias, buried vias, blind vias, and laser formed vias; and those PCBs manufactured from new types of resin, Teflon®-based materials, and chemically inert materials.

What is Plasma?

Plasma is an electrically neutral mixture of physically and chemically active gas phase species including ions, radicals, and reaction by-products. These active gas phase species can perform numerous surface modification processes including surface activation, contamination removal, cross-linking, and etch (Ref. 1). The type of plasma process is determined by the PCB material type and post process requirements, and is controlled by the plasma conditions.

Typical plasma equipment consists of four major components: the vacuum chamber, electrodes, vacuum pump and an RF power supply (see Figure 1). For PCB applications, the PCB panels are suspended between a pair of electrodes located within the vacuum chamber. A vacuum pumping system, such as a rotary vane pump and roots blower, is utilized to maintain a plasma process pressure in the low milli Torr range.

Source gases are introduced through mass flow controllers at a specified flow rate. Once the desired process pressure is achieved, RF power is applied to the electrodes thereby initiating the plasma process.

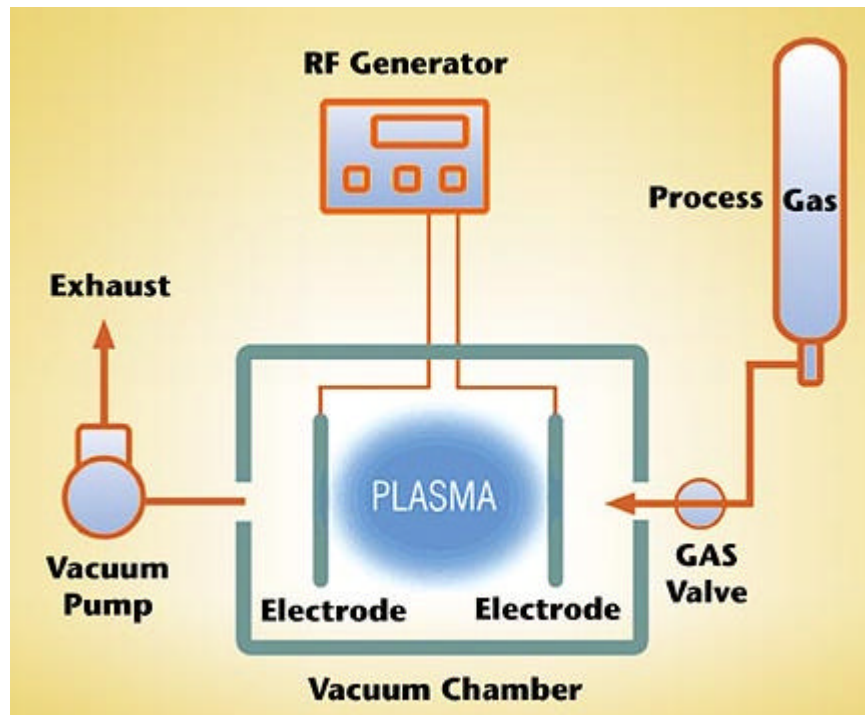


Figure 1. Plasma Treatment System Diagram.

The process gas is ionized and dissociated through the application of RF energy. Typically the RF generators operate in the kHz to MHz range. The processes described later in this article utilized a 40 kHz power supply. Plasma-generated active species perform both physical and chemical processes through ion bombardment and radical/by-product chemical reactions respectively. Depending on the gas or combination of gases, a different reaction can occur on the sample surface. For PCB applications, chemical reactions at the surface are utilized to remove drill smear and resist scum and to increase wettability for laminating and legend adhesion (see Figure 2).

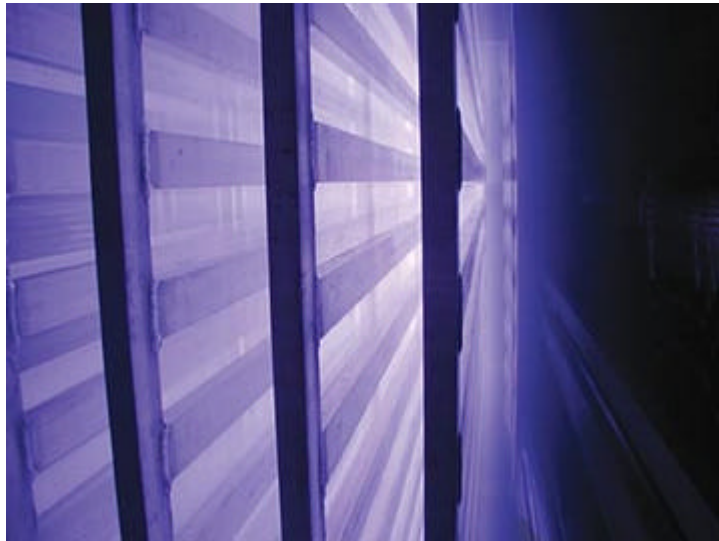


Figure 2. View Inside the Plasma Chamber.

PCB Plasma Processes

Plasma processing solves common problems associated with PCB manufacturing, including smear, residue, poor adhesion and surface activation. Specific applications include desmear, surface activation, descum, and carbon residue removal.

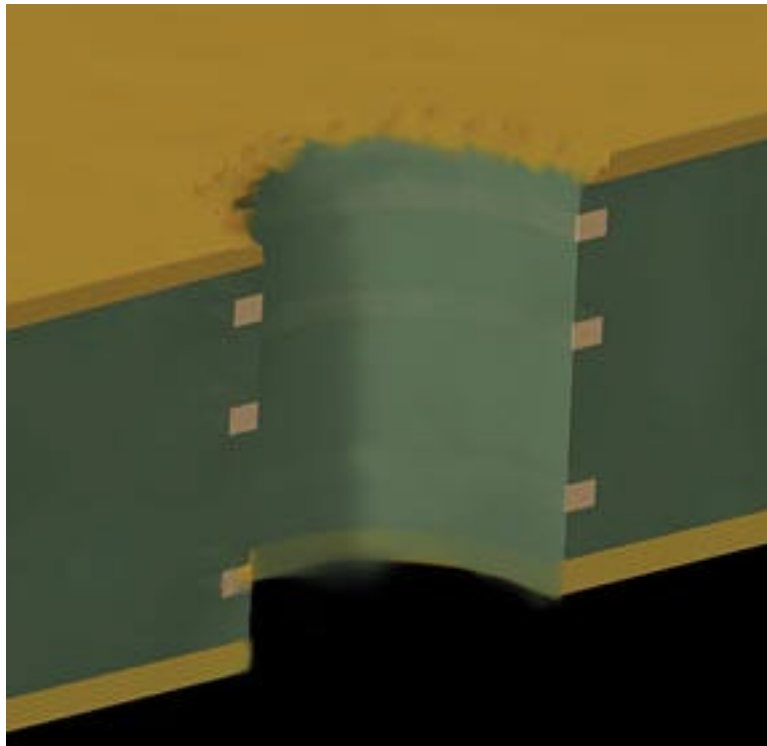


Figure 3. Resin Smear Prior to Etchback.

Plasma is most commonly used for the removal of drill smear after drilling through-holes and vias. Drill smear is a residual resin that spreads along the walls of the vias, blocking metalization to the electrical connections (see Figure 3). Multilayer etchback/des smear is the removal of smeared resin from the barrels of inner-layer posts, ensuring an electrical connection after plating (see Figure 4).

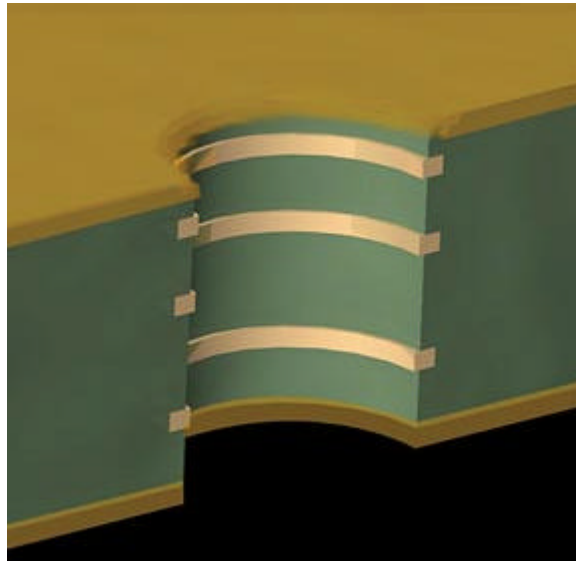


Figure 4. Etchback After Plasma Treatment.

Teflon® activation can also be accomplished by plasma processing. Plasma increases the surface energy of Teflon®, providing excellent lamination and wettability for plating through-holes without use of wet chemicals. All Teflon® materials (with or without fillers) require plasma activation to change the surface energy for electroless copper adhesion.

In another step in the manufacturing process, plasma is employed to remove photoresist residue that can remain after developing fine pitch circuitry on panels and inner layers. This residue can cause a short circuit on the board if not removed prior to etch. The plasma process is capable of removing the resist residue without affecting the circuit pattern.

Inner layer preparation for flex material is also accomplished with plasma. Plasma treatment alters the topography and wettability of unsupported polyimides. Typically the polyimide flex material has smooth surfaces that are difficult to laminate. A physical plasma micro-roughens the surface of the cover coat to enhance lamination.

Forming blind vias requires the use of laser drilling technology. Carbon, a by-product of laser drilling, prohibits electroless adhesion and must be removed prior to further processing. Plasma removes carbon and remaining epoxy from the hole wall and capture pad.

Plasma treatment is also useful for applications where epoxy soldermask does not provide a surface for good adhesion of the legend. In this case, plasma changes the surface energy and wettability of the soldermask to create good adhesion.

Critical Parameter: Plasma Process Uniformity

Plasma treatment equipment has changed with technology advancements in PCB manufacturing. Process treatment uniformity is a critical application parameter. If hole walls are not evenly treated, smear could remain, thereby impeding metalization of electrical connections. Excess etching in isolated spots on a PCB panel can cause plating folds and voids. New plasma equipment designs ensure uniformity, allowing repeatable results within a chamber load, and from lot to lot. Although configurations between manufacturers may vary, the key elements of uniformity include electrode design, gas flow and exhaust.

Electrodes

Parallel plate electrodes with either alternating power and ground, or newer technology with power/power 180° out of phase, allow the PCB panels to be suspended in the primary plasma zone. The primary plasma zone contains the largest concentration of plasma-generated active species. Multiple sets of parallel plate electrodes are typically installed in a single vacuum chamber to accommodate the processing of multiple panels simultaneously. RF feed-through bussing to the multiple electrode pairs is critical in order to evenly distribute power in each cell. Bussing is usually diagonal from one end of the electrode assembly to the other, creating an even current flow throughout the electrodes.

Panels are suspended in the primary plasma zone to ensure each side is equally treated, giving the through-holes a fast, uniform etch rate. Depending on the chamber size, the number of paired electrodes can allow simultaneous processing of up to 32 or more standard 457 x 610 mm (18 x 24 in.) panels.

Gas

Gas is introduced into the chamber through mass flow controllers. Accurate regulation of the mass flow rates of each process gas is critical to successful panel treatment. Control of gas ratios and flow rates is essential to a successful process. Because the active gas species deplete and are exhausted out of the chamber, the product closest to the gas inlets will typically treat faster. For this reason, control of gas distribution must be maintained to ensure uniform treatment of all panels in the load. Uniform gas distribution is accomplished by using internal gas manifolds or by alternately injecting the gas from opposite ends of the chamber.

Exhaust

When the exhaust valves are open, the pump evacuates the chamber to the operating vacuum. The vacuum pump is continuously removing depleted gas, allowing new active species to enter the chamber. The exhaust valve must be properly located to remove gas from the furthest part of the inlets. If located too close to the gas inlets, active species will be removed from the chamber prior to panel exposure.

Process Examples

Desmear

Removal of drill smear requires the use of three gases: Oxygen (O₂), Nitrogen (N₂) and Tetrafluoromethane (CF₄). Three plasma segments are used to complete this cycle.

Segment 1: In order to get a sufficient chemical reaction of circuit board material, the panel must be heated to 80-100°C, depending on the resin. O₂ and N₂ mixtures with flow rates of 2-3 SLM (standard liter per minute) are used to heat the panels. A high RF power accelerates the heating.

Segment 2: A combination of O₂, CF₄ and N₂ gases with 2-3 SLM flow creates the chemical reaction that removes resin from the through-holes. RF power is lowered to provide enough energy for maintaining the proper panel temperature and etching uniformity. Typical desmear process cycles are approximately 15 minutes. Depending on the amount of desmear, the process time may be increased to provide etchback.

Segment 3: This step completes the plasma process by removing by-product ash and fluorine from Segment 2 processing through use of 100-percent O₂ burn.

Teflon® Activation

Teflon®-based materials are gaining popularity in circuit board design. Commonly used for

microwave applications, Teflon® material is now being used for other products, such as voltage controlled oscillators, IF amplifiers, and ground spectrum communication devices. Due to their hydrophobic properties, it is difficult to deposit electroless copper on Teflon® surfaces or to apply direct metalization. Pure Teflon® material and those containing fill materials which are either random or woven (i.e., ceramic and glass) require different processes.

Pure Teflon® material: This material is processed using a single segment to activate through-holes. The most common gases used are a combination of Hydrogen (H₂) and Nitrogen (N₂). Panel heating is not necessary because the Teflon® is being treated to activate and increase wettability. As soon as the chamber reaches operating pressure, the process gases and RF is applied. Most pure Teflon® panels take about 20 minutes to process. Because of the recovery characteristics of Teflon® (i.e., return to a non-wetting surface), the electroless or metalization processing should take place within 48 hours of plasma treatment.

Filled Teflon® material: PCB panels manufactured with filled Teflon® material (fillers include random glass micro-fiber, woven glass reinforced, and ceramic PTFE composites) require a two-step process. The first segment cleans and micro-etches the fill material. Typical process gases for this first segment are CF₄, O₂ and N₂. The second segment is identical to the one used for pure Teflon® material.

Resist Descumming and Flex Cover-Coat Etching

The same process parameters are used for both cleaning resist scum and etching flex cover-coat surfaces. A single-step recipe using O₂ as the process gas works for both applications. Pre-etching flex inner layers normally takes 15 minutes to produce a topography change that will enhance lamination. Fifteen to 30 minutes is usually sufficient to remove the variable thickness of resist scum and leave a clean path for etching.

Carbon Removal

As technology drives to smaller vias, the use of laser formation is increasingly common. The process for removing carbon after laser drilling is similar to a desmear process, except that Argon (Ar) gas is also required. Depending on the quality of the laser-formed via, one or two segments of plasma are required to successfully remove carbon and resin from micro and blind vias.

Certain laser processes leave a significant amount of burnt resin and carbon around the lip of the via and on the destination pad, requiring two plasma sequences.

Segment 1: CF₄ and O₂ are combined to create the chemical plasma that removes the resin at the lip and/or in the hole. Process time is 15-30 minutes.

Segment 2: This step creates the mechanical plasma that removes the carbon, leaving the via ready for plating. Argon gas with a small percent of O₂ removes the carbon and any remaining resin. Processing time is 10-20 minutes.

If the laser-formed vias are fairly clean with minimal burned resin, a single plasma segment is sufficient. In this case, Ar, CF₄, and O₂ are combined in a single segment.

Plasma has a broad processing window that allows flexibility in PCB manufacturing. Plasma results are directly related to power, gas flow, pressure, process time, and panel surface area.

Conclusion

Traditional manufacturing methods for removing residue from vias are losing their effectiveness. New technology, high-performance boards require the use of plasma in numerous manufacturing steps. Typical plasma processes include desmear, Teflon® activation, descum, and carbon removal. Plasma has the flexibility to meet the future challenges of PCB manufacturing today.

Teflon® is a registered trademark of E.I. DuPont Company.

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