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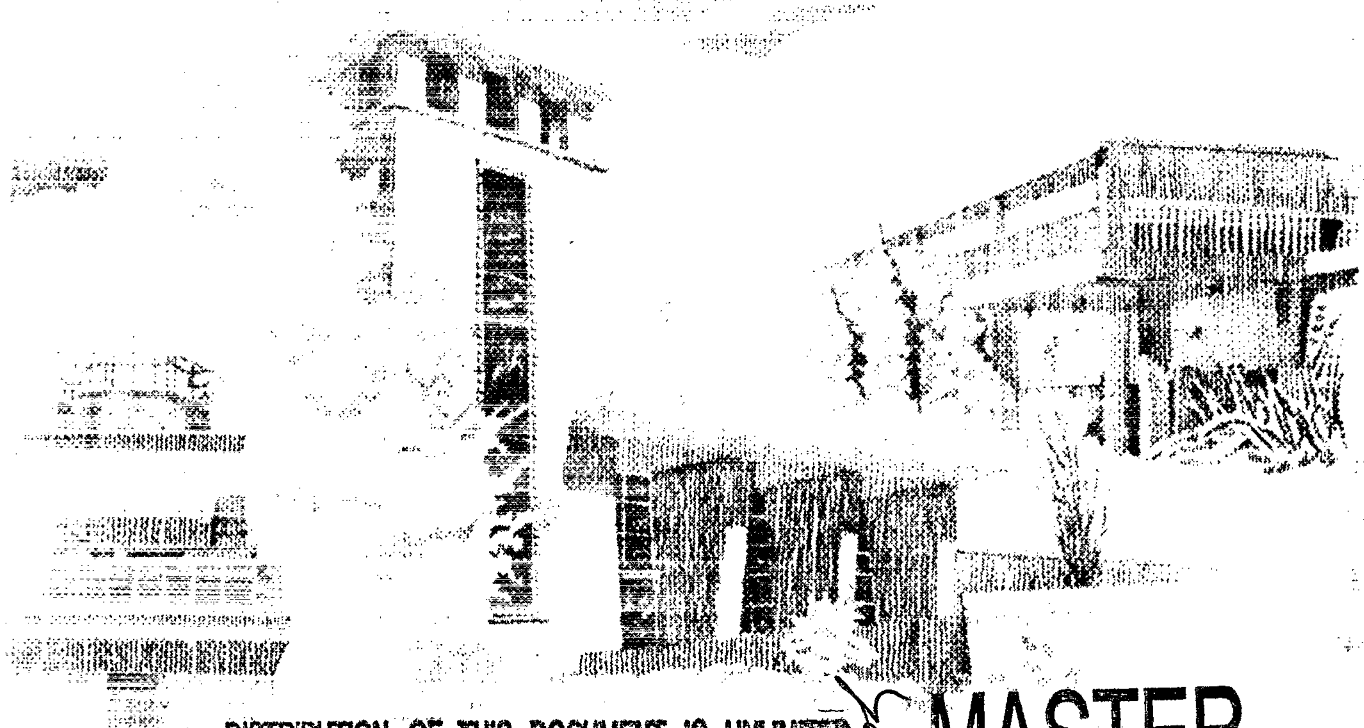



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# Process Uniformity for Plasma Etchback and Desmear in Printed Wiring Board Manufacturing

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## Abstract

In the manufacture of printed wiring boards (PWB), plasma etchback and desmear processes facilitate the making of good mechanical and electrical bonds of copper inner layers to copper plating. Without sufficient plasma treatment, internal layer copper features receive inadequate polymer removal which results in circuit discontinuity during the plating process. Additionally, the plasma serves to "roughen" the polymer wall of drilled holes which improves copper adhesion. To ensure proper plasma treatment, careful adherence to strict production guidelines is essential. These guidelines include attention to several critical criteria in placement, pretreatment and treatment of the PWBs during the plasma process; process verification via post plasma testing; and careful process monitoring throughout. In this brief, some guidelines for process monitoring and control will be discussed. A description of a new plasma monitor utilizing optical emission spectroscopy (OES), developed cooperatively between Sandia National Laboratories, National Consortium for Manufacturing Sciences (NCMS) and Texas Instruments Inc., will be discussed along with possible benefits derived from *in situ* monitoring of plasma systems.

# Background

Plasma treatment has been used throughout industry for various ends, including surface cleaning, roughening, and activation; film deposition; and patterning. In most arenas, the plasma portion of an overall production procedure is difficult to control or predict. Therefore, plasma processes are often under-utilized or only used in less critical applications.

In the PWB industry, plasma etchback and desmear are extremely critical steps in a carefully monitored and controlled production environment. Customers, such as the Defense Department, sometimes require very secure electrical connections to internal copper layers. In those applications, the military specification is a minimum polymer etchback of 0.02 mils; anything less is not acceptable. However, too much polymer removal can result in serious plating problems such as plating voids, solution entrapment and exposed fibers. The military sets a limit of 3 mils maximum. Commercial customers also require reliable internal connections. Although not as tightly controlled as in military applications, commercial customers generally prefer etchback of polymers to depths of 0.01 mils to guarantee complete desmear of all the exposed internal copper features. A consistent plasma process is essential in obtaining good electrical connections. For this reason, careful attention to detail must be maintained throughout the production process of plasma cleaning.

To date, plasma process control has occurred using production controls, i.e., PWB handling before and during plasma treatment, precise plasma chemistries, and process parameters . Post plasma testing for quality control is normally accomplished using weight loss coupons placed strategically throughout the plasma chamber and post-process microsectioning. With destructive testing, some portion of a production lot will be destroyed for optical inspection to ensure the quality of the remaining set.

Because of the non-uniform nature of plasma reactors and the plasma environment, occasionally weight loss coupons or post-plasma inspection yields inadequate or misleading information. Although this is a rare occurrence, misinformation obtained from these methods can lead to further processing of substandard product or product rework. Product rework or further processing of improperly plasma cleaned product is costly.

Ideally, a technique to monitor plasma progress in situ could allow for error detection and correction to occur before any product has been damaged by inadequate or overly aggressive plasma treatment. It is towards this end that the concept for and the invention of the OES plasma monitor is aimed. By monitoring the plasma health and progress, decisions can be made regarding plasma gas mixtures, pressures, powers, etc. that allow for a more uniform system without the need for post-plasma examination. A monitor of this type can also allow for automation of the plasma phase of production in the future.

## Plasma Etchback and Desmear Operations

Plasma etchback and desmear operations are performed in a capacitively coupled, or parallel plate, reactor. In a reactor of this type, a series of parallel electrodes is used. The electrodes are positioned to form alternating ground potential and rf powered planes. The powered electrodes are at approximately 2500 Watts at a rf frequency of 13.56 MHz. PWBs are placed directly on these electrodes for plasma treatment.

For typical plasma etchback or desmear operations, carbon tetrafluoride ($CF_4$) and oxygen ($O_2$) are flowed through the chamber at reduced pressures at approximately a 2 to 1 ratio. The presence of the fluorine containing molecule in the plasma discharge enables the production of atomic oxygen which is the aggressive polymer attacker in systems of this type. By monitoring the etchback rate of a specific polymer while varying the percentage of $CF_4$ to $O_2$, one may optimize the etch rate for any given organic susceptible to oxygen attack. Depending on reactor geometry, product loading, available power, obtainable pressures, and other process-specific parameters, the overall performance of any given gas mixture may vary. For optimum results, it is suggested that a series of survey experiments be conducted prior to placing any new reactor in to service, to identify ideal operating parameters and limits.

Handling of the product before plasma treatment and during the plasma cycle is extremely important for maintaining quality and uniformity. Plasma etching performance is dramatically affected by environmental factors and condition of PWBs. For example, large variations in environmental humidity can severely reduce the performance of the plasma etchback or desmear operation. The amount of available water in the system can negatively impact the expected etch rate leading to inconsistent product from day to day. Likewise, improper handling can increase surface water contamination or cause high molecular weight oil deposits on PWBs prior to plasma treatment. Both types of surface contamination are harmful and can potentially result in poor plasma operation.

Oil residue, such as from fingerprints, locally slow the etchback process by presenting a barrier or mask to be overcome by the plasma before actual product etch can occur. To prevent contamination due to oil residue, caution must be taken to prevent unnecessary handling during production. Workers should limit direct contact with PWBs during assembly and any unavoidable contact should be performed with proper protective equipment such as gloves. Proper storage and handling of the PWBs prior to plasma processing will help reduce cross-contamination from external sources.

Surface water contamination is increased by exposing PWBs to humid environments. To limit exposure, PWBs should be stored in dry areas away from high humidity locations. Also, processing of the PWBs should be performed within a timely manner without unnecessary delays between process steps. Although surface water contamination is unavoidable, proper handling can reduce unnecessary water absorption.

To eliminate the effects of all unavoidable water contamination, pretreatment before plasma treatment is necessary. The PWBs must be baked to remove the water before effective, predictable and uniform plasma cleaning can occur. Industry uses two methods to help drive off water.

A prebake in a separate oven before plasma treatment at approximately 225° F for a period of an hour or more can drive off excess water. However, without vacuum assistance, water comes off more slowly and drying times may vary. Another consideration is the transport between the oven and the plasma reactor. When transport through air is necessary, some water pick up is expected. The boards must be transported as quickly as possible and should be at or near the bake temperature during travel and subsequent loading into the plasma reactor. If the PWBs are transported in a timely fashion while still at an extreme temperature, additional water pick up will be minimized. One consideration for this type of pretreatment is the safety issue of handling hot boards between oven unloading and reactor loading. Severe burns can occur if operators are not familiar with proper handling techniques or appropriate safety equipment.

A second method for water removal is a vacuum bake in the plasma reactor. The reactor plates can be retrofitted to accommodate heating elements. By evacuating the chamber to normal operating pressure and heating the electrodes and PWBs to approximately 180° F, water contamination can be successfully removed in 20 minutes or less. Furthermore, since the operation is performed within the plasma reactor, no further water pickup can occur if the reactor is not opened prior to the plasma cycle. If the PWBs are repositioned mid-cycle for more uniform etch, as is standard procedure in many plasma processes, additional baking may be necessary to eliminate any water contamination that may occur at that time.

Plasma systems are typically non-uniform. Reactor geometry, number and type of PWBs in the system, and inherent plasma non-uniformities such as the boundary sheath region, all affect the uniformity of the plasma processing. The effects of this non-uniformity can be minimized by holding load size consistant and by adjusting the load at mid-cycle. By varying the load size and type, charged regions build in an unpredictable manner. By always using the same amount of exposed polymer (number of holes and thickness of panel) and type of polymer (i.e., epoxy, polyimide), the effects due to non-uniformity can be predicted and controlled. To accommodate loads of varying size, filler boards may need to be used. A filler panel, also referred to as a dummy panel, is a PWB of similar material with a known number of drilled thru-holes. By using filler panels along with actual product, consistant load sizes can be maintained.

Non-uniformity in the plasma can be predicted with the use of consistent load size. To minimize the effects of plasma non-uniformity, mid-cycle board adjustment is necessary. A typical plasma desmear and etchback operation is approximately an hour in length comprised of two 30 minute cycles. At the mid-point between the two cycles, the panels are unloaded from the system and reloaded in a different order. Depending on the reactor, the center set of electrodes may demonstrate a faster etch rate than those spaced farther from center. At mid-cycle, the operator may choose to exchange the panels from the top of the machine with those in the lower half. The panels may also be replaced in reverse order so that the board exposed to the center region of the discharge is now near the edge of the discharge. By repositioning the panels in this fashion, the average etch rate experienced by all panels is the same, resulting in a more uniform etch throughout the load. During the mid-cycle adjustment, filler panels are handled like any other product in the load and also repositioned within the system.

## Plasma Monitoring and Control

Occasionally, plasma processes fail to perform as expected. Often the cause can be directly traced back to the source upon inspection of the system or product after failure. Depleted gas cylinders, wrong feed gas, power supply failure, and air leak are some typical failure modes in which plasma performance may be affected. These occurrences can be easily identified and corrected, but often a load of PWBs is lost before the failure is detected. Occasionally a plasma etchback operation will fail for no discernible reason. These failures, although infrequent, are a costly source of lost product, and for the most part, the cause of these failures remains a mystery. A new technique for monitoring the plasma in situ makes decisions about plasma health, and takes corrective action when appropriate. In order to identify and eliminate all sources of plasma failure, survey scans of each plasma cycle are stored for future reference.

When monitoring plasma systems, one must take care not to perturb the plasma field by introducing a new variable into the complex plasma environment. Remote monitoring, external to the plasma reactor, is more desirable than a probe that resides in the plasma field. Optical emission spectroscopy (OES) is an excellent technique for remote monitoring. OES is a technique that examines the optical emission of the plasma discharge and separates the emission into its spectral components. Details of the plasma operation are provided by analyzing spectral components of normal plasma operation and comparing to those of abnormal plasma operation. By becoming familiar with normal plasma features, any deviation from normal can be readily identified. OES monitoring allows for real-time plasma diagnostics with resulting error identification and correction before product damage has occurred.

Sandia National Laboratories, in cooperation with NCMS and Texas Instruments, developed a tool to monitor plasma etchback and desmear operations. The monitor gains access to the plasma through a retrofitted view port on the reactor. A library of normal plasma conditions and known typical failures (gas failure, air leak, etc.) serves as a resource for the tool. In normal operation, the monitor continually takes spectra of current plasma conditions and compares them with the stored library spectra. If any failure is detected or any deviation from normal is observed, audible and visual alarms are activated alerting operators to an abnormal occurrence. A known failure is logged in a record file for future use. Also logged to the record file are data on all plasma cycles prior to the failed cycle. This will prove useful for product surety in the future. The tool is now capable of diagnosing common failures and taking some corrective actions. For example, if the monitor observes a reduction in process gas, it may choose to deselect the depleted cylinder via a solenoid valve and select a fresh cylinder as a replacement. This operation can take place within seconds, correcting the problem before product damage has occurred. The tool is equipped with a unit to address or receive information from 49 separate pieces of equipment. If desired, the unit can not only perform local corrective action but also page appropriate personnel to the reactor for more in-depth diagnosis and repair.

## Conclusions

Plasma etchback and desmear are critical steps in the fabrication of PWBs. To ensure product excellence, care must be taken to optimize the plasma process and to eliminate sources of inconsistent or non-uniform plasma results. Best performance parameters are individually derived for each type of reactor. Reactor performance can be adversely affected by environmental factors and by the condition of PWBs.

Panel handling prior to plasma processing and during mid-cycle board adjustment must be done with care and consistency. Water absorption is a serious problem and must be eliminated. Either prebake in a separate oven or vacuum bake in the plasma reactor can reduce the amount of water in the system. It is suggested that vacuum bake in the reactor is the better method for eliminating water since transport between oven and reactor can lead to recontamination.

Quality control is maintained through proper processing protocol and post-process testing. Currently the accepted method of testing is performed using weight loss coupons and post-process destructive testing. A new tool using OES has been developed to monitor plasma performance in situ and to correct problems as they occur before the product has been damaged.

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