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Plasma Process Control with Optical Emission Spectroscopy

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Abstract

Plasma processes for cleaning, etching and desmear of electronic components and printed wiring boards (PWB) are difficult to predict and control. Non-uniformity of most plasma processes and sensitivity to environmental changes make it difficult to maintain process stability from day to day. To assure plasma process performance, weight loss coupons or post-plasma destructive testing must be used. The problem with these techniques is that they are not real-time methods and do not allow for immediate diagnosis and process correction. These methods often require scrapping some fraction of a batch to insure the integrity of the rest. Since these methods verify a successful cycle with post-plasma diagnostics, poor test results often determine that a batch is substandard and the resulting parts unusable. Both of these methods are a costly part of the overall fabrication cost. A more efficient method of testing would allow for constant monitoring of plasma conditions and process control. Process failures should be detected before the parts being treated are damaged. Real time monitoring would allow for instantaneous corrections. Multiple site monitoring would allow for process mapping within one system or simultaneous monitoring of multiple systems. Optical emission spectroscopy conducted external to the plasma apparatus would allow for this sort of multifunctional analysis without perturbing the glow discharge. In this paper, optical emission spectroscopy for non-intrusive, *in situ* process control will be explored. A discussion of this technique as it applies towards process control, failure analysis and endpoint determination will be conducted. Methods for identifying process failures, progress and end of etch back and desmear processes will be discussed.

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Introduction

Plasma cleaning, etching and desmear processes are routinely used in the manufacture of PWBs and electronic components. Photoresist removal, plasma etch back for enhanced adhesion and desmear of drill-through holes are some necessary production processes. Non-uniform plasma field and process variation with each cycle require some method by which to test the integrity of the components treated. Most plasma users in industry rely on one of two common test methods. Many users incorporate both techniques into their quality control procedure.

One test method is monitoring the material removed from one or more weight loss coupons placed in the plasma chamber during the cycle. The coupons are placed in the areas in which average plasma performance is expected and the success or failure of the run is based upon whether the amount of material removed fall within some range of acceptable values (based on data from past plasma performance). The difficulty with this method is that if the coupons reveal some abnormality, often the run and all components within the run must either be scrapped or undergo more rigorous testing before being accepted or failed. Further testing is costly and time consuming. If the parts are rejected, either based on the weight loss value or on the results of the postmortem inspection, enormous cost can be incurred and a delay in production is likely. Another disadvantage of this method is the lack of reliability of data obtained from the weight loss coupons. Plasma fields are extremely sensitive to small variations from cycle to cycle. Chamber cleanliness, chamber temperature, sample number, sample placement and relative humidity are only a few factors that may effect process performance on any given day. Predicting the areas in which to sample plasma performance via weight loss coupons may be difficult if not impossible. By misplacing coupons, data may indicate a failure when none has occurred. What is more important, data may also indicate that the cycle performance falls within guidelines when in fact, the parts are substandard.

Another test method is destructive testing of a fraction of parts from each run. With this method, some number of parts is removed and examined for plasma performance. Many of the problems experienced with the weight-loss coupon method of testing are similar to the problems encountered with this method. A batch is accepted or rejected based on post-plasma results; again, this is

costly and time consuming. Poor selection of parts to test may yield false positive or negative results leading to scrapping of acceptable parts or passing of substandard products. Since some portion of parts is sacrificed for testing, the overall cost per part is increased to cover the expenses of a reduced yield. A test method that could indicate process failure as it occurs, before damage to the parts has occured, would allow for correction of the problem, salvage of the parts and less down time. A system that could monitor several areas of the plasma for performance mapping would be a useful tool for plasma users.

In the past, various methods for plasma monitoring have been studied. One method that has been investigated is optical emission spectroscopy. With market-available equipment equipment (a monochrometer, spectrometer or CCD camera), one may observe and identify what species are present in a glow discharge. In a cleaning process, the spectral peaks of the contaminant can be isolated from the cleaning gasses. By identifying and monitoring the peaks due to the contaminant, the process can be monitored for an endpoint, when all contaminant has been removed. This is a relatively straight-forward process. A reference set of spectra may be obtained by recording the emission of the cleaning gasses without any sample present and then compared to the emission observed when the contaminated samples are present. The differences observed are due to the presence of the contaminant in the plasma. When the plasma has consumed the contaminant, these differences no longer exist and an endpoint is determined. If the samples are themselves consumable, such as polymers, the reference spectra should be accumulated with clean samples present and then compared to the spectra of dirty samples. Another advantage to this process is the ability to accumulate spectra from known failure modes such as incorrect gas mixture, air leak, etc., and then to store those spectra as a reference library. With a spectrophotometer linked to a computer; system monitoring, diagnostics, and automatic self-correction or shutdown could occur, allowing for a fully automated system. The spectra can be accumulated through a quartz window or from inside the chamber via fiber optics. By utilizing a multiple fiber optic cable several areas withn a single system or multiple systems can be monitored. This is not a novel approach. Since the contaminant is foreign to the sample, it is easily determined when it is no longer present in the system. Optical emission spectroscopy has been used for this purpose for many years.

Optical monitoring of plasma etching and desmear is not as easily accomplished. Since the material being removed is part of the sample and not a contaminant such as grease, oil or photoresist, no easily identifiable endpoint can be obtained. Spectral peaks due to the material being removed will always be present as long as the samples are present. Process monitoring for system failures such as air leaks or wrong gas mixture can still be performed by accumulating spectra during a successful cycle and comparing it to spectra of subsequent cycles, but endpoint determination has been thought impossible.

To define an endpoint for a plasma etching or desmear operation through optical emission spectroscopy, some aspect of the plasma would have to be changing with time (more or less of the etchant gasses would be consumed or more or less of the etch product would be present). If these phenomena were occurring and detectable, a comparison to etch rate with plasma event could be made and some estimate of endpoint could be predicted. The difficulty with such an approach is that these time related events rarely occur and are not trivial to detect and identify. An endpoint indicator that would rely on such events would have to be uniquely derived for each desmear or plasma etch process. This is a long and time-intensive process but the potential advantage of greater process control and product reliability justifies the endeavor.

Discussion

In a recent study, in cooperation with National Center for Manufacturing Sciences (NCMS), plasma desmear and etch back of PWBs have been the focus of an investigation to identify an endpoint using optical emission spectroscopy. The spectra of various types of PWBs were recorded and monitored with time. The PWBs were treated in a typical CF_4/O_2 etching plasma at an approximately 2:1 ratio as per the instructions of the industrial partners. Cycle times were extended up to 80 hours to observe the relative peaks of interest over a prolonged time. The behavior of the etchant gas as well as etch products were compared throughout the run. Postmortems of samples were observed afterwards to insure that the data accumulated were for average cycles with expected etch rates. Careful inspection of the accumulated spectra revealed a time-related behavior at 325 nm and 333 nm. The peaks observed at

these wavelengths appeared to change intensity relative to each other throughout the cycle in an oscillating fashion (figure 1). The period of these oscillations is not regular, but appears to decrease in frequency with time. The peaks are primarily due to the etchant gasses and are present in the spectra when there is no sample present. However, their intensity does not change with time. These two peaks only begin to toggle when samples are being etched in the chamber. This phenomenon was observed both in the laboratory with a markedly scaled down plasma apparatus and in a production facility on an industrial plasma treater. Efforts are in progress to correlate etch rate with peak oscillation by comparing real-time spectra with test coupons.

The most intriguing question is by what mechanism could an oscillatory behavior of spectral peaks occur when etch gas and etch product should be a constant. One explanation may be that the plasma may be encountering some mechanical barrier so that, from time to time, etch rate is slowed until the barrier is overcome. The barrier in this scenario may be the glass fiber micro-weave fabric used within the interlayers of the PWBs. The PWBs are constructed of alternating layers of copper sheet and epoxy filled glass fabric (figure 2). The voids between the warp and weave of the fabric form relatively large pockets of epoxy which are easily removed by the plasma (figure 3). As these pockets of epoxy become depleted, the plasma is primarily exposed to the glass fibers which do not etch and become a barrier. These barriers are not impenetrable to the plasma. Even though the large pocket of epoxy has been removed, the adjacent pockets of epoxy are now exposed by a small gap in the glass fabric caused by one fiber being laid across another. The plasma etching process has been slowed but not halted. As the plasma opens the gap between fibers by etching away the epoxy that seals it, again a large pocket of epoxy is revealed and the etch process continues at a faster rate, and so the process continues. With each barrier the plasma overcomes, the path through which the plasma must travel becomes longer and more geometrically complex, slowing the processes with time. This may explain why the period of oscillation seems to decrease in frequency with time.

Summary

The benefits of identifying the end of a plasma process, prescribing the amount of material to etch back or identifying and correcting failures are obvious. In this competitive age, industry needs to work faster more efficiently. Post-process testing to insure that a part is acceptable is time consuming and costly. In situ testing for process integrity and immediate adjustment to process when an error has been detected is far more preferable. End point determination of cleaning processes and known failure analysis is relatively easy to perform and require little to implement. Identifying spectral clues for endpoints of processes such as plasma etching or desmear is more difficult. The cost for this sort of study is high, but the potential payoff is enormous with fewer failed parts and greater process reliability. For every process of this nature, many hours of spectral analysis must be conducted with no guarantee of success. It is promising however that of the several types of PWBs examined to date, all have shown some time related behavior.

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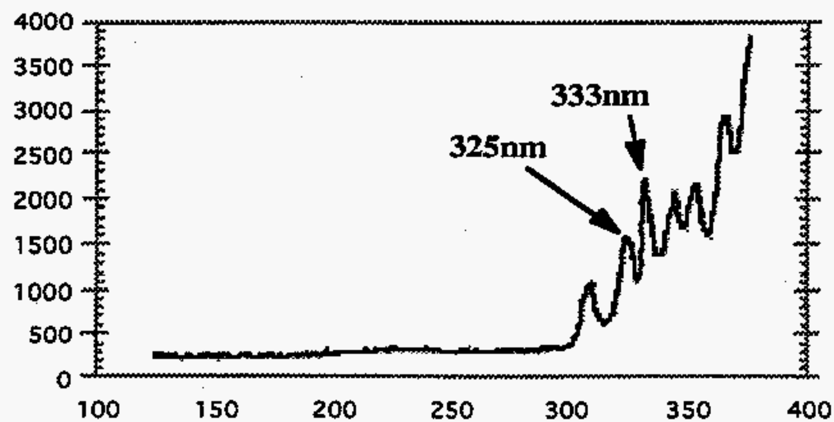
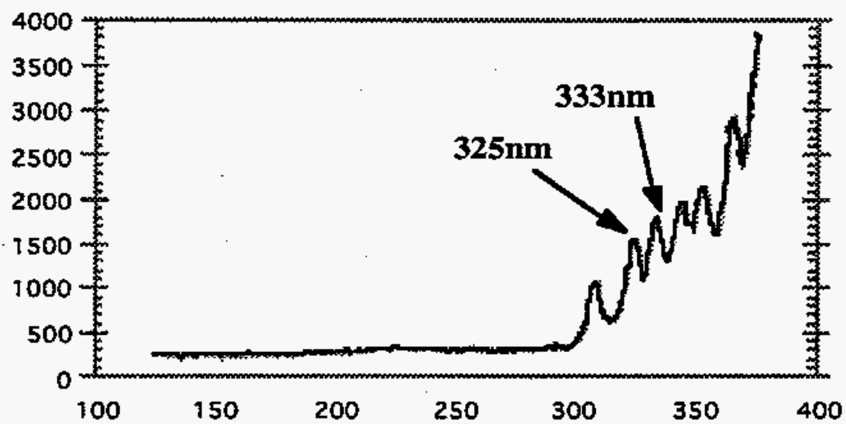
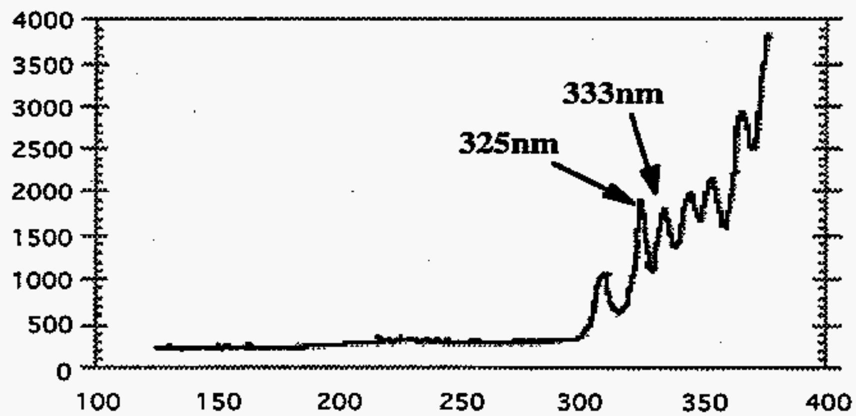
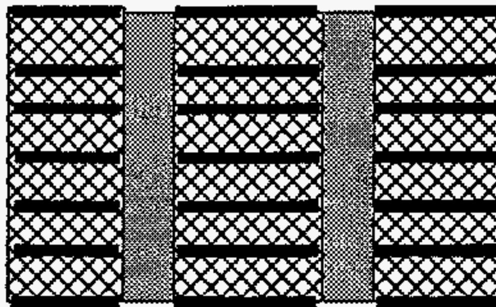






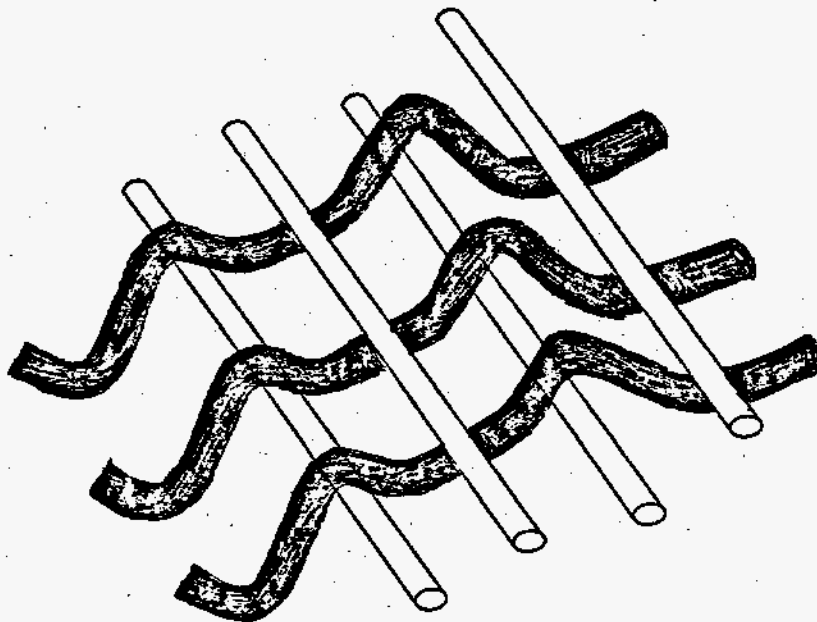
Variation in Relative Peak Height

Figure 1



Multilayered Printed Wiring Board

Figure 2



Voids Between Warp and Weave in Glass Fabric

Figure 3