High Uniformity PCB Processing with Vacuum Gas Plasma

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Abstract
Emerging technologies in the printed circuit board industry including smaller holes, higher aspect ratios, three-dimensional features, fine pitch, blind via holes, and new lead free materials continue to challenge standard manufacturing methods. With these new technologies, plasma has become the chosen method for cleaning carbon/resin from laser formed blind vias, treatment of flex materials prior to lamination and etching lead-free materials and composite material constructions. The processing demand of these technologies has required improvements to the vacuum gas plasma process often used for desmear applications. Additional requirements including processing the high value product at a lower cost per panel are directly opposed to this new performance expectation. The new technology requirements translate directly to improved uniformity specifications for the plasma system, where the high value lower cost proposition drive cost of ownership and equipment configuration specifications. New plasma technology is required to meet the technology and cost demands. This paper describes one aspect of the technology development critical for improved uniformity.

Introduction
Although plasma meets the current requirements for leading edge PCB manufacturing, challenges due to shrinking geometries and new materials are driving the performance expectations of the plasma technology. For example, High Density Interconnect (HDI) panels can be a challenge due to the varied thickness of resin and carbon left on the blind via capture pad on one or both sides of the panel following laser ablation. The plasma process must uniformly remove the residue from the capture pad without promoting outer layer undercut. In flex panel PCB assembly different material types are typically used, including unsupported polyimide and adhesives to laminate. These different materials etch at different rates within the plasma system. The plasma process must be capable of desmearing uniformly to prevent areas that would create plating folds. New lead free materials also present a challenge for plasma due to the variance in drill smear as a result of these material's high decomposition temperatures and chemical resistance. The plasma must etch in a controlled manner to minimize the effect of the non-uniform drill smear. Additionally, as circuit pitch continues to get finer, photoresist residue is a more significant factor. Plasma treatment must be controlled to ensure removing the photoresist scum without risking lifting the fine line resist. Since plasma is done as a batch process the challenge is for equivalent desmear results within every panel and from panel to panel. Plasma tools must now be designed with fundamentals that take into consideration the process control variables such as power, pressure, chemistry, and time as well as the plasma system hardware configuration.

Key hardware components of a vacuum based plasma system include the Electrode System which includes all electrical components required to generate a plasma; the plasma source Gas Delivery and Distribution System which determines the chemistry and efficiency for the plasma process; the Vacuum System which distributes the plasma and maintains the low pressure environment; and the Temperature Control System which ensures uniform plasma treatment within a panel and from panel to panel. These are the critical components for achieving maximum uniformity without sacrificing etch rate for the advanced technology PCB applications.

Experimental
A design of experiments was conducted at March Plasma Systems to determine the impact that these new hardware components have on plasma uniformity. The relative performance of these hardware improvements was determined by comparing the etch rate and uniformity of the new technology to a commercially available plasma treatment system. Enhancements included **an Electrode System** for creating uniform gas ionization; a modified **Gas Delivery and Distribution System** for gas management within each processing cell and a **Vacuum System** to control the plasma distribution. Each of the hardware improvements was studied by both weight loss and microsections of mechanically drilled through holes. The experiments were done on materials and panel construction that represents typical PCB's manufactured today.

Test Vehicles:

A) Microsection Coupons: These samples represent a 10 layer board, 0.080” thick, with polyimide material, 1 and 2 ounce copper, and 0.032"diameter holes. (See Figure 1)
B) Weight Loss Coupons: 3”x 3” epoxy solder masked FR4.

All the experiments were done with the coupons in the same location. This allowed profiling of each individual cell by collecting data from the 4 corners and the center of each cell. The chamber was profiled by loading test vehicles in the right, center, and left cell of the plasma system. The remaining cells were filled with dummies to represent a full load (See Figure 2).

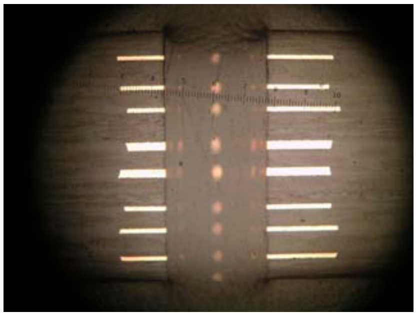

Figure 1: Test Vehicle Microsection

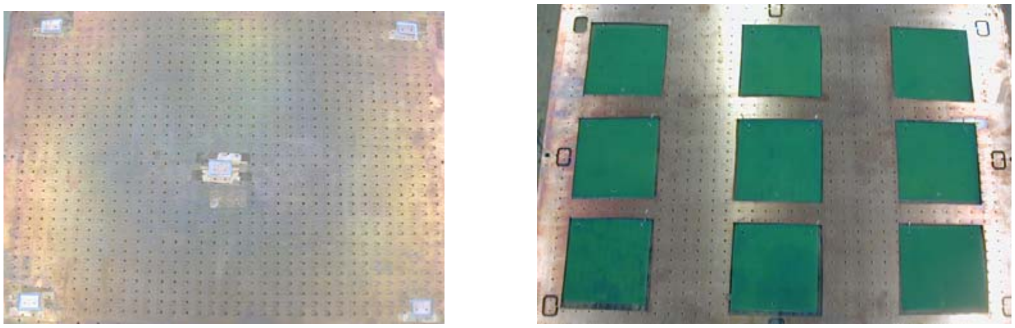

Figure 2: Microsection (Left Picture) and Weight Loss Fixture (Right)

Process conditions

The process conditions including power, pressure, gas chemistry, and process time throughout the evaluation were held constant. In all cases the test vehicles were exposed to an initial pre-heated process segment to ensure that all the samples were at a minimum etch temperature, a second process segment which is the etch step and a final step that removes residual byproducts from the plasma.

Electrode System

The Electrode System consists of the physical electrodes utilized to conduct the applied radio frequency energy to the source gas to generate the plasma, the RF generator, and the electrical bussing. The electrodes must be capable of operating in a direct plasma environment at accelerating and decelerating RF powers. The electrodes specifically are the delivery source of RF energy that ionizes the gas and gives it an electrical charge. It is the creation of the ions and subsequent electrons that allows for conduction and maintains the plasma discharge. The electrodes are also the source of heat, critical for reaching optimum material temperature for etching.

Since electrodes are the key factor in delivering the RF energy to the gas it is also recognized that the greatest etch occurs directly in front of them. Standard commercially available electrode configurations have spaces to allow gas to flow from cell to cell; as a result the open areas have the potential to etch less. To understand the impact of this decision a comparison was made between a set of standard electrodes (which have spaces to allow gas flow) and a set of electrodes without gas channels. The goal was to determine if the etch rate in standard electrodes would effect the uniformity due to the spaces where gas ionization is less and further determine if an any improvement in uniformity is observed without the gas channels. As described previously, all comparisons were made by evaluating the microsection and weight loss data.

The data indicated that the open gas channels do have an effect on the overall uniformity within a processing cell or across individual panel. The standard electrodes had less etch in the areas where the gas channel is located. The enhanced electrode system yielded improved etch uniformity within a processing cell (See Figure 3). This is observations is due to the design of the enhanced electrode where there is no open areas in the electrode which allows for more even distribution of RF potential to the whole electrode. As a result the entire panel sees the same plasma energy which is essential for uniformity. Electrodes with no spaces also create isolation so the plasma within the cell is more active. Comparing the left, right, and center cell data, it is shown that the enhanced electrode allows for improved uniformity from cell to cell when compared to the standard system as displayed in Figure 3. Additionally, the enhanced electrodes generate more heat which is good for warming the panel quicker. This has an advantage when considering throughput but creates a challenge when considering temperature control and its effect on etch uniformity. Temperature control is discussed in detail as a separate section in this paper.

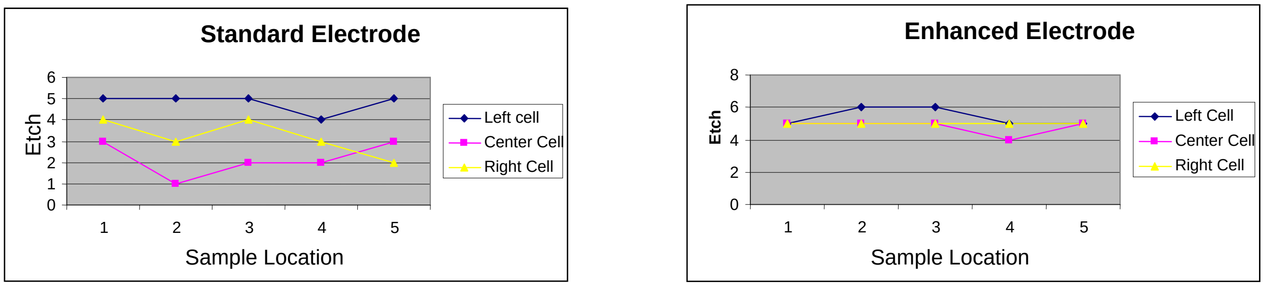

Figure 3: Etch Results Standard versus Enhanced Electrode

Gas Delivery and Distribution System

The gas system is responsible for efficient distribution of the process gas within the vacuum chamber. It regulates where the gas enters and floods the chamber. The distribution determines how much gas is delivered into each cell (between electrodes) and how well it remains active from entry point to exit. The local concentration determines the local etch rate and consequently the uniformity. The gas flow direction is the movement of the gas across the chamber. The direction of gas flow is in relationship to the panel and drilled holes. It must have the capability to travel through holes in a parallel or perpendicular plane. It is the critical component that allows gas to flow through small diameter holes in printed circuit board panels.

The process gas type determines the chemical reaction that occurs in the plasma environment. It is this process gas that once exposed to the applied energy gets ionized and dissociated creating physical and chemical reactive components. Process cells that are rich in reactive gases will etch faster than cells that are starved. Efficient and controlled gas delivery is critical for uniform etching in batch based processing systems. The gas has to travel through the cells and the holes in each panel equally to maintain high uniformity processing.

Evaluating the gas distribution involved creating a gas manifold to direct the gas into each of the individual cells. This is the basis of making sure there is equally active gas in each cell. The experiment compared traditional designs where the gas has one inlet or a main manifold at the opposite end of the exhaust to a new design where there is an injection of gas into each cell. Each of these configurations are depicted in Figure 4. The results showed that by introducing the gas into each individual cell there was better control in overall gas distribution and etch and improved uniformity (See Figure 5). This is due not only to having a controlled direction for the gas to flow but the manifold also allows the active gas to go directly into the cell before it becomes depleted. This experiment has shown that as one of the critical components gas distribution has a direct effect on the uniformity and etch rate in a plasma process.

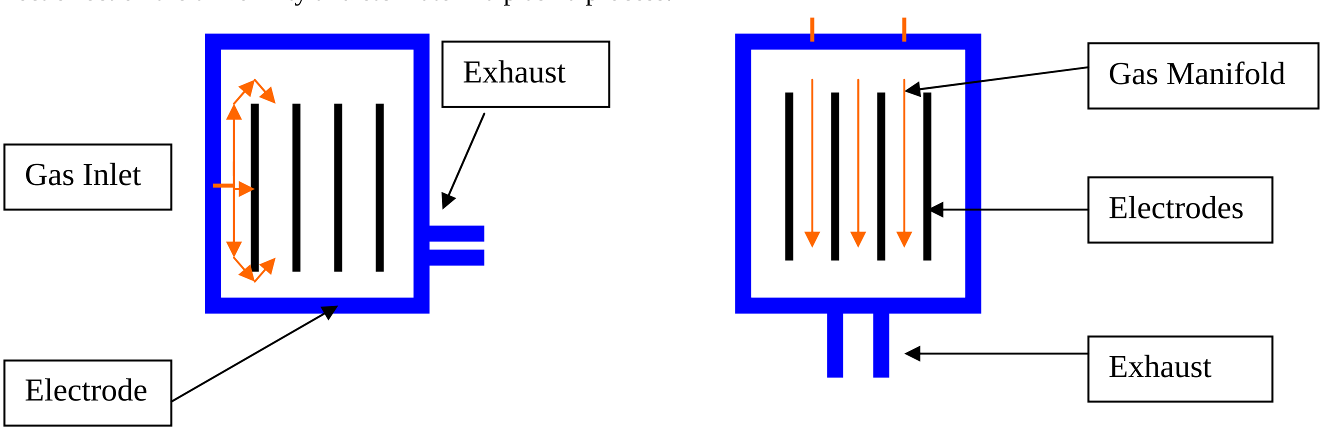

Figure 4 Gas Manifold: Standard (Left) versus Manifold (Right) Gas Distribution

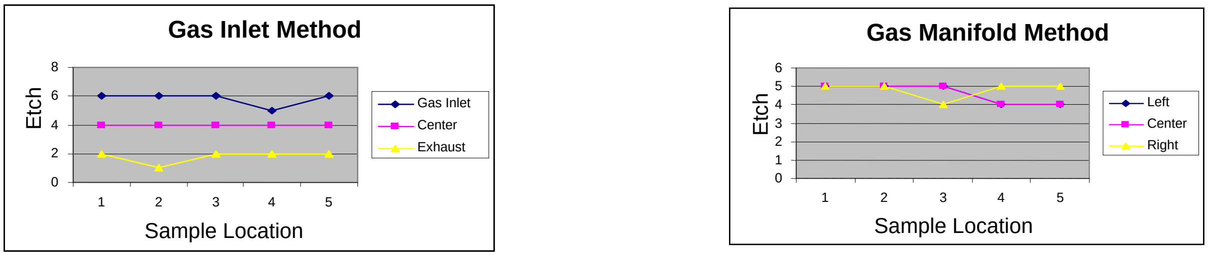

Figure 5: Etch Uniformity Standard Gas versus Manifold

Gas flow works in conjunction with gas distribution. Once the process gas has been distributed into each cell it must have the ability to flow to all areas of the cell equally. With the use of a gas manifold and one exhaust the flow has to be delivered to all the cells while maintaining equivalent concentrations of the active gas. The gas activity at the entry point of the cell must be equal to the exit point. Without this type of control the results will display non-uniform etch within a cell. The flow must also be able to accommodate etch in a parallel and perpendicular axis. When gas is designed to pass along the surface of a panel and not directly through the drilled holes, there has to be sufficient directional flow to etch in the holes. The pump and assist blower are the components that supply the flow rate required through each cell.

To evaluate the effects on gas flow in both the parallel and perpendicular axes, microsections were positioned in a cell with holes parallel and perpendicular to the gas flow (See Figure 6). The results showed that with controlled gas flow from the pump package, gas can flow into a cell and etch through a hole that is in a parallel plane relative to the gas flow direction. It also demonstrates that with a contained cell created by the enhanced electrodes the gas has more ability to fill the cell and etch in three dimensional planes (See Figure 7). This experiment has shown that gas flow control is one of the critical components in achieving uniform etch by ensuring that the gas is distributed evenly within the cell and from cell to cell.

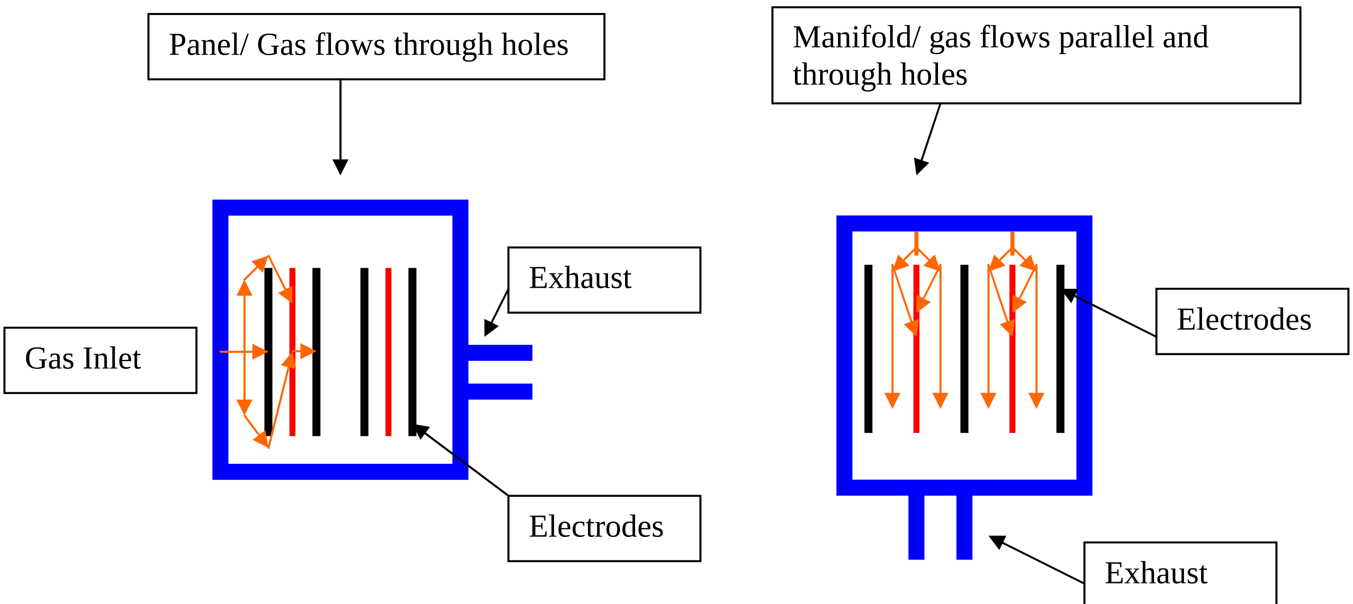

Figure 6: Gas Flow Direction

Figure 7: Gas Direction Effect - Gas Flow Through Via (Left) vs. Gas Parallel to Via (Right)

Vacuum System

The Vacuum System is responsible for maintaining the process pressure and ensuring that the chamber volume is swept of process exhausts. The exhaust also directs the flow of gas from the inlet to outlet of the chamber. This is critical in determining a uniform pattern of etch in all the panels of a load.

The exhaust directs the path of gas flow in the chamber from the gas inlet to the exhaust port. Thus all the gas entering into the chamber is drawn to the exhaust location. Directional flow to a single point robs active gas from other areas in the chamber. As a result there is different etch rates in the electrode cells. Having a gas manifold that delivers gas into each cell is not effective if the exhaust does not distribute the gas evenly. In order to maintain the path of gas flow that the gas manifold creates there must be exhaust control. Exhaust control forces the gas away from a single point ensuring that all electrode cells are exposed to an equivalent amount of process gas. This allows an even amount of active gas from the manifold to flow through each cell and yield a uniform etch rate.

Experiments were conducted to determine how the exhaust dictates the location of the etch within the chamber. First, etch uniformity was evaluated using one exhaust where all the gas was directed to a single point (See Figure 8). The results showed that the panel in front of the exhaust had the greatest etch. This result is due to all the gas being pulled from the gas manifold away from the cells where it was introduced to the single point exhaust. In the second experiment a diffusion plate was placed at the bottom of the chamber above the exhaust port (See Figure 8). This forced the gas to be directed away from the single point and exhaust around the perimeter of the chamber. Implementing an exhaust diffusion showed that the etch uniformity improved from cell to cell throughout the chamber (See Figure 9).

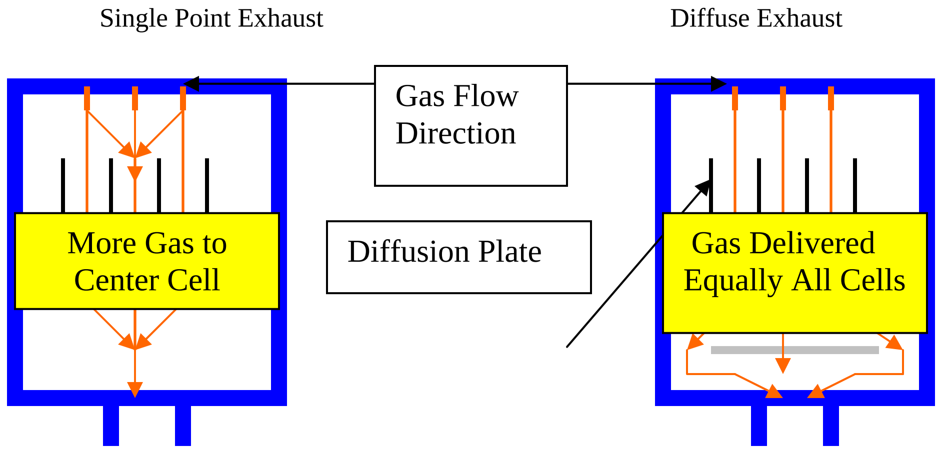

Figure 8: Exhaust System

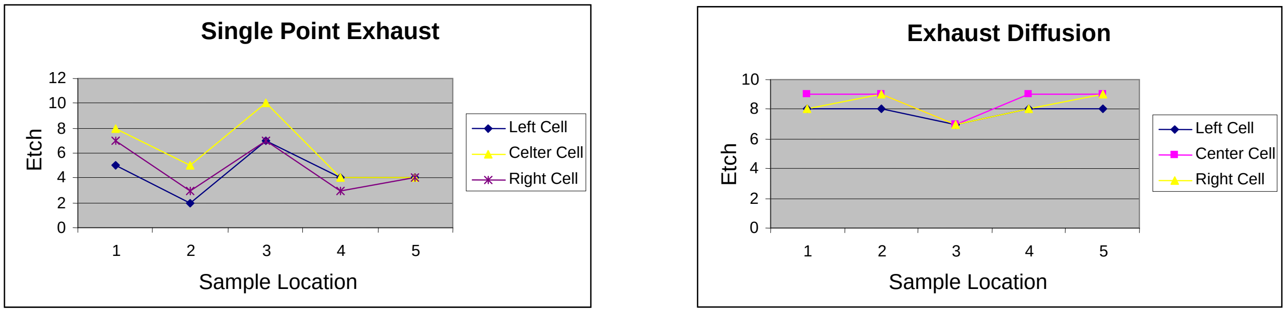

Figure 9: Single Point Exhaust versus Exhaust Diffusion System

Material Temperature Control

The Material Temperature Control System is responsible for creating and maintaining the optimum temperature for etching the PCB panel. Materials are constructed with a large range of glass transition temperatures (T_g) and as a result these materials have different etch characteristics. An optimum temperature for each material allows resin removal to be repeatable from lot to lot. Maintaining the proper temperature throughout the process prevents under or over etching.

The temperature of the material depicts the effectiveness of the process. For example if the material was to go through a plasma process without elevated temperature there would not be a significant chemical reaction and as a result there would be minimal non-uniform etch. Each resin system also has different temperatures where it etches fastest without causing hole wall problems such as wicking and gouging. Epoxies do best between 85°- 95°C, Polyimide at 95°-100°C and Modified Epoxies 100°-105C. In order to achieve the optimum etch rate these temperatures must be reached and maintained throughout the etch portion of the process.

The RF power is used to excite the gas which generates the reactive chemical components which drive the chemical reaction required to etch different resins. However it also provides the means to getting the material to temperature. Too low power and the material will not reach the temperature required to etch and too high power causes wicking and gouging. When the proper power is used the optimum temperature is reached and the results are a straight wall etch. As important as reaching the proper temperature is, holding it in the etch zone is as critical. This is where control is key to a successful process. The control must have the means of maintaining the temperature throughout the entire process. This means there has to be a method of temperature regulation that can turn on and off to regulate the optimum temperature. Continuous heating will cause over etching and continuous cooling will not yield enough etch.

Experiments were conducted to see how large an effect temperature had on etch rate and uniformity. Using coupons representing a 10 layer polyimide panel tests were run with the proper temperature control but with no warm up prior to the etch segment. In each case when the panel did not receive the proper heating etch was low. The cross sections displayed in Figure 10 show the effect of not heating the panel prior to the etch segment versus a successful heating regime. The tests run at the correct temperatures and controls met the etch requirements (See Figure 11). These experiments show that even with all the other critical plasma components at optimum without proper temperature control the etch uniformity is poor.

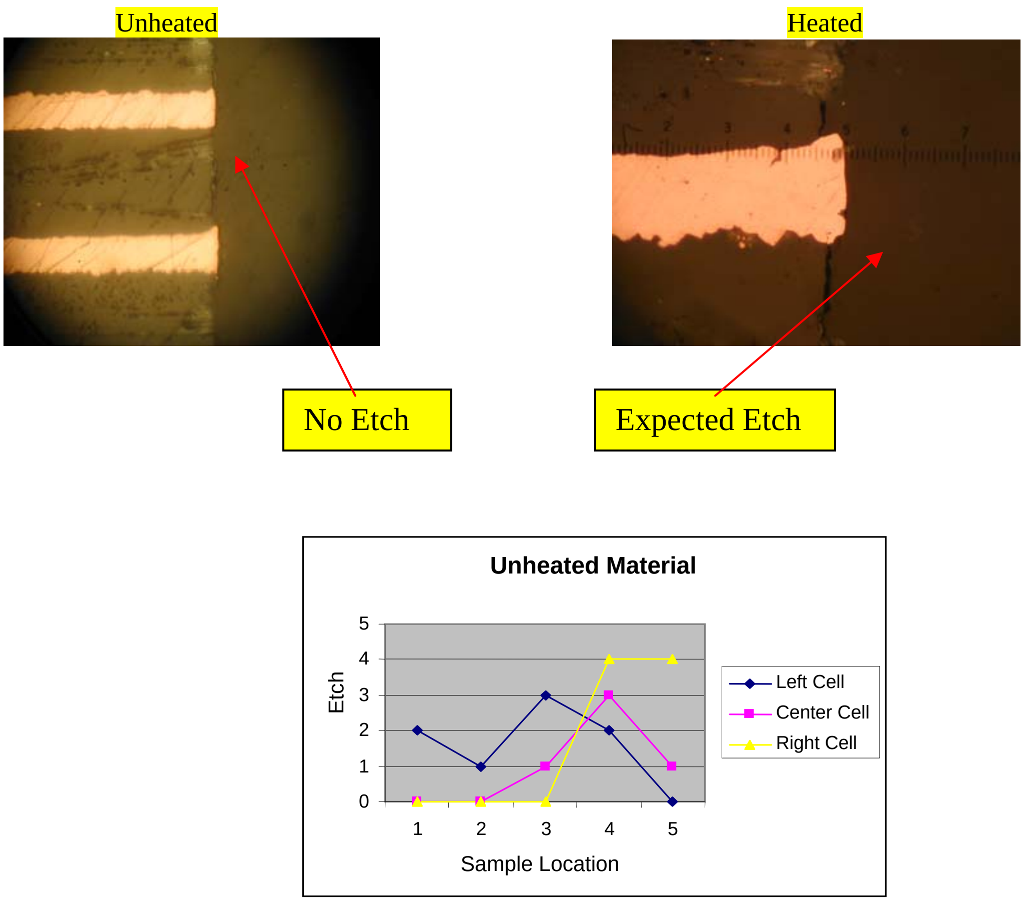

Figure 10: Cross Sections – Pre-Heat Effect

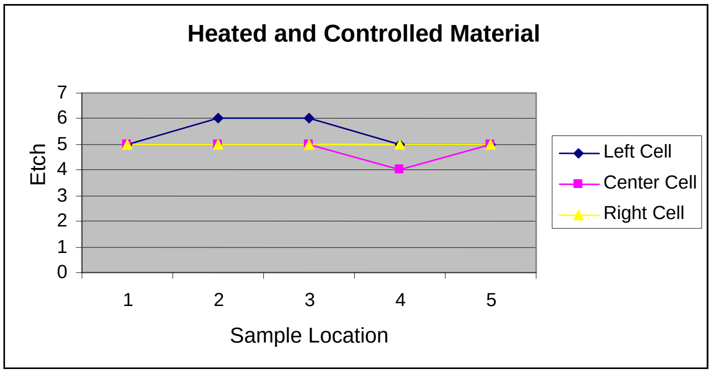

Figure 11: Etch Uniformity: Unheated vs. Temperature Controlled

Summary

Although there are many factors involved in producing a repeatable plasma process the most critical ones are the: Electrode System, Gas Delivery and Distribution System, Vacuum System, and Temperature Control. The experiments that were conducted showed how improvements made to each critical component over standard designs yielded better uniformity and etch. As the electronic industry continues to grow in emerging technologies plasma tools must move to a new level in design for uniformity, but must still meet etch rate requirements. Both must be able to meet more tightly written specifications. In a batch system such as a plasma tool the challenge is even greater because of the number of panels run at the same time. However taking into consideration all of the critical components when a system is designed the tighter requirements can be met and be repeatable.

High Uniformity PCB Plasma Processing

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High Uniformity PCB Plasma Processing

DRIVER

Electronic Devices

- Smaller Electronics
- More functions
- Thinner packages
- Flexible hinges

PCB Technology

- High Density Interconnect (HDI)
- Flexible Materials (FPC)
- Hybrid PCB’s

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Plasma Chosen Method

Drivers:

- Carbon/Resin in blind via's
- Flex material
- Lead Free Materials
- Combination Through and Blind holes

High Uniformity PCB Plasma Processing

PCB Emerging Technologies

- Smaller electronics
- More functions
- Thinner packages
- Flexible hinges

Leads To

- High Density Interconnect (HDI)
- Flexible Materials (FPC)
- Rigid and Flex Combined

Requires Better Plasma Performance
Etch and Uniformity

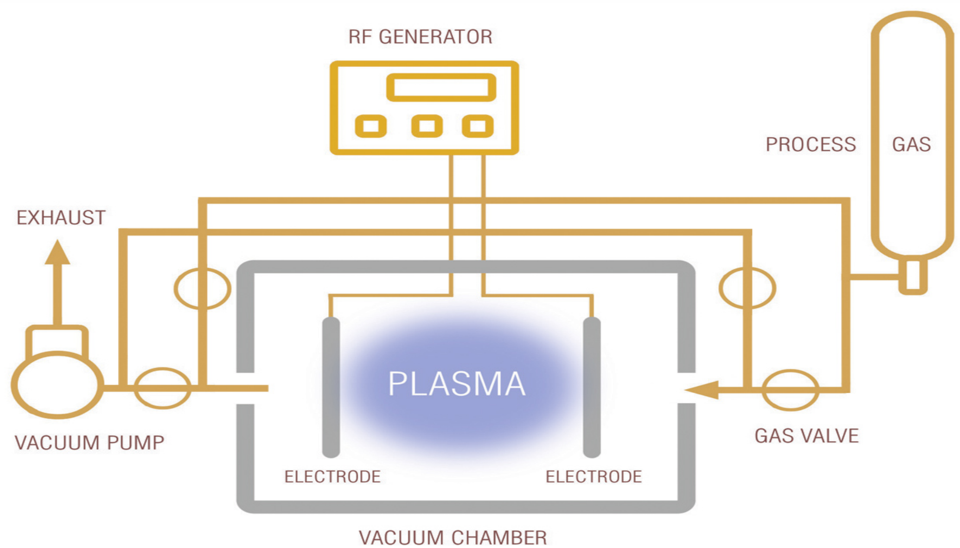
High Uniformity PCB Plasma Processing

Plasma Improvements

Design of Experiments Conducted at March Plasma Systems

Key Hardware Components

- Electrodes
- Gas Delivery
- Gas Distribution
- Vacuum System
- Temperature Control



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Hardware Improvements

- Studied by weight loss and microsection
- Experiments done with materials that represent typical PCB's Manufactured today

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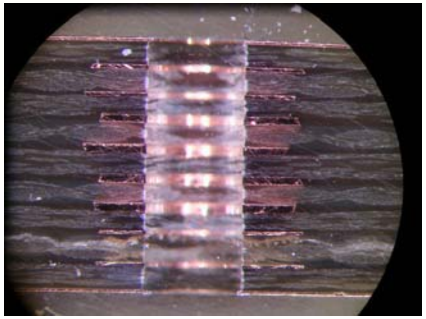
Studied By Weight Loss And Microsection



Microsectoin: Polyimide10 layers
0.080 thick, 1 and 2 oz Cu
0.032 dia holes

Weight Loss: FR4 0.021 thick
3”x3” Soldermask SR1010

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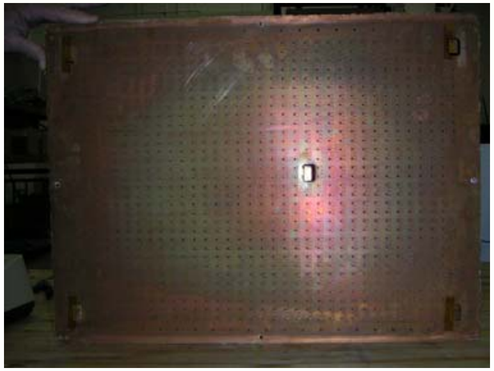
Experiment Constants

- Sample Location
- Cells Evaluated
- Process Conditions

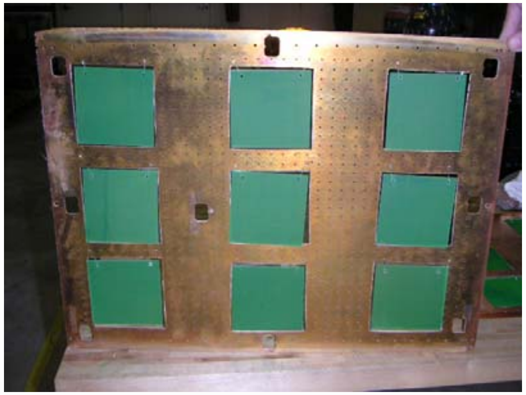
High Uniformity PCB Plasma Processing

Experiment Constants

Sample Location



Microsection 5 Locations:
Centers &Corners



Weight Loss 9 Locations:
3 Rows, Top Center & Bottom

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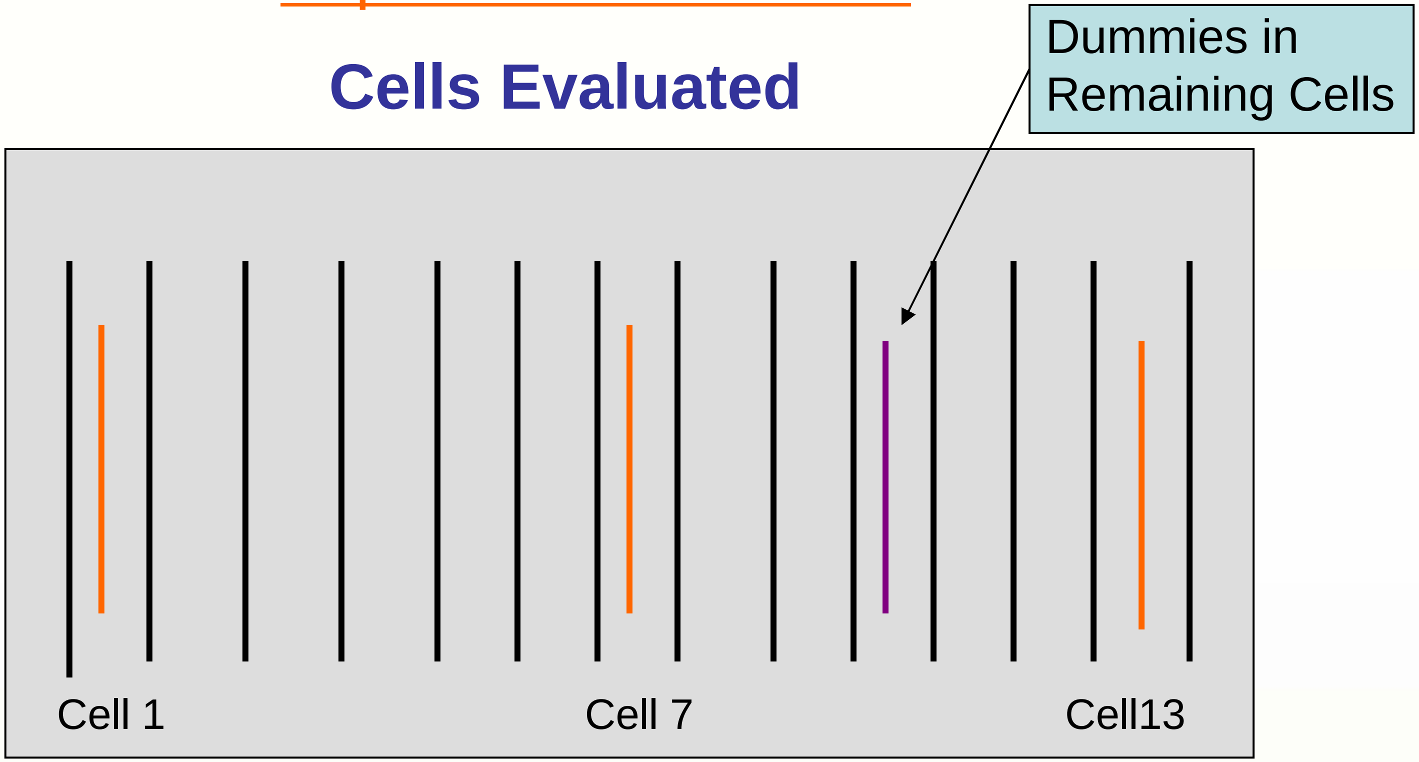
Experiment Constants

Cells Evaluated



High Uniformity PCB Plasma Processing

Experiment Constants

Process Conditions

1. Pre-heat segment to reach etch temperature
2. Power
3. Pressure
4. Gas Chemistries
5. Gas Flow

High Uniformity PCB Plasma Processing

The Experiments

First Evaluation:

Electrodes

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Experiments

Electrodes

- Delivery source of RF Energy
- Ionizes and electrically charges gas
- Source of heat for panel temperature

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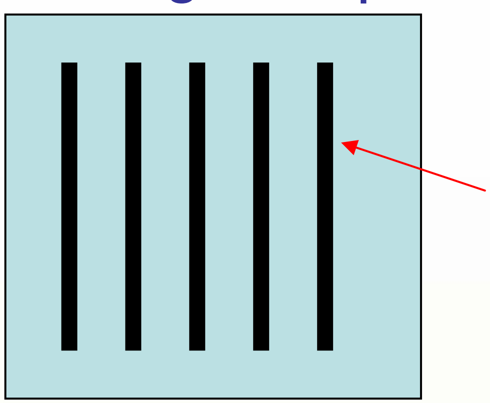
Experiments

Electrodes Configuration

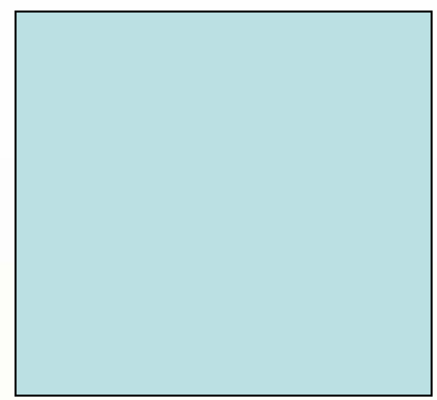
Standard Configuration
Picket Fence Style

- Space for gas to pass through



Enhanced Configuration

- No Spaces



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Experiment Goal

Electrodes

1. Standard electrodes less ionized gas in space
2. Does this equate to less etch and change uniformity
3. Are there improvements without gas channels

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Experiment Results

Electrodes

- Space in electrodes does effect cell and panel uniformity
- Standard electrodes less etch in gas channel areas
- Enhanced electrodes with no gas channels improved uniformity

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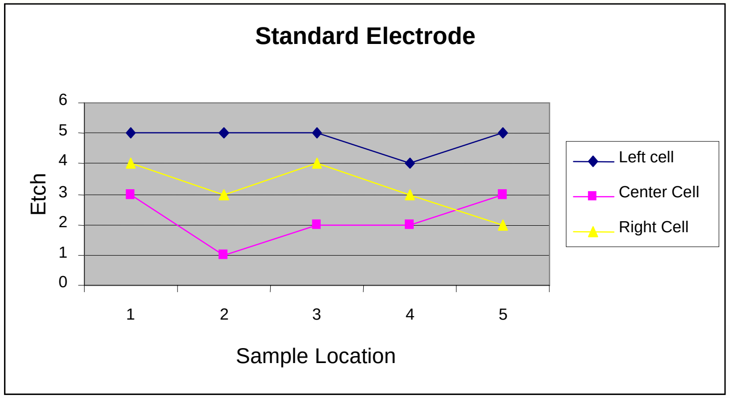
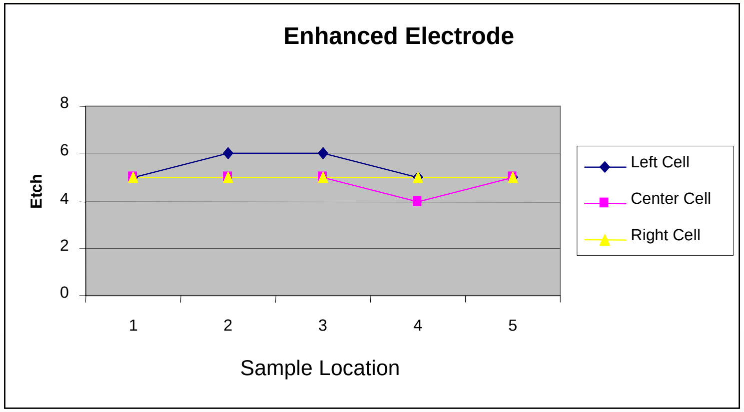
Experiment Results

Electrodes





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Experiment Summary

Electrodes

- Enhanced electrodes: no spaces provides same potential to entire electrode
- Ionized gas is uniform and more active within a cell
- Entire panel sees the same plasma
- Results in improved uniformity

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The Experiments

Second Evaluation:
Gas Delivery

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Experiments

Gas Delivery

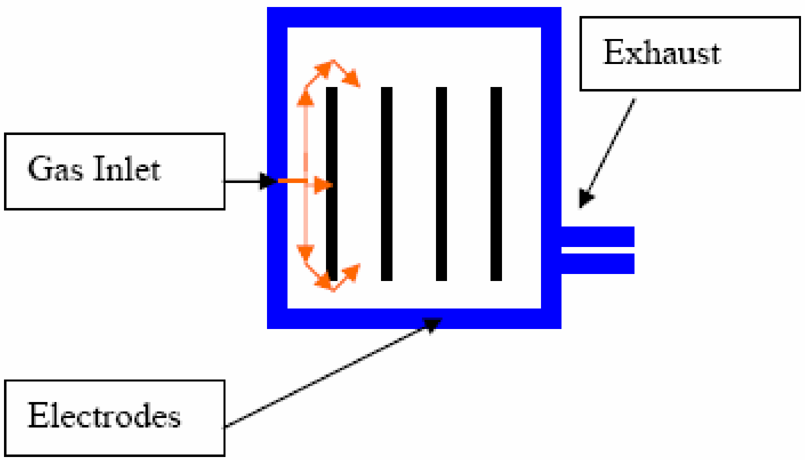
- Supplies sufficient process gas within the chamber
- Determines the distribution of gas into each cell

High Uniformity PCB Plasma Processing

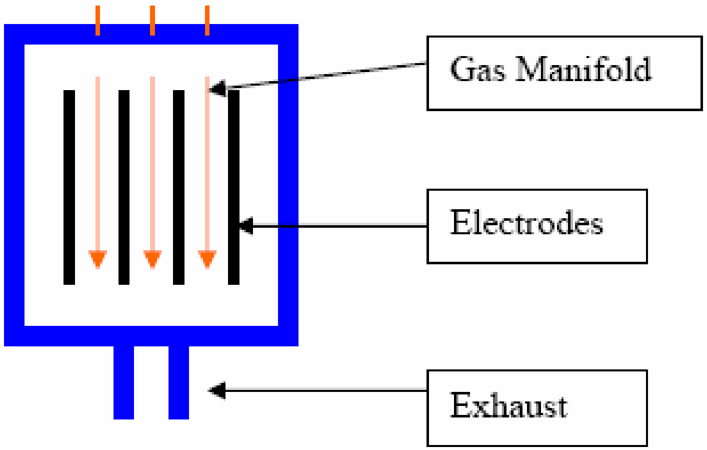
Experiments

Gas Delivery

Standard Configuration



Gas Manifold



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Experiment Goal

Gas Delivery

1. Standard gas deliveries have one inlet/manifold
2. Does the uniformity improve when the gas is injected into each cell

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Experiment Results

Gas Delivery

- Gas injection in each cell does improve the uniformity
- Active gas remains in cell before depletion
- Gas is directed to the product

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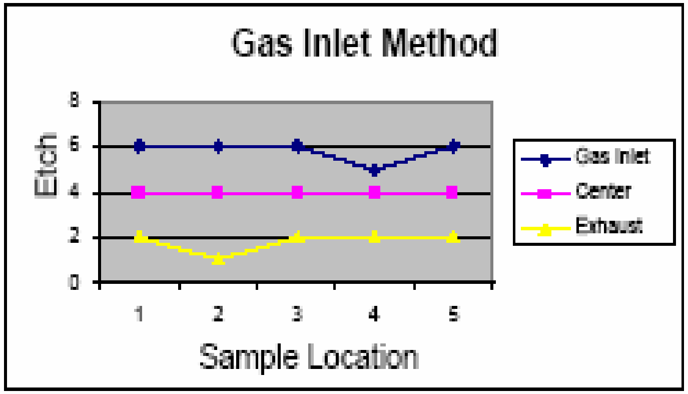
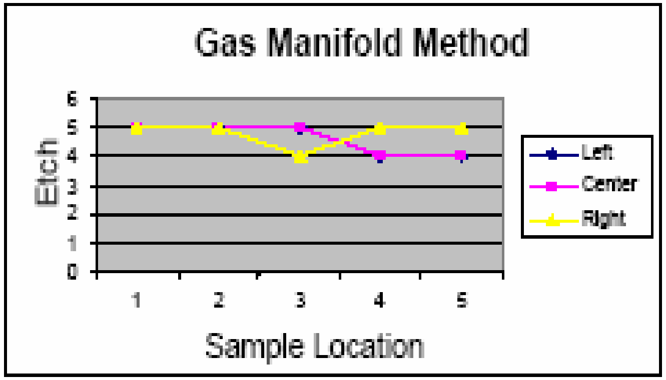
Experiment Results

Gas Delivery





High Uniformity PCB Plasma Processing

Experiment Summary

Gas Delivery

- Supplied the chamber with sufficient gas
- Gas amount controlled in each cell
- Process cells are rich with reactive gas
- Results in improved uniformity

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The Experiments

Third Evaluation:

Gas Distribution

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Experiments

Gas Distribution

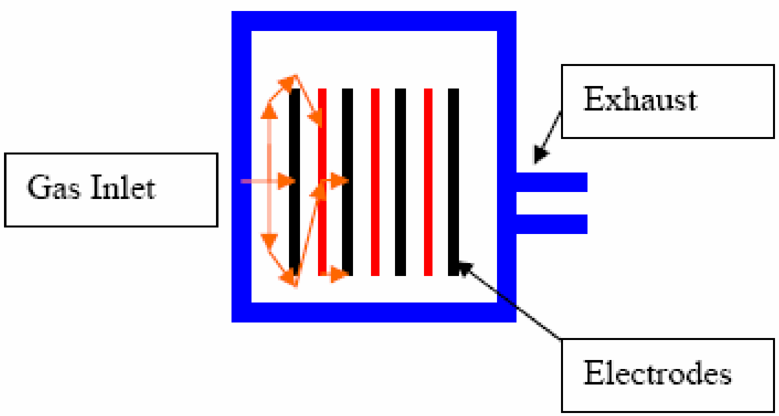
- Determines gas activity from entry to exit point (exhaust)
- Provides direction for gas to flow throughout the chamber

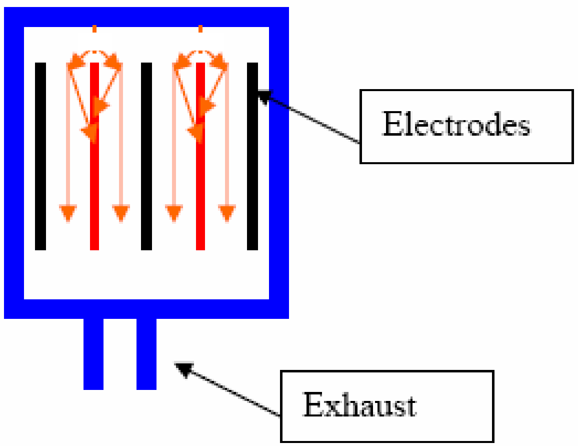
High Uniformity PCB Plasma Processing

Experiments

Gas Distribution

Standard Configuration **Gas Manifold/Distribution**





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Experiment Goal

Gas Distribution

1. Standard cells gas passes through electrode gas channels
2. Does the uniformity improve when the gas passes through a contained cell
3. Can gas travel in holes that are parallel and perpendicular to the flow direction

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Experiment Results

Gas Distribution

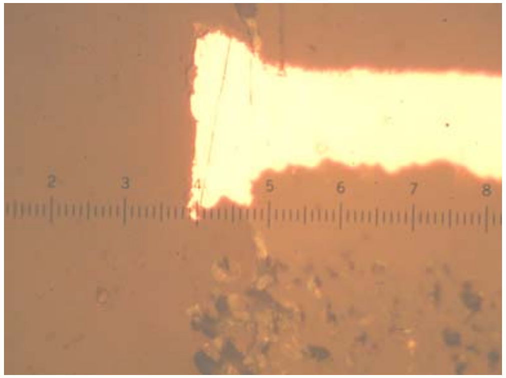
- Contained cells allow gas to fill and etch in 3 dimensions
- Gas remains reactive
- Distribution to each cell etched parallel and perpendicular to holes

High Uniformity PCB Plasma Processing

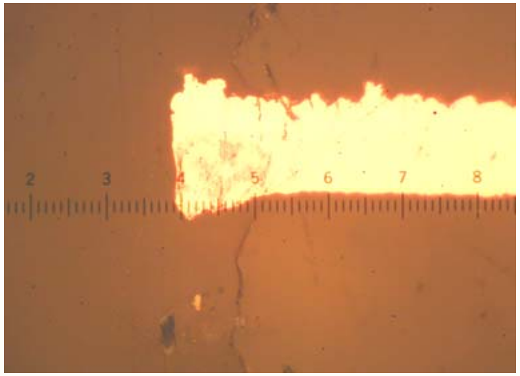
Experiment Results

Gas Distribution

Parallel Flow



Perpendicular Flow



High Uniformity PCB Plasma Processing

Experiment Summary

Gas Distribution

- Distribution in a contained cell showed more etch
- Etch was equal in parallel and perpendicular flow
- Results in improved uniformity

High Uniformity PCB Plasma Processing

The Experiments

Fourth Evaluation:

Vacuum System

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Experiments

Vacuum System

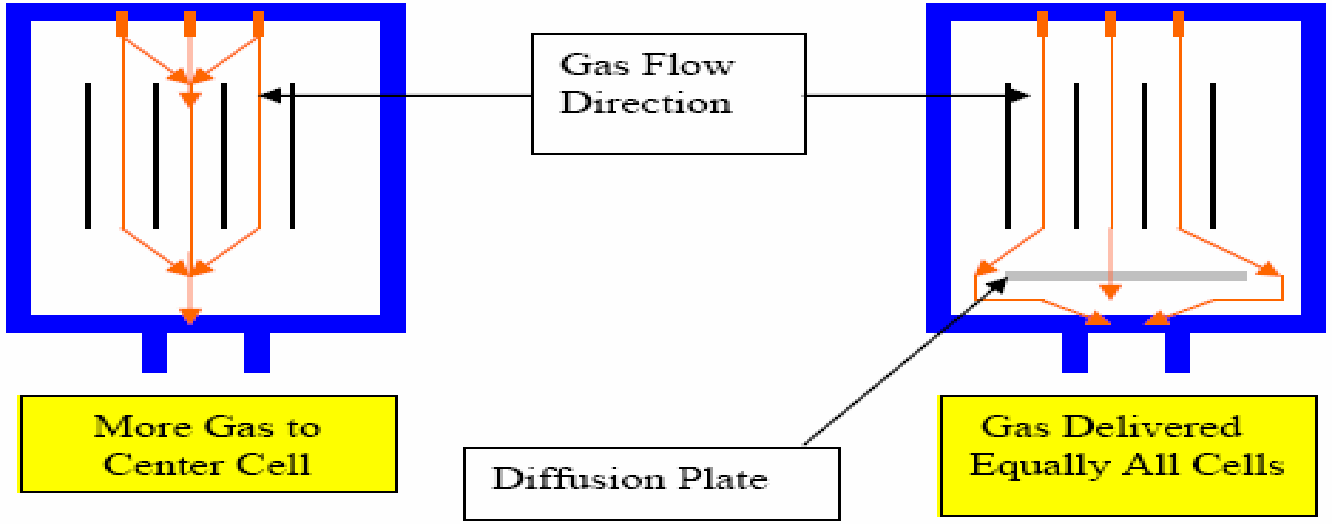
- Maintains the process pressure
- Removes process exhaust
- Directs the flow of gas from the inlet to the outlet of chamber

High Uniformity PCB Plasma Processing

Experiments

Vacuum System

Standard Configuration **Defused Exhaust**



High Uniformity PCB Plasma Processing

Experiment Goal

Vacuum System

1. Determine how exhaust dictates location of etch
2. Evaluate the path for gas flow created by exhaust
3. Demonstrate the difference in etch uniformity when diffusion is introduced

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Experiment Results

Vacuum System

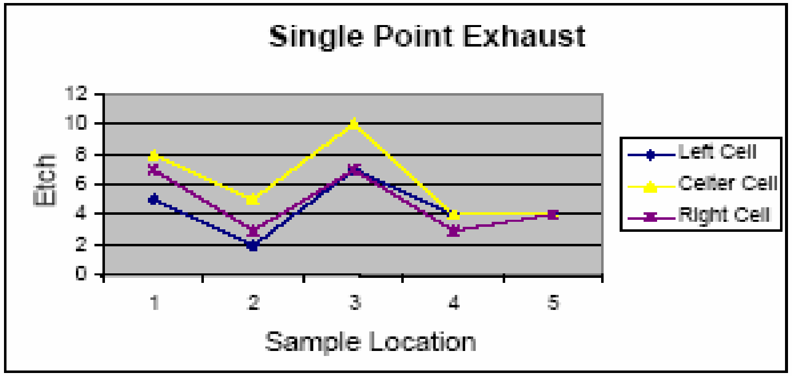
- Single point exhaust, gas directed away from manifold
- Single point exhaust, gas distribution to each cell not uniform
- Diffused exhaust created even gas flow in chamber

High Uniformity PCB Plasma Processing

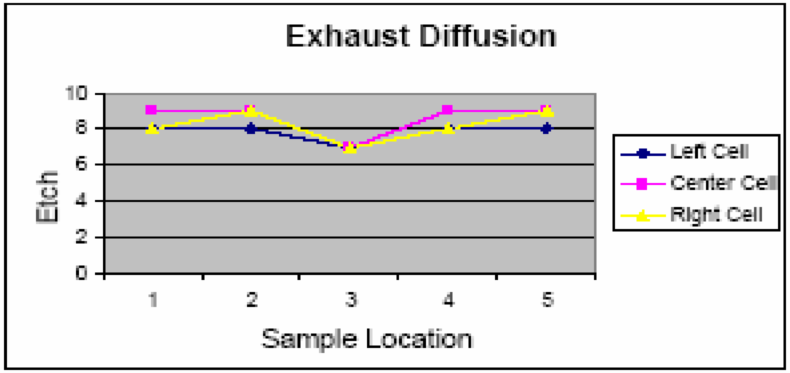
Experiment Results

Vacuum System

Single Point Exhaust



Diffused Exhaust



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Experiment Summary

Vacuum System

- Vacuum exhaust does depict where etch is located
- Single exhaust, most etch at panel closest outlet
- Diffused exhaust created uniform gas flow in each cell
- Results in improved uniformity

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The Experiments

Fifth Evaluation:

Temperature Control

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Experiments

Temperature Control

- Generates and maintains etch temperature of panel
- Provides control for different material Tg etch temperatures
- Prevents over or under etching and associated plating problems

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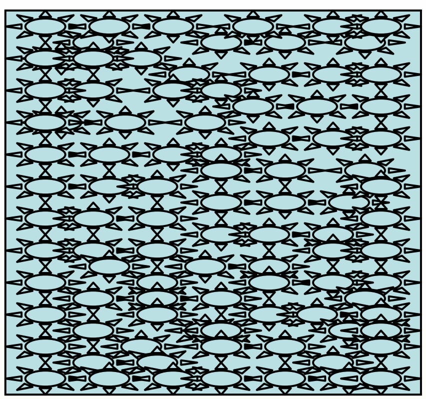
Experiments

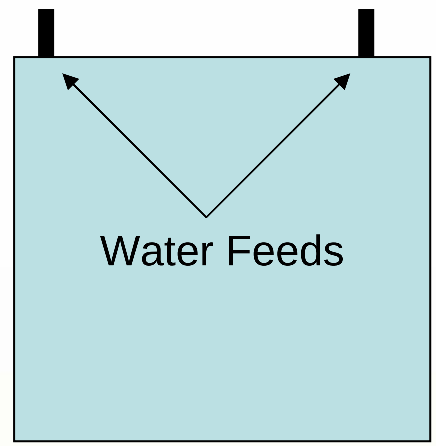
Temperature Control

Standard Configuration
No Temperature Control

Modified
Chilled Water Controlled



Perforated Electrode



Solid Electrode

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Experiment Goal

Temperature Control

1. Determine temperatures effect on etchrate and uniformity
2. Evaluate defects resulting from no temperature control
3. Review the effects from no pre panel warm up

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Experiment Results

Temperature Control

- With no temperature control overetch occurred
- Overetch resulted in plating folds
- When panel did not reach the etch zone the etch was low
- With proper temperature control etch was predictable

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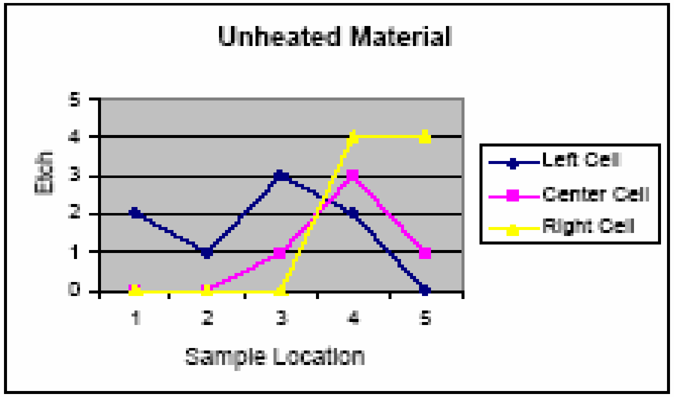
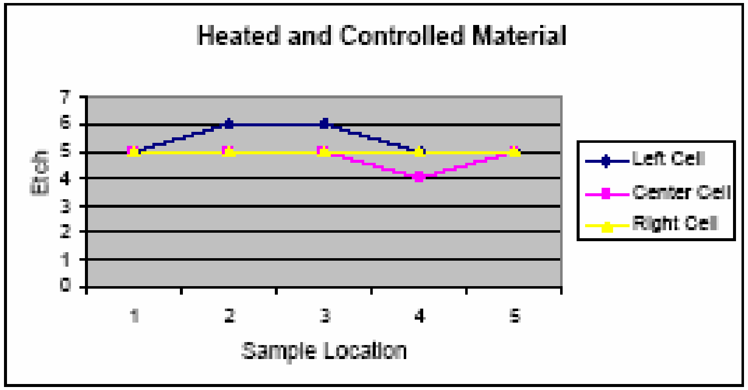
Experiment Results

Temperature Control

Uncontrolled



Controlled



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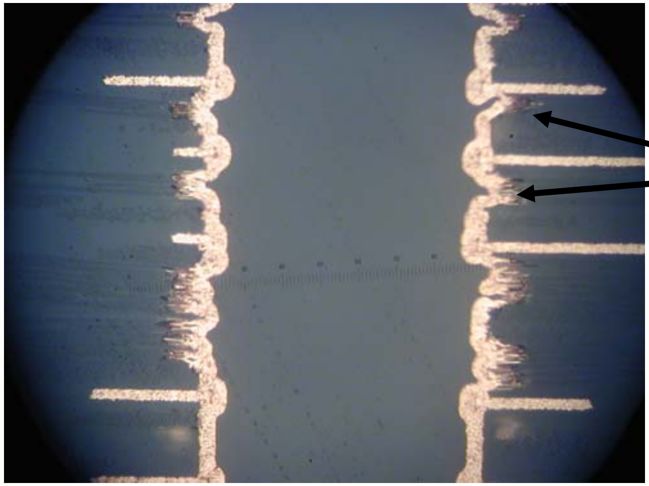
Experiments Results

Temperature Control

No Control To Keep Temperature In Etch Zone



Plating folds from over etch

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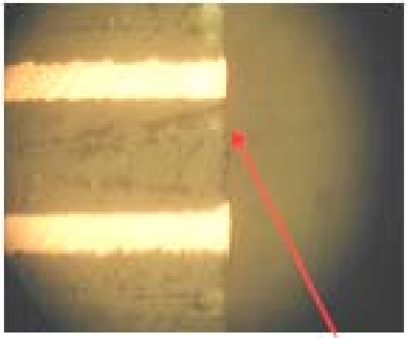
Experiments Results

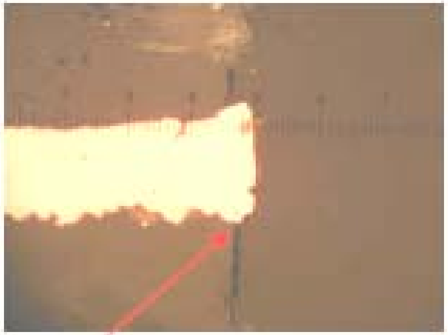
Temperature Control

Below Etch Zone



No Etch

In Etch Zone



Proper Etch

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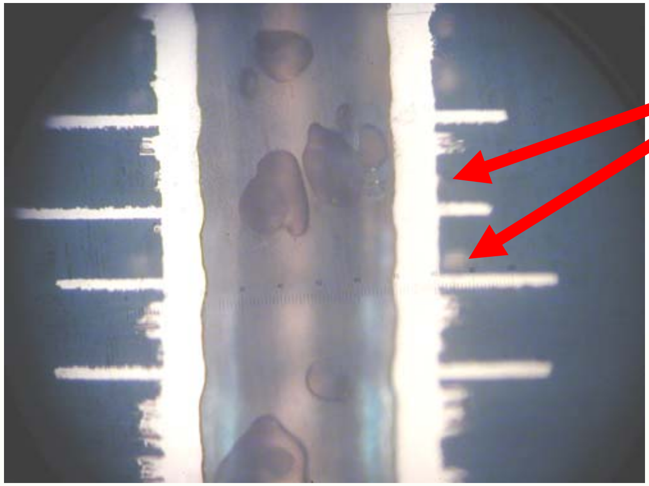
Experiments Results

Temperature Control

Chilled Water Controlled



Proper temperature no wicking or folds

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Experiment Summary

Temperature Control

- Material does react to temperature
- Each material has a different etch zone
- Without control etch is unpredictable
- With temperature control etch and uniformity are improved

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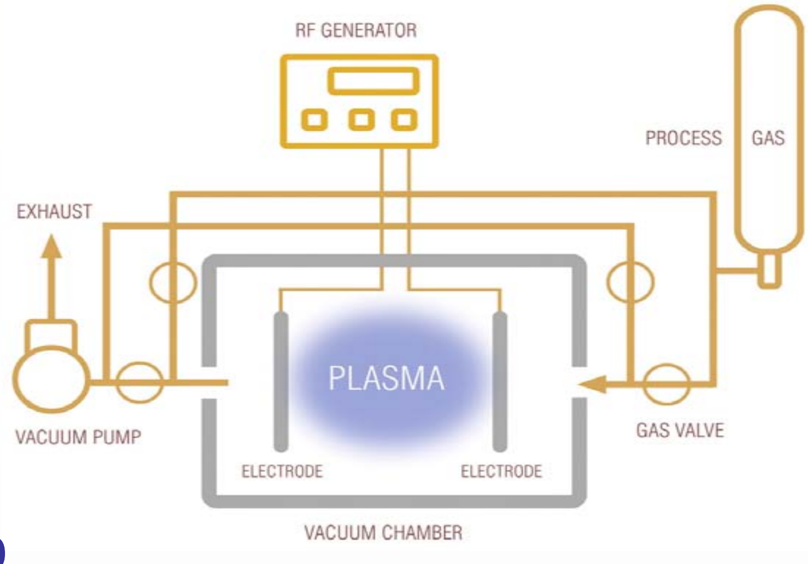
Study Summary

- 5 Key components evaluated: Electrodes, Gas Delivery, Gas Distribution, Vacuum, and Temperature
- Changes in each improved the uniformity and etch
- Improvements maintained proper etch
- Changes in each are required to meet today's specifications



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QUESTIONS??????
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