



The use of Plasma for Surface Modification

Why Plasma Clean?

Significant improvements in adhesion (up to 400 times have been reported) are being achieved in a diverse range of industries by the simple expedient of plasma treating the surfaces to be bonded.

As simple to use as a kitchen microwave, plasma cleaners replace chemical etching (leaving no organic films and requiring no chemical cleanup) and mechanical abrading techniques such as sand blasting etc.

A very real advantage of current plasma systems over other techniques is the uniformity of surface modification and the corresponding uniformity of adhesion results achieved. As will be seen from the following notes, this was not always the case and the whole technology has undergone a transformation over recent years.

Some of the applications in which plasma cleaning is finding routine use include:

- Hybrid cleaning prior to bonding
- Surface modification of a wide range of materials for improved bonding
- Stripping of photoresist for the semiconductor industry
- Etching of silicon surfaces to produce specific edge topographies.

Since each of these applications can have its own set of critical process requirements, a system must be capable of a broad range of operating configurations. These are summarized below.

1. **For sensitive semiconductor samples.** A system must be capable of generating capacitive downstream electron-free plasma which can cause no electron damage to even the most sensitive CMOS devices.
2. **For more aggressive surface modification of parts which are not sensitive to electron damage.** An "active" plasma capability is needed where the sample is located within the plasma field.
3. **For aggressive cleaning with limited electron damage.** This one is "tricky" and requires a "double grounded" electrode mode where both the sample tray and an electrode positioned between the samples and the active electrode are both grounded.
4. **For Stripping applications.** The system must be capable of use in the RIE mode where the sample tray is "active" and the electrode above it is at ground

potential. This configuration provides the most aggressive plasma action.

What is a Plasma?

The plasma state is generated when a gas is subjected to sufficient energy to break down its molecular integrity and dissociate it into ions, electrons and other sub-atomic species. Photons are generated during recombination.

In a plasma system, the plasma is formed by a high energy discharge between two (or three) electrodes. Dependent on the polarities involved, the ions (+ polarity) that are formed are accelerated in one direction and electrons (- polarity) are accelerated in the opposite direction. Ideally, the surfaces to be cleaned (or modified) are positioned on a sample tray that is parallel to the electrode sets so that the plasma action is evenly distributed across the sample plane and all samples get the same degree of cleaning.

Everyday examples of plasma are fluorescent and neon lights, the aurora borealis and the surface of the sun.

The Mechanism of Plasma Surface Modification

One mechanism by which a surface is modified is by the ablative effect of "molecular sandblasting." In this mode the high energy plasma particles "knock off" molecules from the sample surface. The surface area of any given planar dimension is thus increased by the molecular peaks and valleys produced. (See figure 1)

Plasma gases that clean by ablation alone are inert gases such as argon and nitrogen.

A secondary treatment occurs when a chemical reaction also occurs between the plasma gas and the surface undergoing treatment. Gases that fall into this category are oxygen, sulfur hexafluoride, carbon tetrafluoride etc.

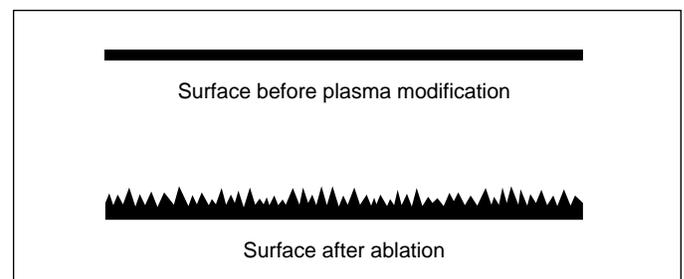


Figure 1. Surface modification effect.

The appropriate gas(es) are selected according to the nature of the surface treatment required or the nature of the contaminant to be removed.

To remove organic contaminants, an oxygen plasma followed by an argon plasma is commonly used. In this process, the oxygen plasma will crack the organic hydrocarbon molecule generating water, carbon monoxide and carbon dioxide. Any remaining oxide layer is then ablated from the surface during a subsequent argon plasma cycle.

A variety of gas mixes are used for an ever increasing array of applications. Some of these include:

- Sulfur hexafluoride to remove silicon.
- Oxygen plasma to ablate quartz prior to depositing a metallic film.
- Argon plasma to render viewing surfaces non reflective and to clean lead frames prior to bonding.
- Oxygen/Argon plasma to ablate polyimide surfaces prior to epoxy gluing them to a stainless steel surface.
- Freon (CF₄) plasma is used to remove and/or ablate silicon and other non-metallic deposits. Sulfur hexafluoride will perform the same function quicker, due to the extra fluorine atoms, but can leave an unpleasant odor (Sulfur) which requires a purge cycle after etch.
- Gas mixes will sometimes cause faster reaction times than single gases. - The addition of a small amount of oxygen (2%) to such gases as SF₆ or CF₄ will speed up the etch rate, sometimes significantly.

Plasma Systems - A brief Review

A wide selection of plasma systems is currently available. These range from modified microwave ovens, to more serious process systems such as Barrel Etchers, Parallel Plate Systems and Capacitive Downstream units. There are advantages and disadvantages to all three.

Barrel Cleaners

Early plasma systems used a "barrel" design and were designed to ash biological samples for subsequent analysis. The generic term "asher", which is still in use today, came from this early application.

Although the barrel shape is ideal for cylindrical samples or samples which can be centrally mounted in tubes or capillaries, very real restrictions in uniformity occur when planar samples are to be processed. In this mode, the very characteristics that provide even plasma along a central cylindrical dimension, provide graduated plasma intensities across flat sample shelves placed within the barrel. Samples positioned at the outer edges of the sample trays (closer to the plasma source) receive significantly greater cleaning than samples in the center of the tray where little, or no cleaning or surface modification can occur. (See figure 2)

Another real limitation of the Barrel configuration is the "shadowing" effects produced when one sample blocks the plasma from an adjacent sample.

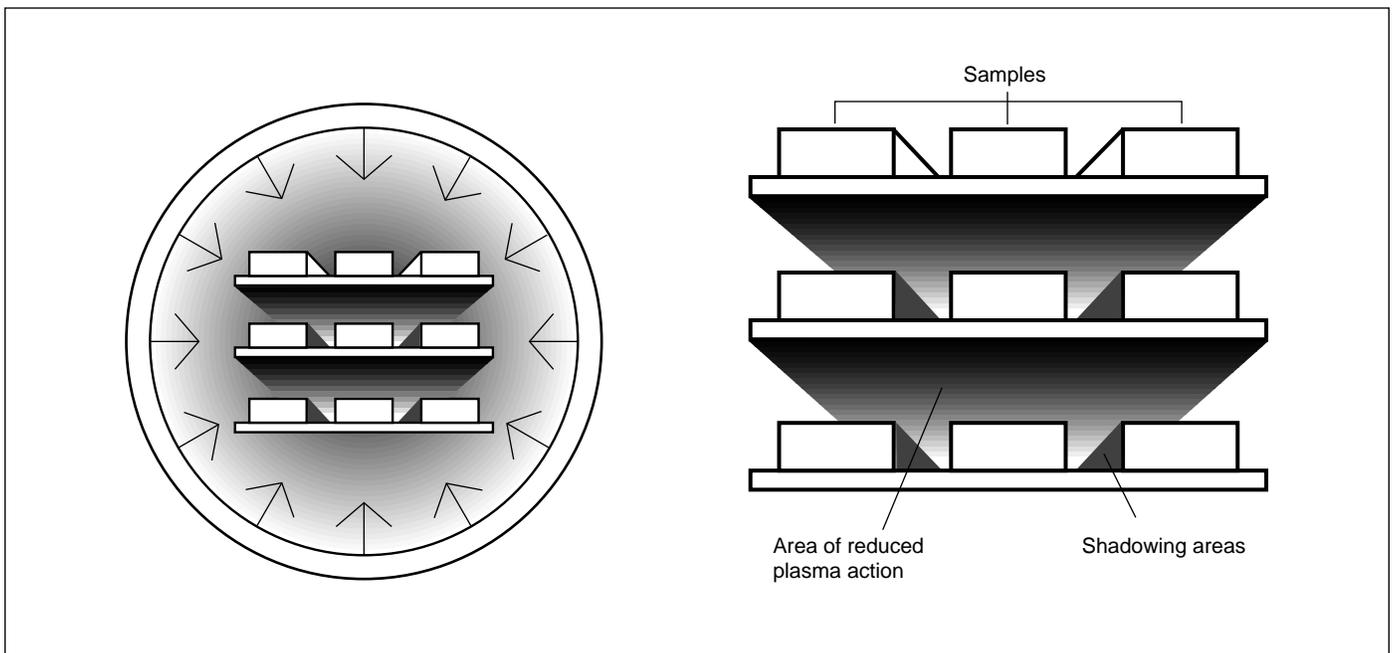


Figure 2. Barrel system showing direction of plasma and energy drop-off towards the center of the chamber.

Parallel Plate Cleaners

More recently, the Barrel type of cleaner design has been updated to a parallel plate type of design. In general, this design carries the obvious advantage of even plasma distribution across planar sample trays.

(See figure 3)

There are some serious considerations involved in selection of the “right” system, however. These are as follows:

In the early “parallel plate” designs, manufacturers (with all good intentions) designed the basic system as simply as possible. They used a two electrode design where the tray on which the samples were positioned was held at ground potential and the active electrode was positioned directly above it. In this configuration the systems generate plasma that found use in surface modification of inert materials that were not damaged by the full components of the plasma

After a brief “moment in the sun”, reports started coming back of sputtered particles (particularly at higher frequencies) from material of the sample shelf being deposited on the samples being etched or cleaned. This coating often seriously affected the quality of the subsequent bond and, in some cases, changed the very characteristics of the materials undergoing process.

To avoid this effect, more recent designs use either a downstream plasma or a double grounded grid, or both. (See figure 4)

So what constitutes an “Ideal” System?

Given the above considerations, a plasma system must have some clearly defined “do’s and don’ts” incorporated in its design.

The following listing came from a broad cross section of engineers who said they were unhappy with their current plasma systems. To keep this review on an “up” note, I have listed their “wishes” rather than their complaints.

The system should:

1. Provide uniform plasma across all sample shelves so that samples on the outer edges of the shelf receive the same degree of plasma cleaning as samples in the center.
2. Have an operational mode where the optimal plasma settings remain the same no matter how lightly or heavily the system is loaded with parts.
3. Offer broad flexibility in shelf spacing to accommodate a range of sample sizes and topographies.
4. For Hybrid applications, include an operational mode where electronically sensitive parts can be cleaned without causing electron damage to those parts.
5. Acknowledge the fact that plasma gases all have their ideal set of operating parameters which will differ from the ideal set of parameters of other gases. To reflect this, the system should have, in memory, the ideal settings for each plasma gas (or gas mix) selected. Subsequently any program selection of that gas will automatically institute those preset parameters. (A further nuance was a request from several of our clients to have the ability to ramp the plasma power so that as endpoint was approached, the power levels could be made decreasingly aggressive).
6. Price and reliability. The system of choice must be extremely reliable, should be simple to use and should not cost a fortune to purchase.

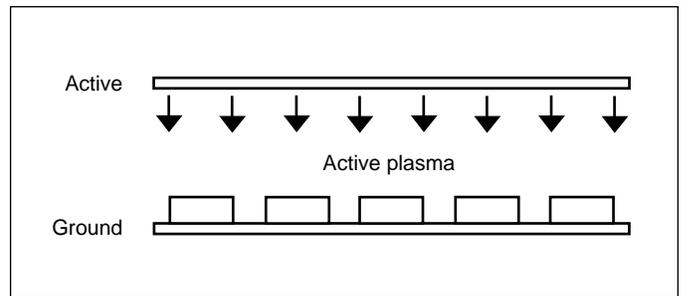


Figure 3. Parallel plate plasma system.

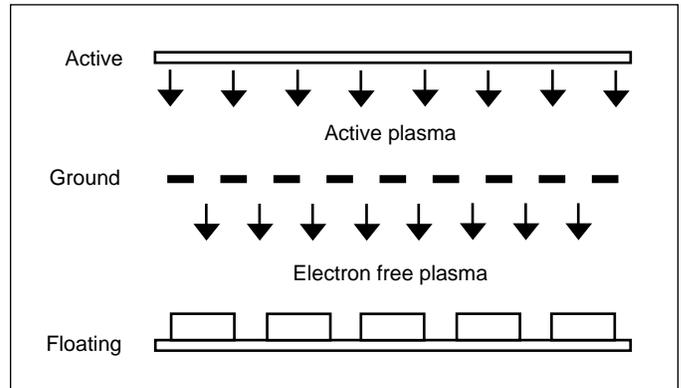


Figure 4. Downstream parallel plate system.

Design Concept - Glen 1000P

The Glen "1000P" Series conforms to all the preceding specifications. Plus we couldn't resist adding a couple of extras features.

The microprocessor

The basic design concept called for a system that was simple to use but had the capability of expansion for an extended range of current as well as future requirements. And, of course, the system had to be completely solid state for the ultimate in reliability.

The microprocessor selected was the GE Fanuc.

Each system operating program (which can be loaded directly on the built-in keypad or downloaded from a PC) can control:

Plasma power and, when necessary, power ramp.
*For example, in a three gas plasma cycle, the power settings can be automatically varied for each of the three gases and one, two or three of the gases can be put through a pre-programmed power ramp.
(This facility is sometimes used to avoid driving active species, such as sodium ions into a semiconductor wafer or device during a stripping operation).*

Plasma duration for each and every gas used.

The system also safety checks pressure, gas flow and power supply output continuously. - In the event of any one of these parameters falling outside preset limits, the system will shut down, an alarm buzzer will sound and the problem area will be defined on the control panel.

Chamber Design

(For more important details of the Chamber Design, please request Application Note GT-115).

To achieve the required uniformity across all sample shelves, the parameters that each sample "sees" must be identical. This includes gas flow across the samples which directly affects plasma intensity at any given site.

To accomplish this, the plasma gas must pass evenly across all sample surfaces and no "dead areas" should exist.

The Glen "P" Series is designed so that the plasma gas is introduced centrally through the chamber roof. The gas is then drawn down uniformly to the exhaust port which is centrally located in the chamber base. Both input and exhaust are fitted with dispersion mechanisms to ensure a "full chamber" flow.

Conclusion

The above review itemizes just some of the "considerations" that led to the design configuration of the Glen "P" Series Plasma Systems. Obviously, to keep this overview as brief as possible, there is a great deal that has been left unsaid. Also there are applications (which are becoming more diverse, almost on a daily basis) that have either been omitted or were not "discovered" at time of writing.

We invite your calls or faxes to discuss how plasma might be applied to your bonding needs.



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