Plasma Surface Cleaning

*Eco-friendly Alternative to Wet Chemical Processing*

**Overview**

In semiconductor processing, plasma cleaning is commonly used to prepare a wafer surface prior to wire bonding. Removing contamination (flux) strengthens the bond adhesion, which helps extend device reliability and longevity.

In biomedical applications, plasma cleaning is useful for achieving compatibility between synthetic biomaterials and natural tissues. Surface modification minimizes adverse reactions such as inflammation, infection, and thrombosis formation.

Plasma as a cleaning agent is an environmentally friendly, safe alternative to traditional wet chemical cleaning methods since it doesn’t require use of hazardous solvents.

**What is Plasma?**

Plasma is an ionized gas capable of conducting electricity and absorbing energy from an electrical supply. (Lightning and the Aurora Borealis are naturally occurring examples of plasma). Often, plasma is referred to as the fourth state of matter, since it is neither gas nor liquid. Manmade plasma is generally created in a low-pressure environment by evacuating a reaction chamber, refilling it with a low-pressure gas, and energizing the gas.

**How it Works – Ion Excitation**

When a gas absorbs electrical energy, its temperature increases causing the ions to vibrate faster. In an inert gas, such as argon, the excited ions can bombard a surface (“sandblast”) and remove a small amount of material. In the case of an active gas, such as oxygen, ion bombardment as well as chemical reactions occur. As a result, organic compounds and residues volatilize and are removed. Radio frequency (RF), microwaves, and alternating or direct current can energize gas plasma. Energetic species in gas plasma include ions, electrons, radicals, metastables, and photons in the short-wave ultraviolet (UV) range. The energetic species bombard substrates resulting in an energy transfer from the plasma to the surface. Energy transfers are dissipated throughout the substrate through chemical and physical processes to attain a desirable surface modification – one that reacts with surface depths from several hundred angstroms to 10µm without changing the material’s bulk properties.
History of Using 13.56 MHz

In the 1940s, coroners used diffusion tubes, also known as ashers, as forensics tools. Samples from a deceased body would be placed inside a quartz diffusion tube and brought to temperatures exceeding 1000°C, and a spectrophotometer would be used to view the burning samples in a stream of oxygen. Viewing the samples at varying frequencies enabled coroners to measure light at the electron level and perform chemical analysis to determine whether poisoning had occurred. However, early diffusion tubes had a slow rise in temperature that allowed heavy metals to escape before they could be read correctly.

In these early years, ashers were made by industrial medical equipment manufacturers. Since the allowable frequency standard for building medical equipment was 13 – 14 MHz, this became the target range by default. Original ashers fell in one of two frequency ranges: 13.54 or 13.46 MHz. For two decades, ashers were sold solely to the medical industry, and their demand remained small and isolated.

Semiconductor Industry

In the 1960s, process engineers became interested in ashers. They needed an alternative, safe way to remove photoresist from 1- and 2-inch wafers. Until then, they’d been using a dangerous mix of sulfuric acid and hydrogen peroxide (known as “piranha”) to eat away thick layers of resist. The problem was that this exothermal mixture boiled and ate through anything organic, destroying processing equipment such as wooden etch benches and posing immediate harm to process engineers who came into contact with it.

For this reason, ashers were readily adopted for use in semiconductor fabrication. The tool, sometimes called a barrel resist stripper, inherited the legacy frequency standard for medical equipment established in the 1940s. However, there was no underlying physical reason to prefer 13.56 MHz to 12 MHz to 14.5 MHz (or even a lower 40 kHz frequency). Eventually, barrel resist strippers lost favor due to issues with slow heat processes and electron damage to wafers.

As research on plasma energy became more advanced, the optimum frequency was found to be more a function of plasma chamber design and the shape of the object to be cleaned. Today’s commercial plasma equipment may run DC, 40 kHz, 13.54 MHz, or 2.54 GHz. As long as the plasma generator is designed to correlate with the appropriate frequency, there is no discernable difference in power level between any frequencies.

As a rule of thumb:

- DC to below 100 Hz is used for sputtering plasma, with electron guns providing the plasma energy.
- 30 to 100 kHz is used for capacitive plasma generators, typically used for flat pieces.
- 10 to 100 MHz is used for inductive plasma generators where a circular or tube is needed with the plasma being generated at the outside of the tube.
- 2.54 GHz and above is microwave range and used for small chambers with power beamed in, typically single wafer resist strippers where a large amount of energy is needed in a small space, i.e. one circular wafer up to 12” diameter.
Benefits of Low Frequency

Plasma processing equipment commonly uses RF to generate gas plasma. A variety of parameters can affect the physical characteristics of plasma and subsequently affect the surface chemistry obtained by plasma modification. In order to achieve uniform, superior results, YES often recommends low frequency plasma (40-50 kHz) over high frequency plasma (13.56 MHz or 2.54 GHz) for the following reasons:

- **Higher Ion Density.** Low frequency plasma provides more energy per square inch than high frequency cleaning. While this may seem counterintuitive, high frequency plasma cleaning systems actually lose considerable energy through heat loss. Energy loss with a 13.56 MHz system is up to 850 times greater than with a 40 kHz system.

- **Increased Efficiency.** The efficiency of a plasma system is the ratio of the energy used in producing the plasma vs. the energy dissipated in losses such as heat. A low frequency plasma system acts like a perfect capacitor with infinite capacitive impedance, or zero current drain when in standby mode. Current applied across the capacitive pair (electrodes) causes the gas to ionize, and the impedance is bridged causing current flow (plasma) between the electrodes.

- **Better Uniformity.** Low frequency systems have no “shadowing,” which occurs when samples on upper shelves form a mask that prevents plasma from reaching samples on the lower shelves (see figures below).

![Fig 1: High frequency systems require a wider capacitor (represented by “d”), which leaves less loading space in the chamber. Shadowing is a result of overcrowding samples.](image1)

![Fig 2: Low frequency systems use a thin capacitor, providing more room in the chamber for optimum sample arrangement; energy distribution is even.](image2)

**Chamber**

Design of the chamber and plasma gas circulation is critical to achieving uniform results. The entire chamber must be evenly purged and maintained at a uniform temperature so that no preferential area exists, such as the “barrel problem” that occurs in a cylinder chamber (as ions bombard toward the center, the outer surface gets cleaned, but not the inside. Often, the outer surface gets overdone, or “cooked,” creating quality issues with sensitive electronics).
Chamber designs with inputs located adjacent to outputs are prone to “dead areas” (see figure 3). However, efficient chamber design paired with laminar gas flow technology overcomes dead areas (figure 4). The laminar flow, sometimes known as streamline flow, directs airflow so it streams in one end of the system and out the other. This ensures there’s no air turbulence, allowing particle reduction in most applications.

**Conclusion**

Choosing the appropriate system and frequency for your specific process depends on multiple factors. It’s important to note that a higher RF power doesn’t necessarily equate to higher plasma density (especially at low pressures). The additional power is often wasted through increased ion bombardment and through the creation of hot electrons, not in promoting ionization. Also, if the average voltage between the plasma and chamber walls (plasma potential) becomes too high, it can cause sputtering and contamination to substrates.

YES builds equipment to meet the needs of innovative engineers, lab managers, and fabrication houses. When you’re ready to run tests using your samples, we have a demo room and process engineers available.

For more information call: **1-510-954-6889** (worldwide) or **1-888-YES-3637** (US toll free)

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