Optimization of Ion and Electron Properties in IC Packaging Applications

Plasma surface-treatment techniques can improve wire bonding and eliminate substrate delamination.

Christa Fairfield

Nordson MARCH
Concord, CA, UCA
info@nordsonmarch.com

INDRODUCTION

Plasma surface treatments used in IC packaging applications can improve wire bonding and eliminate delamination of the substrate. In order for these processes to be successful, both chemical and physical plasma reactions must be achieved. This requires optimization of the ion and electron properties in the plasma field.

This paper defines the properties that must be considered for plasma processing, provides an overview of common plasma systems, and supports the position that a 13.56 MHz system provides the desired balance of plasma properties for IC processing applications.

ION AND ELECTRON PROPERTIES

Properties that must be optimized in plasma processing include ion energy, ion density and DC bias.

Ion Energy

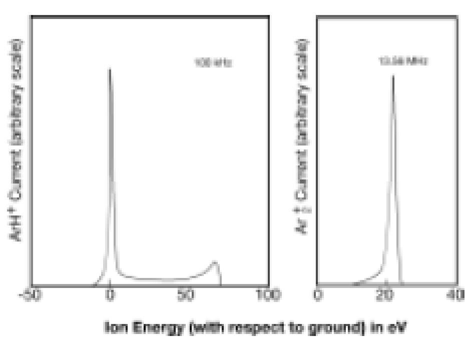
Plasma is an ionized gas comprised of an equal number of positively and negatively charged particles. The ionization of these particles is brought about through an initial excitation source such as RF or DC, and with secondary ionization via the charged species of the plasma. The active plasma species includes ions, free electrons, free radicals, and photons.

Sputtering is a common—and often misunderstood—application for plasma. The term refers to the phenomena of the charged species physically colliding with a surface, breaking bonds and releasing the surface material. An adequate amount of ion energy is an important component because it contributes to the sputtering capability of the plasma. There are several applications such as wire bond improvement where ion bombardment (sputtering) is needed.

For example, during wafer fabrication, dies are exposed to hydrogen fluoride (HF), which results in fluorine contamination on the die. "The presence of fluorine on aluminum bond pads is detrimental to the reliability of gold wire bonds."[1] There have been numerous studies confirming these findings. The removal of fluorine and other contaminates such as oxides, metal salts, magnesium and lead are enhanced by the physical component of ionic bombardment. In these cases, chemical cleaning is either inefficient because a volatile by-product cannot be realized, and/or the additional kinetic energy is needed as a catalyst to the chemical reaction.

However, excess energy can result in unwanted results such as sputtering of the bond-pad site. Sputtering the bond-pad material can lead to redeposition of that material on other parts of the die or package, which can result in short circuiting. Therefore, it is necessary to maintain a narrow energy range for control purposes. As Fig. 1[2] indicates, this is accomplished at higher frequencies such as 13.56MHz.

Figure 1



Ion Density

Ion density refers to the number of ion species in the plasma region. Higher ion density equates to an increased number of reactive species in the chamber. This contributes to the efficiency,

---

[1] Pavio, J; Jung, R.; Doering, C; Roebuck, R & Franzone, M.: Texas Instruments "Working Around the Fluorine Factor in Wire Bond Reliability"

[2] Coburn, John W. "Plasma Etching and RIE" AVS Short Course Program, Orlando, FL 1997

uniformity and speed of the plasma cleaning process. Adequate and uniform ion density requires efficient coupling of power to the process chamber and adequate reionization energy within the process chamber. Without adequate ion density, it may be necessary to increase plasma treatment times, which can lead to undesirable results.

DC Bias

DC bias refers to the stable negative voltage found at a powered electrode in the process chamber when a plasma exists. The presence of DC bias requires the initial presence of ions. The bias increases as charged species move toward and accumulate at the powered electrode. Changing process parameters, such as power, pressure and process gas choice, can control the DC bias. The presence of self-bias can be an important influence in the processing step as it provides enhancement and anisotroiopic directionality of ion movement. This is valuable in applications requiring directionality such as treating in magazines, ion bombardment such as fluorine contamination removal, flip chip underfill improvement, and processes requiring faster etch rates (i.e. faster processing times) found in production environments.

PLASMA FREQUENCIES

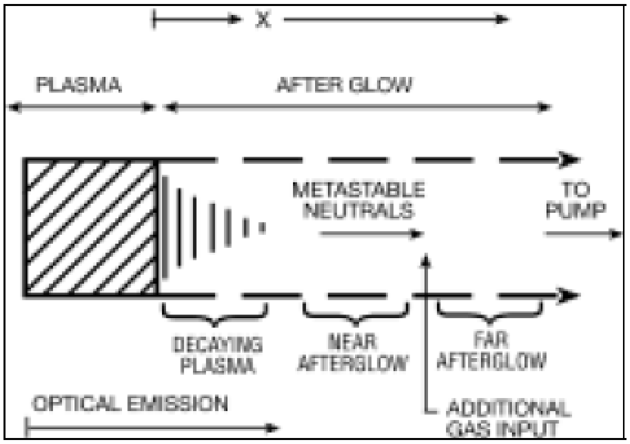
The evaluation and comparison of frequencies requires a broader scope discussion, as two of the power choices, DC and 2.45 GHz (microwave), are commonly designed to provide only a secondary plasma field. This is an important consideration since the referenced properties are different in the primary or secondary plasma fields.

The first field referred to as primary (or direct) plasma is typically found in systems utilizing lower frequency RF systems. In these cases, the initial ionization of the plasma is accomplished by coupling the RF to electrodes, which are in a vacuum chamber. The product is then processed in the area between the electrodes, the primary plasma field.

Plasma can also be provided as an indirect process where the excitation takes place outside of the sample process chamber. This is referred to as secondary plasma. In this case, a primary chamber is attached to a secondary chamber. The gas is ionized in the primary chamber. The reactive species are then made to migrate toward the secondary chamber where the samples are processed. This configuration affects the ion density, energy and DC bias properties beyond any frequency impact.

The diagram in Figure 2[3] indicates that there are three separate regions found in the secondary plasma field. The first is the decaying plasma region. Here, the ion species immediately decrease due to diffusion and recombination. The second region is the Near Afterglow region where the primary active species are the longer- lived free radicals. The last region, Far Afterglow, has virtually no active species. The impact of these three areas is a non- uniform distribution of species in the process chamber.

Figure 2



[3] Thin Film Processes II, Academic Press, Inc. 1991 Edited by John L. Vossen, Werner Kern "Plasma and Sources for Etching and Deposition" Stephen M. Rossnagel pg. 37-38

PLASMA TYPES

Most plasma systems, including 13.56MHz, can be configured for secondary plasma generation. This approach can be beneficial in rare circumstances.

One case would be wafer fabrication processing where non-passivated devices are exposed to hours of aggressive etching. In these situations, sophisticated downstream systems such as ECR are often the design of choice. However, it should be a design chosen for its benefits, not due to limitations of the excitation source.

The most common systems found in the IC packaging market that utilize DC and microwave are limited to secondary plasma generation. In the case of DC, the downstream design is utilized because DC voltages do not effectively couple well inside plasma, and therefore, require the use of extremely high voltages for initial excitation. The exposure of these high voltages would very likely damage the product. Consequently, this excitation must take place outside of and separate from the main sample chamber.

2.45 GHz Microwave

At 2.45 GHz, the RF follows the skin of the chamber, which results in complexity for coupling. Consequently, the plasma must be generated in a separate region where impedance is maintained at constant factor and parts are processed downstream.

This design results in a non-uniform plasma field across the process chamber, so several approaches are sometimes utilized to address the problem.

In the case of the microwave system, three approaches are often used. The first is to effectively turn the parts around in the plasma region (turntable design), in an attempt to uniformly move the parts around in a non-uniform environment. Although this approach can be effective, it reduces the capacity of the process chamber.

Another approach is to speed up the movement of the active species. This is done through the implementation of larger pumps. However, this is an expensive solution and can result in reduced dwell time of active species which, affects the results of processes requiring more aggressive cleaning such as wire bond improvement, oxidation reduction and flip chip applications.

A third approach to increase the effectiveness of downstream microwave processing with the use of oxygen because of its longer life. This can be effective. However, many epoxies and metal lead frames are prone to oxidation, which eliminates the viability of this option.

Direct Current (DC)

A common design choice for a DC system is the utilization a Tantalum filament (or similar material such as Tungsten) to ignite very intense argon plasma in the primary chamber. Magnetic force is then used to draw the ions into the main process chamber cavity where secondary hydrogen plasma is ionized. The magnetic force is used in the system as a means to improve the uniformity of species distribution.

Like microwave systems, the design can limit the choice of process gas. For example, oxygen is not recommended, as it quickly burns out the costly Tantalum filament. Another potential concern is cross contamination from the filament, which has been found on parts processed in these chambers.

The lack of ion species in the plasma chamber may be beneficial in aggressive wafer fabrication processes. However, it is important to remember that at RF frequencies such as 13.56 MHz, the energy is low, the plasma is at neutral potential and it does not create an ESD threat. Actually, ions play an important role in IC packaging applications, as they increase plasma density and enhance reactions.

40-100 KHz/Low Frequency (LF)
As frequency ranges decrease the wavelength increases. At 40 KHz, the wavelength is 339 times

longer than that at 13.56 MHz. This results in ions that are energized at 40 KHz having a much higher energy level than those found at higher frequencies.[4] This results in two occurrences worth noting. The first is the presence of higher temperature electrons.
This increases the temperature of the plasma, directly impacting the temperature of the parts. The second consequence is the presence of higher energy ions, which can be beneficial for sputtering, but unwanted in some applications.

Further, at this frequency, there is increased impedance, and low frequency systems are not typically designed for variable impedance matching. Consequently, there is a high-energy loss due to the elevated impedance present at this frequency. This loss results in a significant reduction in ion density. Consequently, the power supply efficiency is not equal to that of 13.56 MHz plasma. There can be some benefits to the longer wavelength and increased plasma energies found in 40 KHz systems. However, these benefits are lost in systems utilizing secondary plasma designs.

The 13.56 MHz System

With an understanding of the other RF ranges, one can then evaluate the benefits of the design for the 13.56 MHz system. This frequency offers the advantage of the increased ion energies realized at 2.45 GHz without the complications of impedance matching.

Unlike 40 KHz, a well-designed 13.56 MHz system utilizes a variable capacitance- matching network. This network matches the impedance of the chamber and plasma to the power supply at 50Ω through a system of simple, variable capacitors. This permits greater power efficiency than that found in 40 KHz systems.

With the optimization of ion density, the system provides increased control over ion energies. With the optimized ion densities and ion energies, a larger range of chamber designs can be developed, including both primary and secondary plasma systems. The opportunity to select between ion-enhanced or ion-free plasma allows for flexibility in process development that provides superior results in all applications.

CONCLUSION

Although each frequency has its own benefits, the frequency of 13.56 MHz gives the greatest range of choices in process development. Since 13.56 MHz provides the desired balance of plasma properties, one must ask why the other alternatives are utilized when their benefits are not realized.

Typically, low-frequency RF plasma systems can be built at a lower cost because they do not require the development of a complex coupling or variable matching network system. They can also be effectively utilized in applications where high-power applications are advantageous.

Downstream microwave systems require less technology development. They often utilize common magnetron systems combined with a vacuum chamber. The design choice of DC plasma excitation offers the benefit of an inexpensive power source to generate plasma.

Considering the requirements for IC applications, 13.56MHz systems provide the greatest flexibility and superior results.

[4] Chapman, B. Lucas Labs "Physical Electronics of Plasmas"