Critical Plasma Processing Parameters for Improved Strength of Wire Bonds

Plasma surface-treatment techniques can improve wire bonding and molding.

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ABSTRACT

Bond pad cleaning, prior to wire bonding, through the employment of radio-frequency-driven, low-pressure plasmas has been demonstrated to improve the wire bond pull strength.[1] The successful application of plasma technology relies on an optimization of process parameters including process pressure, plasma power, time, and process gas type. These key plasma process parameters and their impact on wire bond pull strength are discussed.

INTRODUCTION

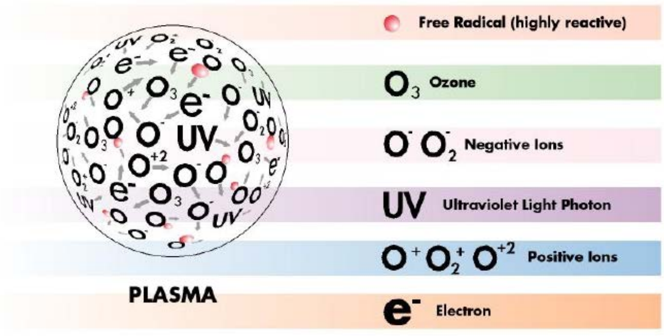
Decreasing feature sizes in advanced packaging, both on the die and the substrate, especially the wire bond pads, result in packaging challenges due to bond pad contamination. Wire bond pad contamination can result in poor bond pull strength and poor bond strength uniformity. Thus, it is particularly important to remove all contaminants from the bond pad surfaces prior to wire bonding.[2,3,4,6] An efficient and cost-effective method for preparing the wire bond pads prior to wire bonding is with the use of radio-frequency-driven, low-pressure plasmas.[5,6]

Not all plasma technologies are the same, nor are all integrated circuit packages the same, thus an understanding of plasma technology and integrated circuit packaging is critical for successful results. In developing a successful plasma cleaning process for wire bond strength improvement, one must consider numerous factors including the substrate material, its chemical and temperature sensitivity, the process required, methods for handling the substrate, throughput, and uniformity. Understanding these requirements ultimately defines the process parameters for the plasma system. Parameters including power, pressure, time, and gas type have been evaluated and the wire bond strength as a function of these parameters is highlighted.

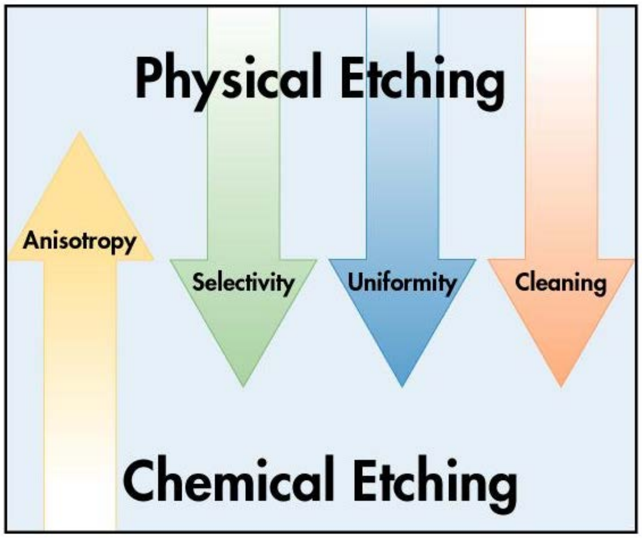
PLASMA PROCESS PARAMETERS

The objective of the plasma process is to maximize wire-pull strength therefore minimizing failures and increasing yields. This must be achieved while minimizing the impact on the throughput of the packaging production line. Therefore, it is critical to optimize the plasma process through the judicious selection of process gas, operating pressure, time, and plasma power. Incorrect selection of the process conditions can result in negative or little improvement on the wire bond strength.

A typical plasma consists of electrons, ions, free radicals, and photons generated from the application of electromagnetic radiation to a gas volume at low pressure.



There are various ways to produce plasma, but the preferred method is the use of radio frequency excitation at 13.56 MHz. The highly energized non-equilibrium plasma is capable of surface cleaning and surface activation through physical, chemical, and physical/chemical mechanisms without changing the bulk properties of the materials. The degree of selectivity, anisotropy, uniformity and cleaning rates are a function of process parameter selection.



The process parameters also dictate whether the process is physical, chemical or a combination of these mechanisms. Each have distinct advantages and disadvantages when it comes to cleaning bond pad sites. The selection of the process gas, the chamber pressure, the power applied, and the time of the process determine the type of cleaning mechanism and its effects. These are the key process parameters.

PROCESS GAS

In a physical process, ions such as those generated in an argon plasma bombard the surface with sufficient energy to remove contamination from the surface. The positively ionized argon atom will be attracted to the negatively charged electrode plate in the plasma chamber. This electrical attraction pulls the ion forcibly toward the electrode. As the ion impacts the bond pad surface, the impact force is sufficient to dislodge any contamination on the surface. This effluent is then removed via the vacuum pump.

The advantages of bombardment are that it is not a chemical reaction, and it cleans the surfaces of parts without leaving any oxidation. The ions are an important component in removing contaminates such as metal salts and other non-organic contaminates that are not easily removed through chemical processes. The resultant cleaning effect is a surface made up entirely of the substrate material. [2,4,6] However, disadvantages include possible over etching of organic substrate material and re-deposition of the contaminant or substrate onto other, undesirable areas. Nevertheless, these disadvantages are usually relatively easy to control by fine tuning the process parameters.

Chemical processes use the plasma generated gas phase radicals to react with the compounds on the sample surface to produce gas phase byproducts that are subsequently pumped from the plasma system. For example, organic contamination is effectively removed with an oxygen plasma where the oxygen radicals react with contamination producing carbon dioxide, carbon monoxide, and water. Cleaning speed and greater etching selectivity are the advantages of chemical cleaning in plasma, and as a general rule, chemical reactions will do a better job removing organic contamination.[2,4,6] The main disadvantage arises from the fact that oxides can be produced on the surface of the substrate, and in many wire bonding applications, oxidation can be most undesirable.[2,4,6] As in the case of bombardment, these disadvantages are relatively easy to control with the proper selection of the process parameters.

PRESSURE

Process chamber pressure is a function of the gas flow rate, and the product outgassing rate versus the pumping speed. The gas flow rate and outgassing rate determines the process chamber pressure coupled with the pumping speed in a March Plasma Systems process tool. The selection of the process gas dictates the plasma cleaning mechanism (physical, chemical or physical/ chemical), and ultimately the gas flow rate and process pressure regime.

In general physical processes require lower pressures than chemical processes. Physical plasma cleaning requires that the energized particles impact the substrate surface prior to deactivation through collisional de-excitation. If the process pressure is high, the energized particle will experience large numbers of collisions with other particles prior to arrival at the bond pad, thus reducing its cleaning capability. The distance that the energized particle travels prior to a collision is known as the “mean free path” of the particle and is inversely proportional to pressure. The mean free path, l is defined

$$l = (3.1 \times 10^7 \text{ pm}^3 \text{ atm K}^{-1}) (T/\sigma^2 P)$$

where “P” and “T” are the pressure and temperature of the gas respectively, and “σ” is the diameter of the gas molecule.

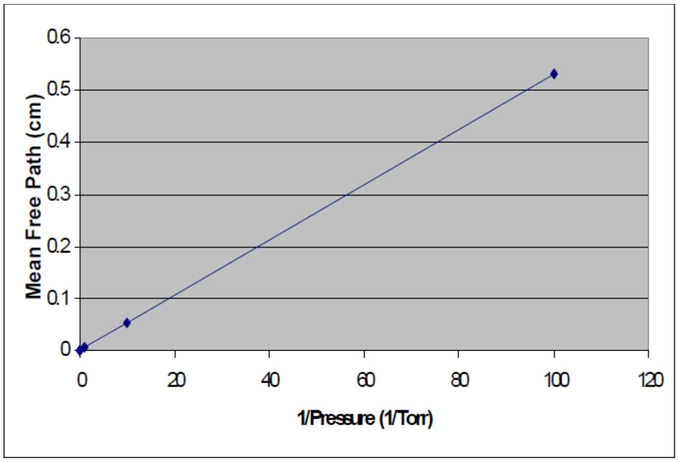
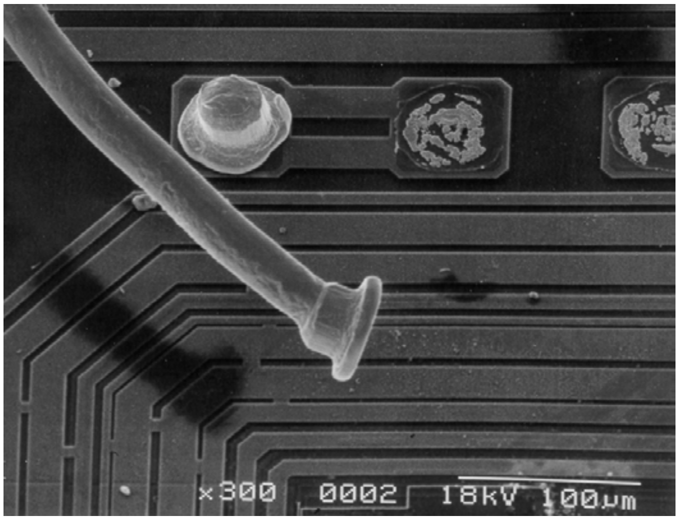


Figure 1 displays the mean free path of argon as a function of pressure, where at 100 mTorr the mean free path is 5.3 x 10-2 cm. Physical processes require low pressure in an effort to maximize the mean free path thus maximizing bombardment impact. However if the pressure is reduced significantly, there will not be sufficient reactive species available to clean the substrate in a reasonable amount of time.

Chemical processes rely on the chemical reaction of the plasma generated gas phase radicals with the substrate surface and use higher pressure. The use of higher process pressure in chemically reactive plasma processes is due to the need for a high concentration of reactive species at the substrate surface. Because of the higher pressure, chemical processes have faster cleaning rates.

Process pressure as a function of wire bond pull strength was evaluated for the physical cleaning of bond pads on PBGA substrates treated in magazines.[1] For the high pressure/high flow (140-160 mTorr) conditions the pull strengths were not appreciably better than the untreated substrates.



The lack of improvement is likely due to a short mean free path as a result of the high pressure thereby reducing the number of energized particles reaching the substrate surface. Low pressure/low flow (100 mTorr) conditions also resulted in poor wire bond pull strengths due to an insufficient concentration of reactive species as result of the lower pressure.

However, selecting an intermediate process pressure (120 mTorr) resulted in an improvement of wire bond pull strength of over 20%. The results illustrate that although the general pressure regime is defined by the selection of the process gas, further refinement of the operating pressure is critical for optimal performance.

POWER

Plasma power increases the cleaning rate by increasing the ion density and ion energy within the plasma. The ion density is the number of reactive species per unit volume. Maximizing the ion density will maximize the cleaning rate due to the relatively large concentration of reactive species. Ion energy defines the ability of the reactive species to perform physical work.

Plasma process power was evaluated for wire bond improvement. Increasing the power has a dramatic effect on wire bond improvement. With a factor of two increase in power, the wire bond pull strength doubled. One must be aware however, that increasing the power too much can be detrimental to the substrate as well as ineffective to the process. More in not necessarily better and as with gas selection, pressure, and time, the careful selection of parameters is important.

TIME

In general, the objective is to minimize the process time in an effort to maximize the throughput of the packaging production line. Process time must be balanced with power, pressure, and gas type. Evaluation of process time at optimum process pressure, and power as a function of wire bond strength for PBGA type substrates demonstrates the importance of process time. A less than standard plasma process time gave less than a 2% improvement on the wire bond strength versus untreated substrates, where with an additional 28% increase in process time, the wire bond pull strength increased by more than 20% versus the untreated substrates. Longer process run times do not necessarily provide increased bond improvement results. The window of acceptable wire bond pull strength should be optimized to minimize process times.

CONCLUSION

Plasma cleaning of integrated circuit packaging substrates prior to wire bonding has demonstrated a significant increase in wire bond pull strength when compared to non-plasma cleaned substrates. However, successful application of the technology requires an understanding of not only the substrate material, but also the effect of key plasma process parameters. Without proper optimization one will not fully realize the benefits of plasma cleaning.

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