Technology Drivers for Plasma Prior to Wire Bonding

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ABSTRACT

Advanced packaging is challenged by ever decreasing integrated circuit sizes while requiring more functionality in these smaller packages. The continued progress in materials evolution and new assembly techniques pose challenges often resulting in opportunities for plasma where plasma is emerging from a yield and reliability enhancing technology to an enabling technology. Specifically in wire bonded packages as the die continues to shrink in size the associated decrease in the size of the wire bond pad on the both the die and substrate represent significant manufacturing challenges. In addition to the challenges with the small geometries, the use of materials such as thin metallization, low-k dielectric materials, alternative substrate manufacturing techniques, and new coating technologies often require the use of plasma. Specifically, the use of thin film metallization and additive plating methods in substrate manufacturing often require careful considerations when applying plasma technology for improved wire bond pull strengths and yield. Examples of the use of plasma for both thin film metallization and additive substrates will be discussed.

INTRODUCTION

To ensure high device reliability and minimize manufacturing costs, it is important to optimize the wire bonding process to ensure good bond strengths and yields. Poor bond strengths and low yields are often due to upstream contamination sources or the selection of materials in advanced packaging. Gas plasma technology can be used to clean pads prior to wire bonding to improve bond strengths and yields.

Gas plasma is a powerful, efficient resource, and when used appropriately can dramatically improve the manufacturability, reliability and yield of advanced semiconductor packages. Plasma is employed to improve the pull strength and uniformity of wire bonds; increase fillet height, fillet uniformity, and underfill adhesion for flip chip devices; and alter surfaces for better adhesion in mold and encapsulation processes. Numerous factors dictate the effectiveness of a plasma process including choice of chemistry, process parameters, power, time, part placement and electrode configuration. The electrode configuration and the process chemistry are the key factors when considering a specific packaging application. Successful implementation of plasma in packaging these challenging devices requires an understanding of both the device to be packaged, including its materials of construction, the pre-processing steps and any sensitivity, as well as plasma technology.

THIN FILM METALLIZATION

In today's advanced substrate technologies low cost substrates are manufactured using very thin gold plating typically on nickel or palladium metallization. The gold thickness is very thin typically less than 50 nanometers. The thickness of this gold represents a challenge to the plasma system when considering the use of plasma for bond pad contamination removal due to epoxy bleed-out from the die attach step. The presence of the epoxy can lead to poor wire bond pull strengths and bonding yields. The challenge is to successfully remove the organic resin bleed with plasma without damaging or removing the thin film gold required for the wire bonding step.

Two plasma modes can be employed to treat the substrate prior to wire bonding: direct or downstream plasma. The direct plasma mode employs an energy source to ionize and dissociate a source gas creating a gas plasma consisting of physically and chemically active components. Samples to be plasma-treated are placed directly in the gas discharge, on or near the electrode plates of the system with full exposure to the working species of the plasma (i.e., ions, free radicals, and byproducts). The type of working species that the substrate is exposed to is a function of the source gas selected. For example, if argon was used as your source gas the plasma generated argon ions would impact the substrate surface and remove the organic residue via a sputtering mechanism. In the following example, a quad flat no-lead (QFN) package with 25 nm of gold on palladium was evaluated for wire bond improvement with and without argon direct plasma. The die was attached with conductive epoxy, oven cured, direct plasma treated, and wire bonded with 25-micron wire. A statistically valid set of samples yielded a mean pull strength of 10.00 grams with a CpK of 2.07 with plasma, as opposed to a mean pull strength of 3.89 with a CpK of 0.03 without plasma. This example shows that with tightly controlled process conditions, direct plasma can be employed to dramatically improve wire bond pull strengths.

Oxygen can also be selected as the source gas. In this case, the direct plasma generated active species include oxygen ions, oxygen radicals, and byproducts such as ozone. The oxygen radicals generated in the plasma oxidize the organic resin, producing gas phase carbon dioxide and water with a slight assist from the oxygen ions. An alternative to direction plasma is downstream ion free plasma. Ion Free Plasma (IFP) plasma is a pure chemical plasma, free of both ions responsible for the physical component and photons. The IFP process consists of the generation of active species upstream of the sample processing area, followed by diffusion of active species through a gas baffle assembly. The gas baffle removes the ions, electrons, and photons allowing the substrate to be exposed only to the radicals, and byproducts generated in the upstream plasma. The downstream plasma mode is utilized when the substrate or die is sensitive to the exposure of ions or photons generated in the direct plasma.

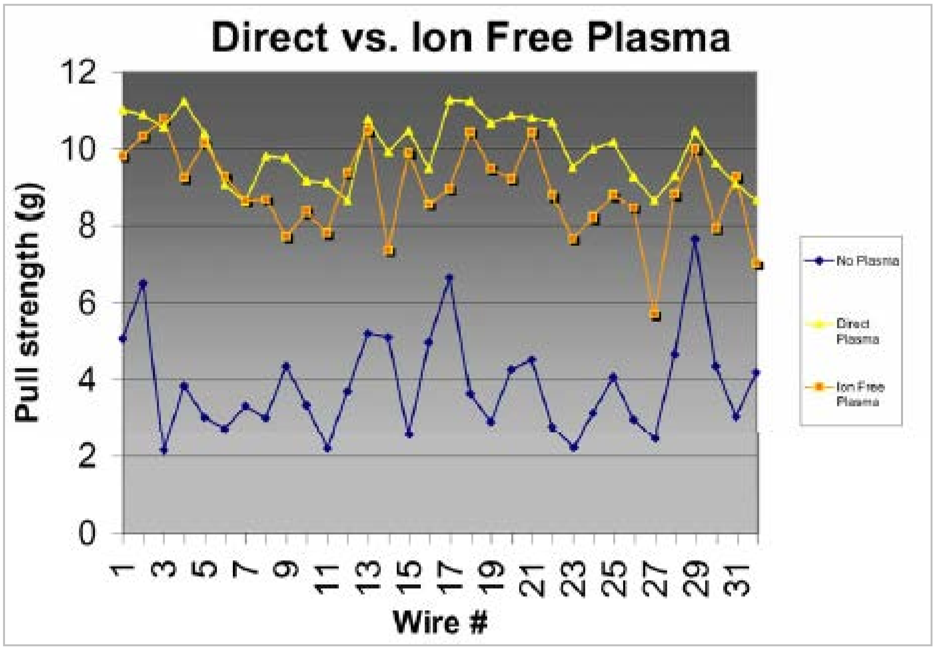
An example when considering the use of direct plasma versus downstream plasma is when processing substrates with thin metallization. It is possible in a single plasma cycle to remove all of the gold on the substrate bond pads which will dramatically impact the wire bond pull strengths. In the following example, identical QFN packages with wire bond pads consisting of 25 nanometers of gold on palladium, were die attached with conductive adhesive, oven cured, direct plasma treated using argon source gas under different power and time conditions, and wire bonded with 25 micron wire.

Table 1 displays the importance of tightly controlling the plasma process to ensure that all the organic resin bleed is removed without sputtering the thin film gold on the bond pad. The pull strength data in Table 1 was collected with a constant plasma power, pressure and argon source gas while varying the plasma process time. The “Under Treated” sample showed some improvement over the “No Plasma” sample, but when compared to the “Optimized” conditions it can be concluded that the process did not remove all of the epoxy bleed. An additional set of experiments was conducted to illustrate the importance of tightly controlling the plasma process. The “Over Treated” sample yielded poor pull strengths due to the removal of the thin film gold bond pad material.

Sample Conditions	Mean Pull Strength (grams)	CpK
No Plasma	3.72 g	0.07
Under Treated	4.67 g	0.35
Optimized	8.52 g	2.15
Over Treated	4.82 g	0.45

Table 1.

IFP plasma can be used in cases where the substrate metallization or the semiconductor device technology is sensitive to the direct plasma exposure. A thin film gold QFN package was die attached with conductive adhesive, thermally cured, plasma treated under direct and ion-free plasma conditions, and wire bonded with 25 micron wire. In ion-free plasma, the QFN will only be exposed to the chemically active oxygen radicals, thus limiting the effect of sputtering the gold. Figure 3 displays pull strengths for these QFN packages under no plasma, direct oxygen plasma, and IFP oxygen plasma. In both plasma cases, the wire bond pull strength and CpK improve dramatically when compared to the no-plasma condition. However, the direct plasma condition is slightly better, indicating that removal of the organic resin bleed is not the only mechanism for improved bond pull strength.



Ongoing studies are underway to further understand the above observation.

ADDITIVE SUBSTRATE TECHNOLOGY

In the manufacture of substrates there are three major types of metallization methods: subtractive, additive, and semi-additive. The traditional methods utilize subtractive metallization which involves the application of a blank metal followed by photolithography and metal etch of the metal to form the substrate traces. In additive plating the metal traces are directly built on the substrate. Additive plating is often being utilized as it offers advantages for small geometries required in high density substrates. With additive plating there are two typical sources of contamination: organic contamination from the substrate manufacturing process and nickel diffusion from the plating that can impact wire bonding pull strength and yield. An appropriately configured plasma system can effectively treat these sources of contamination and improve wire bond yields.

An additive plated substrate was used to study the effectiveness of plasma for improving wire bond pull strength under conditions of no plasma, oxygen based plasma, and argon based plasma. The results are displayed in Table 2. The results indicate that both plasma processes significantly improve the pull strengths while maintaining high CpK values. The pull strength data does not indicate however whether the pull strength improvement is due to the removal of organic contamination or the reduction of nickel on the bond pad surface.

Condition	Average Pull Strength (grams)	CpK
No Plasma	0.86 grams	2.80
Oxygen Based	10.03 grams	3.82
Argon Based	10.93 grams	5.44

Table 2.

To further understand the plasma enhanced pull strength improvement, X-ray photoelectron spectroscopy (XPS) was employed to evaluate the performance of the two different plasma processes for removal of the organic and nickel contamination. Relative concentrations of carbon, nickel, and gold we measured on the substrate bond pads. The results are presented in Table 3. The no plasma condition data shows that the gold bond pad is contaminated with both organic contamination as indicated by the high carbon content and nickel. The oxygen based process is efficient for the removal of the organic contamination via a chemical mechanism but does not effectively treat the nickel. An argon sputtering process will be more efficient in removing the nickel contamination.

Condition	Carbon (%)	Nickel (%)	Gold (%)
No Plasma	70.9	1.4	27.7
Oxygen Based Plasma	54.1	3.3	42.6
Argon Based Plasma	50.3	Not Detected	49.7

Table 3.

Looking closer at the oxygen based data it can be concluded that the majority of the organic contamination that limits the wire bond pull strength is effectively removed and the remaining organic is adventitious carbon as seen both by the increase in pull strengths displayed in Table 2 and the relative increase concentration of gold displayed in Table 3. Additionally, the relative increase in the nickel content for the oxygen based plasma is likely due to the effective reduction of the top layer organic contamination and the exposure of the bond pad nickel contamination lying below the organic. It is noted however that the relative small amount of nickel does not appear to be the significant factor in the pull strength improvement when comparing the no plasma condition in Table 2 to both of the plasma conditions.

The argon based plasma employs a sputtering mechanism to remove both the organic and the nickel. The data in Table 3 illustrates both the reduction in the carbon levels as well as the nickel. It is likely the slight improvement in the pull strengths for the argon process as displaying in Table 2 is due to the reduction in the nickel content on the bond pad. When considering the type of plasma chemistry required for the additive plated substrates you have to balance throughput requirements with the chemistry. Typically, the chemically based processes such as the oxygen plasma will provide shorter cycle times then those driven only by sputtering processes. In either case, the plasma process enables these substrates to be wire bonded.

CONCLUSION

Advanced packaging technologies continue drive material innovations to satisfy the requirements of more functionality in smaller packages. With the use of these new materials plasma processing is often required in wire bonding applications to enable acceptable pull strengths and improved bonding yields. Considerations for the contamination sources, and sensitivity of materials must be considered when configuring the plasma system. When optimally configured, plasma is an enabling technology for the enhancement of advanced package yields and reliability.