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Effect of Plasma Cleaning Process in the Wettability of Flip Chip PBGA Substrate of Integrated Circuit Packages

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Abstract: This study investigated the plasma cleaning effect on two different commercially available packaging substrates used in the flip chip PBGA substrates for integrated circuit packaging. Investigation and related evaluation have been carried out to determine the wettability of the substrate surface. Contact angles on each substrate are measured by observing the spreading area of the water droplets that referred to the surface tension of the droplets towards the substrate surface. Further investigation has also been conducted by applying plasma cleaning and prebake process before and after flux reflow process together with the staging process. Moreover, substrates are subjected to prebake process followed by plasma cleaning and vice versa. Investigated result shows that plasma cleaning at later time has shown significant improvement (a quantitative 70% decrease in contact angle) in achieving better wettability of the solder bumps on packaging substrates.

Key words: Semiconductor packaging, flip chip, PBGA, plasma cleaning, wettability

INTRODUCTION

Flip chip is a method of attaching Integrated Circuits (IC) to substrate boards which involves a series of controlled collapse chip connection (C4) high lead solder bumps on the IC which form metallurgical interconnections with the eutectic metal bond sites on the board substrate. The die with the integrated circuit board is flipped downward in order to make sure the contact between the C4 bumps on the chip and the eutectic solder bumps on the substrates are well aligned. Plasma treatment becomes a useful method for surface modification and deposition of various materials in recent years which has also created a greater impact in IC packaging applications. Plasma-enhanced contamination removal is used to prepare surfaces prior to eutectic die attach and wire bonding (Getty, 2002). The plasma treatment can effectively remove a very thin layer of contaminants from the substrate surface. For this reason, plasma treatment is widely exploited to improve the interfacial adhesion and wire bondability (Djennas *et al*., 1993; Lee *et al*., 1999; Hsieh *et al*., 1999). Plasma-enhanced surface preparation prior to the underfill process has proven to increase underfill wicking speed, fillet height, uniformity as well as to improve underfill adhesion for flip chip devices. Plasma treatment alters surface of the substrate for better adhesion in mold and encapsulation processes (Zhao and Getty, 2005). Moreover, plasma-enhanced contamination removal and surface activation processes improve the reliability and yield as well as enhance the manufacturability of advanced technology products.

Plasma is partly ionized gas, consisting of ions, electrons, free radicals, neutral species and photons. It is also an electrically neutral mixture of physically and chemically active gas phase species (Zhao *et al*., 2004). Physical interaction is performed by ionized atoms and molecular species throughout sputtering, physical bombardment of the ionized atom and molecular species change the topography of the surface by increasing the surface roughness at the molecular level, thereby improving the interface adhesion (Egitto and Matienzo, 1994; Getty, 2002; Zhao *et al*., 2004). Chemical reaction is done by radical species. Free radicals decrease the activated energy in a chemical reaction resulting material removal. Plasma treatment process is conducted by activating the vacuum pump which is attached to the chamber, is capable in removing the volatile materials or chemical reaction grown products from the substrate surface.

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Table 1: Effect of various plasma processes towards surface enhancements

Plasma source gas	Surface modification processes	Advanced technology application
Argon (Ar)	Contamination removal-ablation	Wire bond
	Crosslinking	Die attach
		Substrate polymer-metal adhesion
Oxygen (O_2)	Contamination removal-chemical	Wire bond
	Oxidation process (organic removal)	Die attach
	Surface Activation	Mold and encapsulant adhesion
	Etch	Photo resist removal
Nitrogen (N_2)	Surface Activation	Mold and encapsulant adhesion
Hydrogen (H_2)	Contamination removal-chemical	Wire bond
	Reduction process (metal oxide removal)	Eutectic die attach
Carbon Tetrafluoride (CF_4) and Oxygen (O_2) or Sulfur Hexafluoride (SF_6) and Oxygen (O_2)	Etch	Polymer etch-fiber stripping
		Photo resist removal
		Thin film etch-oxides, nitrides

Plasma mode can be categorized into two types which are direct and downstream plasma. Direct plasma mode is a process where ion bombardment of the plasma occurs directly onto the surface of substrate under glow discharge zone which has a faster and more effective plasma process. Meanwhile, direct plasma mode is not applicable for certain devices which are sensitive to ion bombardment and ultraviolet (UV) light. For the devices that have the limitation mentioned above can be solved by using downstream mode. In the downstream mode, Ion Free Plasma (IFP) is used. Most of the ion bombardment and UV is filtered before it reaches to the substrate surface. It is a mild plasma process in which the substrate is normally placed outside the plasma glow discharge zone in the downstream of the gas flow. The ITP plasma can be employed to improve the pull strengths for certain epoxy strength test.

Performance of plasma in the surface modification process in semiconductor packaging can be classified into 4 categories, which are contamination removal, surface activation, etch and lastly cross linking (Getty, 2002). Surface modification is sensitive to time and environmental exposure where the surface may lose its plasma-induced physical and chemical properties (Getty, 2002). Surface modification enhances the fluid and adhesion. Adhesion between underfill material and die passivation depends on the surface properties. Surface contaminants reduce the wetting action and interfere with the flow of underfill material under the chip. When the substrate and die surfaces are clean and activated, they hold a higher surface energy, increased wicking speed, improved fillet height, uniformity and good adhesion (Takyi *et al*., 1998).

In this study, two types of commercially used flip chip PBGA packages are investigated and experimental results are demonstrated. Table 1 shows effect of various plasma processes towards surface enhancements. The main objective of this research is to study the effect of the plasma cleaning process in enhancing the surface wettability as well as package robustness.

MATERIALS AND METHODS

In this study, two different commercially available substrates named as package A and B are used to investigate the effect of plasma treatment and prebake process in enhancing the wettability of flip chip PBGA substrate. Substrates A and B are using two different types of solder masks namely SR7200G and AUS 703. Both substrates have the same size of 33×33 mm with 1023 I/O pins and 0.18 mm bump pitch. Meanwhile, the substrates have different die size of 10.9×11.6 mm and 12.3×8.3 mm, respectively. Figure 1 shows the process flow of fresh substrates A and B that promotes better wettability to the substrates as found from the contact angle measurement shown in Table 3.

At first, VCA Optima is used to conduct the contact angle measurement. Figure 2a and b show the contact angle measurement by using VCA Optima before and after the liquid dispensing. A syringe of 100 μL, which is attached to the VCA Optima, is initially filled up with deionized (DI) water. One drop of 0.3 μL DI water is set for each dispensing. Contact angle of a group of six substrates per boat are obtained at the beginning. The droplets are then dispensed at the four edges of the die cage to ensure that the dispensing area is always near to the flux dispensing area located at the center of the die cage.

The process then proceeds to prebake process in the Blue M oven at temperature of 125±5°C, which is in nitrogen ambient of 120-180 Standard Cubic Feet per Hour (SCFH). The duration of prebake time is between 10 to 96 h. The main purpose of the prebake is to remove unwanted moisture that appears on the flip chip PBGA substrate surface. In this experiment, bake time of 10 h has been found sufficient since the prebake process has not shown a significant result in enhancing the wettability in this case. The third contact angle measurement takes place when the substrates are sent for the plasma treatment. The batch plasma treatment system is equipped with oxygen and argon plasma where,

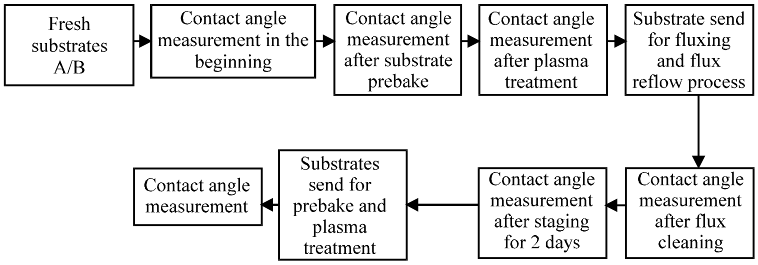
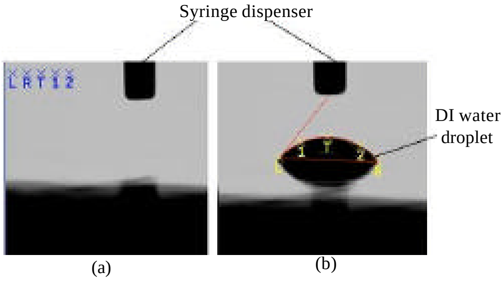


Fig. 1: Process flow of substrate cleaning and evaluation



(a) (b)

Fig. 2: Contact angle measurement by VCA Optima (a) before and (b) after the liquid dispensing

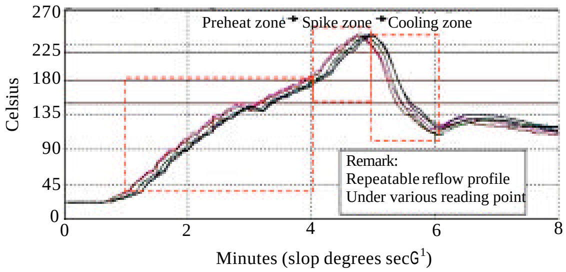


Fig. 3: Experimental temperature profile of reflow process

Table 2: Reflow specification for the interaction of clean flux

Reflow specification	Condition
Peak temperature	235-255°C
Preheat temperature	150-180°C
Preheat time	30-60 sec
Time above 215°C	30-60 sec
Rising slope	1-3°C $\sec^{-1}$

Table 3: Contact angle measurement results at different conditions

	Plasma treatment+prebake		Prebake+plasma treatment	
	Package A	Package B	Package A	Package B
Condition	----------------------	-(deg)-	----------------------	
Time zero	88.3	82.7	90.89	81.7
After substrate bake	88.9	80.39	89.86	82.59
After plasma	13.1	24.13	14.25	23.39
After fluxing+cleaning	49.33	51.25	52.25	49.55
Staging for two days	46.94	50.73	49.29	54.24
Before underfill	49.74	49.76	11.17	15.14

gases were supplied at the rate of 250 and 1500 mL $\min^{-1}$, respectively with a power supply of 800 Watts and pressure of 9.992 mbar. The plasma treatment is conducted to six substrates per boat per loading. The clean flux is water soluble, halide free and non-corrosive to under bump metallization with viscosity of 60 cst which is in deep amber to yellow color. The clean flux consists of 48-58% wt. of proprietary alcohols, 24-28 wt.% of isopropyl alcohol and 18-24 wt.% of proprietary activators. The substrates are then forwarded to reflow process after the clean flux is dispensed on the center die cage area. The peak temperature reflow profile should be in the range of 235-255°C to ensure the complete interaction between the clean flux and activator. Moreover, both preheat time and temperature are essentially important to ensure that flux is active with the required rising slope rate which fulfills the specification shown in Table 2. Figure 3 shows the reflow oven profile that matches to the s pecification in Table 2. Various color lines in Fig. 3 have shown the repeatability of the reflow profile. Next, the contact angle measurement is done after the clean flux is sent back from cleaning. The substrates are then staged for two days under nitrogen ambient to observe the changes of the contact angle. The contact angle did not show any significant change at this point of process flow. Thereafter, substrates are divided into two groups where one group is sent for plasma treatment followed by prebake process, whereas the other group of substrates is at first subjected for prebake process followed by the plasma treatment. Further study has also been conducted to observe the changes between both processes which contribute to the better wettability on the substrate surface. The whole process is repeated for the substrate package B.

RESULTS AND DISCUSSION

Contact angle measurement results conducted at different stages are shown in Table 3. It has been found that the prebake process of 10 h is sufficient since, the prebake has not shown significant impact on reducing the contact angle that indirectly improved the wetting of the substrate. Prebake process only removes the surface moisture, whereas plasma cleaning process improves the surface wetting. Upon plasma treatment, substrate surface becomes cleaner and wettability improves as well. Therefore, the substrates that were subjected for the plasma treatment at later time have shown better wettability as the contact angle obtained is smaller as can be found in Table 3.

Both substrates A and B do not show significant changes in contact angle measurement although these have used different solder masks. There is no visual difference between plasma treated and untreated substrates in microscopy as well. However, the difference of contact angle measurement can be observed as shown in Table 3 when DI water is dispensed on the four corners of the die cage.

There has been approximately 70% decrease in contact angle which means significant improvement as a result of plasma treatment. The active plasma will dissociate and react with the substrate surface by creating different chemically functional groups on the surface with the aid of different gases such as oxygen, hydrogen, nitrogen and ammonia. Better adhesion on a larger area can be created by implying different functional groups which modify the chemical activity of the surface and create stronger chemical bonds with the bulk material.

The physical process involves the positive ions which employs ablation process dislodges the contamination by bombarding the ions onto the substrate surface. The contamination on the surface has been removed by both physical and chemical energy at micron level. The substrate surface becomes rough by the ion bombardment at atomic scale which creates better wettability of flux reflow at later time. The chemical process widely employs the reduction and oxidation chemistry through the gas phase radicals. Plasma chemistry has the capability to etch the surface selectively in the presence of other materials. The dissociation of carbon tetrafluoride (CF4) and oxygen in the appropriate concentrations produces highly reactive oxy, oxyfluoro and fluoro radicals that rapidly break carbon-carbon bonds within numerous materials (Getty, 2002).

Plasma induces cross linking in removing the atomic species from the surface and generates reactive surface radials. The cross linking improves the adhesion of metal layers to the plasma treated polymer laminate (Getty, 2002). The plasma treatment process has been optimized by varying the time, power, pressure and gas flow rate to substrate (Noh *et al.*, 2007). Different composition of plasma source gas has its own process applications. Argon plasma treatment induces the cross-linking between substrate and polymer and it has the ability to remove the ablation contamination (Liu *et al.*, 2005). Whilst for the oxygen treatment is able to remove the chemical contamination on the substrate and induces surface activation by decreasing the surface energy of the polymers which can etch away the organic contamination on the oxidation process and indirectly improves the adhesion properties (Alberici *et al.*, 2004).

The plasma treated substrates demonstrate the better wettability. Gibbs equation defines the wettability as any spontaneous change occurs at an interface such as oxidation of metals must lower the interfacial energy. The driving force for wetting can be expressed as $F_{wet} = \gamma\cos\theta$. A reduction in the organic and oxide contamination levels leads to an increase in the wetting force, F_{wet}. Plasma cleaning or flux application removes some of the surface contaminants leading to a lower contact angle and thus an increase in the surface energy of the substrate happens (Takyi *et al.*, 1998). Introduction of plasma treatment has the capability of enhancing the surface wetting of substrate from hydrophobic to hydrophilic. This is attributed to the oxide layer removal and plasma etching on the solder mask for both substrates. When the substrate surface becomes cleaner, obviously better wettability will be achieved. Although, these substrates have different die size and solder mask material, no significant difference was found in contact angle measurement. Plasma surface activation prior to die-attach provided better contact, improved heat transfer with minimal voiding. The purpose of the mold or encapsulant material for semiconductor applications is to provide adequate mechanical strength, adhesion to various package components, good corrosion and chemical resistance, matched CTE to the materials it interfaces, high thermal conductivity and high moisture resistance in the temperature range used (Getty, 2002).

CONCLUSIONS

The prebake process does not have any constructive influence to the wettability, however plasma treatment shows significant impact in removing the contamination on the substrate surface to contribute in a better wettability. Both packages give positive results although vary in specification. As found in this study, the prebake process is recommended to be conducted in the beginning since prebake at the later time does not have any positive influence to wettability. Better wettability can be achieved when the plasma treatment is conducted at the end of each process.

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