A case of arcing phenomenon on Radio Frequency device caused by polyimide removal

Warly A. Dela Cruz, Mona Liza M. Abalos, Jeffery D. Concordia
Quality and Reliability Department
Intel Technology Philippines Inc.
phone: (+06346) 433-5331
e-mail: warly.dela.cruz@intel.com

Abstract - Polyimide (PI) removal caused the present Electrostatic Discharge (ESD) resistivity specified limit of water to induce electrostatic arcing. The small amount of charge accumulated in the passivation layer jumps in the form of mini electrical arc to device metal layers causing dielectric breakdown and resulting to an Electrical Overstress (EOS) like damage. This paper aims to show how an electrical arcing discharge happened during wafer saw and wash process and how it was aided.

I. INTRODUCTION

The advancement in semiconductor device has driven the integration and compactness of integrated circuits. This has posed lots of challenges, not only in the device fabrications but to the company as well in order to be competitive and cost effective. In this case, PI was decided to be removed. The industrial application of polyimide resin to the semiconductor devices began with its use as the interlayer insulating film of two layer metallization bipolar integrated circuits. With the special properties of polyimide such as planarization and thermal stability, semiconductor devices have benefit with stress reduction on passivation layer and Al top metal layer during assembly, improved adhesion between packages molding compound with die surface and reduced the soft-error-rate caused by Alpha particles from molding compound and solder component. However, the removal of the said component had triggered new problem. The change done in the product did not match to the long established ESD control on one assembly process. This had resulted to EOS damage on the device.

Electrostatic Discharge is a subclass of the failure causes known as EOS. This class applies electrical stimulus to a part outside of its designed tolerance. ESD is a charge device mechanism because the event occurs as a result of charge imbalance [1]. It is a sudden transfer of charge from one object to another through a contact or non-contact process. The most common ESD type is through contact process such as metal to metal or a charged object touches a grounded conductive material. On the other hand, non-contact ESD event happens when charges jump from one point to another point via dielectric breakdown due to strong electric field or high potential difference. This type of ESD is also known as arcing. It is a sudden release of energy in the form of mini-lightning strike typically lasting for 1 to 100 microseconds or maybe longer [3]. The direct effect is thermal damage, disruptive mechanical force, arc root and arc point damage, acoustic shockwave, sparking and lightning.

High electrical-sort yield loss and in-process failure were encountered on RF products during die-prep assembly. Investigation showed that the wafer saw and wash process is the source of the problem. These are the two of the three major steps in wafer fabrication in which wafer is singulated into individual dice in preparation for assembly in IC packages. It consists of the following steps: 1) the frame-mounting of wafer to align wafers in position for cutting automatically; 2) wafer sawing according to the program die dimensions using a resin-bonded diamond wheel rotating at very high revolution per minute (RPM). De-ionized water is also dispensed on the wafer to wash away silicon dust particles and to provide lubrication during the dicing process; 3) wafer washing using a high pressure DI water sprayed on the rotating work piece and then dried by oil free air (OFA) blowing in order to remove dust and water from saw process.

Sample failed devices were subjected to failure analysis (FA). Passivation cracks and burnt marks were observed specific to metal 6 edge/corner area only during visual inspection at 200x and 500X magnification, as shown in Figure 1.a) and b)

Figure 1: a) 200X magnification of burn mark signature.

b) 500X magnification of burn mark showing where the thermal energy dissipated resulting in arc point damage.

Focus Ion Beam (FIB) analysis verified the extent of the damage. Figure 2 shows passivation cracks filled with molding compound and blown-up damage.

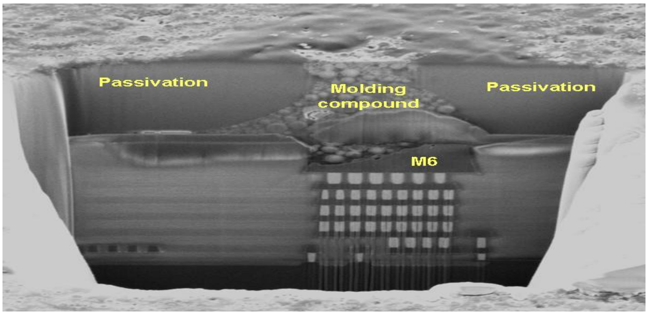

Figure 2: FIB image of the cross-sectioned metal 6 of the RF device showing the filling of molding compound to the cracked passivation and blow up metal.

This observation confirmed that the failure happened before molding compound process. This also consequently led to further investigation of the arcing failure mechanism. This study involves a kind of arcing damage when electric field at the passivation layer exceeds and cause dielectric breakdown. Such arcing damage results in the passivation cracks and burns on metal 6, since it is the point of discharge of the high electric field. Figure 1 shows localized heating and microcracking as the damage's characteristic signature.

Arcing will not happen if passivation is not charged-up. Static charge generation can be caused by a contact and separation process. This could be greatly affected by the amount of friction or pressure of contact encountered by the two objects, materials type specially insulators, surface type, humidity and temperature. During the wafer saw and wash process, De-Ionized (DI) water and device passivation layer experienced high pressure action between them. This could possibly result from the passivation static charging. For this reason, the experiment focused on two basic questions which are 1) Does the ESD resistivity level of water induce arcing damage because of the reduced dielectric insulation? 2) What is the most efficient ESD resistivity level of water in order to prevent arcing damage during wafer saw and wash?

II. EXPERIMENT SECTION

Ten legs of experiments were done to answer question number 1. The first leg was the Plan of Record (POR). This was the leg that checked the actual practices in the company. The second leg was to check if the high ESD resistivity on water can duplicate the same arcing damage. This was done when Carbon Dioxide (CO2) was turned-off or removed from the DI water. This usually measures at the range of approximately 18 Megohms. CO2 gas is used to improve DI water resistivity in order to reduce damage in the wafer due to static electricity and deposition of swarf or wafer debris during sawing and washing process. A device called “load point CO2 bubbler” is used to control the CO2 gas injection and measure the ESD resistivity of water for dicing and post dicing washing application. The third leg was to check if a very low ESD resistivity level about 0.2 Megohms of water also induced arcing damage. The fourth, fifth and sixth legs were also checked if the speed at slow, medium and high rate of the spinner table can also be the source of the failure. The seventh leg was to check if washing duration of about 180 seconds can produce the arcing failure. The eight and ninth legs were to check if water pressure could also cause an arcing damage. The last leg was to check if the cutting speed could induce the same problem. Visual inspection at 500X was used to determine if there is a failure on each leg.

An experiment on controlling the values of ESD resistivity level of water while sawing and washing was done in order to answer question number 2. Six values, 0.4 Megohms, 0.7 Megohms, 1 Megohms (Spec Limit), 1.5 Megohms, 2 Megohms (Max Bubbler capability) and ~18 Megohms (when CO2 was turned-off) were set. An electrostatic fieldmeter was used to verify and measure the static charge voltage accumulated on the wafer of different ESD resistivity settings of water from the experiment. Visual inspection at 500X was used to determine if there is a failure on each resistivity setting.

III. RESULT AND DISCUSSION

Out of the ten legs, arcing damage was observed only on leg number 2 as shown in table 1. Two out of the 90 units with PI and eleven out of 90 units without PI were found to have similar arcing signature such as burn at metal 6 and crack on passivation layer. This confirms that CO2 is very critical during wafer saw and wash process because it improves ESD resistivity of the DI water to avoid static charge accumulation on wafer surface. The data also showed that units without PI are much sensitive to arcing.

Leg	Variable	VI Result on wafer w/PI (Post Die saw/wash)	VI Result on wafer w/o PI (Post Die saw/wash)
1	POR	0/90	0/90
2	DI Water Resistivity (turned-off CO2)	2/90	11/90
3	DI Water Resistivity (0.2 Megohm)	0/90	0/90
4	Spinner table revolution for washing (700rpm)	0/90	0/90
5	Spinner table revolution for washing (350rpm)	0/90	0/90
6	Spinner table revolution for drying (2500rpm)	0/90	0/90
7	Washing time (180 seconds)	0/90	0/90
8	Water pressure (2L/min)	0/90	0/90
9	Water pressure (1L/min)	0/90	0/90
10	Cutting speed (40mm/g)	0/90	0/90

Table1: Critical wafer saw parameters that were identified to be the culprit of passivation layer charging that causes the arcing damage.

Bubbler gauge was also checked for consistency along with the reliability of the reading it provides. Investigation showed that there were no problems on the gauge at any condition. All of the devices that go through the 9 legs in which no failure was captured were electrically tested and passed all electrical validation.

On the other hand, table 2 showed that similar arcing damage at metal 6 was captured at the ESD resistivity level of water from current spec limit, which is 1 Megohm up to 18 Megohm. It confirms that ESD resistivity level of water really causes the charge accumulation on the wafer surface. It indicates that the wafer static charge during saw and wash increases as the water ESD resistivity increased. Table 2 also shows that the current 1 Megohm control limit is able to tribocharge the wafer surface up to 115 Volts to 134 Volts, enough to induce an arcing event due to the increasing sensitivity of devices caused by the thinning of dielectric and circuit integration.

Water Resistance	No PI Wafer (ESD reading in Volts)	With PI wafer (ESD reading in Volts)	Passivation Defect
0.4 Megohm (POR)	34 V	38 V	No
0.7 Megohm	42 V	63 V	No
1 Megohm Spec Limit	115 V	134 V	Yes
1.5 Megohms	122 V	178 V	Yes
2 Megohms	166 V	212 V	Yes
CO2 Off (~18 Megohms)	508 V	878 V	Yes

Table 2. Electrostatic field measurements (in volts) on varying ESD resistivity level of water using an electrostatic field-meter.

Figure 3: A photo showing the method of verifying the static voltage accumulated on wafer saw using electrostatic field-meter.

The electrostatic field-meter was used to verify the static charge voltage accumulated on the wafer while being washed at different water ESD resistivity levels as shown in Figure 3.

IV. CONCLUSION

No PI devices are more prone to arcing damage during wafer saw and wash process. ESD resistivity setting of water during wafer saw and wash is a very critical parameter to control ESD. Since passivation is an insulator, it can be tribocharged to an electrical potential higher than the passivation breakdown voltage, leading to a static discharge in the form of electrical arcing that punches through the metal layers of the die and causes EOS damage. This finding resulted in a tightened current control limit on the ESD resistivity level of water from 0.9 Megohm to 0.6 Megohm.

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