Decapsulation of Plastic Encapsulated Microelectronics with Copper Wire Bonds

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***Abstract*— A novel method for copper wire bond decapsulation was developed, which involves conducting a sequential process to ensure minimal corrosion or, in some cases, no corrosion/degradation of the copper wire. It requires a pre-treatment which involves mechanical milling or acid etching; the main decapsulation process, utilizing a mixture of nitric and sulfuric acid under electrically biased conditions; and a post decapsulation procedure of encapsulant debris removal using a solvent. Previous studies use decapsulation methods that reveal either the ball bond or the wedge bond, separately, and thus cannot be used to perform wire pull tests. Exposing both the ball and wedge bond is not trivial, as the wire tends to break at the loop due to the long exposure time. The three-step process, when properly executed, ensures that the entire wire along with both ball and wedge bonds are exposed with minimal damage. Five parameters were found to affect the decapsulation process. These are as follows: acid ratio, biasing voltage, time of exposure, temperature and mold compound type. Careful control of these parameters can result in little to no copper wire degradation.**

***Index Terms*—Copper wirebond, decapsulation, electrolysis, failure analysis, bond shear strength**

I. INTRODUCTION

Copper wirebonding is replacing gold wirebonding in the microelectronics industry due to its lower cost and the better electrical and thermal properties [1]. Copper wire bonds pose several challenges to reliability as well in conducting failure analysis [2]. Decapsulation of a device is necessary to permit shear and pull tests to be performed for estimating ball and wedge bond strength. The decapsulation process must effectively remove the molding compound and at the same time not affect the wires. In the case of gold wire bonds, nitric acid can be used to decapsulate the device without attacking the wire. Copper, on the other hand, readily corrodes in the presence of nitric acid; thus, a way to protect the copper wire is needed.

Murali et. al [3] performed decapsulation using nitric and sulfuric acid mixtures in different ratios at room and elevated temperatures which resulted in removal of the mold compound over ball bonds alone. It is reported that use of laser ablation can be helpful in removing top layers of mold compound in a package but cannot be used near the wires as it can cause local heating of the wires leading to vaporization Microwave induced plasma etching is another method that can be used for decapsulation of mold compound. Apart from being slow, it leaves behind the silica fillers in the mold compound as a white powdery residue that hinders further etching [4].

All decapsulation methods presented in the literature either reveal the entire wire, but only on dimensionally small devices, or remove mold compound only above the ball bond in case of dimensionally larger devices. Hence there is a need to develop a decapsulation method that can reveal the entire wire and is not dependent on package dimensions.

II. DECAPSULATION PROCEDURE

The decapsulation procedure presented here contains three sequential steps starting with the pre-decapsulation process where there is removal of a small fraction of molding compound; the main decapsulation process where the majority of the molding compound is removed; and a post decapsulation process, which is done to remove debris that is left behind in small amounts on the die and in between wires.

First, all the leads of the device that are to be decapsulated are shorted together using solder. This is needed to ensure all of the wire bonds can be electrically biased and thus prevented from corrosion due to acid.

The pre-decapsulation step then starts with making a pocket in the epoxy molding compound. It was found by Lall et al. [5] that a predefined pocket in the mold compound will speed up the acid decapsulation process, while also restricting etching to within a predefined area. A few drops of nitric acid (95% red fuming) can be used for this process as it has a faster etching rate than mixed acid, and it will not contact the wires. A micropipette can be used to perform this process. For devices of very small dimensions, acid etched pockets may not be possible and hence a mechanical milling process can be used to make a pocket of defined dimension. An X-ray image of the part is useful prior to performing this step to identify the dimensions of the die, wirebond and lead frame and to determine the necessary area of the pocket to reveal the entire die along with the ball and wedge bonds.

The decapsulation step is done next. It is known that copper readily reacts with nitric acid; hence, a mixture of acids was suggested in the literature [2,5]. A mixture of sulfuric acid and nitric acid can etch molding compound but not the copper wire bonds because the sulfate ions from the mixed acid form a layer of copper sulfate on the wires that prevents the wire from being etched. It was found that under extended duration etching (i.e., several minutes) the copper sulfate protection on wires was compromised leading to copper corrosion. However, several minutes are required to fully decapsulate a device to reveal both ball and wedge bonds. This requires a protection method for copper wires that has been achieved by electrolysis, which uses DC current to drive a chemical reaction. Copper wires are made the anode and a cathode rod is immersed in an electrolyte consisting of the acid mixture (nitric and sulfuric). It was found that the negatively charged sulfate ions were then attracted to the positively charged copper wires and the positively charged hydrogen ions moved towards to the negative terminal to form hydrogen gas.

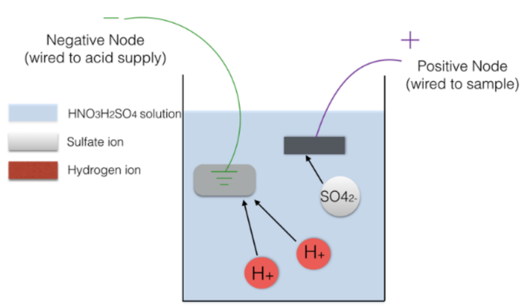


Figure 1: Electrolysis method of decapsulation

To ensure all wirebonds are connected to the anode, the leads are shorted with solder connecting all of them. A wire is soldered along with the leads which is connected to the positive terminal of the power supply.

The post-decapsulation step is done to ensure complete removal of both mold compound and the sulfate ion protective layer from the wire surface. It is done by washing with acetone followed by rinsing with water and isopropanol to remove mold compound debris from the die surface and sulfate ions from around the wire. A clean die surface is needed for bond shear testing. Acetone is also used to wash away excess acid that can cause further etching of the wire or lead frame. An isopropanol rinse dissolves the water, and then evaporates quickly leaving behind a dry surface devoid of chemicals.

III. Parameters Influencing Decapsulation of Copper Wire Bond Devices

Acid Mixture Ratio

Concentrated acids have been used for decapsulation of plastic encapsulated devices previously. However, with copper wire bonds this is not a straightforward process because copper readily reacts with nitric acid and corrodes (equation 1) [6]. Depending on the exposure times, copper wire develops pits or fully evaporates in the presence of acid.

$$Cu + 4HNO_3 \rightarrow Cu(NO_3)_2 + 2H_2O + 2NO_2 \uparrow \quad [1]$$

Concentrated sulfuric acid is another etchant to decapsulate PEMs. Though sulfuric acid does not corrode the copper wire bonds it etches the aluminum (equation 2) [1] bond pads, thus causing the ball bonds to lift off after the decapsulation process.

$$Al + 3H_2SO_4 \rightarrow Al_2(SO_4)_3 + 3H_2 \uparrow \quad [2]$$

It is seen from the previous works that a mixture of concentrated fuming nitric acid (>98%) and concentrated sulfuric acid (90%) etches the mold compound while also preventing corrosion of copper and aluminum. However the mixing ratio needs to be adjusted for different components and their mold compounds.

Nitration occurs upon mixing the two acids according to equation 3, the products of which are utilized to form a protective layer over copper.

$$H_2SO_4 + HNO_3 \rightarrow HSO_4^- + NO_2^+ + H_2O \quad [3]$$

Murali et al. [3] found that the ratio that minimizes copper corrosion is different for different temperatures. Hence for the current process, at temperature of 60°C, the ratio was chosen to be 3:1 (nitric to sulfuric acid), which yielded minimum (in some cases, no corrosion) of copper wires.

Voltage

Biasing voltage and current is important in this method, which determines the level of sulfate ion deposition on the wires. Higher biasing voltage attracts more negatively charged sulfate ions but there is a limit to the voltage that can be passed without melting or fusing the wire. For this study, a maximum limit of 16V was set on the DC power supply.

Temperature

High temperature increases the decapsulation rate, leading to a faster decapsulation process. However, it was found that the copper wires are etched at a temperature higher than 100°C [3]. Repeated experiments with temperature below 100°C revealed the optimal temperature for fast etching and prevention of copper corrosion was 60°C. It must be noted that the device actually experiences temperatures a little higher than 60°C due to the exothermic reaction of the etching process and due to biasing involved in the electrolysis process.

Mold Compound Type

The decapsulation process depends on the type of mold compound used on the device. Mold compound usually consists of epoxy resin (5–20 wt%), phenol-based hardener (5–10 wt%), and silica/alumina/AlN filler (60–80 wt%) mixed with tertiary amine-phosphorous, epoxy silane, stearic acid, wax, carbon black, and silicone or synthetic rubber (each at < 1wt%) [2]. It was found that etching takes longer with 3:1 acid mixture at 60°C for mold compounds that have a larger concentration of fillers.

Time

The etching duration is also important as longer duration can lead to etching of copper wires and short durations can leave large amounts of residual epoxy that cannot be cleaned with the solvent cleaning method. To lower the time, a pre-decapsulation method was performed either by nitric acid etching to make a pocket (for larger devices) or by mechanical milling (for small devices). These pre-defined pockets helped concentrate acid mixture within a small region and quicken the decapsulation process. After few minutes of electrolysis the component was taken out and remaining mold compound that was attached to the die and in between wires was washed away with solvents thereby reducing the time of actual contact with acid. This is of utmost importance to prevent copper wire bond corrosion even though copper is protected by sulfate ions.

IV. Results and discussion

Copper wires were imaged after the three-step decapsulation with a scanning electron microscope. Imaging software (Image-J) was used to measure the wire diameter to ensure the process had not etched copper. This process yields decapsulation of the entire device revealing most of the wire bonds, including both ball and wedge bonds. The aluminum of the bond pad can also be seen intact.

Device 1

It is a 64 lead, TQFP package with green molding compound. An X-Ray image of the device and other properties are shown below.

Package Type	64 - TQFP
Package Dimension	12.2 X 12.2 X 1.2mm
Silica Filler Content	85%
Wire Diameter	20 microns

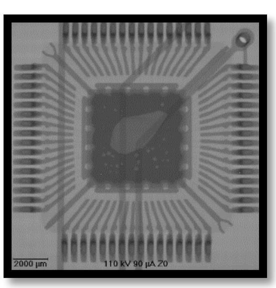


Figure 2: XRay Image of device 1

A scanning electron microscope image of the device after the three-step decapsulation process shows that almost all of the ball and wedge bonds are visible.

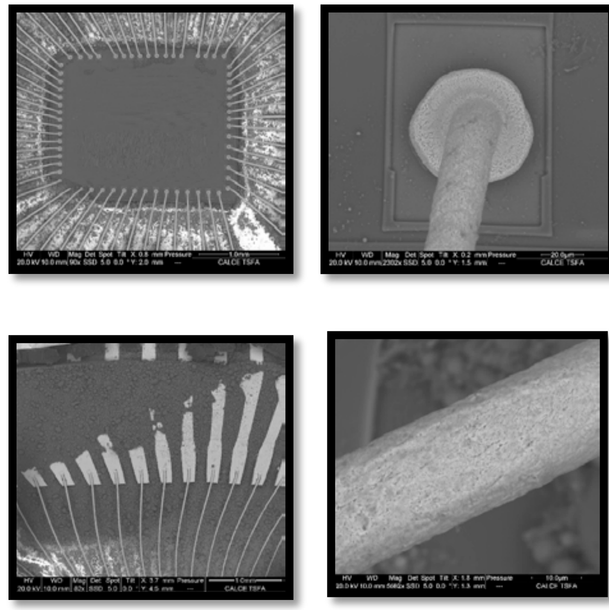


Figure 3: Scanning electron microscope image of device 1 after decapsulation.

Device 2

It is a 48 lead, QFN package with green molding compound. An X-Ray image of the device and other properties are shown below.

Package Type	48 - QFN
Package Dimension	6 X 6 X 1.2mm
Silica Filler Content	88%
Wire Diameter	17 microns

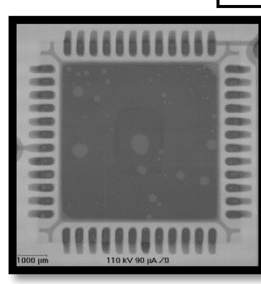


Figure 4: XRay Image of device 2

A scanning electron microscope image of the device after the three-step decapsulation process shows that almost all of the ball and wedge bonds are visible.

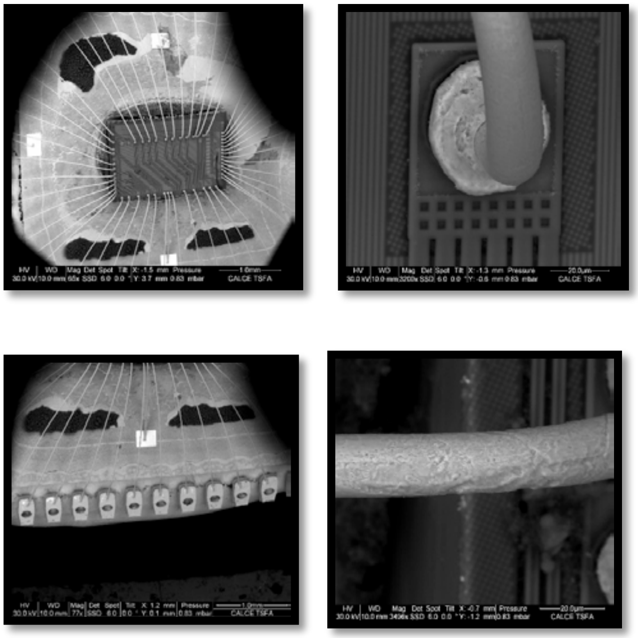


Figure 5: Scanning electron microscope image of device 2 after decapsulation.

The wire was measured after the decapsulation process to check for reduction in the diameter (figure 6). Measurement showed no significant variation from the expected value. However, wire bonds could have inherent variations in the order of few microns (<10 microns). Hence wire diameter measurement may not the best method for identifying copper wire corrosion.

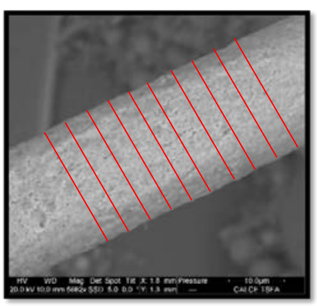
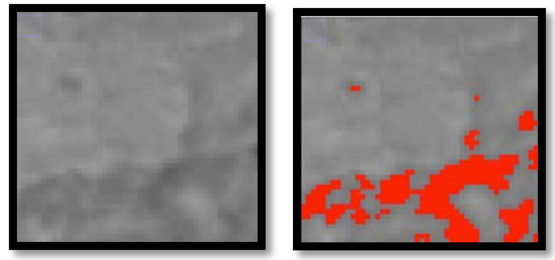
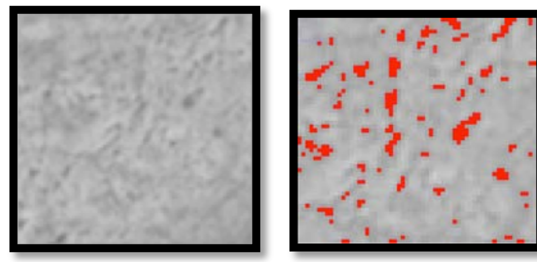


Figure 6: Wire diameter measurement

As a result, image analysis was also used to find grey scale variation. Pits formed on the copper wire appear darker in the SEM images. The area of dark pits was measured for the decapsulated parts. A magnified region of the wire was chosen for pit area measurement, as shown in figure 7. It was found that the around 15% of the area was slightly affected and 85% of the region was not attacked by the acid mixture for one part and that around 7% was slightly affected and 93% area was not affected for the other part.



Device 1: Corroded area ~15% (shown in red)



Device 2: Corroded area ~7% (shown in red)

Figure 7: Pit area measurement

V. Conclusion

A decapsulation process for copper wire bonded plastic encapsulated devices was presented that can be used to reveal all of the ball bonds and wedge bonds in the device. This is essential to perform bond shear and bond pull tests on the wires. All parameters affecting the procedure were found and described in detail. Using this procedure, a TQFP and QFN devices were decapsulated and the results were shown. It was found that the wire diameter did not change after the decapsulation process, but pits were formed, whose area was measured. From the SEM image it was observed that the wires had very little damage from the decapsulation process.

VI. ACKNOWLEDGMENT

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VII. References

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