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2015

Kor, K. H. B., Liu, Q., Siah, Y. W., & Gan, C. L. (2015). Decapsulation of 3D multi-die stacked package. 2015 IEEE International Symposium on the Physical and Failure Analysis of Integrated Circuits, 465-468. doi:10.1109/IPFA.2015.7224433

<https://hdl.handle.net/10356/143489>

<https://doi.org/10.1109/IPFA.2015.7224433>

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Decapsulation of 3D Multi-Die Stacked Package

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Abstract- Although a combination of laser, mechanical and chemical techniques can be used to expose a very large and thin die from a multi-die stacked package, package warping and die crack occur in the process of gaining access to each die. The aim of this paper is to investigate the sample preparation technique to access each individual die from a four-die stacked package, while maintaining the structural integrity of each die for further failure analysis.

I. INTRODUCTION

The relentless requirement for faster speed and better performance of devices drove the invention of the three-dimensional (3D) package technology, and one of the most commonly used is the multi-die stacked technology [1-3]. To completely decapsulate a microelectronic package, the entire package is usually immersed into heated fuming nitric acid, and individual intact die could be obtained for further failure analysis. Various works have been carried out to obtain individual die from multi-die stacked packages, such as a combination of laser, chemical and mechanical approaches [4, 5] and also on how to remove epoxy [6] and to prevent die crack.

Although these decapsulation techniques can be used to expose an individual large and thin die from a multi-die stacked package, package warping and die crack occur in the process of gaining access to each die. The aim of this paper is to investigate the sample preparation technique to access each individual large and thin die from a four-die stacked package, while maintaining the structural integrity of each die for further failure analysis.

II. EXPERIMENTAL DETAILS AND RESULTS

Four-die stacked, very thin land grid array (LGA) packages of dimensions 18 mm × 14 mm × 1 mm were used for the investigations. The dimension of each die (16 mm × 12.5 mm) is almost as large as the package itself, and each die thickness is about 100 µm. Fig. 1 shows a X-ray cross-section image of the four-die stacked package, and Fig. 2 shows the schematic of the cross-section of the four-die stacked package and the thicknesses of the epoxy molding compound (EMC), dice, die attach (DA) and substrate layers.

Fig. 1: X-ray cross-section image of the four-die stacked package

Fig. 2: Schematic of the cross-section of the four-die stacked package

Various experiments were carried out to expose each individual die by removing the EMC, silicon dice and DA. The details are described in the following sub-sections.

A. Full chemical decapsulation

According to Y. Jiang *et al.* [5], acid soak experiments on different kinds of thin die packages with different die count were carried out with no die crack issue. In addition, it was reported that acid soak at room temperature will result in much higher redistributed stress of a stacked package compared to acid soak at higher temperatures. Thus, experiments were carried out on our four-die stacked package by soaking it in 100% fuming nitric acid on a hotplate at 120°C for about 2 h, followed by cleaning with isopropyl alcohol (IPA) and hot water also at 120°C, to avoid differences in temperature. Air gun and ultrasonic bath were omitted. However, cracked top die resulted as shown in Fig. 3.

Fig. 3: Cracked top die during acid soak of the four-die stacked package

B. Laser and chemical (manual acid) decapsulation

Pre-laser decapsulation was carried out with the Sesame 1000 solid-state Nd:YAG laser decapsulation system, at 70% laser power, 16 kHz (maximum power is 8 W), to remove the EMC till the first wires were exposed. Manual acid decapsulation was

then continued on the package cavity opened earlier by the laser, by dripping a few drops of the heated (100°C) 100% fuming nitric acid onto the laser decapped area and left to react for a few minutes. The package was then soaked in acetone in ultrasonic bath during cleaning, and blown dry with an air gun. EMC at the edges of the package is tougher to remove compared to that at the centre, thus the manual acid decapsulation took hours. Cracks appeared on the top die (die 4) during manual acid decapsulation, even when the EMC had not been completely removed. Fig. 4 shows the results of laser and manual acid decapsulation of the stacked package.

Fig. 4: Laser and manual acid decapsulation of the four-die stacked package, (a) cracks (red arrows) on top die. Optical images of package (b) top left corner, (c) bottom left corner and (d) bottom centre area.

C. Laser and chemical (automatic acid) decapsulation

Due to the cracked top die from the earlier experiment, it was hypothesized that if the duration of the acid decapsulation could be shortened, the cracked die issue might be alleviated, if prolonged thermal heat was the cause. Pre-laser decapsulation was carried out similar to the previous section, followed by automatic chemical decapsulation using 100% fuming nitric acid, at 60°C, for 30 mins with the PS103S decapsulation system. Cleaning was done with acetone, deionized water and IPA, and the use of the air gun and ultrasonic bath were omitted. However, the top die still cracked even when the EMC had not been completely removed. Fig. 5 shows the cracked top die after laser and automatic acid decapsulation.

Fig. 5: Laser and automatic acid decapsulation of the four-die stacked package, (a) cracks (red arrows) on top die. Optical images of package (b) top right corner, (c) centre left corner, and (d) top left corner.

D. Combination of mechanical and chemical approach

Since full or partial chemical decapsulation resulted in cracked dice, the next approach was to combine mechanical (grinding) and chemical means. However, package warping resulted after removing DA3 to expose die 2, as shown in Fig. 6.

Fig. 6: Package warping after removing materials from EMC to DA3. The total thickness of die 2 and the remaining package is about 300 μm.

One of the factors which might have caused the package to warp could be that the package was too thin. Thus, the sample preparation methodology was modified, by encapsulating new packages in cold mount epoxy for mechanical support and relief of stresses during decapsulation and thinning.

Firstly, a 1 mm × 1 mm opening was made at the centre on the backside of the stacked-die package using the laser decapsulation system, at 90% laser power, 15 kHz. The substrate was ablated till the first copper was exposed. Next, automatic chemical decapsulation was carried out using a gasket with an opening size of 2 mm × 2 mm, with 100% fuming nitric acid at 60°C, for 4 mins, on the same opening created earlier by the laser. This creates a reflective silicon backside opening for optical/laser alignment to the ultracollimator of the UltraPol Advance grinder/polisher system (Fig. 7).

Fig. 7: Creation of a reflective silicon backside opening for alignment of the four-die stacked package to the ultracollimator

The purpose was to improve the surface uniformity while removing the EMC and each individual die within the stack during mechanical grinding. The etched opening was cleaned with acetone in ultrasonic bath for a minute, and brushed with cotton swabs briefly soaked in acetone, to expose the Si cleanly.

Before encapsulating the new stacked package with the exposed Si opening, the package was placed on the hotplate at 180°C for a few minutes, and a wax coated wooden stick was quickly bonded onto the opening. This prevents the epoxy from filling it and obstructing optical/laser alignment. Next, the epoxy encapsulation was carried out. The wax coated wooden stick was removed after the epoxy cured, so that the encapsulated package could still be aligned to the ultracollimator, with the exposed and cleaned Si opening. Removal of the wax coated wooden stick was done by wrapping the epoxy encapsulation in aluminium foil and soaking it for about 2 days in acetone. From

previous experiments, if the epoxy was soaked for a longer time without the aluminium foil, the acetone will etch and soften it, causing it to be irregular in shape and thus uniform grinding will be difficult. After removing the wax coated wooden stick from the epoxy, the backside of the epoxy was ground flat so that it could be attached to the sample holder and front side grinding could next be carried out. Fig. 8 shows the modified sample preparation setup.

Fig. 8: Modified sample preparation setup, (a) bonding of wax coated wooden stick to exposed Si backside, (b) encapsulation, (c) cured sample, (d) soaking of encapsulation wrapped with Al foil in acetone, (e) frontside and (f) backside

The exposed silicon backside of the encapsulation was aligned precisely (by using a marker pen to indicate the package outline) onto the sample holder of the UltraPol Advance grinder/polisher. It was attached to the sample holder using carbon tape (not covering the hole of the sample holder, so that the laser beam can pass through for optical/laser alignment). The tilt controls on the grinder/polisher system were next adjusted for proper alignment and planarity, prior to grinding. Table 1 summarizes the steps to gain access to individual die within the four-die stacked package.

Table 1 Combination of mechanical and chemical approach to obtain individual die		
	Step	Conditions
1	Automatic grinding of EMC	Grit 180 (75 μm) SiC paper EMC
2	Manual grinding of EMC	Grit 180 SiC paper pasted onto SEM stubs with double sided tape
3	Removal of DA5	Fuming sulphuric acid (20% SO_3) mixed to 100% fuming nitric acid (1:1), 100°C
4	Automatic grinding of the metallization and bulk Si of die 4	Grit 400 (25.8 μm) SiC paper
5	Manual grinding of the metallization and bulk Si of die 4	Same as step 2
6	Repeat steps 3-5 for DA4, die 3, DA3, die 2 and DA2, till die 1 was exposed	

The automatic grinding was carried out at 100 rpm for about 3 minutes. Fig. 9 shows the manual grinding setup.

Fig. 9: Manual grinding setup, (a) SiC paper pasted onto the front-side of a SEM stub with double sided tape and (b) backside of stub

Fig. 10 shows the results of material removal of the epoxy encapsulated four-die stacked package.

Fig. 10: Combination of mechanical and chemical approach to gain access to individual die of encapsulated four-die stacked package. (a) Before grinding, (b) DA5, (c) die 4, (d) DA4, (e) die 3, (f) DA3, (g) die 2 and (h) DA2.

There was no obvious package warping or die crack from the modified sample preparation method. Fig. 11 shows the optical images of the exposed die 1 at the four corners and centre, with some dirt and scratches from the mechanical grinding step, which could be improved using finer grinding or polishing techniques.

Fig. 11: Optical images of exposed die 1 of encapsulated four-die stacked package, (a) top left corner, (b) top right corner, (c) bottom left corner, (d) bottom right corner, (e) centre and (f) overview.

From the results, it can be observed that decapsulation of the four-die stacked package with very large and thin individual die of similar dimensions as the package using the conventional decapsulation methods resulted in die crack or package warpage. Thus, it is impossible to segregate each die from the package without destroying the preceding die. The package warpage or die crack could be due to stresses around the dice being relieved as the package gets thinner during the process of removing die by die.

Y. Jiang *et al.* [5] reported that the residual stress, σ , of a stacked package at room temperature can be described by the equation below:

$$\sigma = E\alpha\Delta T \quad (1)$$

where E is the modulus, α is the coefficient of thermal expansion and ΔT is the difference in temperature between the peak temperature in the package assembly process, and the temperature at which the decapsulation experiments were carried out. If the thermal expansion mismatch or ΔT increases, the residual stress in the stacked package is likely to build up, resulting in package warping or die crack when it surpasses the tensile strength of silicon. E and α are also parameters that may lead to increased warpage and stress on the bottom die. The redistribution of stresses on the substrate during the material removal process will accelerate package warping and die crack. Thus, a mechanical support is necessary to reduce the stresses at the package substrate, hence minimizing package warping and preventing die crack.

III. PERSPECTIVES

Automatic grinding was carried out until the removal was not efficient anymore (i.e. corner rounding observed, signs of nearing the underlying die surface with the four corners of the die slightly exposed). In manual grinding, the SiC paper has to be replaced frequently for effective material removal. Care has to be taken not to grind too hastily, to prevent overgrinding the DA and the die below it. For removal of DA, the acid mixture is left to react for a few minutes on the package cavity before brushing off the reacted acid/peeled DA using cotton swab soaked with a little of the acid mixture. From repeated experiments, it is best to brush as much of the DA as possible at this step, otherwise, some tough DA might remain. Another cotton swab soaked with acetone was used to brush off the residue. These steps were repeated until each DA was completely removed, and each die surface exposed and clean. Care has to be taken not to use too much force during the brushing, as scratches may be introduced on the die surface. The grinding of each individual die consists of the Si changing from a reflective surface to a matte surface with a change in sound, indicating that the underlying DA is getting near.

IV. CONCLUSION

The combination of mechanical and chemical approach is recommended for the decapsulation of the four-die stacked package, with the incorporation of epoxy as a mechanical support. Besides allowing easier handling and the decapsulation of the four-die stacked package die by die, the epoxy mechanical support reduces the stresses in the die during decapsulation, thus minimizing package warpage and preventing die crack. In addition, sample surface uniformity is also improved with the alignment of the exposed Si backside of the epoxy encapsulation to the ultracollimator of the UltraPol Advance polisher/grinder.

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