Laser focus depth adaptation for decapsulation of copper wirebonded devices

Kor, Katherine Hwee Boon; Liu, Qing; Siah, Yu Wen; Gan, Chee Lip

2014

Kor, H. B., Liu, Q., Siah, Y. W., & Gan, C. L. (2014). Laser focus depth adaptation for decapsulation of copper wirebonded devices. Conference Proceedings from the 40th International Symposium for Testing and Failure Analysis, 94-99.

<https://hdl.handle.net/10356/107318>

© 2014 ASM International. This paper was published in Conference Proceedings from the 40th International Symposium for Testing and Failure Analysis and is made available as an electronic reprint (preprint) with permission of ASM International. The paper can be found at the following official URL:

[http://www.asminternational.org/web/edfas/technical?p_p_auth=ob3PcFz5&p_p_id=101&p_p_lifecycle=0&p_p_

One print or electronic copy may be made for personal use only. Systematic or multiple reproduction, distribution to multiple locations via electronic or other means, duplication of any material in this paper for a fee or for commercial purposes, or modification of the content of the paper is prohibited and is subject to penalties under law.

Downloaded on 26 Apr 2023 22:21:06 SGT

Laser Focus Depth Adaptation for Decapsulation of Copper Wirebonded Devices

H. B. Kor¹, Q. Liu¹, Y. W. Siah^{1,2}, C. L. Gan^{1,2}

¹Nanyang Technological University, Temasek Laboratories @NTU, 9th Storey, BorderX Block, Research Techno Plaza
50 Nanyang Drive, Singapore 637553.

²Nanyang Technological University, School of Materials Science & Engineering,
50 Nanyang Avenue, Singapore 639798.
hbkor@ntu.edu.sg, +65-6592 3725

Abstract

Although pre-laser decapsulation reduces the time to acid exposure for subsequent chemical decapsulation of copper wirebonded devices, it can result in severely damaged or broken copper wirebonds if carried out at a focused depth followed by chemical decapsulation. Thin quad flat packages (TQFPs) of dimensions 22 mm × 22 mm, with copper wirebonds were pre-laser decapped (Nd:YAG laser, 1064 nm) at three depths of focus, at focus, (z-0.5) mm and (z-1) mm. Reducing the laser focus depth by 1 mm, followed by subsequent chemical decapsulation, resulted in the least damage to copper wirebonds. Average percentage reduction in copper wirebond diameter after complete (laser and chemical) decapsulation is about 2.30%.

Introduction

Copper wires are replacing gold wires in microelectronic packaging due to their relatively lower cost and superior properties in terms of electrical and thermal conductivities and mechanical strength. It can be found from literature that various recipes or combination of recipes in terms of plasma (dry), laser and chemical decapsulation have been developed for the successful decapsulation of copper wirebonds. Some of these are related to the chemical etching temperature, mixed acid ratios and concentration, etc. [1-7].

Pre-laser decapsulation is often carried out prior to chemical decapsulation during the opening of copper wirebonded packages to reduce the time to acid exposure for copper wirebonds. However, a focused laser depth during pre-laser decapsulation followed by subsequent chemical decapsulation could result in severely damaged or broken copper wirebonds. The aim of this paper is to study the effects of defocussing laser during pre-laser decapsulation of copper wirebonded devices, while maintaining the integrity of the copper wirebonds for further failure analysis.

Experimental Details

Thin quad flat packages (TQFPs) of dimensions 22 mm × 22 mm, with copper wirebonds consisting of 97.28% of copper, 2.70% of palladium and 0.02% of impurities were pre-decapped by laser (with Sesame 1000 laser decapsulation system), followed by chemical (using Nippon Scientific

PS103S system). The copper wires were examined under both the optical microscope and scanning electron microscope (SEM).

The copper wirebond diameters were measured after pre-laser decapsulation and after complete (laser and chemical) decapsulation. Table 1 shows the laser decapsulation parameters used for the pre-laser decapsulation of the copper wirebonded TQFPs.

Table 1: Laser decapsulation parameters used for the pre-laser decapsulation of copper wirebonded TQFPs

Laser power (%)	70
Frequency (kHz)	16
Duty cycle (%)	95

The depth of focus of the laser was varied at focus, (z-0.5) mm and (z-1) mm. The samples were chemically decapped using fuming HNO₃ and concentrated H₂SO₄ (10:1), at 22°C, for a duration of 1 min 30 s, followed by cleaning using IPA, acetone and water.

Results and Discussion

Figure 1 shows the SEM images of the copper wirebonds after pre-laser decapsulation and after complete decapsulation, at a focused laser depth, while Fig. 2 shows the overview optical image after complete decapsulation.

(b)

(c)

(d)

Figure 1: SEM images of copper wirebonds (a) after pre-laser decapsulation, (b) diameter measurement of copper wire after complete (laser and chemical) decapsulation, (c) broken wires and (d) debonded wires, laser depth at focus

Figure 2: Optical image of TQFP after complete (laser and chemical) decapsulation, laser depth at focus

It can be observed from Fig. 1(a) that when the laser depth is at focus, burn marks formed on the surface of the copper wirebonds. This can be explained by the relationship between the laser intensity and the beam spot size in the following paragraphs.

The design of the laser machine can be found in Fig. 3, where the laser galvo head consists of the laser with the galvanometer and focusing lens.

Figure 3: Schematic of laser galvo head design (Sesame 1000) [8]

Assuming that the laser beam is a point source and there is no energy absorption or scattering by the medium through which it propagates, the laser intensity is a function of the power over the beam area. This relationship can be described in Eq. (1) – (3) [9].

$$P = \int \vec{I} \cdot d\vec{A} \quad (1)$$

where P is the net power irradiated, $\vec{I}$ is the intensity as a function of position, and $d\vec{A}$ is a differential element of a closed surface containing the source. Performing integration over a spherical surface of uniform intensity I , Eq. (1) becomes:

$$P = |I| \cdot A_{surf} = |I| \cdot 4\pi w^2 \quad (2)$$

where I is the intensity at the surface of the sphere and w is the radius of the sphere. Rearranging Eq. (2) gives:

$$|I| = \frac{P}{A_{surf}} = \frac{P}{4\pi w^2} \quad (3)$$

The Gaussian function in Eq. (4) can be used to represent the transverse profile of the laser intensity of the beam with a power P [9]:

$$I(r, z) = \frac{P}{\pi w(z)^2 / 2} \exp\left(-2 \frac{r^2}{w(z)^2}\right) \quad (4)$$

where r is the radial distance from the centre axis of the beam, z is the axial distance from the beam's narrowest point, $w(z)$ is the beam radius, the distance from the beam axis at which the intensity of the beam drops to $1/e^2$ of the maximum value [9, 10]. This is illustrated in detail in Fig. 4.

Figure 4: Irradiance vs distance plot of a Gaussian beam [10]

With a fully focused laser beam, the laser beam spot size is reduced, resulting in peak laser intensity on the copper wirebonds, which can be described by Eq. (5) [9]:

$$I_P = \frac{P}{\pi w^2 / 2} \quad (5)$$

The laser heats the surface of the copper wirebonds and finally melts it [11], leaving behind striation marks. Subsequently, after complete decapsulation, besides the severe shrinkage of the copper wirebonds (Fig. 1(b)), some copper wirebonds broke (Fig. 1(c)), while some stitch bonds debonded from the leadframe (Fig. 1(d)).

The severe shrinkage of the copper wirebonds after complete decapsulation could be due to the chemical interaction of the mixed acids with the palladium on the copper wirebond surface. Palladium reacts slowly with fuming nitric acid and concentrated sulphuric acid, forming palladium nitrate, palladium sulphate and hydrogen gas, respectively, as shown in Eq. (6) and (7):

Without the protective layer of palladium on the surface of the copper wirebonds, copper wirebonds are readily attacked by the mixed acids, resulting in corrosion on the surfaces, as explained in Eq. (8) and (9):

The corrosion could be a result of the combined effects from the laser peak intensity, as well as the chemical reactions between the mixed acids with the copper wirebonds. Pre-laser decapsulation at laser focus depth of ($z=0.5$) mm was carried out next to see the effects.

Figure 5 shows the SEM images of the copper wirebonds after pre-laser decapsulation and after complete decapsulation, at laser focus depth of ($z=0.5$) mm, while Fig. 6 shows the overview optical image after complete decapsulation.

(b)

(c)

Figure 5: SEM images of copper wirebonds (a) after pre-laser decapsulation, (b) after complete (laser and chemical) decapsulation and (c) diameter measurement of copper wire after complete decapsulation, at laser focus depth of (z-0.5) mm

Figure 6: Optical image of TQFP after complete (laser and chemical) decapsulation, at laser focus depth of (z-0.5) mm

It can be observed from Fig. 5(a) that when the depth of focus of the laser is (z-0.5) mm, there is still some damage in the form of burn marks on the surface of the copper wirebonds. With a slightly defocused laser beam, the laser beam spot size is increased, resulting in a reduction in laser intensity on the copper wirebonds. Subsequently, after complete decapsulation (Fig. 5(b)), although pits formed on the surface of the copper wirebonds, the damage to the palladium coated copper wirebonds is reduced. The copper wirebonds are slightly deformed and there is still shrinkage in wire diameter, but there were no broken or debonded wires. Thus, the pre-laser decapsulation was next carried out at (z-1) mm to verify if the damage could be reduced further.

Figure 7 shows the SEM images of the copper wirebonds after pre-laser decapsulation and after complete (laser and chemical) decapsulation, at laser focus depth of (z-1) mm.

(a)

(b)

(c)

Figure 7: SEM images of copper wirebonds (a) after pre-laser decapsulation, (b) after complete (laser and chemical) decapsulation and (c) diameter measurement of copper wire after complete decapsulation, at laser focus depth of (z-1) mm (defocused)

It can be observed from Fig. 7(a) that when the depth of the laser is defocused at (z-1) mm, the laser does not cause much damage in the form of burn marks on the surface of the copper wirebonds due to much lower laser intensity with an increase in laser beam spot size. After complete decapsulation, although pits still result on the surface of the copper wirebonds (Fig. 7(b)), the damage to the palladium coated copper wirebonds is reduced significantly. The copper wirebonds are no longer deformed and shrinkage in wire diameter is minimal.

The overview optical image of the TQFP after complete decapsulation is shown in Fig. 8.

Figure 8: Optical image of TQFP after complete (laser and chemical) decapsulation, at laser focus depth of (z-1) mm (defocused)

Table 2 summarizes the measured average diameters of the copper wirebonds after pre-laser decapsulation, and after complete decapsulation, as well as the average percentage reduction in wire diameters after complete decapsulation, at the various laser focus depths studied.

Table 2: Average diameters of copper wirebonds after pre-laser decapsulation and complete (laser and chemical) decapsulation

Laser focus depth, z (mm)	Average copper wirebond diameter after pre-laser decapsulation (μm)	Average copper wirebond diameter after complete decapsulation (laser and chemical) (μm)	Average percentage reduction in wire diameter after complete decapsulation (%)
At focus	21.7 ± 2	0 – 14.7	Severely damaged, broken and debonded wires
(z-0.5)	21.7 ± 2	14.5 – 18.5	24.0
(z-1)	21.7 ± 2	20.4 – 22.0	2.30

From the results, it can be observed that carrying out pre-laser decapsulation at a defocused depth of (z-1) mm preserves the integrity of copper wirebonds, compared to (z-0.5) mm or at focus depth which resulted in broken and debonded copper wirebonds.

When the laser beam is focused, the spot size is reduced, resulting in greater laser intensity on the surface of the copper wirebonds. However, with a defocused laser beam, the spot size is increased, thus the laser intensity on the surface of the copper wirebonds is lowered, and damage to the copper wirebonds is minimized. Although the average copper wirebonds diameter after pre-laser decapsulation is similar for laser focus depths at focus, (z-0.5) mm and (z-1) mm, the damage to the surface of the copper wirebonds is more at a fully focused depth, compared to defocused depth. The palladium protection layer will also be less at focused laser depth. Subsequently, during chemical decapsulation, this damage will be even greater, as the mixed acids can easily access and etch the already damaged copper wires from the pre-laser decapsulation step.

Conclusion

The pre-laser decapsulation step in the decapsulation of copper wirebonded devices is crucial in preserving the integrity of copper wirebonds. If copper wirebonds are already severely damaged at this step, subsequent chemical decapsulation will exacerbate the damage. It is recommended to carry out pre-laser decapsulation with a defocused laser depth to reduce the amount of damage on copper wires.

References

- [1] S. W. Ng, H. B. Zhang, K. N. Liew, W. Lee, and R. D. Lin, "Copper wirebond package decapsulation technique using mixed acid chemistry," in *19th IEEE International Symposium on the Physical and Failure Analysis of Integrated Circuits (IPFA)*, 2012, p. 5 pp.
- [2] H. Wu, A. Chiang, D. Le, and W. Pratchayakun, "Failure Analysis on Power Trench MOSFET Devices with Copper Wire Bonds," in *37th International Symposium for Testing and Failure Analysis (ISTFA)*, 2011, pp. 223-229.
- [3] M. J. Lefevre, F. Beauquis, J. Yang, M. Obein, P. Gounet, and S. Barberan, "New method for decapsulation of copper wire devices using LASER and sub-ambient temperature chemical etch," in *IEEE 13th Electronics Packaging Technology Conference (EPTC)*, 2011, pp. 769-773.
- [4] Y. H. Chen, M. Hsiao, and C. E. Tseng, "The properties comparison between Au and Cu wires bond in DRAM component," in *18th IEEE International Symposium on the Physical and Failure Analysis of Integrated Circuits (IPFA)*, 2011, pp. 207-210.
- [5] J. EKlein and L. Copeland, "Decapsulation of copper bonded plastic encapsulated integrated circuits utilizing laser ablation and mixed acid chemistry," in *36th International Symposium for Testing and Failure Analysis (ISTFA)*, 2010, pp. 133-136.
- [6] K. D. Staller, "Low temperature plasma decapsulation of copper-wire-bonded and exposed copper metallization devices," in *36th International Symposium for Testing and Failure Analysis (ISTFA)*, 2010, pp. 127-132.
- [7] S. Murali and N. Srikanth, "Acid decapsulation of epoxy molded IC packages with copper wire bonds," *IEEE Transactions on Electronics Packaging Manufacturing*, vol. 29, pp. 179-183, 2006.
- [8] "Manual: Machine Design and Description of Functions," ed: Baublys Control Laser, 2007, p. 3.
- [9] R. Paschotta, *Optical intensity, Gaussian beams. RP Photonics. Encyclopedia of Laser Physics and Technology* vol. 2, N-Z: Wiley-VCH, 2008.
- [10] A. Laboratories. (2014). *Laser beam divergence and spot size*. Available: <http://amrita.vlab.co.in/?sub=1&brch=189&sim=342&cnt=1>
- [11] P. E. B. Paranal, "Localized die metallization damage induced during laser-marking of a semiconductor package," in *33rd International Symposium for Testing and Failure Analysis (ISTFA)*, 2007, pp. 226-230.