

A STUDY OF UNDERFILL MORPHOLOGY AND FILLER CONTENT USING SCANNING ELECTRON MICROSCOPY AND THERMOGRAVIMETRIC ANALYZER

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Abstract The filler content of two type capillary underfill materials for flip chip packaging were studied using Thermogravimetric Analyzer (TGA) and Scanning Electron Microscopy (SEM). An epoxy based resin and cyanate ester based resin were subjected to TGA to determine the percentage of filler content and their morphology were studied using SEM. The results show that these two underfills materials have a very similar percentage of filler content which is around 70% and shows good morphology properties for capillary underfill application.

KEYWORDS: Flip chip, underfill, filler content, morphology, SEM, TGA

Introduction

Flip chip technology becomes popular in today's microelectronic packaging because this type of packages can support higher I/O pad counts and power distribution required due to the increase of device density on the chip (Gilleo *et al.*, 1999; Lau *et al.*, 1999; Wong *et al.*, 2000; Frank Stepniak, 2004; Lee *et al.*, 2004). Flip chip packaging uses a variety of interconnection technology such as eutectic and lead-free solder to connect the active side of silicon chip to multilayered substrate (Lau *et al.*, 1999).

There is a structural integrity issue in the early stage of flip chip development. The deformation of solder joint when exposed to high temperature environment (due to coefficient mismatch between silicon chip and multilayered substrate) will lead to stress strain in solder joint resulting in solder fatigue failure (Wong *et al.*, 2000; Frank Stepniak, 2004;). Two solutions is made, first is using multilayered substrate with Coefficient Thermal Expansion (CTE) matching the silicon chip such as ceramic substrate. But, this solution will increase a significant cost in flip chip production because ceramic comparatively has a higher cost. Second solution is using underfill encapsulant to redistribute stress and protect solder bumps. The introduction of underfill encapsulant was transformed flip chip packaging as a today's popular IC packaging method (Wong *et al.*, 2000).

By adding an amount of low expansion silica filler in epoxy/cyanate ester based resin materials, the CTE will be reduced and the mechanical strength of resin system will be improved. Silica filler is usually used for capillary flow underfill. Silica is prefer than carbon fiber, silver and others filler because their properties and morphology (Lee *et al.*, 2004). The main purpose of this paper is to study silica filler content of capillary underfill in terms of percentage of filler, filler shape, distribution and filler ratio to die and substrate gap in flip chip packages. Methods used in this study are suitable for reverse analysis if the filler type, amount and morphology are unknown.

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Material and Methods

Two types of uncured underfill materials, epoxy based resin and cyanate ester based resin which all filled with low expansion silica material were subjected to Mettler Toledo Thermogravimetric Analyzer to determine their percentage of filler content. About 30-40 mg of underfill materials was heated up from room temperature to 600°C with 10°C/min heating rates (Ye *et al.*, 2000). This experiment was conducted in air atmosphere with 0.1 µg sensitivity. Underfill morphology was examined using Scanning Electron Microscopy. Morphology examination and measurements will include the shape and geometry of silica filler particle, particle size, particle surface smoothness, gap size ratio and filler particle distribution or filler settling. A flip chip packages using both type of underfill system are used for gap size ratio and filler settling or distribution. The samples were mounting, polishing and cross sectioning and subjected to SEM after gold coating to prevent electron charging.

Results and Discussion

Percentage of Filler Content

TGA curve of 41.45 mg epoxy based resin samples was shown in Fig. 1. After heated up to 600°C, the silica filler remaining was about 70.29%. Figure 2 shows TGA curve for 42.81 mg cyanate ester based resin samples. From TGA graphs, cyanate ester based resin has a higher level of silica filler compare to epoxy based resin which is about 71.56%. Both levels can reduce coefficient of thermal expansion (CTE) of underfill resin system to match CTE of solder bump in flip chip since the CTE of typical epoxy and cyanate ester resin without filler is around 70-80 ppm/°C (Ken Gilleo, 2001). The level of silica filler alone can only used to estimate CTE because the chemical formulation of resin system also contributes in changing underfill thermal expansion behavior (Miles *et al.*). However, based on TGA results, cyanate ester can give better performance as capillary underfill in term of percentage of filler content.

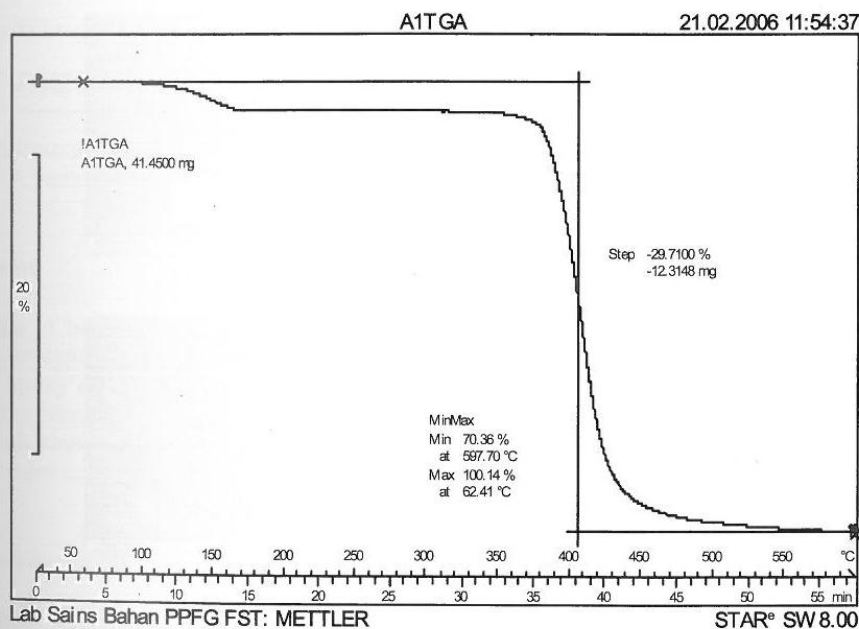


Figure 1. TGA scan of uncured epoxy based resin underfill materials

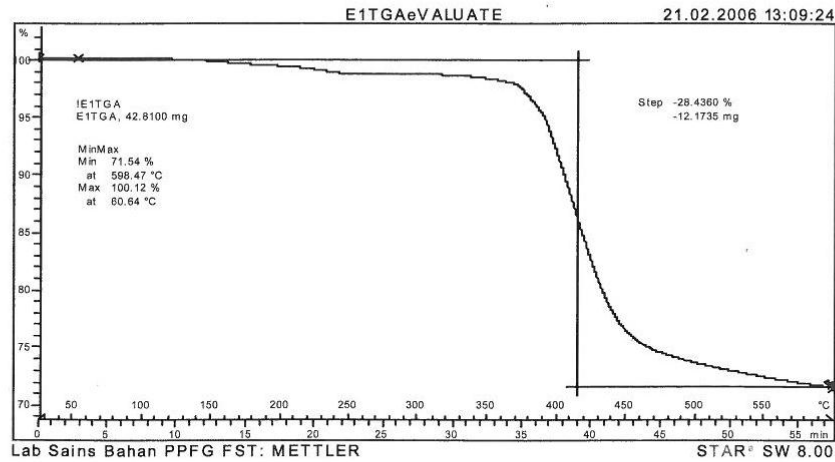


Figure 2. TGA scans of uncured cyanate ester based resin underfill

Underfill morphology

Figure 3 (a) shows a cross sectional view of the flip chip package and their gap distance between silicon die and substrate which is about 63.80 μm . Cross sectional view also shows that low expansion of silica filler is spherical in shape. Spherical shape will give underfill more conducive to flow compare to other type of filler because an irregular particle sweeps out a larger effective diameter than a sphere (Ken Gillieo). In addition, a nearly perfect spherical shape will produce a lower viscosity compared to other particles shape. SEM images also shows that the microspheres of silica filler has a very smooth surface. Spherical shape only will not give good lower viscosity unless the particles have very smooth surfaces. Both underfill shows identical of silica filler morphology.

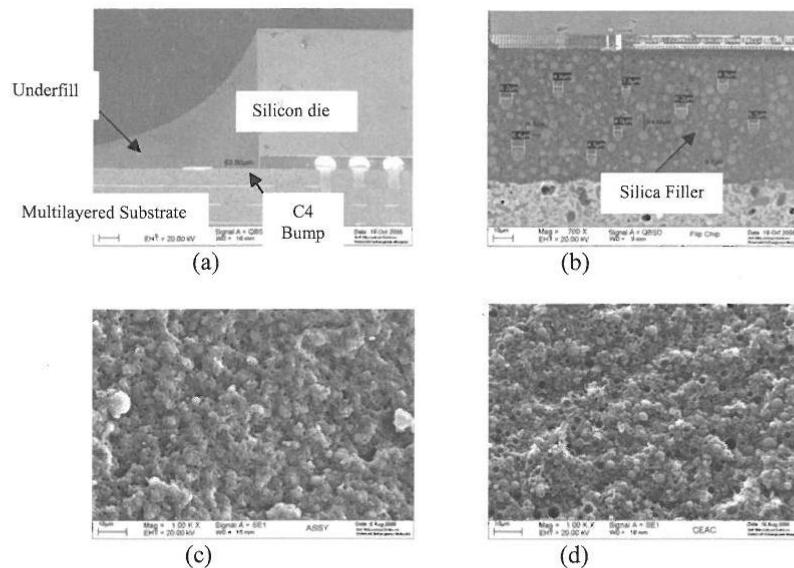


Figure 3. SEM images show (a) silicon die to substrate gap size for flip chip package (b) cross sectional morphology of silica filler distribution for epoxy (c) and (d) is fracture morphology for epoxy and cyanate ester based respectively

Figure 3(b) shows the good uniformity of silica filler which the big size and small size silica filler particles distributed randomly without agglomerations (Yangyang *et al.*, 2004). This type of distribution shows underfill have enough viscosity to hold filler particles at underfill flow temperatures, the flow process is not impeded and silica filler particles is not pulling to each others. The measurement made shows that the maximum size of silica filler particles is 6.4 micron for epoxy and 5.7 micron for cyanate ester underfill and both distributed randomly. The maximum size of silica filler particles must be suited for narrower gap and tighter pitch trends for future ic packages. This gives the ratio for gap to maximum silica filler particles size 10:1 and 11:1 for epoxy and cyanate ester respectively. This ratio is higher than 3:1 ratio and suitable for capillary flow application (Miles *et al.*). Fracture morphology as shown in Fig. 3(c), 3(d) and 4 can be very useful to investigate silica filler bonding to resin system this morphology will change after thermal and moisture treatment (Shi *et al.*, 2002).

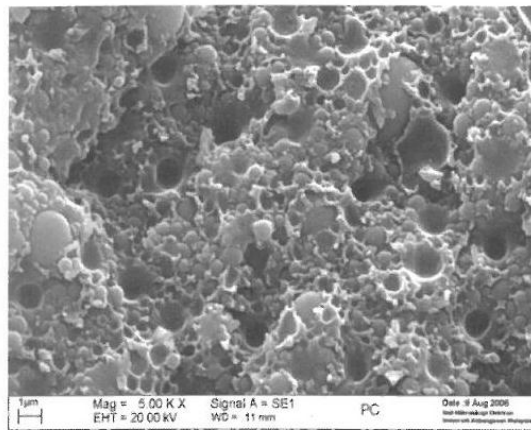


Figure 4. Close up of fracture morphology of epoxy based underfill

Table 1. TGA and SEM results summary

Resin Type	Filler (%)	Shape	Distribution	Max Size (μm)	Gap Ratio
Epoxy	70.36	Spherical	Random	6.4	10:1
Cyanate Ester	71.54	Spherical	Random	5.7	11:1

Conclusion

Both type of underfill materials, epoxy and cyanate ester based resin were studied and was found suitable for capillary flow application in terms of filler content. This amount of silica filler can reduced CTE of epoxy or cyanate ester resin to match CTE of solder bump and improved flip chip packages reliability. From morphology study, it was shown that both type of underfill have spherical shape of silica with smooth surfaces, good distribution and gap size ratio as summarized in Table 1. TGA measurement is useful in determination of percentage of underfill filler content.

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References

- Frank Stepniak. 2004. *Microelectronics Reliability* (200)44:805-814.
- Gilleo, K., M. Witt, D. Blumel and P. Ongley. 1999. *Microelectronics International* 16(2):39.
- Ken Gilleo. *The Chemistry & Physics of Underfill*.
- Ken Gilleo. 2001. *Microelectronic Packaging Handbook*.
- Lau, J. H. 1999. *Flip Chip Technologies*. McGraw-Hill, New York.
- Lee, W. S., I. Y. Han, Jin Yu, S. J. Kim and T. Y. Lee. 2004. *Electronics Packaging Technology Conference*.
- Miles, T. R., L. P. Rector and S. Gong, *Semicon West 2000*, San Jose, Ca.
- Shi, X. Q., Z. P. Wang, H. L. J. Pang and X. R. Zhang. 2002. *Polymer Testing* 21:725-733.
- Wong, C. P., S. Luo and Z. Zhang. 2000. *Flip the Chip*. *Science* 290:2269-2279.
- Yangyang Sun, Zhang, and C. P. Wong. 2004. In 9th Int'l Symposium on Advanced Packaging Materials.
- Ye He, B. E. Moreira, A. Overson, S. H. Nakamura, C. Bider and J. F. Briscoe. 2000. *Thermochimica Acta* 357:1-8.