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STENCIL PRINTING TECHNIQUE FOR MICRO-SOLDER BUMPS PATTERNING

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ABSTRACT

Advancement in integrated circuit (IC) chips packaging involves three-dimensional (3D) versus two-dimensional (2D) packaging technology. 3D packaging involves stacking of daughter die/s on to a mother die in a vertical configuration for obvious reasons. Interconnections had been done either through wire bonding or a combination of wire bonding and flip chip technology. Flip chip technology requires the formation of solder bumps on processed silicon wafers, which were diced to form a single diced die. Relatively expensive and elaborate evaporation and electroplating processes used in the formation of solder bumps leads to a development in a simpler and cheaper bumping technology. The present experimental work describes challenges and updates methods in stencil printing for the development of solder bumps on copper as an arbitrary substrate. Both, lead-containing and lead-free solder pastes were used as the bumping materials of construction. Green solder bumps were heated in an atmospheric furnace with controlled heating rate and heating time. Solder pastes characterisation used in this study were done using solder checker equipment. Solder bump characterizations include bump height and uniformity, composition, shear force magnitude using solder bond analyser and bump profiles and cross section analysis were conducted using scanning electron microscopy.

INTRODUCTION

Flip chip package technology has been established for many years. However, only in recent years has it found widespread in usage as the solution for application in high performance packaging. For example, in applications where there are requirements for high pin counts or high routing density and when there is requirement for increased thermal and electrical performance.

The advantage of flip chip technology is due to its superiority in electrical performance, higher thermal conductivity, relatively small size and higher I/O counts which are some requirements for advanced semiconductor applications. However, a real shift towards flip-chip interconnection technology will be realised with the accomplishment of cost reduction, reliability improvement and development of high density substrate technology [1,2].

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The size of solder particle is an important factor, and solders pastes with homogenous particle distribution of less than 25 µm is recommended. Volume and height of the deposited solder depend on the thickness and diameter of pores of stencil used, as well as the type of squeegee material used [3].

Stencil printing technique is widely used in surface mount assembly. The conventional printing method and materials used are not suitable for ultra fine pitch application. In order for the paste to be released from the stencil and remained on the pad, the wetted area of the stencil must be minimized. Therefore, the stencil thickness should be less than the aperture diameter, therefore setting a lower practical limit on the possible bump diameter. For example, stencils less than 50 µm thick are fragile and dimensionally unstable as the squeegee drags the paste over them [3-6].

The purpose of a stencil is to allow the transfer of solder paste, through its aperture openings and onto a given substrate surface. Stencil printing technique is the lowest cost process for depositing interconnects for flip-chip packaging. Laser-cut stencil is produced by mounting a foil onto a frame, and a high-power laser is then driven in a predefined manner relative to the layout file. The most commonly material used in the manufacture of laser-cut stencils is stainless steel. Recent refinements in laser-cutting processes result in improved quality of stencil apertures for small laser-spot sizes. One advantage in laser cutting is that the material is pre-tension prior to the cutting process [7].

Printing at fine pitch requires a reduction in the particle size distribution (PSD) of the alloy from 20-45 µm (type 3) to less than 15 µm (type 6 and 7). These finer particles in the solder paste will alter paste rheology. Rheology is the behaviour of the paste with regard to flow and deformation. This affects shear stress, strain, and rate. Having the correct rheology is critical for the printing process as it impacts paste roll and apertures fill and release. Flux composition and alloy volume determine paste rheology [7-11]. In the on-going research, the developed flux and the formulated pastes were used and stencil printing technique produced equivalent quality micro-solder balls to those available commercially.

METHODOLOGY

Solder Powder

Pure SAC 054 and Sn5Sb in powder form were purchased from EURAMCO (M) Sdn Bhd, (manufactured in USA) and were used in this experiment. The powder is stored in controlled atmosphere (glove box) to reduce the oxidation and sample contamination prior to experimental work.

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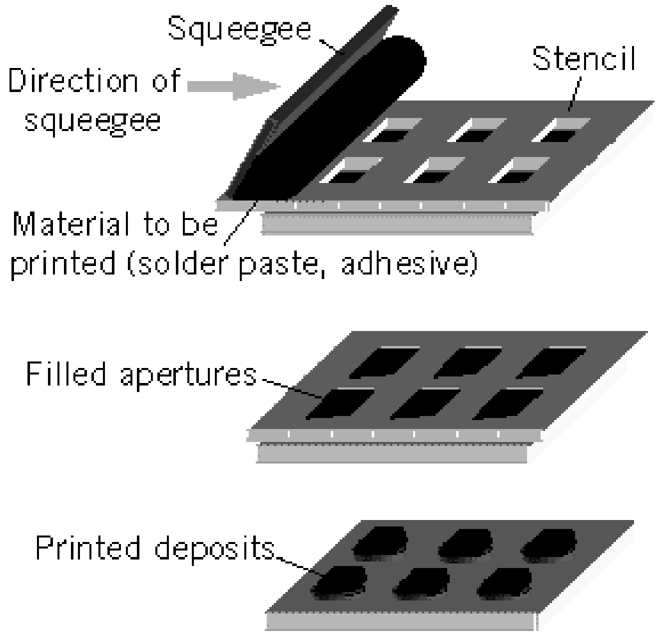

Figure 1: Schematic stencil printing processes for green micro-solder bumps formation [4].

Solder flux
A standard method for preparing the flux is as described elsewhere [12]. The prepared flux was stored in a controlled atmosphere prior to mixing to reduce component chemical activity and chemical decomposition at room temperature. This flux will be used to prepare SAC 054 and Sn5Sb pastes.

Solder paste
The solder paste (SAC 054 and Sn5Sb) for performance evaluation was prepared as described by H.Z. Saadiah [12]. The commercial solder pastes (SAC 305, SAC 405 and SnPb) were purchased from Indium Corporation of USA for performance comparison. The pastes were stored in a chill box (to around 5^{o}C or lower) to maintain or reduce constituent chemical decomposition. It is recommended by the supplier that these pastes need cooling down to room temperature prior to application.

RESULTS AND DISCUSSIONS

Morphology of developed bumps
Figure 2 shows morphology of SAC 054 and Sn5Sb powder from scanning electron microscopy (SEM). On arbitrary examination, the individual particle diameter of SAC 054 powder varies from 3 to 6 μm, compared to SnSb powder particle which vary from 2 to 8 μm. Both powders show clean particle surfaces, that is, there is absence of satellites

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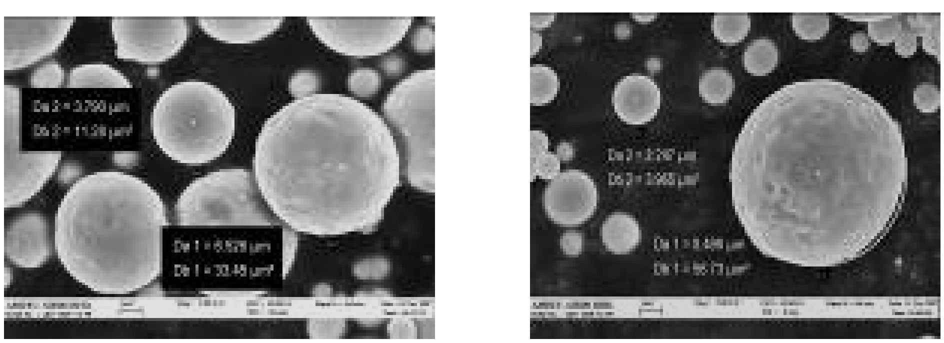
on particles surfaces and the powder particles do agglomerate. Further, the particle surfaces do not show stains or indication of surface oxidation. These characteristics indicate the suitability as solder paste material for fine pitch solder bumping material.

Table 1: Temperature and time differences during sample reflow.

Type paste	Re-flow Temperature (°C)	Total re-flow time (min)	Determined melting temperature using DSC, (° C)
Sn5Sb (developed paste)	290	179	248.9
SAC 054 (developed paste)	350	199	226.5
SnPb (commercial paste)	233	160	185.3
SAC 305 (commercial paste)	270	173	226.2
SAC 405 (commercial paste)	270	173	224.6



(a) (b)

Figure 2 Morphology of solder particles for (a) SAC 054 and (b) Sn5Sb.

Re-flowed solder bumps

The morphology of reflowed solder bump is as shown in the Figure 3. Most re-flowed

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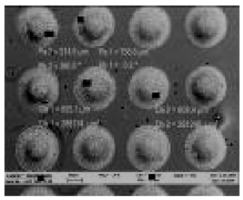
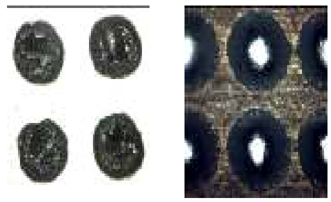
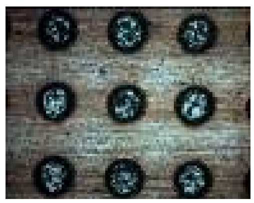
solder bumps exhibited “bleeding” characteristics. This is perhaps due to the fluidity of the constituent chemicals which make-up the formulated flux, and due to the working ratio of solder powder to flux. The unmatched fluidity and incorrect working ratio resulted in differences in paste viscosity which resulted in bleeding phenomenon of solder paste prior to curing in furnace. Figure 3(b) and 3(d) show bleeding phenomenon of solder paste, and often results in deformed ball and short-circuits.


(a) Sn5Sb


(b) SAC 054 bumps


(c) SAC 405


(d) SAC 305

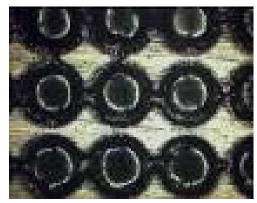

(e) SnPb

Figure 3: Re-flowed micro-solder balls formed through screen printing technique.

Wetting characteristics

Figure 4 (a) and 4(b) are wetting balance curves for selected substrates under test, at two arbitrarily selected temperatures, i.e 245^{o}C and 260^{o}C. These temperatures were selected to observe wetting characteristics of test alloys with respect to operating temperature. From the experiment conducted, it is observed that eutectic tin-lead has lowest “time-to-wet” the surface during soldering process (Figure 4(c)). The longest “time-to wet” the substrate surface has been SAC 405, followed by Sn5Sb, SAC 450 test alloys. Some known factors which affect the soldering parameters are operating temperature, flux composition, flux viscosity and surface tension and solder alloys composition.

Lead-free solder alloys used in the present work have a melting point of around 215°C to 225^{o}C, which is 30^{o} C higher than that of eutectic SnPb solder (T_m = 183^{o}C), meaning that its use should be able to be implemented into existing soldering processes with minimal process modification. The temperature used to attach components with eutectic SnPb solder is closed to 220^{o}C (industry accepted criteria for the testing of the eutectic SnPb solder is 235^{o}C). However, in order to choose the right reflow profile that would not cause damage to components or boards, the lowest possible temperature would be required. The decrease in the test temperature to 245^{o}C from 260^{o}C, revealed that some of the Pb-free

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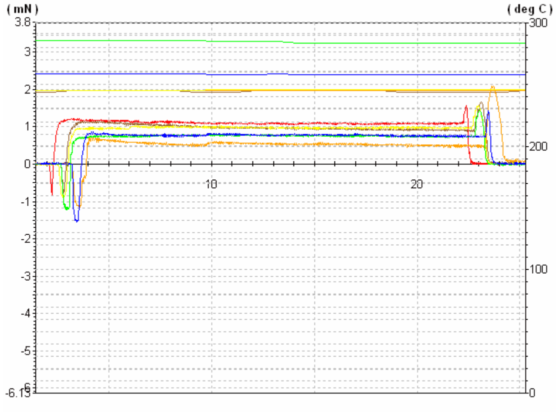
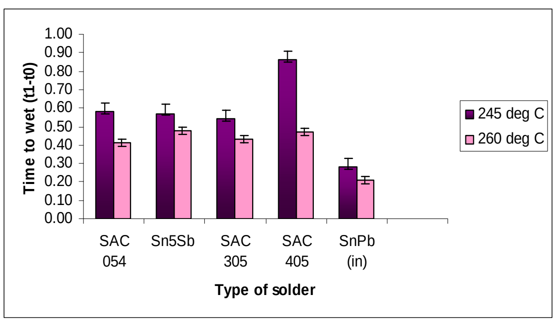
solder alloys investigated would not perform as required.

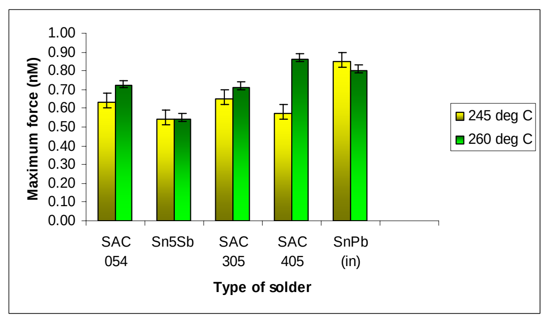


(a) 245^{o}C

(b) 260 ^{o}C



(c) Relative time to wet



(d) Relative maximum wetting force

Figure 4: The wetting performance of solder pastes at (a) 240 ^{o}C, (b) 260 ^{o}C, (c) Relative time to wet and (d) Relative maximum wetting force.

Shear force
A method used to investigate the reliability of the solder bumps is by measuring the shear strength using the solder bond analyser equipment. The load distance used for this test was 2 µm and the set speed was 5 mm/sec. Load used was set to 5000 g-force. The results showed a shear force of 505.5 g-force for ball developed using SAC 405 paste, and the lowest shear force was 124.0 g-force for ball developed using Sn5Sb paste.

The micrographs show the shear strength required to push one ball until a joint failure occurs, and the peak value in the graph shows the maximum strength needed to shear one ball. The drop in the magnitude of force shows that the test to shear the ball is finished. Figure 5 showthe SAC 405 and SAC 305 that has the highest shear strength followed by the SAC 054 SnPb material.

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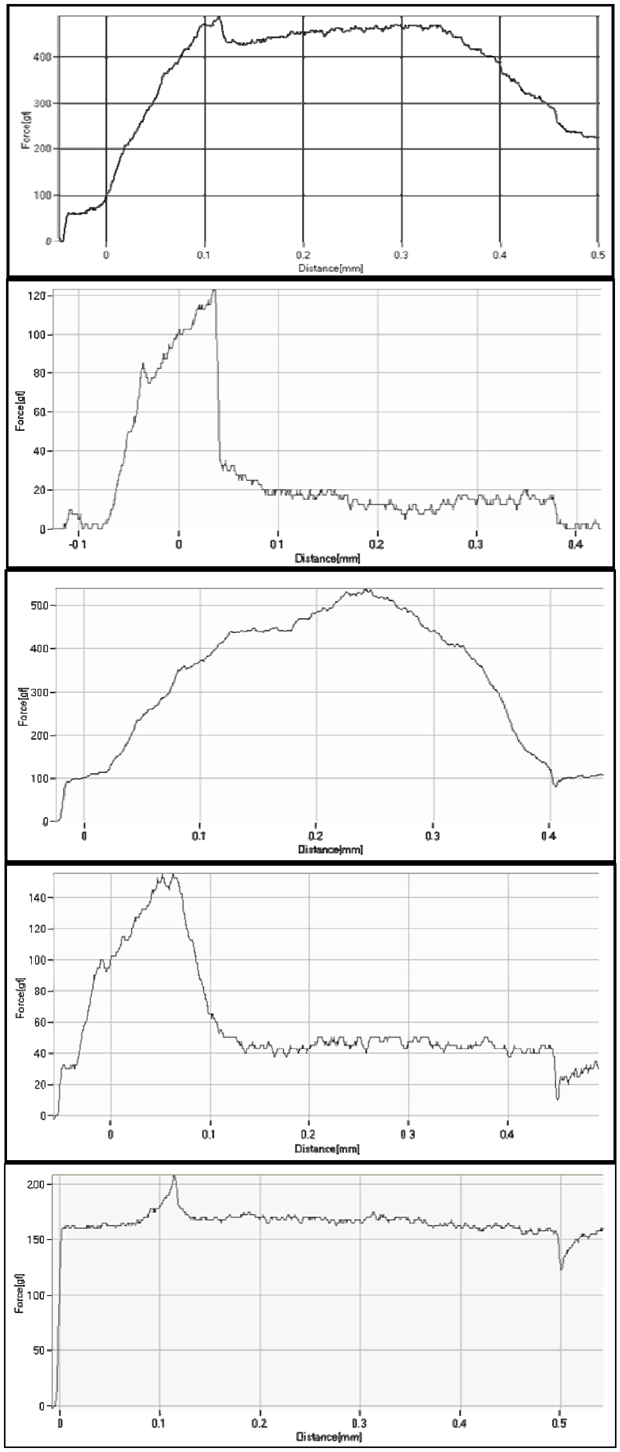

Figure 5: Variation in the magnitude of force required to shear one to complete failure.

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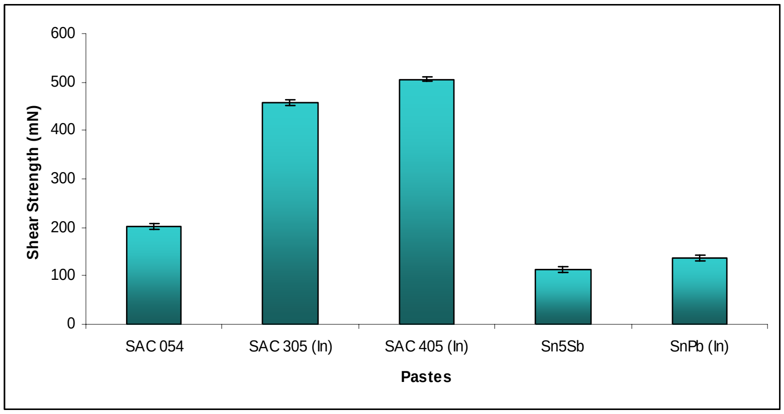
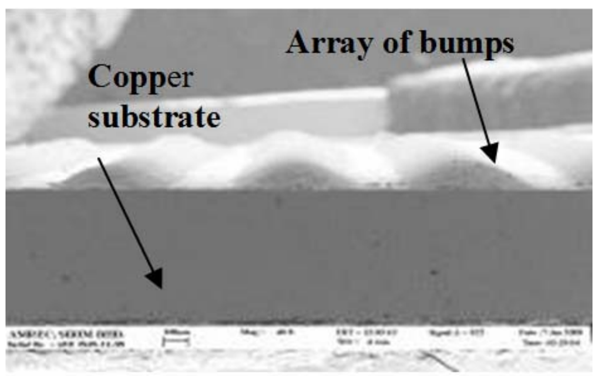
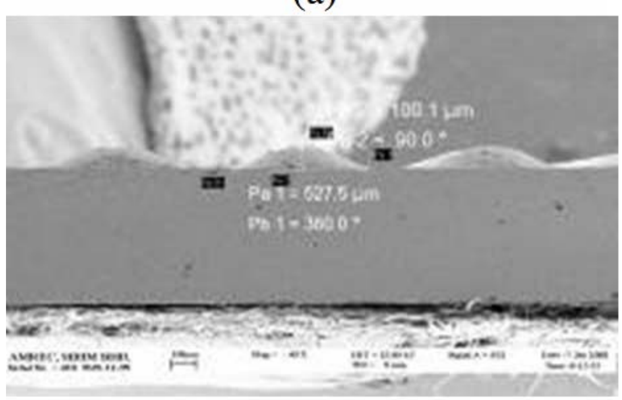


Figure 6: Distribution of maximum shear force with different solder paste.

Cross section analysis



(a)



(b)

Figure 7: Cross-section of re-flowed micro-balls.

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CONCLUSION

The study showed that the formation of micro-balls on copper substrate using stencil printing method was possible and could be further improved. The initial diameter of the stencil was 400 µm and 800 µm pitch. This technology is suited for high volume applications. Alloy SAC 405 was found to give a higher shear force (505.5 g-force) while the lowest was Sn5Sb (124.0 g-force).

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