New Generation of Lead Free Solder Spheres "Landal - Seal"

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New Generation of lead free solder spheres and paste

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Abstract

A new alloy definition will be presented concerning increasing demands for the board level reliability of miniaturized interconnections. The damage mechanism for LFBGA components on different board finishes is not quite understood. Further demands from mobile phones are the drop test, characterizing interface performance of different package constructions in relation to decreased pad constructions and therefore interfaces. The paper discusses the characterization of interfaces based on SnPb, SnPbXYZ, SnAgCu and SnAgCuInNd ball materials and SnAgCuInNd as solder paste, the stability after accelerated tests and the description of modified interfaces strictly related to the assembly conditions, dissolution behavior of finishes on board side and the influence of intermetallic formation. The type of intermetallic as well as the quantity of intermetallics are observed, primaliry the hardness, E modules describing the ability of strain/stress compensation. First results of board level reliability are presented after TCT-40/+150. Improvement steps from the ball formulation will be discussed in conjunction to the implementation of lead free materials.

In order to optimize ball materials for area array devices accelareted aging conditions like TCTs were used to analyze the board level reliability of different ball materials for BGA, LFBGA, CSP, Flip Chip. The paper outlines lead-free ball analysis in comparison to conventional solder balls for BGA and chip size packages. The important points of interest are the description of processability related to existing ball attach procedures, requirements of interconnection properties and the knowledge gained the board level reliability. Both are the primary acceptance criteria for implementation.

Knowledge about melting characteristic, surface tension depend on temperature and organic vehicles, wetting behavior, electrical conductivity, thermal conductivity, specific heat, mechanical strength, creep and relaxation properties, interactions to preferred finishes (minor impurities), intermetallic growth, content of IMC, brittleness depend on solved elements/IMC, fatigue resistance, damage mechanism, affinity against oxygen, reduction potential, decontamination efforts, endo-/exothermic reactions, diffusion properties related to finishes or bare materials, isothermal fatigue, thermo-cyclic fatigue, corrosion properties, lifetime prediction based on board level results, compatibility with rework/repair solders, rework temperatures of modified solders (Impurities, change in the melting point or range), compatibility to components and laminates

Preconditions for Implementation

International ranking of preferred solder alloys, "Minor Impurities" and solder properties, physical properties of Pb-free solders, temperature-profile reflow and wave, thermal resistivity of components and laminates against soldering heat, interconnection reliability, topology of lead-free solder joints (quantity and reproducebility of soldering), visual inspection / comparison to conventionell solders, criterias of visual inspection, residues of lead-free pastes / Resistivity agains migration, mechanical characterisation of lead-free solder joints, isothermal and thermo-cyclic fatigue properties of preferred solders, damage-behavior under different test conditions, board level reliability compared to conventionell solders, definition/right choice of test parameters based on the knowledge of the main damage mechanisms, evaluation of the significant damage discriptions, availability (Second Source).

The goal of this sudy was to determine the feasibility of using modified lead-free balls and solder pastes in conventional assembly processes and to answer the questions related to the board level reliability. Specifically, modified balls on the metallurgical basic system SnAgCu were used for primary wetting and interaction analysis. Reliability results were obtained for conventional balls in relation to modified balls on area array components, which indicate that the use of SnAgCuInNd under conventional reflow conditions can be successful for extended temperature ranges.

Introduction

The paper outlines:

- Discussion of lead-free ball materials / BGA / CSP and lead-free solder pastes

- Comments / processability of lead-free solder balls / pastes
- Reflow characterization compared to the package and resulting interfaces
- Characterization of interfaces, wetting, dissolution, intermetallics
- Interconnection quality dependent on reflow conditions;
- Destructive evaluation examples;
- Overview about test files, test strategy, readouts, criteria, interrupts and localization of interrupts,
- Test files used for reliability studies
- Methods of characterizing the degradation behavior of lead-free soldered interconnects with exploitation of relevant features concerning the reliability;
- Microsections of interfaces (first and second level);
- Destructive measurements to describe limitations of the functional stability on board level – exploitation of detected failures
- Comments on the adoption of ball composition as a basic alloy for general interconnection technologies

Experimental

A short list of lead-free solder balls and pastes tested, are listed in Table 1. Solder balls were used for ball attach on commercially available laminates (pads) and solder paste for the assembly procedure.

Sn63Pb37
SnAg3.8Cu0.7 (reference)
SnAg5.5Cu1.0In1.0 (reference)
SnAg5.5Cu1.0In1.0Ni0.2
SnAg5.5Cu1.0In1.0Nd<0.2
SnAg5.5Cu1.0In1.0La<0.2

Table 1: Lead-free solders balls for ball attach and assembly tests

DSC results

To know the melting and wetting behavior of SnAgCu based balls the DSC results were taken into account to select differences in melting ranges.

Table 2 shows the DSC measurements (Tliquid and Tsolid).as a pre-condition optimizing the ball attach and the reflow profile.

Alloy	T_S in °C	T_{Peak} in °C	T_L in °C	Melting heat in J/g
SnAg3,8Cu0,7	217	221	224	65,8
SnAgCuIn	213	218	221	63,2
SnAgCuInNi	213	218	221	62,2
SnAgCuInNd	213	219	222	62,1
SnAgCuInLa	213	218	221	62,0

Table 2: DSC measurements on SnAgCuXY balls

In addition to Table 2, Figure 1 explaines the results in detail.

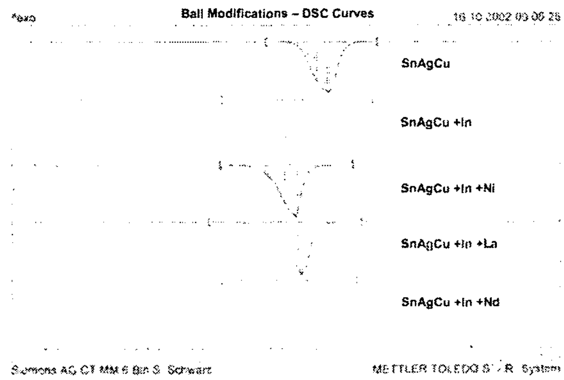

Figure 1: DCS results on modified ball materials

Based on the knowledge about the melting behavior the ball attach of different balls were applied.

To evaluate reliability data for the new ball materials, different packages were assembled. Of importance is the knowledge about the attaching parameters required to make it comparable to existing technologies.

Table 3 gives an overview about packages and finishes used in the test.

LFBGA 208, package size 12 x 12
Laminate interposer
Ni-Au pad metallization
Die size 5 x 5, die thickness 600 µm
Die attach 2035Z - 15R SMD glue (85 °C, 30 min)
PCB HDI Cu OSP finish
Landal-SEAL solder paste

Table 3: Components vs Finishes for the ball attach and assembly test

For the solder balls listed in Table 1 the wetting characteristics are presented in Figure 2. The wetting characteristic is a question of metallurgical compatibility

and temperature-dependent surface tensions of high Sn containing solders added by defined "impurities". Interface properties were analysed by X-ray and microsections. One result after transmission analysis is presented in Figure 4. The well known number of voids must be explained in relation to conventional and SnAgCu ball materials, the acceptance must be answered after reliability tests strictly related to the product.
Ball materials listed in Table 1 were attached under nitrogen (reflow peak 245 °C) to interposer structures with Cu OSP, the Test-LFBGA is shown in Figure 3. The number of voids inside the ball material is more or less comparable to Pb-containing and Pb-free solder balls. Whether the number of voids depend on additional thermal loadings must be analysed after assembly.

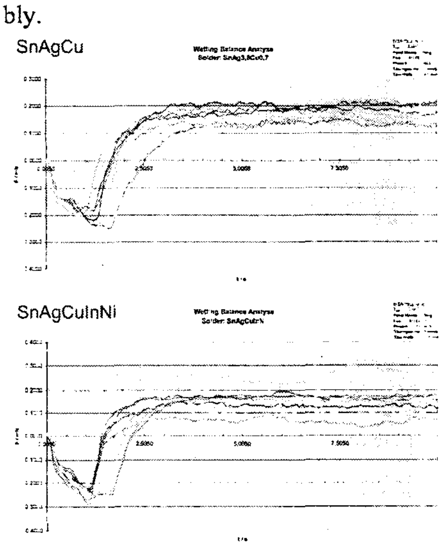

Figure 2: Wetting properties of SnAgCu alloys (Cu wire 0,5 mm diameter, flux see above) depend on temperature

LFBGA208 with 6 different balls (Table 1) were assembled using SnAg3.8Cu0,7 and SACInNd solder paste under air (reflow peak 245 °C). One sample of the testboard used for reliability studies is presented in Figure 3.

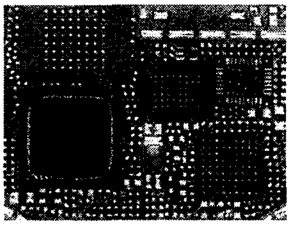

Figure 3: Part of the testboard with LFBGA208 and modified ball materials

To analyse extended TCT requirements the testboards were taken for the test conditions TCT-40/+150, N = 2000 cycles. First only destructive methods were used to explain interface properties and the degradation behavior compared to conventional and SAC balls.

As the result show, the wetting speed of Pb-free solder alloys is limited compared to conventional solders. That must be taken into account for choosing the reflow profile of ball attach in the case of lead-free solders. On the other hand it should be possible to take reflow temperatures between 230 and 240 °C for a successful interconnection quality. For this reason the wetting characteristics for different peak temperatures were analysed by studying the topology of the solder fillet. An overview about the wetting quality on component terminations is given in Figure 2. Properties of concern are appropriate electrical and thermal conductivity and viable strength of the solder joint formed by such balls as well as high resistivity against thermo-mechanical, isothermal fatigue and mechanical shock test like drops for portable electronics. The characterization of interfaces after ball attaching is compared for SnPb, SnAgCu, SnAgCuIn and SnAgCuInNd in the Figures 4 and 5.
The laminate used for this tests has a Ni-Au-finish. LFBGA208 with 0.65 mm pitch, ball diameter 400 µm, pad diameter 350 µm. The temperatures for ball attach were: SnPb 200 °C, for SAC based balls 235 °C after reflow profile was varied in speed, preheat, peak temperature; flux: SMD-KOLOPASTE 10g (WBTFC-Nr.: STA-165099-H.).

Quality and quantity of metallurgical interaction as well as the formation and structure of intermetallics is responsible for the application dependent stability of interfaces.
This is the major concern of most applications using miniaturized packages. The ratio between pad area and ball volume are of biggest concern, the influence of intermetallics depends on this ratio, responsible for the board level performance.

Studies of the board level reliability were done by accelarated aging tests like temperature cycling (TCT). In the present test of ball modification TCT-tests between –40 / +150 °C were performed. The reason is the increasing demand for extended ambient / operating conditions for applications like automation & drive, automotive, etc..

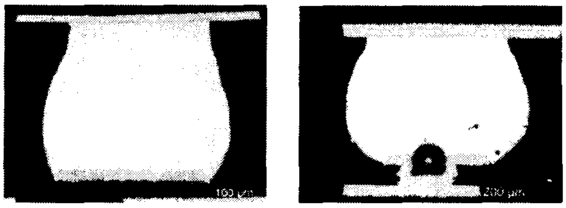

Figure 4: Microsection SnPb- / SnAgCu-Ball Interconnection

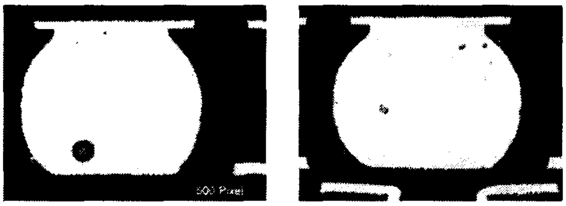

Figure 5: Microsection SACIn- / SACInNd-Ball Interconnection

Based on the interface characteristic (Figure 4 and 5) it was important to know, what kind of fatigue happens for different ball constitutions.

Figure 6 includes higher magnificated detail of interface between Cu-Ni-Au / SACInNd-ball with details describing the intermetallics as a kind of dispersion hardening. Furthermore the interaction (formation of intermetallics) at the interface is decreased, that will influence the performance.

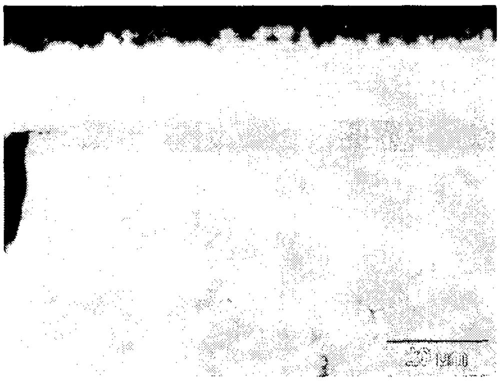

Figure 6: Detail of Interface Figure 7 (SACInNd)

Properly wetted interface with small, homogeneous distributed intermetallics in the ball matrix.

Figure 7 shows SACInNd-interconnection after extended TCT-cycling for N = 500 cycles. Total interconnection quantities were influenced by µvias in the PCB. Independent from the decreased wetted area on board, the interconnection on package and PCB side is more or less stable. The following microsections (Figure 8, 9, 10) can be used to compare the fatigue behavior for the elected TCT conditions.

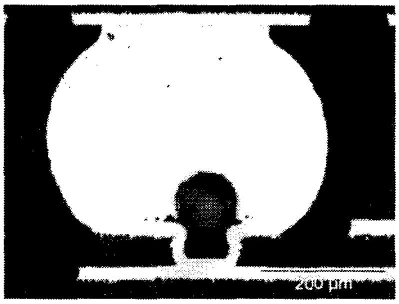

Figure7: SACInNd, TCT –40/+150, N = 500 cycles

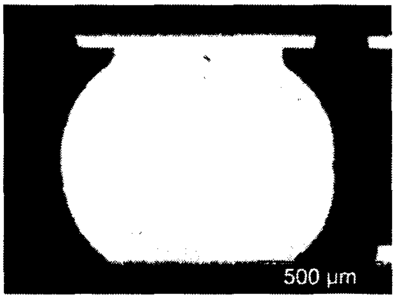

Figure 8: SACInNd, TCT –40/+150, N = 1000 cycles

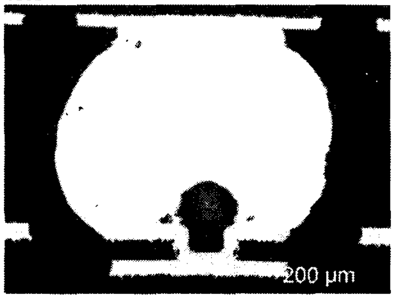

Figure 9: SACInNd, TCT –40/+150, N = 1500 cycles

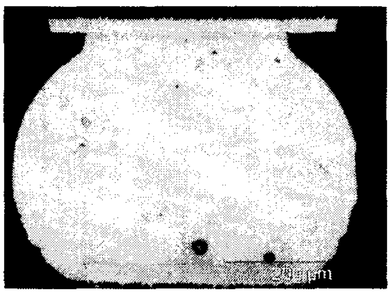

Figure 10: SACInNd, TCT –40/+150, N = 2000 cycles

The Figures 8 to 10 implements the results after TCT for different numbers of cycles. No cracks were observed after extended TCT. The impurities used in the original SAC ball formulation will decrease significantly the intermetallic formation known for SnPb / SAC balls. For conventional CSP interconnections the limited board level reliability is the result of more-element intermetallics like $(Cu, Ni, Au)_xSn_y$ and the dramatic differencies in hardness and E-modulus. Electrical interrupts happen in the bottom interface of the package, cracks are not in the SnPb solder but in the interface formed by intermetallics.

Figure 11: SACInNd interconnection , Detail from

The modification of SAC with In, Nd is minimizing the risk of intermetallic driven failures. That will influence the application possibilities not only in the case of extended temperatures. The potentials of the modified ball material are clearly marked by the increased resistivity against thermo-mechanical stress.

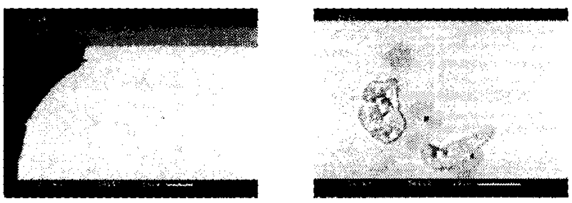

Figure 12: SEM Analysis to Detect Impurities in SACInNd (after N = 1500 cycles TCT-40/+150)

Figure 13 shows the element distribution in the SACInNd ball after TCT-40/+150, N = 1500 cycles. The effect of dispersion hardening close to the bottom interface is the efficient driver for thermo-mechanical stability and also the limited metallurgical interaction between pad finish and ball material with decreased numbers of intermetallics at the interface.

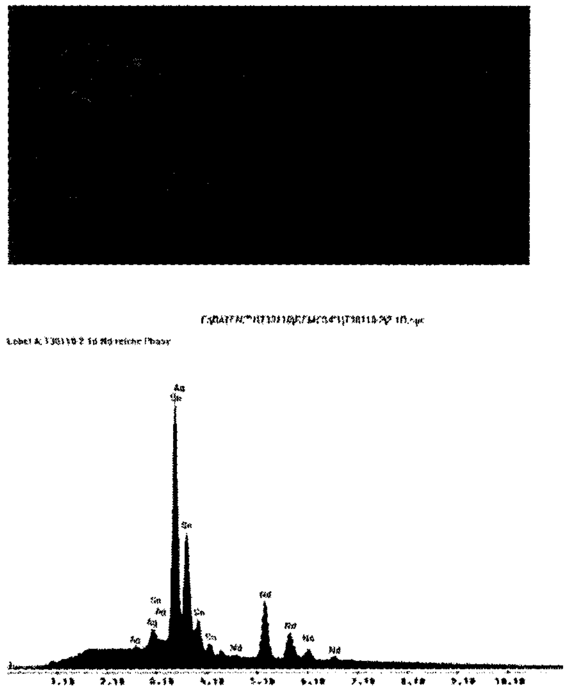

Figure 13: SEM/EDX Analysis to Detect Impurities in SACInNd (after N = 1500 cycles TCT-40/+150)

Impurities are dispers distributed in the solder matrix. That must be considered by interpreting crack initiation and growth after thermo-mechanical aging compared to SnPb and SnAgCu.
But the fact is that the failure mechanisms that are responsible for reliability problems are not specified and poorly understood for lead free interconnects..

To implement Pb-free solder it is to guarantee, that the solder joint formation is in minimum comparable to SnPb. To modify only the ball material for area array devices can't fit the requirements for the whole product. Therefore tests are running to take the SACInNd alloy as a precondition of solder paste formulations.

The implementation of SnAgCuInNd based alloys for solder pastes Heraeus Seal V2 (F620) SnAgCuInNd was studied. The following figures are selected to characterize fundamental requirements and demands for the assembly process.

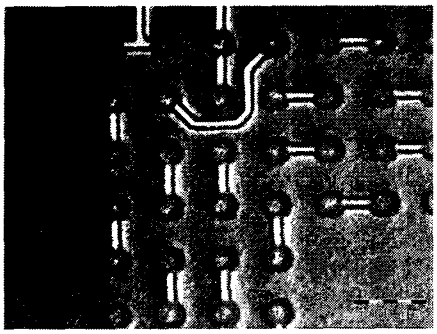

Figure 14: Print results of Heraeus Seal V2 (F620), SnAgCuInNd – LFBGA Pitch 0,8 mm

Specified testboards were used to study the interconnection formation for SACInNd solder pastes taking all the component cluster into account.

Figure 15: Wetting characteristic of Heraeus Seal V2 on QFP leads, Pitch 0,5 mm

Wetting speed and quantity are also important as the formation of volume defects like voids, responsible for the board level reliability.

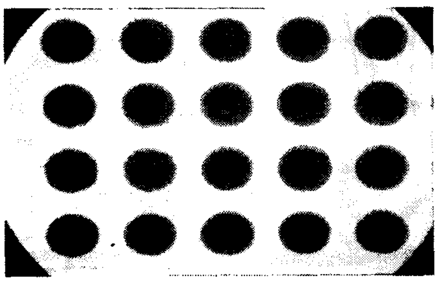

Figure 16: X-ray figure of CSP 64 components based on Heraeus Seal V2 solder paste

Furthermore the dissolution behavior is responsible for the interface formation in the reflow process and during accelerated test conditions. Figure 17 offers the first results with significant differencies.

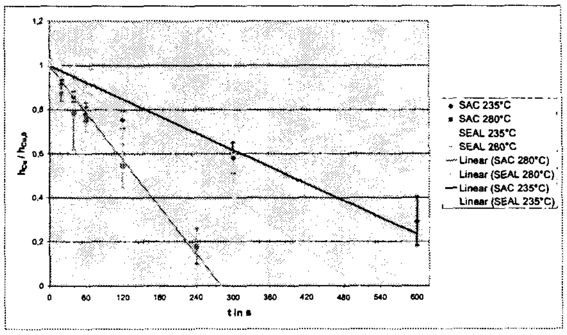

Figure 17: Dissolution behavior – comparison between SAC and SACInNd at elevated temperatures

Based on visual examinations, x-ray-studies, interface analysis describing intermetallics, the mechanical performance must be analysed. Figure 18 shows first data for SAC vs SACInNd solder pastes based interconnects.

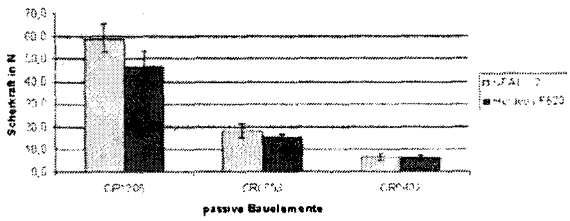

Figure 18: First mechanical exploitations Seal V2 for passive devices

Discussion of the Results

- Ball materials (Area Array) and solder paste based on the system SnPb, SnPbAg, SnPbAgXY, SnAgCu and SnAgCuXY were analysed as attached / reflowed and after aging (X-In. Y-Nd).
- SACInNd ball materials were used to simulate package ball attach procederes
- SACInNd with a melting range between 213 and 222 °C
- Ball attach temperature 235 °C offers sufficient interface interaction to different laminate finishes (interposer)
- The testpackage LFBGA was assembled lead free (SAC / SACInNd solder paste) to HDI substrates and TCT-test –40/+150 °C was applied to analyse the fatigue behavior for extended aging conditions
- After passing N = 2000 cycles of TCT-40/+150 no cracks were observed in the interfaces analysed. Conventional ball materials like SnPb, SnPbAgYX, SAC will fail early for such kind of stress conditions.

- SAC with In, Nd impurities has the potential to support the demand for extended temperature ranges.
- Actual studies are performed to transform the ball based results into the interconnection level using solder pastes. Spheres (25-45 μm) were analysed after producing the powder to describe the uniformity of the powder based on minor impurities In, Nd. Assembly tests were done.
- Testboard were assembled with the cluster of SMD packages. All acceptance criterias for standard solders and lead free solders must be compared with the new solder paste. First results were collected and will be analysed quickly.
- More accelerated reliability data are required to understand the failure mechnanism correctly. That indicades the responsibility to discribe the fatigue behavior under the current test conditions and/or test conditions to analyse the physics of failure for all the constructions on the product level.

Conclusions

The goal of this sudy was to determine the feasibility of using modified lead-free balls in conventional assembly processes and to answer the questions related to the board level reliability. Specifically, modified balls on the metallurgical basic system SnAgCu were used for primary wetting and interaction analysis. Reliability results were obtained for conventional balls in relation to modified balls on area array components, which indicate that the use of SnAgCuInNd under conventional reflow conditions can be successful for extended temperature ranges.

Acknowledgments

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References

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