Head-in-Pillow BGA Defects

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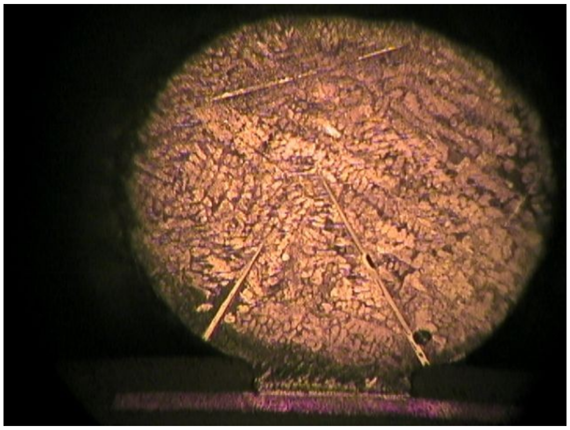
Head-in-pillow (HiP), also known as ball-and-socket, is a solder joint defect where the solder paste deposit wets the pad, but does not fully wet the ball. This results in a solder joint with enough of a connection to have electrical integrity, but lacking sufficient mechanical strength. Due to the lack of solder joint strength, these components may fail with very little mechanical or thermal stress. This potentially costly defect is not usually detected in functional testing, and only shows up as a failure in the field after the assembly has been exposed to some physical or thermal stress.

Head-in-pillow defects have become more prevalent since BGA components have been converted to lead-free alloys. The defect can possibly be attributed to chain reaction of events that begins as the assembly reaches reflow temperatures. Components generally make contact with solder paste during initial placement, and start to flex or warp during heating, which may cause some individual solder spheres to lift. This unprotected solder sphere forms a new oxide layer. As further heating takes place, the package may flatten out, again making contact with the initial solder paste deposit. When the solder reaches the liquidus phase, there isn't sufficient fluxing activity left to break down this new oxide layer, resulting in possible HiP defects. Since component warpage is unpredictable and inconsistent, the focus must turn to the interaction of process variables and those that can be altered to reduce the incidence of HiP defects. These variables include BGA ball alloy, reflow process type, reflow profile, and solder paste chemistry. Each of these variables are studied and discussed below.

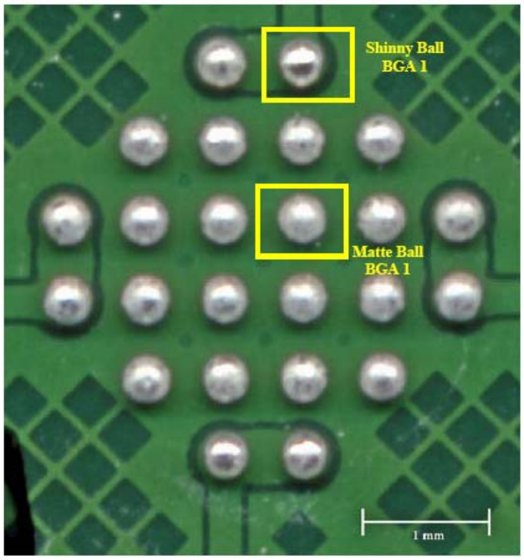
With the need for better drop resistance, many lead-free BGAs are being made in alloys other than SAC305. Since SAC305 has significantly lower drop resistance when compared to Sn63/Pb37, component manufacturers have been moving away from this type of alloy and towards alternative lead free alloys such as SAC105, which is composed of tin plus 1% silver and 0.5% copper. There also are many alloys competing for market share that are SAC105 plus a fourth element, often referred to as a dopant, such as antimony (Sb), magnesium (Mg), nickel (Ni), cobalt (Co), or indium (In). These additives create finer grain boundaries and reduce the intermetallic formations of the tin with silver or copper, resulting in a more reproducible grain as well as a more uniform grain formation in the lead-free alloy. These also yield a different oxide and surface condition, depending on the element used and cooling rate during assembly. This different oxide and surface condition can cause some issues with the flux activity which impacts solder wetting and complete joint formation of the BGA.



SAC305 with tin-silver intermetallic and coarse grain structure that leads to fractures during drop

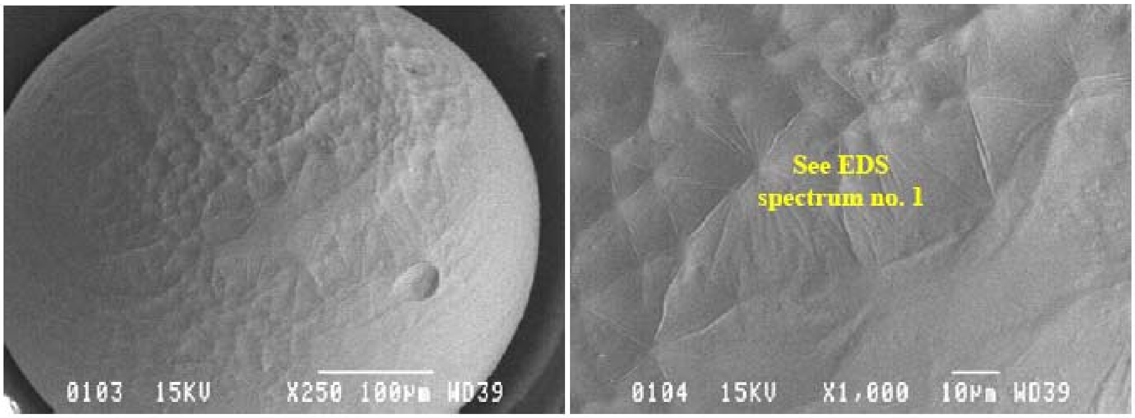
<u>Solder Sphere (Ball) Issues:</u>

The following images are analyses of BGAs that are known to have had head-in-pillow problems. The balls were inspected under SEM and it was determined that there are very distinct grain structure variations within the balls. Inspecting these components demonstrates that there are three distinct classifications of balls on the component; these were labeled these as “shiny”, “matte”, and “spotted”.

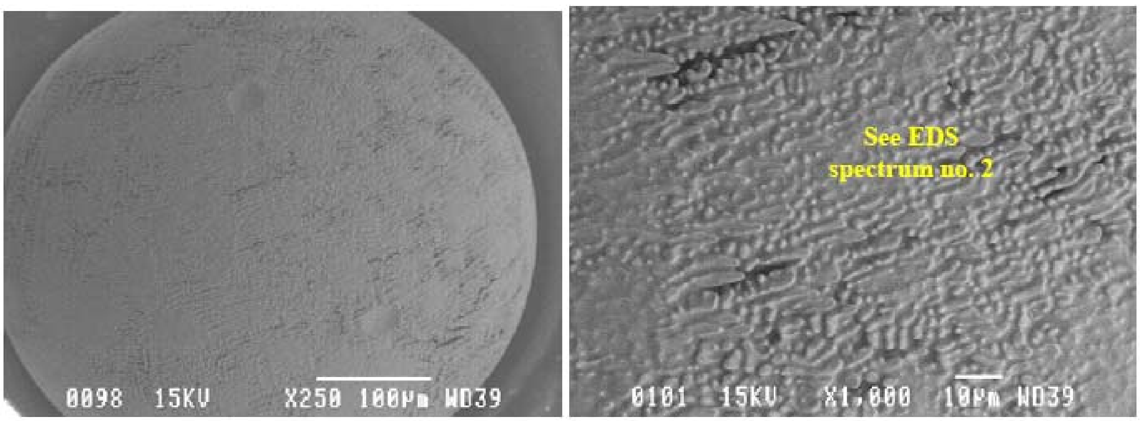


Further inspection shows grains structure differences and chemical composition differences.

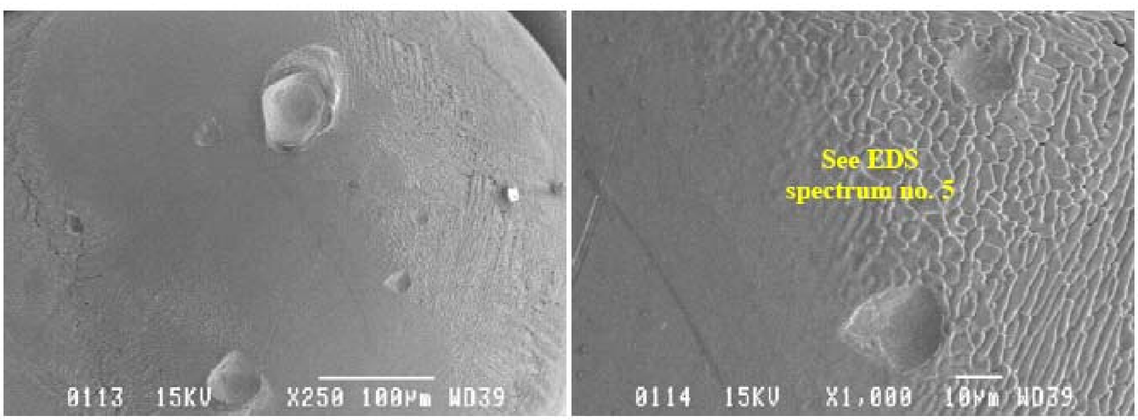
As a point of clarification, the large dimples on the ball surfaces are from test probes which easily penetrated any of the surface irregularities or containments during component testing by the manufacturer.



Shiny BGA

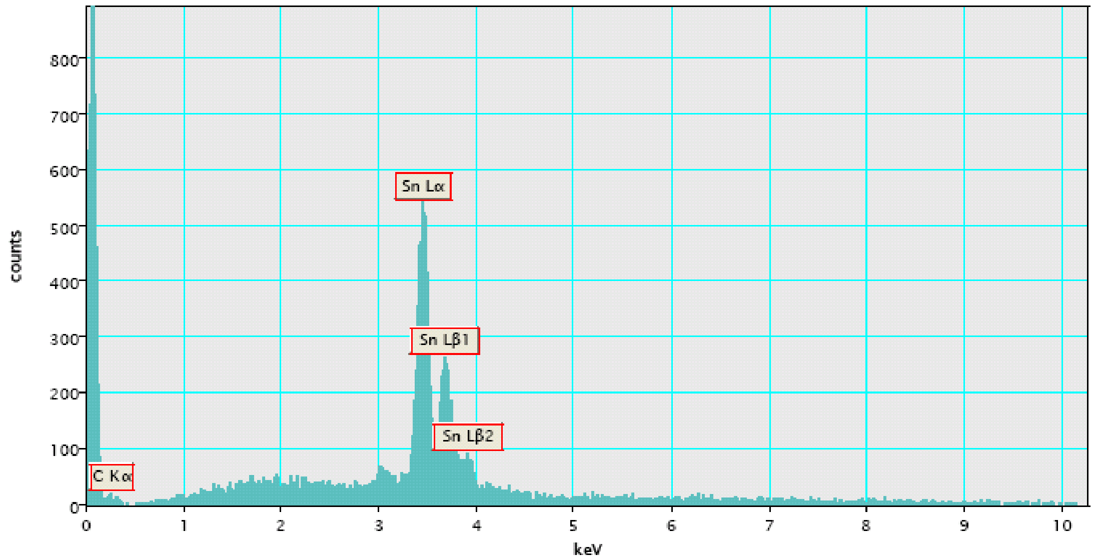


Matte BGA

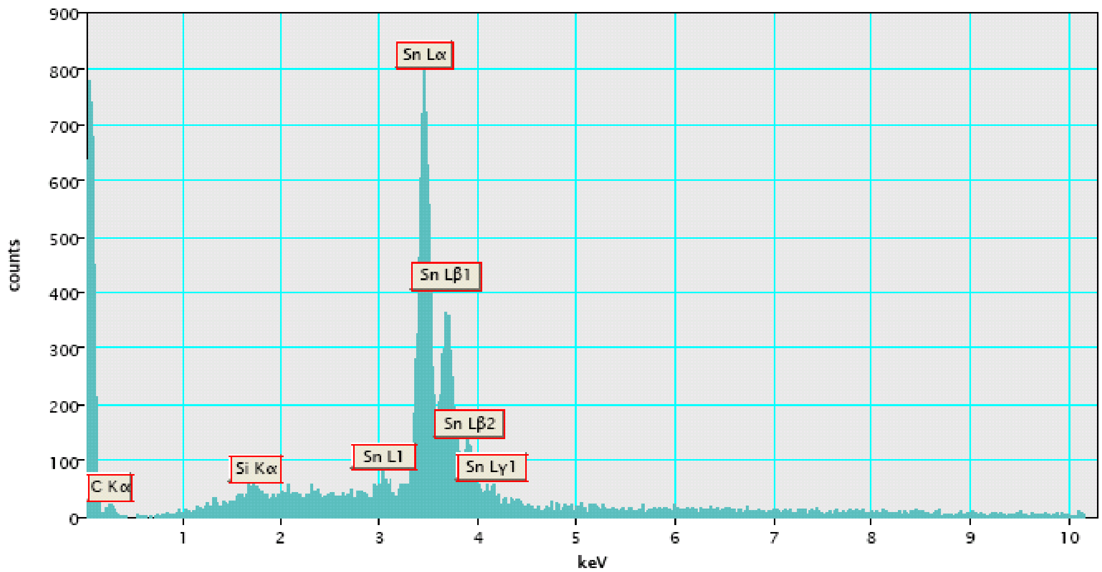


Spotted BGA

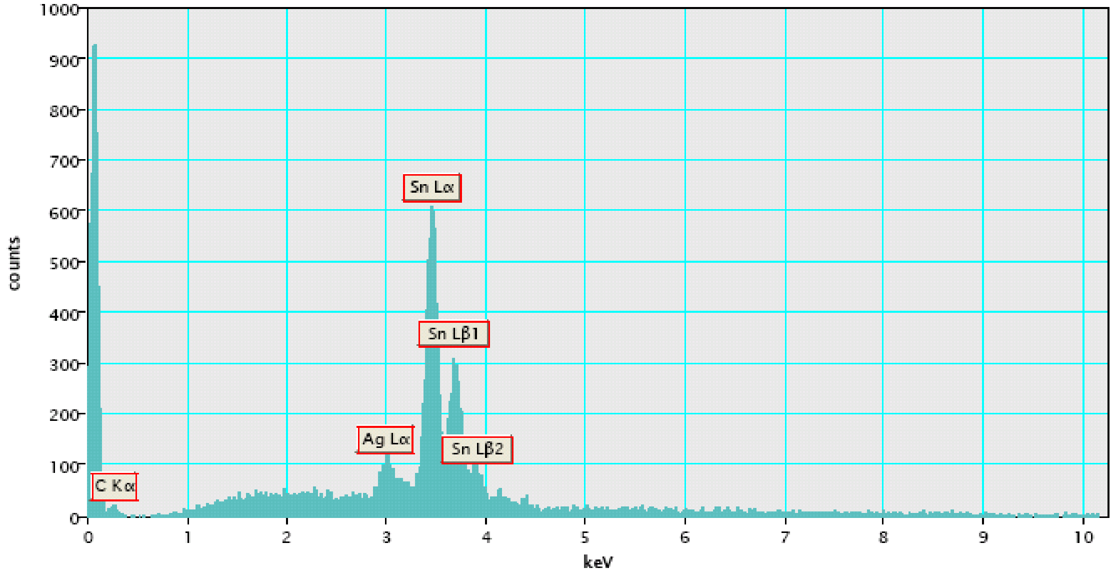
The spectrums of the BGA balls also are different:



EDS spectrum no.1, Shiny ball of BGA 1 (Sn and C)



EDS spectrum no. 8, Matte ball of BGA 4 (Sn, Si and C)



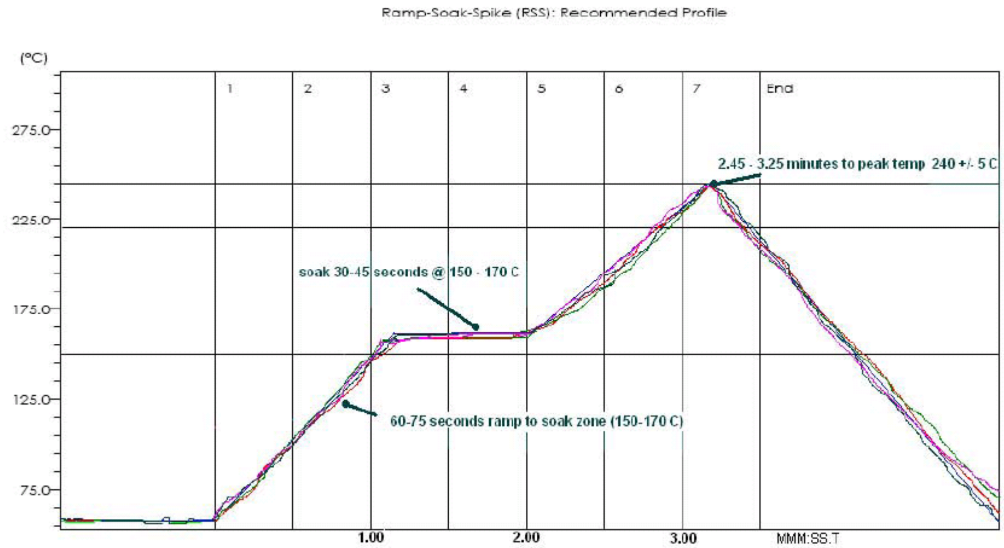
Spotted with Sn, Ag and C

On this single BGA there exist three different grain structures and surface elements. One theory explains that this is due to variations in cooling rates when the solder ball was initially formed.

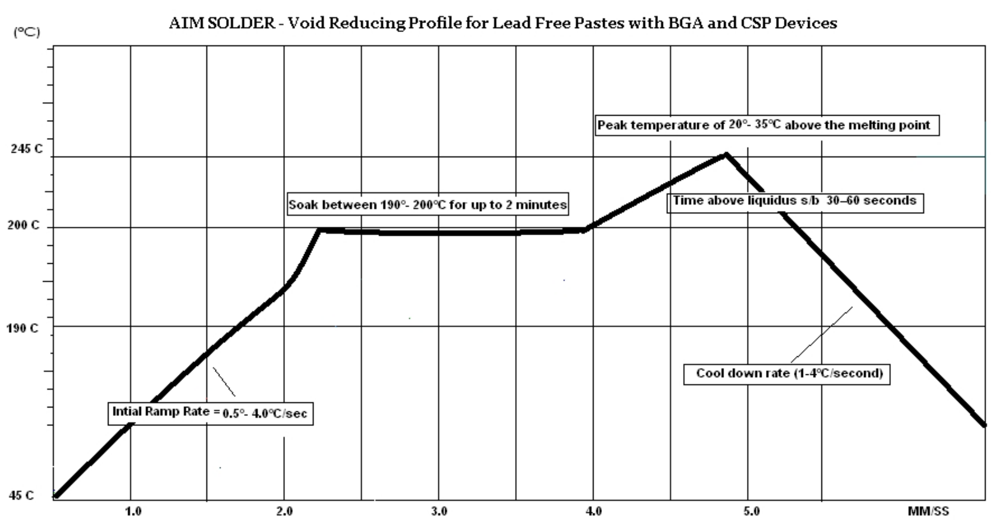
AIM developed a test procedure to understand the interaction of these elements with specific paste chemistries. This allowed a classification of reactivity levels of some of these dopants. It was discovered that very low levels of magnesium directly affect standard solder paste flux chemistries in the 30 ppm level, while indium affects them in the 500 ppm range, nickel and cobalt in the 400 ppm level, and antimony in the 1000 ppm level. Although the grain structures all appeared similar, the flux interaction was different. This difference was determined by a viscosity test that was conducted while the paste medium was in contact with the solder alloy doped with the aforementioned elements.

Other factors that appear to influence the head-in-pillow issue include; types of reflow, reflow profiles, and solder paste chemistry. Some data obtained suggests that vapor phase reflow may result in more head-in-pillow defects than does convection reflow. It is not clear whether or not this is truly related, however, as it has only been seen as a trend.

An experiment was performed to measure the impact of reflow profile on head-in-pillow solder joint formation. The experiment utilized two different reflow profiles. The first profile was a standard ramp-soak-spike, as seen below.



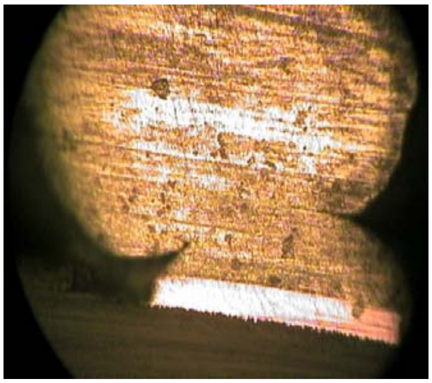
The second profile, as shown below, included a hotter soak zone and longer dwell time at liquidus.

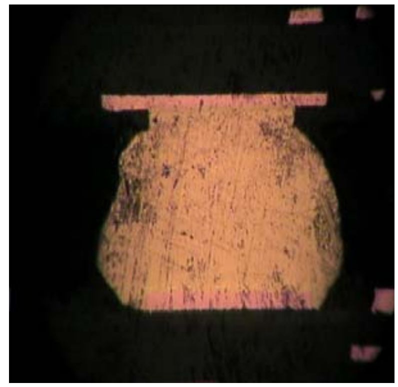


There was not any perceived difference in the defect rate depending upon the profile utilized; each resulted in random cases of head-in-pillow depending upon the component tested.

The next factor tested to determine its impact on head-in-pillow was solder paste chemistry. During this experiment, it was found that solder paste chemistry appears to have the single greatest effect on the head-in-pillow defect. When changing from an older lead-free solder paste to a new higher-temperature activation paste, the defect, in many cases, was eliminated. In other cases, it was more difficult to remove. However, in the experiment run, the solder paste chemistry appears to have the largest impact on head-in-pillow.

An experiment was conducted utilizing various solder paste chemistries to measure their effect on head-in-pillow incidents. It was determined that irrespective of the reflow profile used, simply by changing to the AIM NC257 solder paste, head-in-pillow was completely eliminated. Although this solder paste is halide-free, a solder paste containing >0.5% halide also was used in this experiment, and the defect was once again eliminated. This indicates that solder pastes (such as NC257) with an activation system able to provide sustainable high-temperature fluxing activity are capable of creating a homogenous connection beyond the ball and the paste alloy interface. Below left is a picture of a head-in-pillow that was formed using a lower activation temperature activation system. To the right of it is a joint formed with a high-temperature activation system with no evidence of head-in-pillow.





Based on the above experiments, the following chart was generated to show the relative impact of variable(s) that contribute to the head-in-pillow issue, rated on a scale of 1 to 10, with 10 as the most likely to eliminate head-in-pillow.

Variable (s)	**Impact**
Reflow profile	1
BGA ball alloy	4
Reflow Profile plus BGA ball alloy	4
Solder paste chemistry	8
Solder paste chemistry plus reflow profile	8
BGA ball alloy plus solder paste chemistry	10

Based on this preliminary study, it appears that the two most significant factors are solder paste flux chemistry and wetting of the BGA alloy ball. Frosty, non-uniform structures appear to perform the worst for BGA head-in-pillow. This is logical, as these are intermetallic regions on the surface of the solder ball. The intermetallic connection of Ag/Sn and Cu/Sn possess much higher melting temperatures than the alloy themselves. They are also crystalline in structure and can repel wetting. Although additional studies are necessary to corroborate these results, there is a strong indication that this surface structure is one of the leading causes of the head-in-pillow defect that is so costly to board assemblers.