Thermal Performance Enhancement for CSP Packages

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Abstract

Attaching heat spreader into the IC package is a known and common solution for devices with specific thermal requirement. This is usually seen on medium to big size packages such as PBGA where space is not a constraint. However, for chip-scale package (CSP) where the chip is occupying most of the area of the package, placing a heat spreader is evidently the biggest challenge. There are few packaging solutions explored to boost package thermal capability without compromising the package size but the accompanied challenges and barriers seem inevitable; difficulty in manufacturing, quality issues, reliability failures and high assembly cost. For a chip scale FBGA package that is built in a matrix or panel type mold layout, attaching heat spreader to the package transpires as the top most challenge. Placement accuracy for the individual unit and preventing mold bleed on heat-spreader surface during molding are equally challenging. There are few established ways to address those assembly issues but mostly require additional non-standard process steps, jigs, fixtures and new machines, which is obviously not favorable for manufacturing. Unit cost can be high as well.

UTAC developed a simple yet effective method that can embed a heat-spreader into a CSP FBGA package without compromising the package size, no additional assembly process steps, low quality and reliability risk and best of all, low cost. The unique package structure and the way it is built were developed in consideration of all the known challenges and barriers. The new FBGA package with embedded heat-spreader, labeled XP-FBGA (eXtra Performance FBGA), can improve junction-to-ambient temperature (Theta ja) by 30% at 3mm/sec air speed for a 2W device in a 15x15 body size.

Further in this paper discusses the unique solutions to overcome challenges in embedding heat-spreader for CSP package and the thermal simulation studies demonstrating the performance of different package structures. The effect of each IC package component in thermal capacity of the package was also studied and will be discussed further in this paper.

1.0 Introduction

The emergence of advanced technologies in computing, communications and networking demand an enormous enhancement in features and increase in speed & power for the integrated circuit (IC) device, which implies higher junction temperature on the chip during operation. This continuous pursuit in device improvement is also coupled with the aggressive reduction in package form factor. This poses great challenge to assembly house as conventional packages like Ball Grid Array (BGA) often cannot meet the thermal requirements of some high power devices. To cope with this increasingly popular trend in technology, IC package thermal performance needs to be enhanced to manage the damaging heat emitted by the chip during operation.

One common solution for thermal performance improvement for BGA packages is by attaching aluminum or copper heat-spreader on top of the die. Heat-spreaders are normally designed such that it can be individually attached to the substrate using epoxy. However, with the market continuous pursuit for miniaturization and the increasing popularity of CSP packages, the applicability of BGA's with pre-attached heat-spreader shown in Figure 1.1 narrows down consequently.

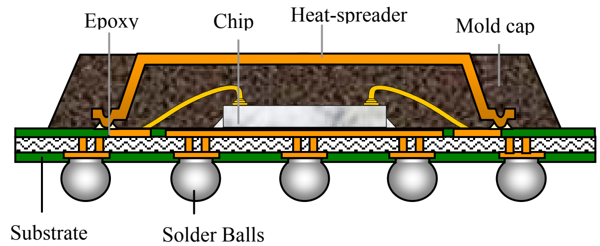

Figure 1.1. Common BGA with heat-spreader (HS-BGA)

One obvious concern for the above structure is the space allocated for the portion of heat-spreader that is attached to the substrate. Adding up all the tolerances for the heat-spreader dimension, placement variation and the required distance between heat-spreader & mold cap parting line will equate to an enormous loss in die size. This normally compromises the package size and consequently the board real estate. Not to mention the implication on unit cost.

With the migration of devices from a relatively huge PBGA to a much smaller and cost effective FBGA package, maintaining the same thermal performance surfaced as one of the challenges. The big reduction in package to die ratio for FBGA packages leaves minimal space on the substrate which makes conventional attachment of heat-spreader impossible. The difficulty is further aggravated by employing the substrate configuration into high density matrix where panel molding is applied.

Various package structures and methods were evaluated to attach or embed heat-spreader into a CSP package but numerous packaging assembly concerns seem inevitable. Assembly cost also tends to increase for every attempt to overcome barriers. With the objective in mind to finding manufacturable and cost effective solution, UTAC team developed a simple yet effective method of embedding heat-spreader on chip scale FBGA package without attaching to the substrate.

2.0 Manufacturing Challenges & Barriers

The quickest way to attach heat-spreader for CSP package is to put on top of the unit after package singulation using thermal interface material (TIM) as depicted in Figure 2.1. The attachment method is similar to die attach process where epoxy is dispensed on top of the package and the HS is placed by applying force.

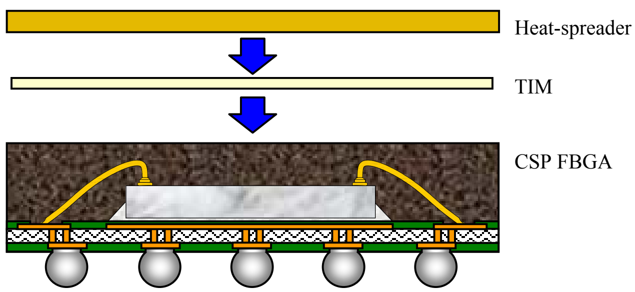

Figure 2.1: External heat sink (H/S) on an FBGA

FBGA packages are usually molded in arrayed format thus it is a bit tricky to attach heat-spreader for each unit while still in strip form. There is no traceability from the top of the molded panel for determining the singulation line. That's the reason why attaching heat-spreader is commonly done on singulated units. However, the whole process may seem straight forward but it actually entails complicated processing issues and some quality concerns that may lead to deterioration of thermal or even reliability performance. Below are some of the concerns associated with the lid or heat-spreader attaching process.

1) Firstly, a lid attach machine is needed to dispense TIM material and attach the heat-spreader. This is not a standard process for post mold area.
2) Since the units are already singulated and attached with solder balls, special tooling such carrier boat is needed to precisely handle and protect the parts during lid attach process. The tooling becomes more complex if the FBGA package is full ball matrix, as the space allowed to support the unit is very much limited. There might be high possibility of ball damage during lid attach.
3) To insure good TIM coverage and wetability, bridge clips need to be used to press and hold the heat-spreader during epoxy curing. This method is necessary especially for bigger packages to ensure uniform bond line thickness. This process may require equipment or at least a specially designed jig to attach and detach the clips.
4) Another issue is dispensing the right amount of HS attach epoxy or TIM. Less amount of HS attach epoxy will lead to insufficient coverage and might lead to HS fall off. It may also affect the thermal performance of the package as the contact area will be less. On the other hand, excessive amount of epoxy dispense will lead to bleed-out or overflow which may later interfere with the test or burn-in sockets. Severe TIM epoxy bleed-out can also contaminate the solder balls at the bottom.
5) Selection of TIM epoxy is also crucial. Due to inherent poor adhesion of epoxy to mold compound, the heat-spreader tends to fall off after thermal cycling (around 500 cycles). Cost is also a concern, usually lid attach epoxies are expensive as they cater for high thermal conductivity.
6) The other major mechanical challenge is the heat-spreader placement accuracy. Any offset issue during lid attach, might result in heat-spreader damage and cosmetic issues.
7) Unit cost might also increase significantly due to the addition of non-standard processes, investment for equipments, jigs & fixtures and inclusion of TIM material in BOM list.

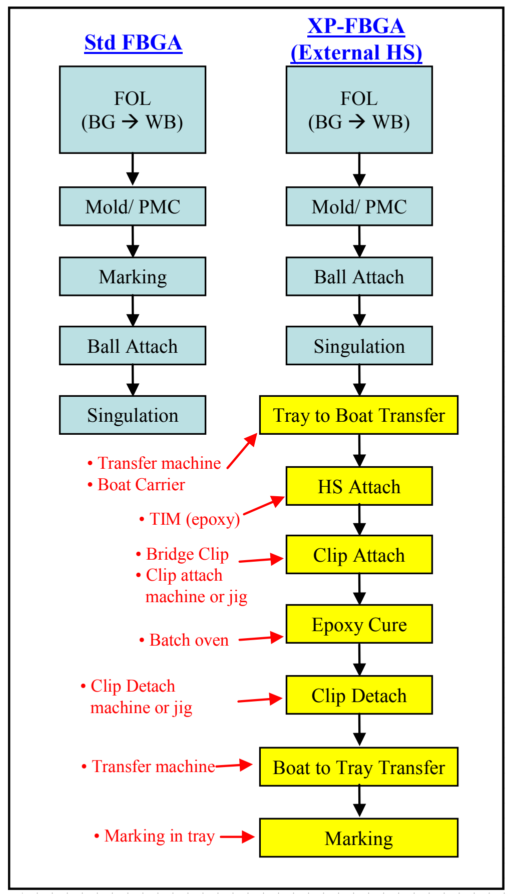

Figure 2.2: Assembly process flow for 'standard FBGA' and 'XP-FBGA with lid attach' process.

Figure 2.2 list down the number of non-value added steps, equipments, jigs and fixtures that are added to the whole assembly process by just attaching heat-spreader on top of a FBGA package. Manual operation can be done to avoid investment of non-standard equipments, but it might not be sensible for high volume production.

To address the overwhelming issues, the whole concept of attaching heat-spreader needs to be changed. The only way to prevent all the above-mentioned concerns is to embed the heat-spreader inside the package. That means the heat-spreader needs to be attached before the molding process. Figure 2.3 shows the eventual structure of the XP-FBGA package with embedded heat-spreader.

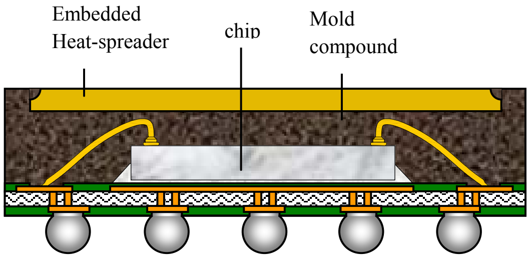

Figure 2.3: XP-FBGA with embedded heat-spreader

The first approach taken to make the simplified XP-FBGA structure is by designing a panel type heat sink that fits well within the molded cavity panel and can accommodate the arrayed format of the substrate. The arrayed heat-spreaders are held by a metal frame that has a bump or some sort of downset that is used to attach to the in-active area of the substrate using epoxy. Heat-spreader (panel type) attach is now done after wire bond or before molding. This concept does not require TIM material any more as the mold compound will act as epoxy and hold the heat-spreader during and after molding. The unwanted portions will be cut off during package singulation.

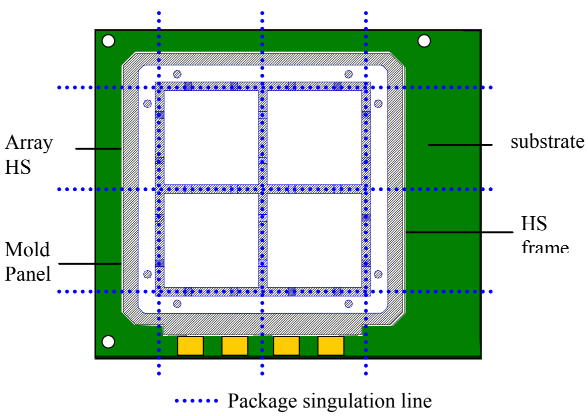

Figure 2.4: Panel type HS attach concept.

The concept seemed to be a perfect solution, but there are still some barriers surfaced that need to be addressed technically:

1. HS attach process prior to mold. This also requires lid dedicated lid attach machine as conventional DA machine is not able handle such a big area of material (panel type HS).
2. Placement issues of the heat sink within the mold panel like X/Y offset issue and rotation of the whole panel HS.
3. Cost of epoxy used to attach the panel type heat sink (indirect material).

As illustrated in Figure 2.5, the biggest challenge in processing panel type heat sink is the heat-spreader attach process itself, which is prone to X/Y offset and rotation issues.

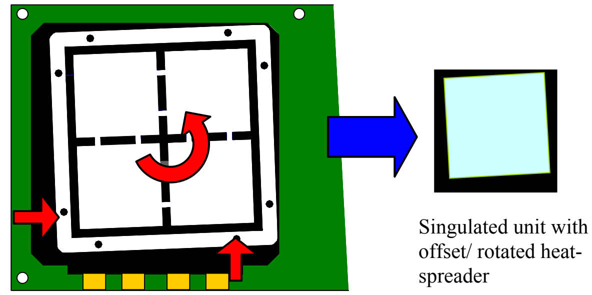

Figure 2.5: Panel HS offset & rotational issues associated with heat-spreader attach process before molding.

3.0 UTAC's Optimized Solution

To overcome all the barriers, UTAC further improved the concept and developed a more simplified method –"**mold drop-in strip heat-spreader".**

It involves a specially designed heat-spreader in strip form that is dropped onto the mold (refer to Figure 3.1 for illustration). The size of the arrayed heat-spreader follows exactly the size and layout of the substrate. Heat-spreader design makes use of the same locating pins in the mold tooling that are used to locate the substrate, thus resolving X/Y offset and rotational issues. The strip heat-spreader design also eliminates the need of any epoxy attach process thus saving on cost of epoxy and as well as the lid attach processing and material cost. A carefully selected mold release film is used to prevent mold bleed on heat-spreader surface. Figure 3.1 illustrates the method of attaching heat-spreader using drop-in concept.

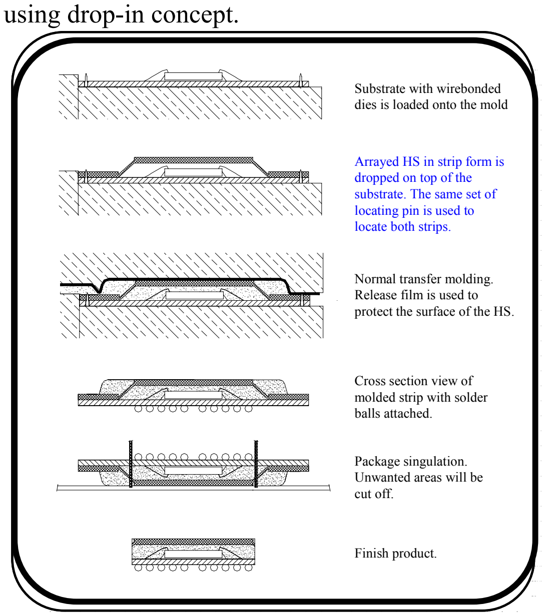

Figure 3.1: Method of making XP-FBGA with embedded heat-spreader.

The ring structure that carries all the arrayed heat sinks (FBGA) or individual heat sink in case of PBGA, acts as a barrier to prevent any mold compound flash on the heat sink. It also acts as a cushion to keep the heat-spreaders in contact with release film during the molding process.

The optimized process for attaching heat-spreader is now following the standard flow for conventional FBGA package as shown in Figure 3.3. No special jig is required, no additional direct or in-direct material aside from the heat-spreader itself, no additional process and most of all, the quality and reliability risk went down to minimal level. Unit cost also improved significantly.

UTAC's simplified version of XP as schematically shown in Figure 3.2 below is not limited to wire bonded FBGA or PBGA packages only but also for other applications as well.

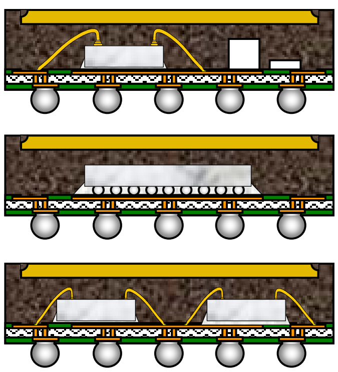

Figure 3.2: Some examples of the many application of UTAC XP package with embedded heat-spreader.

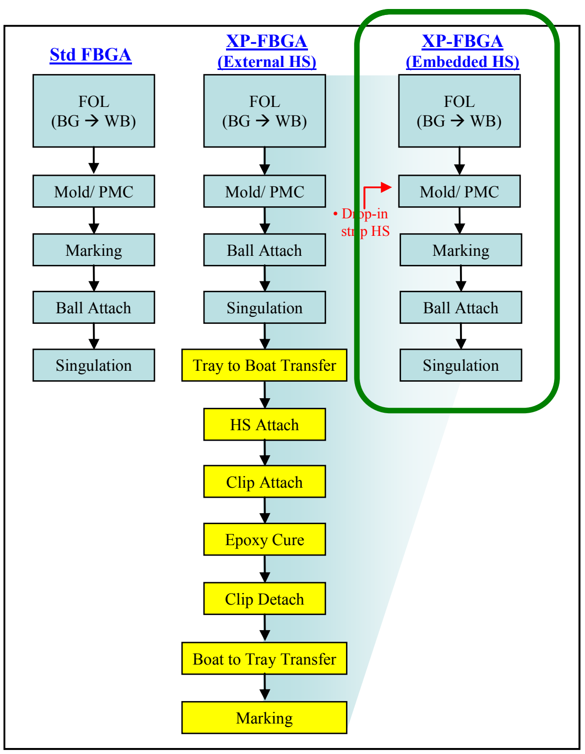

Figure 3.3: Assembly process flow comparison for the two methods of attaching heat-spreader.

4.0 Thermal performance modeling

To provide electronics packages with sufficient cooling during applications to secure improved reliability and performance of the packages has been one of the major concerns for both manufacturers and users of electronic products. Since the introduction of the standard Ball Grid Array (BGA) package, continued efforts by package developers have successively resulted in a family of thermally enhanced BGA packages.

4.1 Effectiveness of XP concept

In order to assess effectiveness of the XP concept in terms of its thermal performance improvement for BGA packages, an FBGA 15x15 mm package was selected as test vehicle for evaluation.

It has a full array of ball population matrix of 18x18, among which there are 10x10 array of center thermal balls. The substrate is 4 metal layer BT with total thickness of 0.288mm. There are 10x10 thermal vias in substrate connecting all the thermal balls to the GND planes. Ball pitch is 0.8mm. A Si die of 6.5x6.5mm in size, dissipating power of 2W, is over-molded with mold thickness of 0.6mm.

Various thermal enhancement techniques such as XP, Bottom Heat Slug (BHS), combination of XP and BHS, and Enhanced cavity–down (E) were applied to the test vehicle. There are no substrate thermal vias or thermal balls for packages using E or BHS for thermal enhancement as in either case the die is directly attached to the heat spreader instead of substrate.

Steady state thermal simulation was carried out using finite volume simulation tool Flotherm V6.1, a leading thermal analysis software for electronics industry.

Table 1. Thermal properties for FBGA families

S/n	Material	K (W/mK)
1	Mold compound	0.8
2	Die attach	0.3
3	Substrate dielectric	0.337
4	Substrate trace	390
5	PCB dielectric	0.3
6	PCB trace	390
7	Solder	60
8	Heat spreader	390
9	Die	Temp dependent*
10	Bond wire	296

*K (Si) = 117.5 - 0.42 x (T - 100)

Due to the limitation of computational resource, it is not practical to model detailed package structures. For all the cases studied package components were represented as a series of embedded conductive solid cubical blocks with either isotropic or orthotropic thermal conductivities. Table 1 lists the material properties used for this study.

Localized grid was employed to capture temperature profile and flow pattern in the areas of interest or where rapid changes are expected. Grid-dependent solution studies were performed by systematically adjusting grid size. It is assumed that a converged result has been achieved if the junction temperature decreases by less than 1% with a finer grid. A cross-sectional temperature plot can be found in Figure 4.1.1.

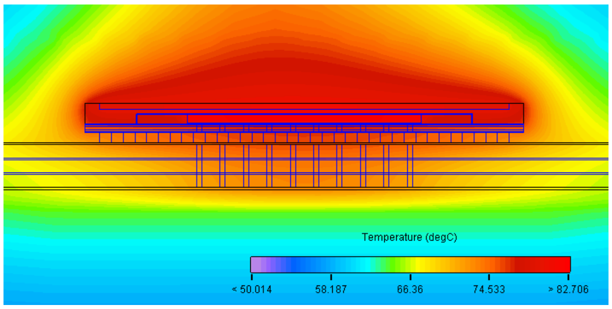

Figure 4.1.1: Temperature profile for XP-FBGA (Still air)

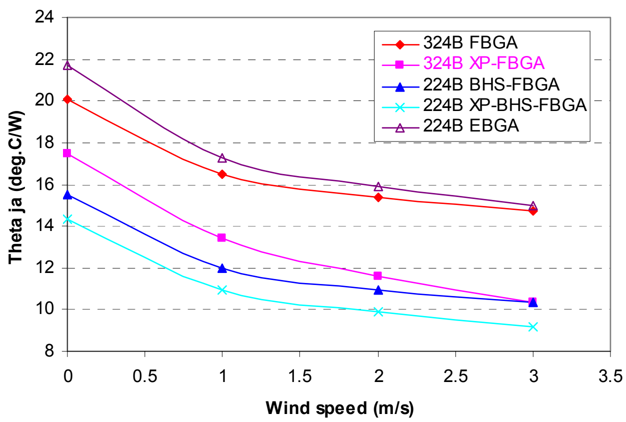

Figure 4.1.2: Thermal performance comparison

Simulation result for FBGA 15x15mm family was shown in Figure 4.1.2. A 17% reduction in the free convection θ_{JA} is observed when XP concept is applied to a standard FBGA. As can be seen that the heat spreader in XP-FBGA helps the heat flow from the active die to the top surface of the package, comparing with normal FBGA, a reduction of up to 30% in the thermal resistance is observed at an air speed of 3m/s. In terms of thermal performance, the FBGA 15x15mm family can be ranked (worst first) as follows,

1. 224B EBGA
2. 324B FBGA
3. 324B XP-FBGA
4. 224B BHS-FBGA
5. 224B XP-BHS-FBGA

One may be surprised to find that the thermal performance of the EBGA is the worst of the family. It is due to the fact that its unique cavity-down configuration makes it impossible to add any thermal balls under the die. Therefore, EBGA is not a popular thermal enhancement method for BGAs with small package body size.

4.2 Effect of XP structure

To study the impact of different XP structures on package thermal performance, FBGA using embedded HS with (II) and without (III) dummy Si die were compared with standard FBGA (I) in terms of θ_{JA}. The same test vehicle was used again except that the size of the active die was 8x8 mm in this case.

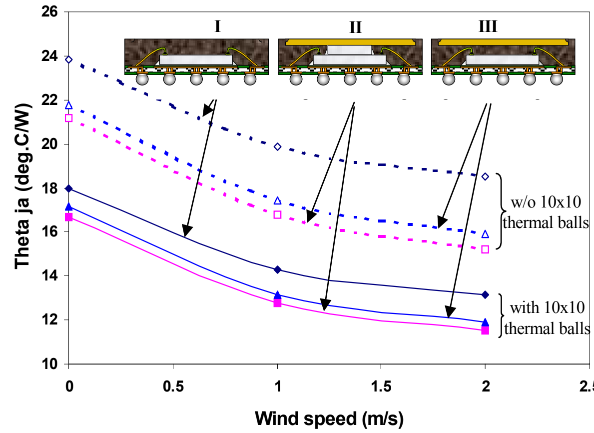

Figure 4.2.1. Effect of XP structure

It can be seen from Figure 4.2.1 that for all the cases studied XP-FBGA improves thermal performance by about 15%. However, θ_{JA} increases by less than 4% when structure III was compared with structure II. The impact of a dummy Si die is insignificant. It is the embedded heat spreader that helps reduce the spreading resistance and hence the overall thermal resistance of the package.

4.3 Effect of Die-to-HS clearance

Since the presence of a dummy Si die does not help reduce θ_{JA} very much, it is interesting to study how θ_{JA} changes with the distance between active die and heat spreader (HS) when there is no dummy die in the XP-FBGA.

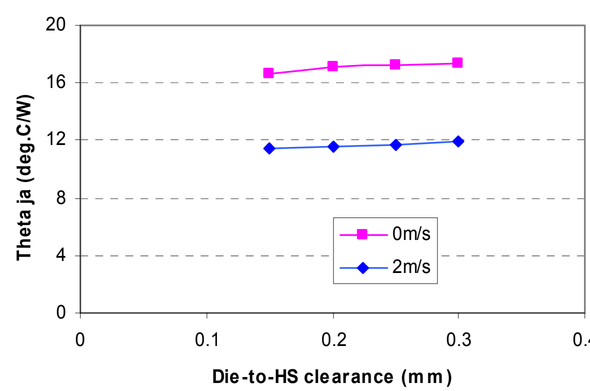

Fig. 4.3.1. Effect of Die-to-HS clearance on θ_{JA}

As can be seen in Figure 4.3.1, when the Die-to-HS clearance increases from 0.15mm to 0.3mm thermal resistance at still air and moving air speed of 2m/s was observed to increase respectively only about 1.5% and 2%. The impact of Die-to-HS clearance is very limited when there is no external heat sink on top of the XP-FBGA.

Although the Die-to-HS clearance does not play a significant role in reducing θ_{JA}, θ_{JC} increases by 79.6% when it increases from 0.15mm to 0.3mm as shown in Figure 4.3.2. A thinner Die-to-HS clearance promotes heat conduction from the chip to the heat spreader, which is important in applications with an external heat sink. Alternatively, if process control of a thin Die-to-HS clearance is difficult, then one may consider using a mold compound with high thermal conductivity.

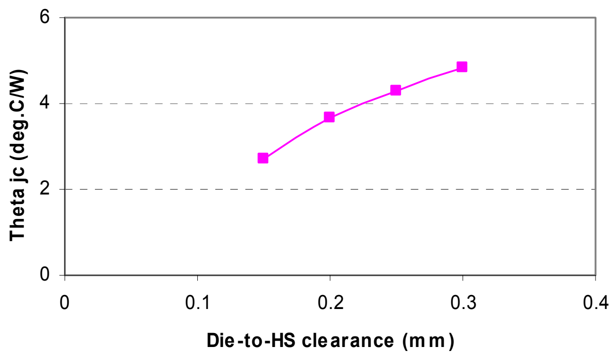

Figure 4.3.2. Effect of Die-to-HS clearance on θ_{JC}

Conclusions

Complex problems may not necessarily require complex solutions. UTAC's simple yet effective method of attaching heat-spreader for chip scale BGA packages addressed all the known manufacturability, quality and reliability issues attributed to stand alone lid attach process. The patent pending method developed by UTAC eliminated not only seven non-value added assembly process steps, but also simplified the overall structure of the package. The simplification of assembly process flow likewise benefited the company in many ways; cost avoidance for the investment of non-standard equipments, faster assembly cycle time, higher productivity, higher product yield, and many more. It also significantly improved unit cost which favors both the company and customers.

As for the thermal performance, the embedded head-spreader indeed helps to improve θ_{JA} of the device regardless of the thickness of mold compound between the die and the heat-spreader. It can also equal the θ_{JA} performance of a package with a thermal chimney attached to the die and heat-spreader.

Acknowledgments

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