CONSIDERATIONS - LED DIE ATTACH TECHNOLOGIES

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***Abstract*: Die attach material plays a key role in performance and reliability of mid, high and super-high power LEDs. The selection of the suitable die-attach material for a particular chip structure and application depends on several considerations. These include packaging process (throughput and yield), performance (thermal dissipation and light output), reliability (lumen maintenance) and cost. Eutectic gold-tin, silver-filled epoxies, solder, silicones and sintered materials have all been used for LED dieattach. Often, use of a particular technology platform results in trade-off between different attributes. This white paper reviews process, performance and reliability attributes of the die attach technologies. Then it addresses the fit between these die-attach materials, different chip structures (like lateral, vertical and flip-chip) and their operating power levels. Finally it describes the positioning of different technologies for applications in general lighting segment. This review clearly shows that given the diversity in chip structures, package designs and applications, all material platforms have a place in LED die attach. A diverse portfolio that provides die attach options to LED device makers and packagers is required to meet the process and performance demands in this rapidly changing market.**

***Keywords*: LED, Packaging, Die Attach, Silver Sintering, Conductive Adhesive, Solder, AuSn**

LED Performance, Reliability & Die-Attach

Mid power to super-high power LEDs are being operated at increasing current and power levels (for applications such as lighting and mobile flash among others). This trend has again brought the need for robust thermal dissipation to the forefront. If the heat dissipation is not managed properly, the LED performance can degrade significantly – resulting in loss of radiant flux, change in forward voltage, wavelength shift and eventually reduced lifetime.

Die-attach is the first layer that comes into contact with the LED die and its thermal performance and stability has a direct impact on LED light output, light extraction and lumen maintenance over time. The die-attach material and (more importantly) the process together have a significant effect on the cost of ownership of the light engine.

LED Chip Structures, Power Levels and their Performance Factors

There are three main LED chip structures as shown in Figure 1. The Lateral structure consists of laterally spaced electrodes (with one wirebond for each electrode) and is used in low power applications. The Vertical structure, used for most of the high and super-high power applications, consists of a conductive substrate at the bottom which forms the bottom electrode with the current flowing vertically. The flip- chip structure has both electrodes on one side and is put face down on the substrate. It provides the highest lumen density at cost lower than vertical structure. These three structures can also be mounted directly on a board, next to each other, to form modules called **Chip-on-Board.**

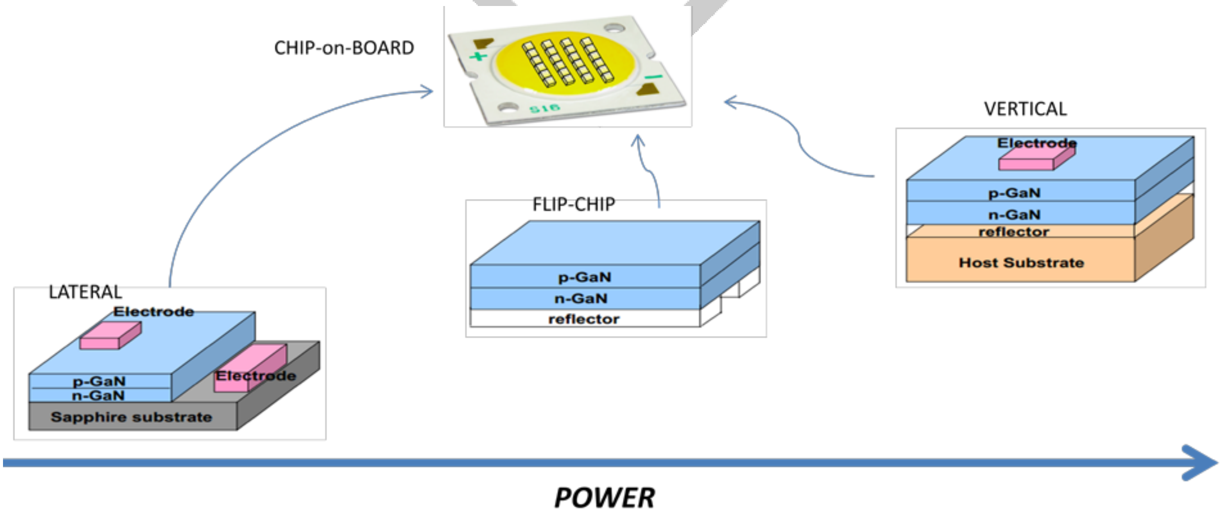


Figure 1: LED Chip Structures

Die-Attach Technology Platforms – Gold-tin eutectic, Solder, Conductive Adhesive, Sintered Materials

Eutectic gold-tin (80/20 Au/Sn by weight) has been the "gold standard" die-attach material for high reliability applications for several decades. For LED die attach it is used either as a pre-coated layer on LED backside, or a preform or in form of solder paste. All these forms involve different processes and performance. Although the cost of ownership of AuSn die attach is much higher than other materials, it is still the material of choice for high power applications due to its proven thermal (57W/mK) and reliability (high creep & fatigue resistance with second reflow compatibility).

Conductive Adhesives (mostly silver filled epoxies) constitute the largest class of thermal die-attach materials (by unit number), not just for LEDs, but for all semiconductor packages. They are compatible with the existing back-end packaging equipment and provide an attractive cost and performance balance (50W/mK thermal with second reflow compatibility). Since they stick to bare silicon, they are the preferred material of choice for dies without back-side metallization (like GaN on silicon).

Sintered silver materials consist of micro/ nano scale silver particles which undergo atomic diffusion to fuse together at 180-300°C to form nano-porous yet predominantly metallic silver joint (961°C melting point). They can applied in either paste or film format and sintering can happen either in a press (requires new equipment) or a regular oven. These materials, with cost in-between conductive adhesive and eutectic-AuSn, have been shown to provide superior mechanical reliability and higher thermal performance (than AuSn). For LEDs, sintered materials have been shown to improve the lumens output by 30+% for red & green LEDs as well as UV LEDs.

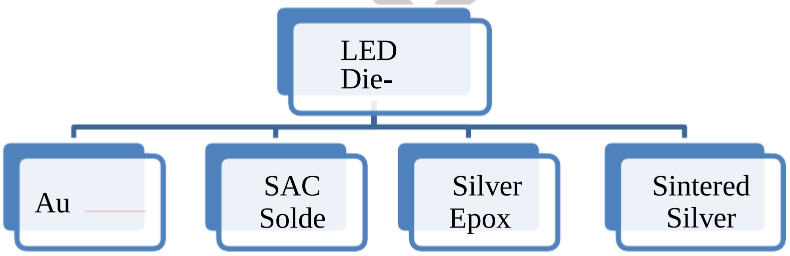
Solder (mostly SAC based), provides exceptional value with low cost, fast assembly process with reasonable thermal performance (50-60W/mK). Lately there has been a trend to make flip-chip structure compatible with solder on SMT lines. However, since SAC solder melts in 217-221C range, its use is limited to applications where either high temperature stability is not required in operating conditions or during further processing (like secondary reflow). SnSb based solder with melting point range 245-251C can survive second reflow below 240C peak temperatures.

LED Die-Attach Materials Comparison

There are three key considerations for selecting material for die attach in a LED application.

1) Thermal Resistance – Among the materials discussed above, sintered silver has the highest bulk thermal conductivity (>100W/mK) and has been shown to have the lowest thermal resistance in head-to-head comparison with AuSn and silver epoxies. Eutectic gold-tin thermal conductivity has been measured around 57W/mk, which at thin bond lines (~5um) results in lower overall thermal resistance than silver epoxies (mostly <50W/mK at ~25um bond lines).
2) Second Reflow Compatibility – LED packages assembled on submount undergo an additional solder reflow step to attach to the board. AuSn, conductive adhesive as well as sintered silver materials can easily withstand the secondary reflow. Obviously SAC based solders cannot be used reliably in these packages, unless low temperature solders such as Sn-Bi based solders are used for second reflow. However, for applications in which the COB module is screwed to the heat sink, second reflow is not needed and solder is the die-attach material of choice.
3) Cost of Ownership – The die-attach step, due to the cost of the die-bonders, is usually the most capital intensive step in LED packaging. So it is important that die-attach material and process is compatible with the existing high throughput dispense/pin transfer bonders. No capital investment and low cost of ownership makes solder, silver epoxies and pressure-less sintered silver materials particularly attractive (over AuSn and pressure-assisted sintering materials).

These three attributes of the die-attach platforms discussed here are compared in Figure 2.



Secondary Reflow Possible	Yes	No	Yes	Yes
Thermal (W/mK)	~57	~53	2-50	>100
Cost of Ownership	High	Low	Medium	Pressure-less : Medium Pressure-Assisted: High

Figure 2: Attributes of LED Die Attach Platforms Chip and Package Structures Fit with Common Die-Attach Materials

The starting point for die attach selection is usually the end application and design. End application determines the operating environment, while design determines the number and power levels of the dies. For example, an outdoor lamp will have higher power dies designed to operate in a harsher environment, compared to mid power dies in some bulb or tube designs for use in relatively benign conditions indoor. Within the bulb/luminaire application, different designers may choose between smaller numbers of high-power dies in packages or larger number of low power dies directly on board (COB).

Once these design and end-use decisions have been made, the three attributes described in the previous section are sufficient to make the selection. The power level of the die determines the heat dissipation requirements - higher power dies require high thermal conductivity die attach to keep the thermal resistance low (while low thermal die attach is okay for low power dies). So for high-power and super high power vertical LEDs sintered materials (both pressure-assisted and pressure-less) and eutectic gold-tin are most suitable to lower the thermal resistance and keep the junction temperature manageable for optimal performance of the LED. The mid-power dies (either vertical or flip-chip in package) can use solder and high thermal epoxy. Finally for the low-power lateral LEDs, lower end epoxies (or silicone) may be good enough thermally.

For assemblies that do not go through second reflow (like COB), solder is the preferred die-attach material. For in-package attach silver epoxy, AuSn or sintered materials are essentially the only options. The final major consideration is the cost of ownership (process equipment and throughput). While eutectic AuSn and pressure-assisted sintered materials provide exceptional thermal performance and mechanical reliability they are not compatible with traditional die bonding equipment. Conductive epoxies and pressure-less sintered silver materials can be adopted easily on the existing lines. Solder, on the other hand, is unique in its compatibility with semiconductor packaging as well as SMT lines.

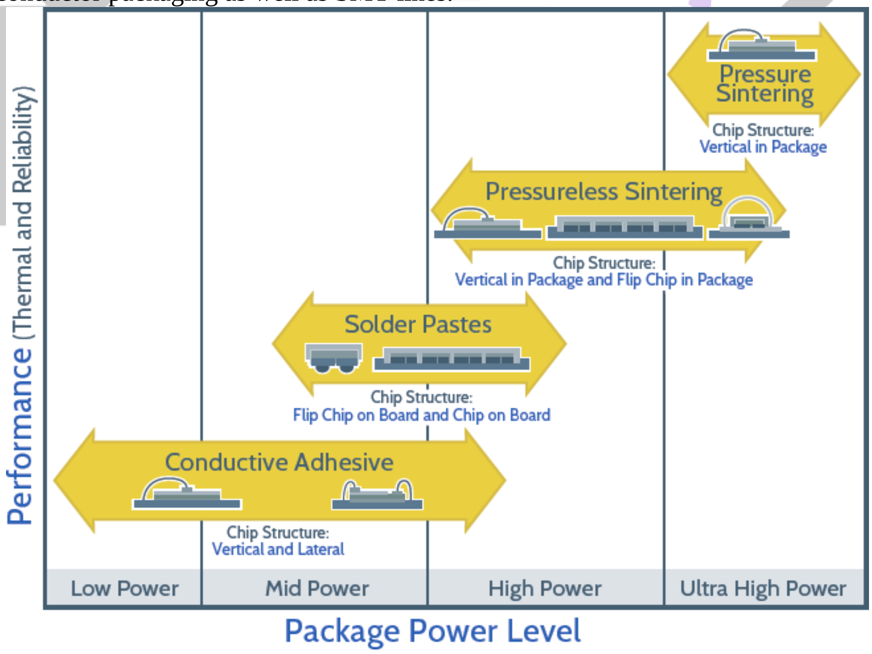


Figure 3: Chip and Package Structures Fit With Die Attach Platforms

The relative positioning of the materials in Alpha LED die-attach portfolio for different applications on different substrates is shown in Figure 4. Argomax® with the highest thermal and reliability is the highest performance option for super-high power applications like projection and entertainment lighting.
Pressure-less sintering Fortibond™, which is compatibile with existing equipment yet provides higher thermal and reliability than silver epoxy, is suitable for most high power applications – like vertical UV, flip-chip on ceramic and lead frames (for general

lighting and mobile flash) and laser diodes. Conductive adhesive Atrox™ can meet the requirements for most of the mid power vertical dies in general lighting applications (like retrofit bulbs), especially with dies without metallization. Finally solder is the material of choice for any low-mid power application that requires die attach directly on the board (no secondary reflow).

Among the products in Alpha's LED die attach portfolio, pressure-assisted silver sintering Argomax® has been used for super high power applications like projection lighting. Pressure-less sintering Fortibond™ has been used for high power vertical UV and VCSEL applications. Atrox™ conductive adhesive has been used in vertical bare silicon dies without back-side metallization. Rapid solder compatible flip-chip adoption has opened new opportunities for Lumet™ series fine-pitch T7 paste for bumping on wafer as well as T5/T6 by printing / pin transfer. Maxrel™, SAC305 and SnSb based pastes have also been used by several customers for COB assemblies with flip-chip, lateral and vertical structures.

A different price and performance option to the customer has created multiple opportunities for Alpha. Most of our customers do prototype builds with several material technologies on different product platforms and end up making the final decision on cost/performance ratio that is unique to their application and business model is also very important to note that apart from this diversity, the LED market and applications are much more price sensitive and are growing at much faster rate than traditional semiconductor and electronics markets. This has resulted in shorter qualification cycles with renewed emphasis on lower packaging cost with each design cycle. Having a broad portfolio that provides

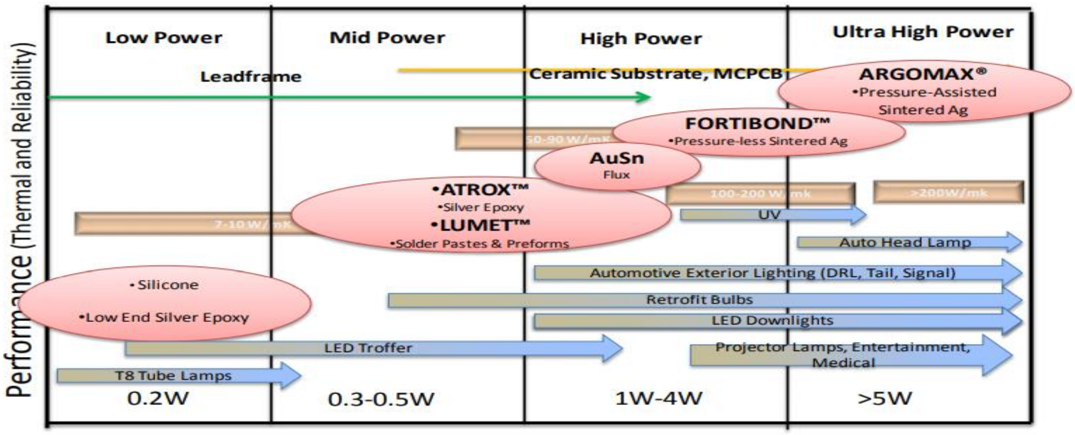


Figure 4: ALPHA® LED Die Attach Portfolio and Applications

Conclusion

This review clearly shows that the diversity of LED structures, power levels, applications and process equipment considerations require different die attach solutions. Every die attach material technology is being used in mass production for packaging LEDs and assembling modules – from silicones and solder to AuSn and sintered silver materials. . It is also very important to note that apart from this diversity, the LED market and applications are much more price sensitive and are growing at much faster rate than traditional semiconductor and electronics markets. This has resulted in shorter qualification cycles with renewed emphasis on lower packaging cost with each design cycle. Having a broad portfolio that provides different price and performance options to the customer has created multiple opportunities for Alpha. Most of our customers do prototype builds with several material technologies on different product platforms and end up making the final decision on cost/performance ratio that is unique to their application and business model.

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