

Jetting- a new paradigm in dispensing of Light Emitting Diode Products

Bob Hoffman,
Asymtek, Carlsbad CA, USA

Abstract

Today's advanced packages for electronics are required to meet a wide range of requirements for reliability, size and cost. Wire bonded, molded devices soldered to printed circuit boards with surface mount technology still prevail in low cost electronics (televisions, VCR's, washing machines, etc). As the need for portability, performance, or reliability increases, so do the challenges in packaging necessarily increase. The attention is on the size and performance constraints of notebook computers, mobile phones, gaming devices and other handheld portable electronics. Virtually all of these devices have multiple LED's within them. The latest environmental regulations that prohibit the use of the most common interconnect material (lead-based solder) will force the packaging engineer to sharpen all the tools in his tool box to be ready to produce products in keeping with these requirements.

Packaging of power LEDs has its own challenges, in the requirement to handle large amounts of heat, maintain color purity and produce a rugged package for outdoor and automotive use. And the mantra "smaller, faster, cheaper" has turned into a fevered battle cry, as with all electronics manufacturing today.

The number of dispensing applications in the production of LEDs is increasing. One of the newer opportunities is in the application of yellow phosphors to blue LED's to make white light. Other applications call for different phosphors to make red green and blue light. These phosphors are born in either an epoxy or silicone base material that can be applied at very high rates in individual shots, while flying over an array of LEDs in wafer or discrete form. Further, silicone encapsulants, thermally or electrically conductive epoxies and gasketing materials are being dispensed in today's power LED packages. Spray processes found commonly at the PCB assembly level are flux application, before reflow and conformal coating after assembly. These processes for LED's have demands often in excess of the "normal" manufacturing process, for the sake of heat and light extraction, color purity and lead free compliance.

Flip-chip manufacturing techniques are now being adopted to increase the extraction efficiency. Only a small portion of the energy consumed in a powered LED is given off as light. The majority of the energy must be dissipated in the form of heat, and a stable temperature is critical to a constant color and intensity. Thus it becomes imperative on the LED packaging engineer to understand the underfill process and how the special characteristics of LEDs make the underfill process even more demanding. The bulk of underfill processing throughout the semiconductor industry has turned to jetting as a new and novel technique because of its inherent speed and precision.

A brief review of the myriad dispensing applications in electronics will establish the landscape into which power LED's fit. Specific dispensing applications are detailed; with traditional fluid application methods shown. The impact that the new jetting technology has on cost and productivity is then revealed.

General overview of electronics packaging

Electronics packaging is mostly a cookbook of making metallic connections to sensors, signal processors and output transducers in such a way that current can flow to and from these devices reliably. The first current carrying devices that would be considered electronics had normally only two or three connection points, or a half dozen at most, and were connected by hand using discrete physical wires. The need for integrated circuits was born of the fact that it was just too hard to make all those connections as the complexity of circuits increased.

The industry has progressed from hand assembled, bare boards with discrete wires to single- and double-layer printed wiring boards (some may remember pre-CAD, hand-taped-up Mylar films). Through-hole technology, wire-wrapped boards and 50 layer super-computer backplanes with embedded passives followed. Where we end up wearable electronics, probably- and futuristic interconnections in 20 or 50 years will certainly cost less and work better. It is interesting to note the drop off of physical connections as wireless technology takes off. Pundits predict the invention of circuits that will draw power from their environment without physical connection to the outside world. In fact that is indeed what an RFID circuit does.

Often, after the metallic connections are made, they are insulated in such a way that the signal paths are kept isolated from each other even as the device is bent, folded, spindled and mutilated. The insulator also provides the assembly some mechanical form and strength. This is true in creating bare PCBs, cables, and tiny IC's in the form of wafers. It happens at multiple levels in electronics assembly, as singular devices are combined into ever more complicated assemblies.

Wafer Processing

The bulk of semiconductor devices are processed at the wafer level to consist of thousands of transistors, capacitors and resistors in a single

integrated circuit (IC), and hundreds or thousands of IC's per wafer. Wafer processes are known as "front end" and are characterized by very high capital investment in facilities, clean rooms with vacuum deposition, chemical processing and furnaces. All specks of dust, even the immeasurably small, are stringently prohibited from in these production areas.



Photo courtesy of Intel website

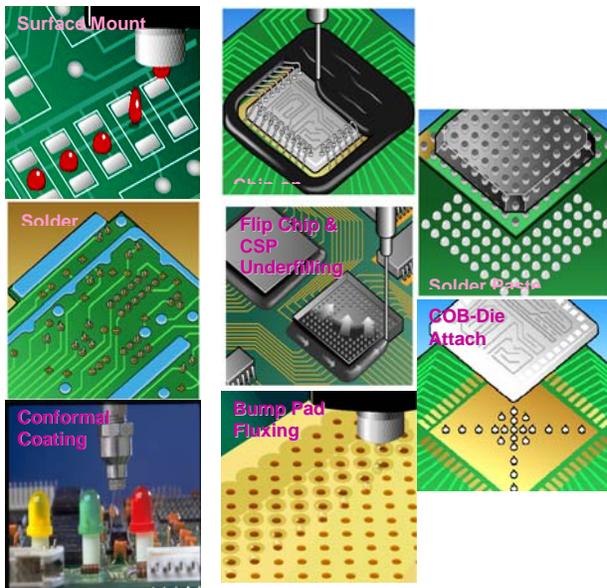
The end result of the front end process is individual IC's that are separated from each other by a scribe or saw (known as dicing), either on a film frame or in some other temporary carrier. This exceedingly complicated and amazing process has been repeated so many times it has been made to look easy. However, the "dies" themselves are of no use until the next level of connection is made, the job of the "back end."

Traditionally, the vast majority of IC's are bonded to a copper lead frame, a process that includes epoxy dispense, a pick and place operation into the epoxy, and subsequent curing of the epoxy. At the next stage wire bond connections are made between the IC and the lead frame. The assembly is over-molded and the leadframe is then excised, leaving a robust package for the fragile IC. This is a package that can be handled with relatively little care by stockrooms and robotic assembly systems.

Note that feature dimensions on the IC range from fractions of a micron to a few hundred microns and are hardly visible to the human eye. Conversely, leadframe dimensions are more on the order of fractions of a millimeter and up. Although some care is needed to keep the molded devices clean and free from static electricity, it is nowhere near the requirements of the bare die's wafer fab world.

Printed Circuit Board Assembly

At the next level, overmolded IC's are assembled to printed circuit boards (PCB's), predominantly by robotic machines that have replaced corresponding human actions. Automation here has been developed for the benefit of repeatability and speed, resulting in low costs. Typically solder paste is applied (using stencil printing techniques) to bare PCB's and then components are placed in the paste. When this combination is taken to a temperature high enough to melt the solder, then a physical and electrical connection is made at each metallic connection point between the IC package and the PCB. Similarly, discrete components (resistors, capacitors, inductors, crystals, and many other devices) are also assembled using this process.



A similar process, though often less automated, is used to connect other electrical components known as "odd form" such as bells and whistles, connectors, cables, displays, sensors and other widgets too countless to mention. Another method of making an electrical connection is with the use of a spring loaded contact, such as those found in virtually all cable connectors. These are chosen

when a certain number of connection cycles are necessary over the life of the assembly. When no disconnection is anticipated, the parts are "hard-wired" via a permanent and reliable means such as solder. Although a mastery of all of these connection practices can mean the difference between success and failure of a manufacturing concern, they are not considered "advanced packaging".

Advanced Packaging concepts

The first methods of electronics packaging were "advanced" by the very nature of the fact that all of the assembly concepts were new and untried. As electronics have become ubiquitous it is easier to draw the line as to what is conventional and what is advanced. As a general guideline, advanced packages deal with the bare semiconductor that is not wire-bonded and over molded to a leadframe. If it costs a lot, relatively, if it has not been done before but shows promise as an emerging technique that may become commonplace, or if it enables a new functionality that was not before even possible, then it may be considered advanced packaging.



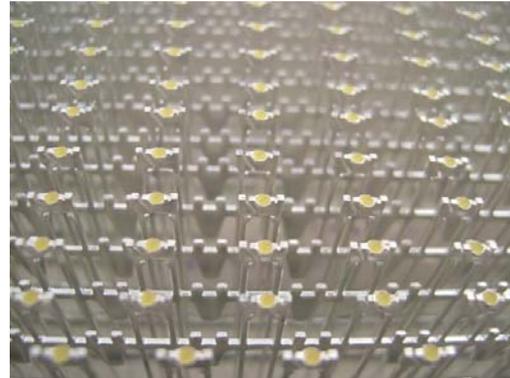
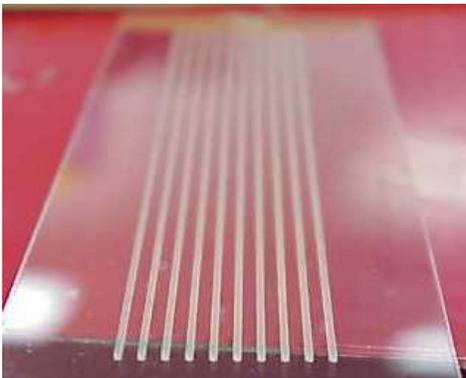
Our whole industry has existed for half a century on developing methods to put "10-lbs of electronics" into the available "5-lb bags", so to speak. That is one of the goals of the IMAPS and a significant number of other technical societies. Advanced packages strive to integrate more than electronics. Advanced packaging takes mechanical or optical or chemical devices and marries them to semiconductor technology.

Advanced packaging takes semiconductor materials other than silicon, such as germanium or compound semiconductors (GaAs, InGaN, AlInGaP) and connects them to the conventional electronics world. Certainly, advanced packages are developed and nurtured by pocket-protector laden, Scotch-taped-glasses-wearing geeks who know that this is about the most exciting thing on earth. But I digress...

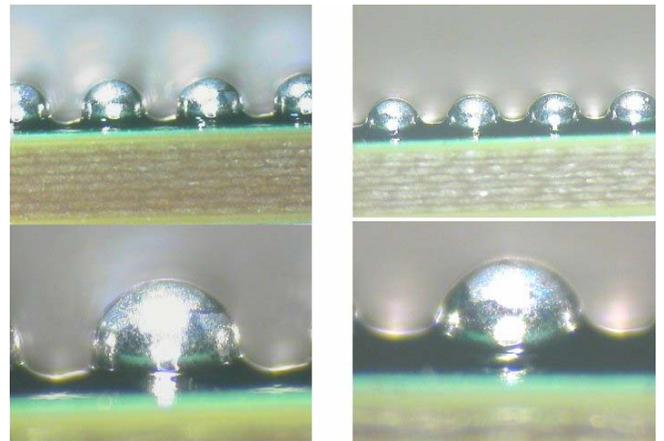
Characteristics	Conventional assembly	Advanced packages
Cost	High	Low
Materials	Readily available and commonplace	Exotic, selected for unique properties
Geometries	Large by comparison	Fine, only achieved by the most capable
Assembly operations	Few	Many
Production volumes	High	Low

Hybrid microelectronics combines some of the conventional assembly processes with some of the novel packaging concepts. Wire bonders for leadframes go fast and do the same thing endlessly. Hybrids need flexibility more than speed, to bond devices on multiple layers and on unconventional materials. Hybrids are found in the nose-cones of missiles and in pacemakers and hearing aids, very low volume products by comparison, thankfully. Hybrid microelectronics is spawned the advanced packaging technologies that are now considered conventional, such as tape automated bonding (TAB), stud bump bonding (SBB) and Multi-chip modules (MCM). The list of interconnection schemes that were once regarded as novel and now look so commonplace does not end there; ball grid arrays (BGA), End-metallized surface mount devices (SMD), Small Outline integrated circuits (SOIC) and chip scale packages (CSP) are other examples. It seems it only takes enough time to give the new process an acronym and it is then a mainstream technique that all manufacturers adopt.

Jetted Hot Wax



Jetted Phosphor on White LEDs



Jetted Solder Ball Reinforcement



Jetted Conformal Coating on Flex

Dispensing applications in electronics manufacturing

Conventional printed circuit board assembly (PCBA)	Semiconductor Packaging	Specialty processes
Adhesive , non conductive (SMA)- holds devices in place through wave solder or reflow process	Die attach adhesive - epoxy, usually filled with silver particles to effect a back side electrical ground of the device as well as a mechanical bond	UV-cure bonding - alternative formulations of silicones or epoxies that are photo-initiated. Generally used on clear optical or plastic components, and coatings
Solder mask - Prevents solder from wetting to metallic surfaces where solder is undesirable	Flux - Acts as a reducing agent to clean oxidation away from soldered surfaces prior to reflow. Becoming more important in lead-free processes	Photoresist and wafer coatings - new and emerging alternatives to front end processes
Potting - provides physical protection and a degree of hermeticity to wires and sensitive devices	Underfill - provides encapsulation and bond strength against thermal mismatch of components or against drop shock mechanical stress	Bump reinforcement - Pre-applied encapsulant to the wafer level or chip-scale package bumps prior to assembly at the next level
Flux - Acts as a reducing agent to clean oxidation away from soldered surfaces prior to reflow	Encapsulation - either glob-top or dam and fill, provides protection of wire bonds and, sometimes, intellectual property	Silver epoxy interconnections - An ever increasing lead-free alternative, also requires lower temperature curing than is needed for solder reflow, (e.g. for plastic substrates)
Conformal coating - provides protection from corrosion, contamination and environmental effects	Thermal grease and thermal adhesive - Filled with thermally conductive particles to promote the transfer of heat from source to dissipative path	Liquid crystal - material used in liquid crystal displays (LCD's) the material is more expensive than gold in some cases.
Encapsulation - provides protection of wires and fragile components	Lid seal, gasketing and general bonding - mechanical bonding and sealing of package components	Hydrophilic getters - A material that absorbs airborne moisture and preserves the service life of various moisture sensitive products
Solder paste - Complements the application of paste from printing, in places where the printing process is insufficient or not possible- such as rework and where large and small components combine	Solder paste - Discrete capacitors and other components that require very small dots or flexible selection of regions. Also used for connection of RF shields	Hot wax, Hot melt thermoplastic Generally used in temporary bonding applications

One process that has taken a slow but very assured path from innovation to industry standard is **Flip Chip**, or more broadly, **area array interconnection**. The premise of this connection scheme is that the package need only be as large as the device itself if the necessary connections can be made within the real estate taken up by the chip (or something very close). This process is now at what may be considered the critical momentum point, where significant resistance to its adoption is vanishing. As

the industry becomes comfortable with this new process, a revival of sorts is in the wings for wire bonding, in the form of stacked die packages which meet many of the same new performance requirements.

It would be easy to neglect the details of dispensing; after all "it is just dots and lines". It is a fact however that there are as many variables that relate to dispensing as there are to wire bonding or

any of the other assembly processes. Manufacturers reap the greatest profits by taking advantage of the controls available on today's high-end dispense platforms. Attention has to be paid not only to the valve control but also the approach of the valve to the dispense position and even the post dispense sequence of events. Many of these variables are made available to the user so that they can optimize both throughput and quality.

Types of Dispensing Valves

Many articles and papers have been written on valve technologies over the past twenty years, starting with *time-pressure (Air-over) syringes*. In this case the "valve" is indirectly controlling fluid flow by turning on and off the air pressure in the syringe. Note that for low viscosity fluids, the "off" pressure may actually be adjusted to a slight negative value (suction) to prevent dripping. Advantages are in simple maintenance and low cost of ownership. However this practice is notorious for poor shot size control and rather inadequate for very high viscosity fluids that need a motorized force to achieve reasonable flow rate and throughput.

Time-pressure syringes are best used for low volume bench top production where an operator can control the process. A variant on the time pressure theme is the many positive shutoff devices, such as pinch tubes, check valves and needle valves, which also prevent dripping. They still are notoriously inaccurate for shot size and have a higher cost of ownership from cleaning and consumables expense.

Auger valves or rotary positive displacement valves are prevalent throughout electronics manufacturing lines developed in the 1990's. The auger valve is at its best performance when the fluid is viscous, such as solder paste, damming fluids and thermal greases /adhesives. These fluids are highly filled and therefore hard to push through a needle. The auger motor provides a motive force that is proportional to the motor speed and is also a function of the auger geometries. Much has been

written about the management of the tip of the needle and its importance on the dispense quality. Inventions such as stand-off pegs, mechanical and laser height sensors, tapered and coated needles have all been directed at solving the problem of transferring to the substrate the material clinging to the tip of the needle. Surface tension of the substrate is used to pull the material from the needle tip.

Underfill is characterized as a low viscosity, short pot-life and highly abrasive fluid. In the late 1990's *linear piston pump technology* was developed to achieve very high shot size accuracy with these fluids. Based on the operating principal of a piston pushing fluid from a chamber, they have the beneficial characteristic that the volume of the piston displacement is exactly the volume of the fluid dispensed when operated correctly. They are complicated by design, requiring multiple wetted chambers and gate valves to achieve the true positive displacement effect, and thus have a high cost of ownership. As with auger dispensing, the business end is a needle and still requires careful management of dispense gap so the last drop of fluid is transferred to the substrate, or it will be carried to the next dispense site resulting in inconsistent shot size and possibly placement of fluid in the wrong place.



Jetting technology has quite taken over the electronics dispensing scene in the past 10 years, and the last 3 years especially. A third generation of mechanical jet design is now in wide-spread use in nearly all of the advanced-package dispensing applications highlighted earlier. In fact the list of fluids that can be dispensed by mechanical jet has increased exponentially. The operating principle of the mechanical jet is the creation of dots and lines formed from a very small fluid stream ejected from an orifice due to a fast-acting, ball-end piston driving fluid through the orifice from the inside of the jet.

This mechanical jet should not be confused with ink-jet printing, which only works with low viscosity inks. Today's bubble jet printers have a fast-acting heater, which vaporizes the ink, forming a bubble within the inkjet head. The expansion of this bubble is what ejects the ink. This technology does not work at all with many of the (filled) fluids that are used in electronics manufacturing, although the development work in this area continues.

Advantages of jetting

Jetting imparts momentum to the dispensed shot, so proximity to the substrate surface is not critical. This contrasts favorably to the earlier discussion of managing the tip of the needle dispenser to take advantage of the surface tension of the substrate to pull material from the needle. With jetting this is simply not necessary. Absent the slow, up and down moves required to position the needle tip at each dispense site, the jet is free to fly above the substrate surface and create a much higher deposition rate, resulting in higher production rates. In addition to the absence of Z-axis motions, there are strikingly fewer dwells and delays associated with getting the material to flow consistently, as in needle dispensing.

Another feature of jetting is that fluid can be directed more precisely to where it is wanted and away from "keep-out zones. The fluid stream dimension is considerably smaller than the outside diameter of the conventional needle with a drip on the end of it. This is the real consideration when it comes to aiming the jet nozzle vs. positioning of the dispense needle. This feature has enabled electronics manufacturers to take advantage of dispensing processes that were simply not possible or feasible at high volume production rates in any case. In one prominent application, a 100 um stream of fluid is jetted into a 200 um gap between semiconductor devices.

For another example, cell phone manufacturers often use Faraday shields on RF circuitry. Prior to the availability of jetting technology, great care was necessary to position low-flow-rate, miniature dispense needles into the holes on the shield in order to deposit underfill on the edges of the chip-

scale packages (CSP) inside the shield. The jet makes RF-shield-compatible underfill a much more reasonable process, considering the rates at which mobile phones are built today (1 every 5 seconds).

Stacked die packages and wafer scale packages are two other relatively new electronics designs that seem to have been designed with the jet in mind. Additionally, UV cure adhesive is used in the manufacture of liquid crystal display (LCD) modules as a gasket between sandwich layers of glass and circuitry. The jet enables a very sharp corner to be achieved on the rectangular gasket pattern. This is necessary to maximize the pixels available to displays used in mobile handsets, computer displays and many other end products.

Jetting in the manufacture of power LEDs

Dispensing operations found in connection with LED's include die attach, bonding, underfill, encapsulation, wafer level coatings, gasketing, phosphor deposition, desiccants and conformal coatings. A major concern of manufacturers is heat management and maximizing luminance and color purity. The flip chip package is a natural choice in LED manufacture, and consequently so is flip-chip underfill. While flip-chip underfill was developed to improve the reliability of dissimilar materials with markedly different coefficients of thermal expansion (CTE), it has been shown to improve the reliability of even silicon on silicon or other well-matched organic materials.

In an excerpt from compoundsemiconductor.net's report on Korean LED manufacturers, it has been reported that, "*Lasemtech's product consists of blue, green and red LED chips in one package. Having improved heat conductance by an order of magnitude over conventional devices, the company is now supplying Samsung with 330,000 LED packages a month.*" This kind of innovation in packaging with regard to heat management is widespread in the industry at the moment. Further need for innovative dispensing applications is indicated from the following passage from the same article below:

“While the falling prices of blue LEDs continue to shrink margins from mobile phone keypad backlights, companies are focusing more on applications of white HB-LEDs in the phone’s LCD backlight unit and camera flash, as well as outdoor billboards and illuminations. Samsung Electro-Mechanics has already made a move into this technology and is shifting away from blue and seven-color LEDs.

Other companies, such as SSI Semiconductor, are becoming specialist suppliers of all kinds of mobile handset parts and components, rather than simply concentrating on HB-LEDs. SSI has diversified its product range to include power amplifiers, LCD-driving ICs and CMOS camera modules.

The dispensing opportunities in LED manufacture and complementary goods abound in all of these areas, as they are well established in existing electronics manufacturing lines.



Pocket sized Miniature Video Projector

Summary

Consumer demand for product improvement and innovation drives electronics manufacturers to continuously work on creating products that exceed the prevailing standards. Often, the improvements are obtained through manufacturing practices that produce more products from fewer resources, in order to preserve and enhance shareholder

interests. This certainly is the case with LED-laden products such as notebook computers, mobile phones and gaming devices.

At the same time a revolution is forming in industrial and consumer lighting, especially in automotive, billboards and hard-to-service areas such as building accent lighting. Eventually pundits predict that all incandescent light sources may be replaced by LED’s, resulting in longer life and lower power consumption. The increase in fuel costs has only accelerated the need for these changes. Without solid manufacturing processes, reliability will suffer and many start-up concerns will not get off the ground. However, global manufacturing companies that have already adopted the newest dispensing and manufacturing techniques are well positioned to grab their unfair share of emerging markets.

Acknowledgements:

Korean manufacturers focus on white LEDs
<http://www.compoundsemiconductor.net/>

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Various technical papers
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The Paradigm Shift in Applying Liquid Underfill for CSP, FCIP, and Stacked Die in Backend Assembly by Utilizing Adhesive Jetting Technology
Alec Babiarz- Sr.VP Asymtek Sales and Marketing

<http://www.designthatmatters.org/k2/archives/000231.html>
Photo of pocket sized projector to the left