Dispensing for the OLED encapsulation process

EXECUTIVE OVERVIEW As OLED manufacturing matures, larger substrates are required as they enable higher dispensing throughput for UV sealants. Jetting the gaskets of seal materials has provided an increase in performance and dispensing capability. This article describes the dispensing process and deposition capability for applying the UV sealants.

The advantages of OLED technology are greater brightness, low power, fast response, thinner displays, and eventually, lower cost. Such displays are brighter than LCD technology because the diode material directly emits red, green, and blue light versus gating a backplane of light with liquid crystal through a color mask. The display can be thinner and lower cost because it eliminates the extra hardware associated with backplane lighting, not to mention the cost of liquid crystal.

The most prevalent applications for OLEDs have been smaller displays for cell phones, MP3 players, etc. Furthermore, because OLEDs offer good readability in bright environments, they are being used in automotive audio displays. Most commercial displays in these markets have been passive matrix (PM). The most recent news is the introduction of large OLED displays from Epson and Sony. It is not practical to use PM in large displays because the power loss in the ITO (indium tin oxide) lines is too great. To drive a passive matrix display, a high voltage at some duty cycle must be scanned to each pixel to maintain brightness. In an active matrix display, each cell has a drive transistor that can be turned on continuously at a low voltage, which results in lower power dissipation. Active matrix OLEDs (AMOLED) have invigorated the market because AM makes the larger screens viable and will work with smaller screens as well.

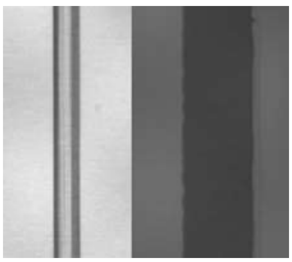

Figure 1. A bead of epoxy (left) as dispensed by a needle and then after lamination when the bead is squashed by placing glass on top (right), which creates a seal.

Encapsulation

The manufacturing process of both types of displays requires encapsulation of the active electroluminescent (EL) materials to protect them against the deleterious effects of moisture. Specially designed UV adhesives are used to bond the glass to the substrate such that each display remains sealed along the edge of the glass after singulation.

To prevent the diffusion of moisture, it would be desirable to have the seal as thin as possible and as wide as possible to offer the smallest cross-sectional area exposed to moisture and a long diffusion path. These two constraints work against each other in that a wide seal takes up valuable display space and the thinner seal yields strength and process issues. Typically, the seals are 1–2mm wide and 6–20μm thick, depending on the application. The thickness of the seal is maintained by a small loading (<5% by weight) of spacers. The spacers control the seal thickness when the encapsulation glass is laminated to the substrate in a vacuum/UV curing lamination press. OLED designs come in both top emission and bottom emission configurations.

In some top emission applications, a special optical fluid may be applied to enhance the transmission of light from the device to the top cover glass. In this case, the fluid is dispensed by what is known as ODF (one drop fill). The nomenclature of ODF may be misleading in that many drops or lines of material are dispensed inside the seal lines. ODF came from the improvement of applying liquid crystal to LCDs over the vacuum injection techniques. After applying the fluid, the fluid spreads out as the top glass is laminated, analogous to die-attach epoxy. This process is carried out under vacuum to prevent any air entrapment.

Needle dispensing process

The seal and fill applications are accomplished with needle and jet dispensing techniques and equipment. Needle dispensing has long been the standard process for applying fluid in FPD applications, but recently the successful application of high viscosity (>500cps) jetting techniques used in flip chip under-filling has brought throughput and quality advantages. A discussion of an application will provide insight on the dispensing issue.

For a typical array of 899 displays on a Gen 4 glass, the seal has a squashed width of 1.5mm and thickness of 12μm. The displays are 25mm × 17mm and arranged in 29 columns and 31 rows equally spaced by 6mm. A typical UV epoxy has a viscosity of 126,000cps with a specific gravity of 1.4. A bead of epoxy is shown in **Fig. 1** as dispensed by a needle and then after lamination.

A volume calculation of the squashed seal yields 0.018mm^3 per mm of line length (1.5 × 0.012). Therefore, each seal requires 1.51mm^3 or 2.12mg of epoxy (0.018 × (25 + 17) × 2 × 1.4). Typically, for needle dispensing, the fluid is dispensed with an Auger pump and a metal cone-shaped needle. The cone tip usually has an orifice

Alec J. Babiarz, Asymtek, Carlsbad, CA USA

of 0.15mm at a dispensing speed of 40mm/sec. The fluid dynamics model explains that this empirical setup is near optimal for needle dispensing. The pressure drop through a cone needle is given by the following equation.

$$\Delta P = \frac{128\mu QL}{3\pi(D_1\text{-}D_2)}(1/D^3_2 - 1/D^3_1)$$

where μ = viscosity, Q = flow rate through needle, L = length of cone needle, D = inlet diameter (1) and orifice diameter (2).

Given a flow rate, the dispensing speed is given by:

$$V_{dispenser} = \frac{Q}{A_{seal}}$$

where V = dispensing speed of robot, and A = cross-sectional area of seal.

For good dispensing quality, the dispenser must not be moving faster than the exit velocity of the fluid from the needle orifice. If the dispenser moves faster, the fluid will be pulled along the surface of the glass, causing a number of quality issues, because the fluid does not have a chance to wet the surface properly.

If the dispenser is running too slowly, the fluid will plow ahead of the needle tip, contaminating the needle, resulting in stringing issues and improper amounts of fluid delivery. The dispenser should be moving slightly slower than the fluid to allow good wetting of the surface and minimum plowing. The fluid exit velocity from the orifice is given by the following equation:

$$V_{orifice} = Q/A_{orifice}$$

where Q = fluid flow rate, and A = cross-sectional area of needle orifice ($\pi D_2^2/4$).

Upon analysis (**Fig. 2**), it can be shown that the larger nozzle will end up dragging material and provide poor wetting. This is somewhat counter-intuitive, because one would think faster dispensing could be achieved; however, the flow rate determines the dispenser speed. The larger needle provides the same flow rate at a lower feed pressure. The smaller nozzle (0.1mm) has a much higher velocity of fluid, which would cause some plowing. The 0.15mm orifice is the best option because the fluid velocity matches the dispenser speed. However, the pressure required to maintain the flow rate starts to get fairly high at 40mm/sec and at 80mm/sec, most Auger pumps reach a pressure limitation.

Another key element for needle dispensing is the dispense height. Typically, the needle tip must be at least half of the orifice diameter away from the surface to provide good line definition. The particles in the UV seal material are 12µm in diameter; therefore, the minimum distance from the substrate is 12µm. This means the dispensing height must be maintained at 44µm ±32µm. Due to the flatness of the glass, tooling, and dispenser, a height sense is required prior to dispensing at each cell. In the case of large displays, the dispenser must map the flatness and then dispense in a 3-axis motion to maintain the height.

A takt (i.e., the maximum time allowed to produce a product in order to meet demand) time estimate for this case would be the number of cells times the sum of dispense time per cell, height sense per cell, up/down Z-motion per cell, and non-dispense move time between cells. At 40mm/sec the dispense time per cell is 2.1 seconds, 0.5 second height sense time, 0.15 second Z-move time, and 0.15 second cell-to-cell move time, it would take 46.5 minutes to finish the panel. Four independent dispense heads would decrease the takt time to 11.7 minutes (**Tables 1** and **2**). Having multiple heads sounds like a good idea; however, the number of defects is directly proportional to the number of heads in the takt time. In other words, if one dispense head could do the work of four, there would be 4× fewer defects.

Table 1. Takt time (=46.5 min) for a one needle auger valve.

Attribute	Time (seconds)
Total vision	2.3
Total height sense	541.40
Total non-dispense moves	136.85
Total dispense	1968.50
Z head up/down to dispense height	140.76

Table 2. Takt time (=11.69 min) for four needle auger valves.

Attribute	Time (seconds)
Total vision	2.3
Total height sense	136.85
Total non-dispense moves	35.19
Total dispense	492.13
Z head up/down to dispense height	35.19

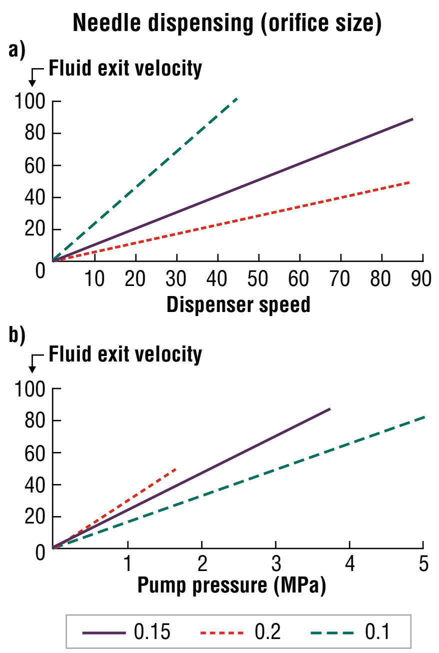

Figure 2. Plots of orifice size of a needle dispenser vs. the fluid exit velocity showing that **a)** a 0.15mm needle matches the dispense speed; and **b)** high pressures are required for dispensing over 40mm/sec with 0.15mm orifice and a 0.1mm orifice.

Jet dispensing process

Jet dispensing is completely different from needle dispensing. A mechanical jet ejects a drop of adhesive from a small orifice. Orifice sizes are available from 50µm–500µm, depending upon the desired dot size. The flow rate from a jet is the firing rate multiplied by the dot volume. The firing rate can range up to 200 dots/sec. Unlike other jetting technologies such as thermal ink jets, or piezoelectric jets, a mechanical jet can eject small dots of very thick adhesives, up to 400,000cps. A typical ink jet works below 20cps.

As opposed to needle dispensing, the jet does not require precise dispense height control. A jet can be from 0.25mm–2mm away from the surface and provide excellent results. In an OLED encapsulation processes, the jet height is typically 0.25mm–1mm. This means a jet dispenser does not have to do height sensing at each cell. Therefore, on a typical Gen 4 glass, between one and four dispense height checks are required. Another advantage of jet dispensing is that a seal line need not be a contiguous line prior to lamination. A series of dots will form a straight line during lamination. As the dots are compressed, they initially form larger and larger dots. However, once the dots merge, the fluid flow moves toward the fluid interface with vacuum/nitrogen/air. Eventually, the merged dots form a straight line that is indistinguishable from a needle dispensed line (**Fig. 3**).

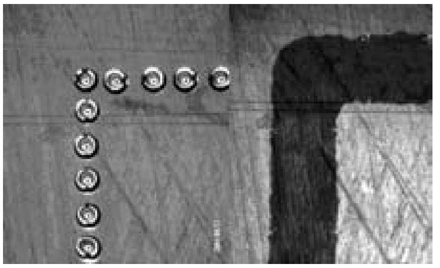

Figure 3. Dots dispensed by jetting squashed out after placement of glass, creating a seal line.

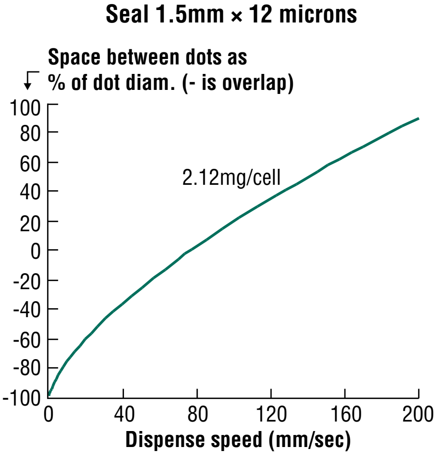

Figure 4. Jet dispensing speed versus spacing.

Dispensing a series of dots also eliminates another needle dispensing shortcoming. Studying Fig. 3, one could ask, "Which dot represents the beginning or end of the line?" One cannot tell the beginning and the end, unlike the case of needle dispensing in which a needle comes down to a surface to start the dispense process and eventually leaves the surface to end a line. These beginnings and endings cause discontinuities that show up as bulbous beginnings or connections, and narrowing endings, or tailing.

The next significant advantage of jetting is speed. Higher flow rates can be used with jetting because there is no plowing or drawing of the fluid. Each jet drop hits the surface independent of the other dots. The balance comes from the individual dot size and the spacing between dots to achieve the required volume of material for a seal. Dot spacing can be up to 80% of the dot diameter and make a good line after lamination (**Fig. 4**).

The jet dispenser can move at 160mm/sec to create the seals, thereby providing a significant increase in takt time. In this case, the dispense time per cell is 0.525 seconds; there is only one height sense required and no Z-move time, and the non-dispense time is the same. This situation equates to a 10.55 minute takt time with one head (**Table 3**). The advantage of one head versus four heads really shows in cost-of-ownership (COO).

Table 3. Takt time (=10.55 min) of jet dispenser under same conditions as a needle auger dispenser.

Attribute	Time (seconds)
Total vision	2.3
Total height sense	2.00
Total non-dispense moves	136.85
Total dispense	492.13
Z head up/down to dispense height	0

Cost-of-ownership

A COO model was built upon the Semi E35 standard [1]. In this comparison, assume the takt time is fixed, at 12 minutes per panel for 899 displays, which yields 4495 units per hour (UPH). Therefore, a needle dispenser will require four heads and the jet dispenser will need one head to get the throughput, but the additional throughput of both systems does not help COO because the takt time is fixed at 12 min. Given that the setup time for a jet head is the same as for an auger pump, it will take 4× as long to set up the needle dispenser. Also, dispensing failures go with the head per time; because the takt times are the same for this case, the number of failures is proportional to the number of heads. Let's also assume the jet dispenser costs 2× as much as the needle dispenser and that initial spares are 4% of the dispenser costs. Material waste and consumable part costs are assumed to be the same for each head; however, there are four needle dispensing heads. It becomes obvious that the payback is in the increased yield. Even if the jet dispenser's initial cost was 2× that of the needle dispenser, the capital cost per part is less than half that of the needle dispenser.

Conclusion

Traditional needle dispensing has been used for the seal process in displays, but using new jetting technology solves the needle dispensing quality issues associated with maintaining the dispense gap and increasing throughput. The advantage that jetting technology brings in reducing COO is enabling AMOLED displays to come to market. ■

Reference

1. A cost-of-ownership calculator can be downloaded at www.asymtek.com/support/coc/coc.xls.

Alec J. Babiarz received his BSE from Arizona State U. and his MSME and MSEE from Stanford U. He is one of the founders and president, new business development, of *Asymtek, 2762 Loker Avenue West, Carlsbad, CA 92010-6603 USA; ph 760 930 3311; e-mail ababiarz@asymtek.com.*