Research Brief

Driver ICs Push Evolution to Next-Generation FPD

Abstract: In the irreversible shift to built-in driver integrated circuits for flat-panel displays, vendors are expected to take a more compound and flexible approach.

By Masao Kuniba

Recommendations

- Next-generation flat-panel display (FPD) manufacturers must establish built-in driver technology infrastructure such as low temperature polysilicon (LTPS) thin film transistor (TFT)-liquid crystal display (LCD) and organic electroluminescence (OEL).

- Although tape-carrier-package (TCP)/chip-on-flexible (COF)/chip-on-glass (COG) packaging techniques will be taken over by built-in driver technology, there are still many uses for TCP/COF tape as flexible module substrates optimized for side-by-side system-in-a-package (SIP).

- FPD vendors must take a more compound and flexible approach to accelerate the shift of the driver integrated circuit (IC) packaging technology for next-generation FPD.

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Introduction

Pervasiveness of FPD-Equipped Electronic Systems and the LCD Driver Market Trend

Today, FPD is everywhere. It is incorporated into an increasing number of electronic products. The trend seems to be accelerated by a new communications infrastructure — broadband. As the broadband connection environment extends to public facilities, such as airports, railroad stations and restaurants, new systems designed to take advantage of the Wi-Fi (aka Wireless Fidelity) communications infrastructure are developed to create emerging markets. Figure 1 shows Gartner Dataquest's production forecast of major electronic products equipped with FPD.

Figure 1
Production Forecast of Major Electronic Products Equipped With FPD
In 2002, total production is estimated to have reached approximately 523 million units, with a compound annual growth rate (CAGR) of 9 percent between 2002 and 2007. The FPD market is roughly divided into several segments according to the implementation method, namely, LCD, plasma display panel (PDP), and OEL or organic light-emitting diode (OLED). The market is further segmented according to the display size, resolution and other requirements for different types of electronic systems, as summarized here:

- **FPD trends for digital cellular phones** — FPD for digital cellular phone, accounting for approximately 80 percent of unit production in 2002, is dominated by black-and-white and color super twisted nematic (STN) LCD. In Japan, where there is strong demand for high-resolution, rich color display, market leadership is being shifted to amorphous silicon (a-Si) TFT LCD. In addition, other FPD technologies are being incorporated into the cellular phone market, including thin film diode (TFD), LTPS TFT LCD and OEL.

- **FPD trends for PCs** — The PC is the most promising market for FPD-equipped electronic products, with a CAGR of 24 percent expected between 2002 and 2007. By segment, the notebook PC market is dominated by a-Si TFT LCD. In the desktop PC market, the cathode-ray tube (CRT) monitor maintains strong advantage in terms of picture quality and cost, but a-Si TFT LCD is eroding CRT's dominance at an accelerated rate. This is because of its competitive edge in low power consumption and space saving, which more than compensates for the price advantage of CRT. In fact, in addition to space saving, power saving and high resolution are drivers for LTPS TFT LCD and OEL to be incorporated into PDAs and subnotebook PCs.

- **FPD trends for digital still cameras (DSCs)** — DSC demands high-resolution, full-color display, while a-Si TFT LCD enjoys the predominant share. Meanwhile, for higher resolution and smoother response for an animated picture, manufacturers are increasingly adopting LTPS TFT LCD and OEL.

- **FPD trends for flat-panel TVs** — While CRT holds the dominant share in 30-inch or larger TVs because of cost and other advantages, the large-screen flat-panel TV market is expected to grow, using a-Si TFT LCD and PDP, which offer an advantage in terms of power consumption and space saving.

These FPD technology trends in the key applications indicate that a-Si TFT LCD holds the leadership position. In turn, future growth of the LCD market can be read from the driver IC market trend. Figure 2 shows the driver IC consumption forecast.
Figure 2
LCD Driver Consumption Forecast for Major Electronic Products

Midsize and large FPDs are expected to serve as a major engine by replacing the CRT in the desktop PC and flat-panel TV markets. Gartner Dataquest predicts a CAGR of 17 percent (on a value basis) between 2002 and 2007. Major factors for the driver IC market growth are based on technical needs as listed:

- Lower power consumption
- Smaller form factor with a larger screen
- Higher portability with functional enhancement
- Higher resolution and display capability for animated picture
- Lower cost

As more and more electronic products support broadband communication, FDP demand led by LCD is growing rapidly to meet these needs. In fact, FDP is gaining a competitive edge in picture quality and cost because of technological advances and economies of scale and is overwhelming the CRT in the midsize and large monitor market.
Diverse Forms of Driver IC Packaging

Driver ICs are a key component of the STN LCD or a-Si TFT LCD and are assembled to the FPD substrate. Assembly techniques vary greatly among LCD manufacturers according to their assembly infrastructure. The driver IC market trend shown in Figure 2 can also be viewed from driver IC assembly technology. Table 1 shows the relationship between FPD size and packaging techniques for each of the key electronic products.

Table 1
Driver IC Packaging Trends by FPD Size for Major Electronics Products

<table>
<thead>
<tr>
<th>Application</th>
<th>FPD Size</th>
<th>Driver IC Packaging Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellular Phone</td>
<td>Small — 2.4 inches or less</td>
<td>TCP, COF, COG, built-in driver</td>
</tr>
<tr>
<td>Digital Still Camera</td>
<td>Small — 2 inches or less</td>
<td>TCP, COF, built-in driver</td>
</tr>
<tr>
<td>PDA, Subnotebook PC</td>
<td>Small to midsize — 3.5 inches to 12 inches</td>
<td>COF, built-in driver</td>
</tr>
<tr>
<td>Notebook PC</td>
<td>Midsize — 12 inches to 17 inches</td>
<td>TCP, COF, COG, built-in driver</td>
</tr>
<tr>
<td>Desktop PC Monitor</td>
<td>Midsize to large — 14 inches to 22 inches</td>
<td>TCP, COF, COG</td>
</tr>
<tr>
<td>Flat-Panel TV</td>
<td>Large — 30 inches or larger</td>
<td>TCP, COF</td>
</tr>
</tbody>
</table>

Source: Gartner Dataquest (April 2003)

The driver IC packaging technology trend is summarized as follows:

- Driver packaging for digital cellular phones — For small FPDs (2.4 inches or less) used for cellular phones, TCP, COF and COG are used. As already pointed out, FPD and electronics manufacturers use different packaging techniques and systems that help establish competitive edges. Yet, the core packaging technology — in addition to the transition from TCP to COF — is in the process of evolution. For instance, COG packaging technology is used to assemble a driver IC to drive a main FPD and a sub-FPD of a fold-type advanced cellular phone. For the FPD for the third-generation cellular phone, the OEL is increasingly used to allow a smooth response for animated features. The OEL allows the driver IC to be built into the FPD substrate. Moreover, the OEL eliminates the backlight mechanism as the display illuminates itself, offering a major advantage in power saving.

- Driver packaging for PCs — For midsize a-Si TFT LCDs (17 inches or less) for notebook PCs, driver ICs are assembled using TCP or COF. On the other hand, midsize a-Si TFT LCDs (14 to 22 inches) for desktop PC monitors use TCPs because of existing technology and other infrastructure. As part of an effort to reduce the cost for 15- to 17-inch a-Si TFT LCDs, however, South Korean and Taiwanese companies are increasingly using the COG solution. Finally, subnotebook PCs (12 inches or less) mainly use the LTPS TFT LCD for power saving and high resolution. The LTPS builds the driver IC in the FPD substrate and offers a competitive edge in a fast response rate — a key factor for high-resolution display. However, it is not self-luminescent and requires the backlight mechanism.
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- Driver packaging for DSCs — Small a-Si TFT LCDs for DSCs (2 inches or less) use TCP or COF, but recent models increasingly adopt LTPS TFT LCD for high resolution and thus have driver ICs built in the FPD substrate.

- Driver packaging for flat-panel TVs — Large FPDs for flat-panel TVs (30 inches or larger — a-Si TFT LCD or PDP) assemble a large number of driver ICs using TCP or COF. As manufacturers are expected to meet technical challenges for higher resolution, lower power consumption, larger screen and lower cost, they are taking various approaches, including the use of OEL.

Today, a great variety of FPD packaging techniques have been developed and implemented for different FPD systems for electronic products. The current technology trend by FPD size class is summarized as follows:

- Large FPD — For higher resolution, driver IC packaging technology for large FPDs such as flat-panel TVs is shifting from TCP to COF. Also, the built-in solution (such as OEL) is being developed for the high value-added market.

- Midsize FPD — The shift from TCP to COF is also apparent in this market segment. Some vendors are adopting COG to reduce the cost of a-Si TFT LCD. For subnotebook PCs and PDAs (using FPDs that are 10 inches or smaller), built-in assembly of driver ICs (LTPS TFT LCD and OEL) is searching for higher resolution.

- Small FPD — In the small FPD market for cellular phones and DSCs, manufacturers are moving to COG for cost-reduction purposes, while COF is becoming the mainstay for high resolution. At the same time, implementation of built-in driver ICs (LTPS TFT LCD and OEL) is under way across the board in an effort to achieve cost reduction and high resolution.

Overall, the technology trend seems to be polarized, aiming at the two distinctive goals (lower cost and higher resolution). The ultimate goal is to implement the built-in driver IC assembly technology covering small to large FPDs, and more specifically, evolving from LTPS TFT LCD to OEL. In other words, the built-in driver IC is designed to address all the requirements for FPDs, including low cost and high resolution. Thus, the current COG and COF approaches are temporary solutions on the way to the final goal. And the major issue facing the driver IC assembly technology is to determine when it will achieve the two goals and in which applications.

Evolution of Driver IC Packaging Technology

Following the review of the FPD packaging technology trend by electronics application, this section analyzes the evolution of the packaging technology per se, from TCP to COF, COG and built-in driver IC. In contemplating a technology road map for the built-in driver IC, it is important to draw a general picture of how the current technologies — TCP, COF and COG — will evolve. This means we must think about the...
changes in industrial infrastructure supporting the technologies, including materials, equipment and packaging techniques.

Originally, TCP was designed to accommodate inner leads (ILs) on an increasingly finer pitch for die-level bonding. As lead frames used for quad flat package (QFP) and other peripheral lead-type packages faced limitations on the fine IL pitch, the use of the tape automated bonding (TAB) technology met the needs for increased pin counts. Note that TCP and COF are essentially of peripheral lead type but are capable of meeting fairly fine pitch requirements. Table 2 summarizes the pitch reduction trend. (Note: Some data are based on those provided in "Japan Jisso Roadmap 2001" by the Japan Electronics & Information Technology Industry Association[JEITA].)

Table 2
IL and Pad Pitch Trends (Micron)

<table>
<thead>
<tr>
<th>Interposer</th>
<th>2000</th>
<th>2003</th>
<th>2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>IL Pitch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lead Frame</td>
<td>160</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>TAB Tape (Flying Leads)</td>
<td>50</td>
<td>40</td>
<td>35</td>
</tr>
<tr>
<td>COF Tape (Flip Chip)</td>
<td>40</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>Pad Pitch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COG (Flip Chip)</td>
<td>60</td>
<td>60-40</td>
<td>35</td>
</tr>
</tbody>
</table>

Source: JEITA and Gartner Dataquest (April 2003)

Generally, LCD driver ICs use slim dies with 400 to 600 pins (input/output [I/O] counts). TAB is essential in accommodating the large number of package I/Os. At present, the TAB tape with the minimum IL pitch of 40 microns and the COF tape with 30 micron are manufactured in volume. Further pitch reduction is expected. While COG is technically feasible to implement a pad pitch using gold bumping of 40 microns or less, mounting on the glass substrate for a-Si TFT LCD presents a yield problem, so that volume production is carried out for the 60-micron to 40-micron pitch. The following is the current account of various driver IC packaging techniques that are being advanced to meet the finer IL pitch requirements:

• TCP — It consists of a polyimide-based TAB tape, which has a hole (device hole) for mounting a driver IC punched out. Inner leads (to which a driver IC is bonded) are not placed on the tape (flying leads). Figure 3 shows a sketch of TCP packaging. As a stamping mold chase for the device hole must be newly made according to a change in IC design (dimension), TCP presents a cost problem. Also, the stamping mold chase must be carefully monitored according to its durability (number of shots) and requires repair or replacement for volume reduction; it is not suitable for small lot production. Furthermore, the thickness of the TAB tape base material (about 50 microns thick) makes TCP less flexible than COF.
Figure 3
TCP Packaging Technique

- COF — While COF also uses a polyimide base, it does not have a device hole for the driver IC and the IL is placed on the polyimide base. Figure 4 shows a general view of the COF packaging. As the manufacturing steps are fewer than those for TCP because of the absence of the device hole punching operation, COF should have a cost advantage. In reality, however, the use of a very thin COF tape material (about 25 microns thick) — in an attempt to achieve a fine IL pitch — has caused poor yield and quality problems in the initial production stage, and cost reduction is still slow as compared with original expectations. COF tapes are divided into two types according to the manufacturing method: the "tape COF" developed by TAB tape manufacturers as a semiconductor package interposer and the "matrix COF" by flexible printed circuit (FPC) makers as a surface-mounting FPC for electronic parts. The COF tape is increasingly used for small a-Si TFT LCD and peripheral electronic products (for mobile electronic equipment) and is establishing itself as the mainstream technology because it can be folded to minimize the packaging area in a limited form factor. Nevertheless, it must still solve a quality problem, which increases with the reduction in thickness of the polyimide base material. In fact, the problem results in a low yield to cause supply shortage of the COF material. Manufacturers use diverse resources to develop and upgrade the COF material as well as to expand capacity, but more time and cost will be required to meet the needs steadily. As pointed out earlier, FPD is based on a mix of packaging technologies, while electronics demand is diverse and changes quickly. In practice, manufacturers seem to rely on COG, TCP and built-in driver IC (LTPS and OEL) to meet demand not covered by COF.
Figure 4
COF Packaging Technique

Source: Gartner Dataquest (April 2003)

- COG — Gold-bumped driver ICs are directly flip-chipped to the FPD substrate. In fact, COG was used in the initial age of LCD (monochrome) and was considered a relatively old technology. Recently, however, an increasing number of LCD vendors are using COG for cost reduction of a-Si TFT LCD by taking advantage of high-density flip chip bonding technology and the availability of a high-precision COG bonder. Figure 5 shows a general view of the COG packaging technology. Some LCD makers, notably Samsung Electronics of South Korea and AU Optronics of Taiwan, are moving to development and volume production for further cost reduction of midsize a-Si TFT LCD for notebook and desktop PCs. At present, a hybrid approach is common (for example, COG is used on the gate side and TCP or COF on the source side).

Figure 5
COG Packaging Technique

Source: Gartner Dataquest (April 2003)
Built-in driver IC — With the introduction of full-color cellular phones in the United States and Europe and the deployment of animated picture content for the third-generation cellular phone, the focal point is shifting from COF to built-in driver IC (LTPS TFT LCD and OEL). Figure 6 shows a general view of the built-in driver packaging technology. The solution improves the response rate and promotes higher resolution and cost reduction. On the other hand, it has a cost disadvantage in the polysilicon production (annealing) process, although it is on the way to improvement as manufacturers make efforts to improve yield, expand annealing size with uniform quality and improve defect reparability. At present, the built-in strategy focuses on volume production of small and midsize FPDs. In the larger FPD market (including the midsize segment in which cost competition is intense), vendors continue to leverage volume production capability of a-Si TFT LCD and rely on interposer-based packages such as TCP and COF.

Figure 6
Built-In Driver IC Packaging Technique

Source: Gartner Dataquest (April 2003)

Japanese FPD manufacturers are working on all fronts (TCP/COF/COG, and LTPS TFT and OEL) for built-in driver IC. As a result, structural reforms of the industry in the area of FPD technology are progressing at a slow pace. This sharply contrasts the strategic shift from the peripheral lead package to the area array type, which was initiated by American and European companies in the late 1980s. That shift was quickly followed by developing industrial standards through Joint Electronic Device Engineering Council (JEDEC). Naturally, quick response is not always right. The strategic shift of South Korean and Taiwanese FPD companies from COF to COG seems to be somewhat opposite to the technology trend. And a major problem facing Japanese companies is the lack of leadership in creating the next-generation FPD industry because they seem to follow the crowd in their approach to driver IC packaging.
Will TCP/COF/COG Die Hard?

As FPD-equipped electronic products increasingly incorporate built-in driver ICs, conventional packages of TCP, COF and COG lose their share. This reduces the need for gold bumping of a slim die and results in the shrinkage of the specialty market. Also, a decline in consumption of the interposer (TAB-COF tape) seriously affects the related markets (for example, TAB and COF tape manufacturers and TAB, COF and COG bonding equipment manufacturers). As the FPD industry is required to continue technology upgrades in terms of resolution, cost and display size, the corresponding shift in the market structure is called for. In reality, however, the cost reduction and the development of a large FPD constitute major bottlenecks, while Taiwanese and South Korean companies controlling share in the a-Si TFT LCD market are delayed in development of volume production capabilities of LTPS TFT LCD and OEL. It is now important to watch the market trends carefully to find when the shift occurs and what signs become apparent. For instance, vendors are active in building LTPS TFT LCD capacity partly because it can easily be converted to the OEL process, and the pace of replacement of TCP, COF and COG is a good indication of how fast the industry is moving toward built-in driver ICs.

Market Opportunity for Flexible Module Substrate

Even if built-in driver ICs become the norm in the industry, the FPD is still to be equipped with power supply devices and other peripheral components, and the need exists for space saving by creating design flexibility. For this reason, COF using the thin polyimide base material is expected to increase in unit shipments — at least on a short-term basis. Also, incorporation of a number of functions into a limited form factor tends to increase the number of parts and packages. And the rigid flexible substrate that combines a multilayer rigid printed circuit board (PCB) and an FPC is increasingly used for high-density surface mounting of power ICs, other peripheral parts, and image processing application-specific standard products (ASSPs). In this arena, technological assets relating to the "matrix COF" are widely used to create healthy demand for polyimide base materials.

Similarly, the tape COF will find new applications such as submodule interposer for high-density packaging of electronic parts. The technology of tape COF will be proven useful for assembly of flexible packages such as fine pitch ball grid array (FBGA) and tape ball grid array (TBGA) by implementing more than 1,000 I/Os on a fine IL pitch. For instance, Sharp's system on film (SOF) and NEC's flexible carrier folded real chip size package (FFCSP) are compound packages, which can be positioned as an approach to SIP using the TAB/COF tape. Thus, FPC and the TAB/COF tape will drive the market as flexible module substrates.
Gartner Dataquest Perspective

Analysis of the LCD driver IC packaging technology trend by FPD system and display size for major electronic equipment indicates that complexity of the packaging processes accompanied by increased capital investment makes process change difficult after volume production capacity has been established. At present, a move has been accelerated to adopt new technology — built-in driver ICs. Meanwhile, South Korean and Taiwanese LCD companies are working to expand the market by strategically controlling the a-Si TFT LCD price using the COG technology. Clearly, it is an attempt to prolong the existing a-Si TFT LCD market because they will be able to maintain share in the FPD market by preserving the present market structure. For Japanese companies to regain share, it is important to lead the technology shift to built-in driver ICs and establish the production infrastructure. In doing so, the TCP/COF/COG market will decline in the long term, but the flexible substrate market will transform to serve the high value-added market such as the rigid flexible board or the flexible module substrate that surface-mounts multiple ASSPs for image processing and other devices around LCD drivers, which serve as the SIP substrate based on the TAB/COF tape. The use of the flexible module substrate creates demand for implementation of multifunctional electronic equipment by assembling dies and packages side by side as an alternative to SIP using the 3-D stacking technology. In the irreversible shift from TCP/COF/COG to built-in driver ICs, vendors are expected to take a more compound and flexible approach.

Key Issue

How will new technologies affect the manufacturing supply chain?