The Future Display Market – Major Discontinuities or More of the Same?

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Introduction - Predicting markets is difficult

The human quest for visual perfection has touched almost every area of earthly endeavour - from art and bodybuilding to architecture and automobiles - even technology. Electronic displays attempt to recreate the visual perfection of the natural world in a synthetic environment. Some succeed, e.g., the CRT and LCD, while others fail, sometimes ignominiously, sometimes with great spectacle. Some "killer" technologies look very promising in their early days of development, but never take off, or end up occupying only a niche market. In some fields there can be technology battles between rivals with one technology losing, yet the field itself, nevertheless, grows rapidly on the success of the winner. A classic example of this was the videocassette recorder, where the end product is now ubiquitous, but the battle amongst the main contenders - VHS, Betamax, and Video2000 - looked like a true struggle for technological supremacy. However many onlookers, and the market itself, saw other factors in the eventual winner that drove it to the forefront. Picking the winners, and accurately predicting the percentage inroad of new technologies has never been easy and continues to be a difficult proposition.

There is little doubt in this electronic age of instant communications, mobile computing, and infotainment that electronic displays are and will remain a strong growth area. The convergence of previously disparate technologies into a single mobile device has resulted in an interdependency amongst the technologies that complicates the analysis of timing for market development. Now that consumers and users have experienced the freedom that comes from untethered use to communications and computer systems, the prospect of returning to the "old days" of restricted access and complicated hardware systems is a losing one. The stakes are very high in the competition for the right combination of features, format and price to drive standards and market share. Displays are increasingly becoming a strategic component in the overall solutions being offered. Perhaps the best example is the quest for broadband wireless communications, information management and entertainment in single platform portable display-centric products. But which display technologies have the right performance/cost ratio to satisfy this latest in technology surges? And, in the overall display markets, as new display technologies emerge and old ones improve, and as new products are introduced with expanded features and performance requirements, which will grow, which will stagnate, and which will decline? Which technologies will enable other new applications and which will grow merely by replacement of existing technologies?

This paper will examine what enables a new technology to take off, and illustrate this with an example from the display world. Specifically, discussion will ensue on the chances that a relatively new organic display technology being developed by CDT and based on light emitting polymers (LEP) will cause a major disruption to the established display order.

Poly-Silicon Thin Film Transistor Technology and Applications in Displays and Other Novel Technology Areas, Apostolos T. Voutsas, Editor, Proc. of SPIE-IS&T Electronic Imaging, SPIE Vol. 5004 (2003) © 2003 SPIE-IS&T · 0277-789X/03/$15.00

Why some technologies are slow to grow and challenge the established order

For some new technologies large capital investment is required and, often, existing assets cannot be used, despite apparent similarities with and the presence of a broad base to choose from of existing technologies and infrastructures. For these technologies, development can be slowed as company boards spend more time in the decision making process to assess the most effective technology development path, the most promising early markets, and especially, evaluate the process of raising capital and converting it into factories. AMLCD has experienced this syndrome due to its inherently complex nature and the relatively disparate technologies in semiconductors, optical treatments and materials necessary to create a finished product. For CDT, an important consideration in assessing the growth potential and rate of penetration of its LEP technology has been the technology change from high voltage vacuum technology based displays, specifically the CRT, to low voltage and solid state flat panel display technologies, best exemplified by LCDs. In particular, how, when, and how rapidly the replacement of investment in relatively lower cost CRT infrastructure with billion dollar AMLCD fabs was going to take place would have a direct impact on the transfer of development and infrastructure to flat panel displays. While the speed of the market conversion to FPDs has been strongly paced by the investment required as well as the performance/cost offered by AMLCDs, the direction has never been in doubt.

In AMLCDs, the large capital equipment investments have created significant pressure to fill manufacturing line capacity as quickly as possible. At times supply and demand imbalance has led to AMLCD industry overcapacity, and, more recently, cycles of reduced laptop sales or low profitability have spurred AMLCD sales into the desktop area as well as non-PC markets. Market analysts and even companies with full access to both sides of the picture, such as Samsung and LG Philips, have found predicting the swings between markets difficult, even for forecasting business and technology development one year into the future. Even more difficult has been predicting price downturns, as pricing becomes dominant in deciding which technology goes into which market. While the supply demand balance has been proven to have a cyclic nature that is somewhat predictable, the effect of sporadic business growth has been a general suppression of investment for technology development and a delay in expansion of manufacturing capabilities.

While the 1970's through early 1990's enjoyed periods of rapid expansion of display dependent markets and the introduction of new display technologies, the current climate has pushed the start up cost for new entrants to levels that are prohibitive to making direct inroads into established markets. Seldom is a new technology such a killer that it naturally takes over. The sheer size of display markets precludes rapid takeover, even with a high degree of compatibility with existing technologies. The incumbent technologies can fight back with cost reductions and continuing innovations. This effect must be anticipated by a new technology, and companies must budget for start up running losses, including the expense to take market share.

Especially difficult to predict accurately can be all manufacturing costs, due to rapid changes in capital equipment, materials and processes. Subjective judgement of technologies based on a mixture of unit sales volumes, application attractiveness, and predicted end cost and price can be generated. For example, many see the CRT dominance in television shrinking in the long term and recent trends bear this out. The prediction of precisely how fast this will occur depends on a variety of factors. Most large corporations have carried out market research into the attractiveness of "flat and thin" and have developed their own "magic ratio", which is usually a price ratio of "Thin flat display price of size X/ CRT price of size X" at which consumers will switch over in volumes. They also have detailed cost reduction roadmaps showing how each technology will reduce in cost over the years. If a company believes the start up cost is too high, or the end achievable price is too high, it will downgrade future growth predictions, and possibly cut programs completely. Examples of this are the jostling for position in the 32" TV display market: some companies believe the CRT will remain dominant here; others that Plasma and LCOS and DLP rear projection can compete effectively in the mass market at this size.

At the 21" TV size there are differences of opinion about how much share LCD's can take, based on the predictions of achievable price, and perceived attractiveness.

For some new technologies the supporting infrastructure does not mature quickly. For example, all flat panel display technologies require semiconductor drivers, which have to be developed in synchronization with the core display technologies and were often not mature or readily available in the early development periods. This has hindered market take up, and made cost model results look very unattractive. An example is AC plasma and plasma addressed LCD. Others have required new equipment infrastructure or materials, which develop slowly, examples here being field emission, LCOS and OLEDs.

Markets have increasingly demonstrated that they do not like a monopoly technology or product. In the past, major electronics companies such as Philips, Toshiba, Fujitsu and Sharp have successfully kept developing technologies secret in their internal labs, and worked to develop new technologies alone. The business models of these companies have included full vertically integrated, components, equipment, materials, and manufacturing. In today's markets, new ideas are often shared early in their development. This is not only to share the technology development costs through a group approach, but also for sake of the customer base. The cost to develop a new display technology and successfully bring it to market has increased rapidly to the point of making it virtually impossible for a single company to accomplish this alone. Also, as a result of the maturation of markets and OEM demands, there is less interest by and less need for OEMs to risk new product entries on a new technology that is either single sourced or immature in manufacturing development, even if it is lower cost and better in performance. Also, current mainstream display technologies have reached a level of performance that is "good enough" to satisfy most market demands, obviating the assumption of risk with a new technology and resulting in additional barriers to entry for new technologies. If a new technology is good, it is vital to attract a pack of co-developers to drive it forward.

Why some technologies make breakthroughs

LCDs have acquired their ubiquity partly due to their reasonable cost, partly because they have enabled some major markets, and partly because they have repeatedly adapted to new market opportunities through continuous innovation, allowing them to dominate new products and commercial opportunities. AMLCDs - LCDs enhanced by an active matrix of thin film transistors – along with semiconductor technology, have enabled portable electronic devices. The AMLCD enabled LCD's portability, flatness and low power to move into the PC arena, launching high quality laptops. The growth thus enabled became a strong market pull that allowed for the learning curve to be driven through, despite high costs, low yields and compromised performance, and ensured that companies kept the faith in those early years. Even when price erosion inevitably kicks in, market growth is a very powerful driver and gives massive incentive to those who think they can be among the winners when the competition thins out as the products and markets hit maturity.

Some new technologies offer no new performance gains, but are measurably lower cost to manufacture than competing technologies. The resulting balance of cost and performance is dramatically better than competitors. This rarely happens, but when it does the effect is dramatic.

Characteristics of LEP and how they relate to the above

LEP displays are a multilayer thin film device that is in design, construction and operation (Figure 1.) and have a variety of relatively simple process routes, including many commonalities with LCD capital equipment and production processing. CDT has capitalized on the common existence of these tools by integrating standard photolithography tools and a Tokki deposition tool into its Godmanchester UK technology development and pilot manufacturing facility, see Figure 2. This is significant as it means that a standard monochrome LCD line can be converted for about $5million (for volumes of approximately 5 million cell phone equivalent displays per year). This represents a conversion cost percentage of less than 15% of the initial investment and offers LCD makers in an extremely competitive world the chance to switch or even mix technologies without major capital investment or losing their investment in existing equipment

LEP's simpler process than LCDs also means a long term lower production cost or higher profitability margin, provided yield can be as high, which has been demonstrated in first generation LEP displays. One of the principle reasons for the delay in LCD market penetration and their relatively high cost is the cost of materials, production process complexity, and required capital equipment investment. LEPs can be fully assembled on a single glass or plastic sheet, the second sheet, metal can, or thin film coating only seals the assembled cell. In contrast, LCDs require both sheets to be processed. LEP displays are solid state with no internal cavity, making them simpler to assemble and finish; whereas LCDs require a cell-type structure that must be filled with LC material.

The extremely large investment in display manufacturing facilities and equipment made by the AMLCD suppliers results in the need for many years of payback from their plants. An AMLCD line with LTPS is also readily convertible to active matrix LEPs (AMLEPs). Of the $1billion investment almost all is compatible: only the LCD display cell assembly operation must be replaced by ink jet printing deposition and encapsulation equipment. Other equipment, such as glass rubbing, polarizer and color filter assembly, are not required. Amorphous silicon lines may be usable, although this has not yet been demonstrated commercially. The result is that AMLCD players need not jeopardize their current infrastructure investment in order to integrate LEP display manufacturing into existing facilities, and LEP technology can be seen as a complementary next step with relatively small conversion costs.

Considering variable and material costs, AMLEP scores well. If an AMLCD manufacturer replaces the back/frontlight, color filter, linear polarizers and LCD assembly costs with LEP polymer deposition and glass sealing/encapsulation, 20-40% can be saved on the cost of a PDA-size active matrix device.

LEP materials can be dissolved in organic solvents, allowing solution deposition through a number of methods. These include spin coating, a mature, low capital equipment cost process that is widely used in applying photo resists and other films. First generation monochrome LEP displays have used spin coating. Ink jet printing has shown great promise to accurately deposit organic materials for full color, high-resolution displays that can scale to virtually any size. This is expected to lead to rapid expansion of market application to large display markets. A cross-sectional view of an ink jet structure for LEP color devices is shown in Figure 3.

Screen-printing technology can be adapted to LEP materials by increasing the viscosity of the solution. Large area, low cost graphic displays are being developed using this method. Figure 4. shows a 17 in. WXGA full color inkjet printed display that has rapidly been developed by Toshiba. Further, laser transfer is under development for LEP deposition, which uses a donor film coated with LEP materials that is then placed over the target substrate and selectively transferred by laser heating to the intended target substrate areas. Finally, contact and Gravure printing are being considered for lighting and graphical displays. This assortment of deposition methods will provide display and lighting manufacturers a wider array of production options for existing display markets as well as new ones. More importantly, they represent a potentially disruptive production paradigm that measurably reduces capital equipment costs, can improve yield and throughput, increases scalability, and provides high compatibility with roll to roll processing of plastic substrates.

The purpose of a display is to visually reproduce images that are electronically generated and transmitted; therefore, a display's visual performance is perhaps its most important attribute. The standards for display performance have been set by CRTs for video images and AMLCDs for graphical images. LEP technology has demonstrated fast moving images with no motion artifacts and high dynamic contrast, significantly improving image quality over LCDs. This is due to the sub-microsecond response time of LEP materials with electrical excitation. The emissive nature of LEP technology provides unlimited viewing angle, which will increasingly become important for a "handsfree" and shared experience in mobile devices providing digital video images, digital photos and web content access.

Equally important for differentiation and mobile device applications are the form factor advantages of LEP technology. Glass substrate displays with standard TAB drivers can be under 3 mm thick, compared with 4-5 mm for back/frontlit AMLCDs. AMLEP glass displays with integrated drivers are less than 2 mm thick. On plastic substrates, LEP displays can be under 1 mm thick. Reduced thickness results in lower weight and plastic substrates will provide unbreakable displays.

Power consumption in mobile devices is critical and becoming increasingly important in most other display systems. While the record for low power flat panel displays currently lies with reflective passive and active matrix LCDs, they lack the visual performance to provide a full range of multimedia imaging, and the frontlight or backlight required for indoor or nighttime operation significantly increases power consumption. Because of its emissive nature, LEP technology consumes power on through the pixels that are activated, allowing text or video images to consume measurably less power than back/frontlit LCDs, estimated at 20-40% reduction. Because of this, LEP technology offers what is considered to be the highest visual image quality at the lowest power consumption, a metric that adds to the attractiveness of this new technology.

The combination of form factor advantages, coupled with superior image performance, lower power consumption, potentially lower manufacturing cost, as well as a future roadmap to plastic substrates, present compelling advantages for current display markets and future ones.

LEP technology has rapidly developed when measured as display technology development cycles go, and has been licensed by CDT to a number of credible display manufacturing companies. This has allowed LEP to avoid the narrow monopolist tag. Because no new display technology has ever succeeded without a robust supply chain, and because the pace of cost and performance improvement in a new technology is driven by advancement in the supporting technologies and infrastructure, much attention has been placed on promoting complete commercial solutions. Presently, more than three companies are developing electronic driver devices for LEPs, LEP materials are being developed for commercial production by more than three companies, and multiple equipment providers are working on each stage of the production process.

The visual, form factor and potential cost improvements that LEP technology offers has not to date identified a significant new market that LCDs do not currently serve. While low cost, low power emissive displays have a “wow” factor that LCDs lack, LEP displays, as well as other candidate technologies, presently need to displace existing LCD displays to reach their ultimate potential. A growing perspective for stronger potential growth in existing display markets and inspiring new applications lies in the prospect for LEP to enable plastic substrate, roll to roll processed, thinner, lighter, unbreakable, conformable and even wearable displays. This is a future vision that is being actively pursued by a number of companies, and, while successively more sophisticated technology demonstrations will be made over the next several years, it is not a commercial reality now.

The most immediate market opportunity for plastic substrate displays is currently existing glass display markets, where the most viable applications will be portable products that can benefit from plastic’s advantages. However, the first plastic displays are expected to be monochrome, where the full set of visual advantages of LEP technology are not used, consequently it is expected that plastic displays competing with existing glass LCDs will need to also be price competitive, which will lower the profitability of the first plastic displays. Nevertheless, a number of markets for true conformable displays have been identified, including automotive interiors, wearable displays, lighting applications, and future mobile products. Eventhough human beings can readily visually process three-dimensional images, all current media that transfers data or images is done essentially in two dimensions. Truly flexible display applications, where the display is in some degree of continuous or repeated flexure, are being touted as the new frontier for displays, but are actually more elusive due to the fact that such applications currently do not exist, and the reliability of such devices is highly questionable with existing technologies. Displays that are totally transparent have been demonstrated and have garnered some limited commercial interest, however, their viability as more than a novelty is questionable because they invert text and images.

What must be demonstrated to make the swing?

With consideration of the above discussion, it looks as though LEP has a number of chances to make significant structural changes to the display market. However, the ”proof of the pudding is in the eating” as they say in the part of England that I come from. What is it that must be done to convince sceptical or reluctant manufacturers to make the switch?

Because the mainstream display market applications continue to be notebooks, desktop monitors, and televisions, LEP displays with active matrix backplanes are required, not dissimilar to the need for active matrix LCDs presently. LTPS has demonstrated the highest compatibility with LEP technology as an active matrix backplane technology. There is a need to demonstrate uniformity of LTPS transistors on large areas, with mobilities of around $300cm^2/Vs$. This work is being lead by Toshiba-Matsushita Displays, TMD, and Seiko-Epson Corporation, SEC, as well as others who may be conference participant and attendees.

Ink jet printing technology progress has resulted in development-scale tools that have produced demonstrator displays. First generation production tools are nearing completion and will soon be put to the test of establishing reliable production yields in facilities with factory pressures and semiconductor/display industry demands. In this area, Philips and CDT are integrating Litrex printers into mass production systems for production of full color displays. CDT has purchased first generation Litrex ink jet production tools that will be installed in the CDT Godmanchester UK Pilot Line facility and integrated into an Ulvac cluster tool. Philips has also made a similar procurement through their automation division. SEC are proving processes using their own equipment and can demonstrate full color high resolution displays at their open labs in Japan and UK. Figure 5. shows a 2.1 in. 130 dpi full color display developed by Seiko Epson using ink jet printing technology.

Full color displays need a balanced red, green, and blue materials performance. While red and green have both achieved 10,000 hours of operation to 50% luminance decrease, the blue polymer operation has currently demonstrated 8000 hours, and progress is accelerating.

Success breeds success. Polymer displays need to show products in the market with lifetime, reliability and market penetration that establish technology viability. In 2002 Philips launched an LEP display product in an electric shaver (Figure 6.), and Delta Optoelectronics of Taiwan has supplied an LEP display for an MP3 player (Figure 7.) and other portable devices. Both Osram and DuPont have announced that sales of LEP based displays will start in 2003. Dupont is actively developing plastic displays (Figure 8.) on the basis of their extensive technology in plastics and polymers. CDT itself will launch a range of products via distribution from its Godmanchester Pilot Line. This enables CDT to establish critical process technology and learning that it can pass on to new licensees to enable them to rise up the process characterisation learning curve quickly.

Conclusion

The quest for visual perfection moves forward, inexorably from the present technologies that continue to incrementally innovate onto future visions of new technologies that attempt to overcome present barriers and limitations. Much work is going on. The credibility of LEP displays, currently making the transition from future promise to present reality, is growing through validation of products in the marketplace, continuing progress in materials performance, increasing participation by the major display manufacturing corporations, and increased technology advancement on all fronts.

The range of possible applications for LEPs in electronic displays actually extends beyond the current markets for conventional displays: new uses for simple lighting devices and more futuristic displays are growing over time with increasing demonstration of the technology. These range from simple test devices for bio medical screening and replacement of electro-mechanical displays to tiled large area passive displays and wristwatch TVs (Figure 9.).

To add additional fuel to the LEP technology development fire, application to lighting systems and photovoltaics is under way. While not intended to directly replace conventional incandescent and fluorescent lighting technologies, LEPs are being developed for area lighting applications, including accent, architectural, emergency, and novelty lighting. Philips and Osram, both CDT licensees, are major suppliers of lighting products. Modifying the formulations and device structures of LEP devices can reverse the energy conversion process used for displays, which converts electrical energy to light energy. Using incident light energy to produce a current raises the prospect of significantly lower cost battery charging and auxiliary power supply films and components that could enable further expansion of the application of mobile devices, e.g., a cell phone or PDA integrated with such a capabilities could augment current batteries, extend tie for recharging as well as battery life. The net effect of these developments is that the momentum for LEPs is increasing and a critical mass of technology developers, infrastructure and supply-chain providers in lighting, displays, printing, semiconductors, energy systems, and manufacturers will drive the technology to its ultimate potential.

Given the similarities with LCD processing, the relatively easy conversion of LCD production lines, LEPs differentiating and superior performance capabilities, the large pool of developers and manufacturers, and the wide range of other applications for LEPs to fuel investment and technology advancement, the foundation is in place for a shift in market share on a scale that is potentially much larger than for any other new technology since LCDs. The cooperation of many organizations and companies around the world in the all of the necessary endeavours of technological support can bring reality to this revolution.

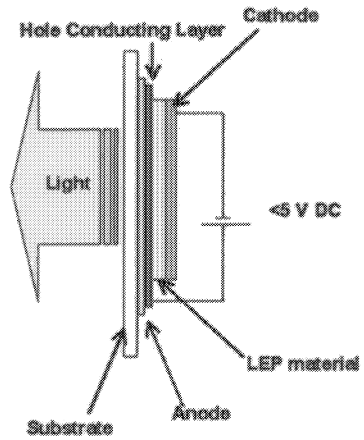

Figure 1. - Cross Section of LEP Display

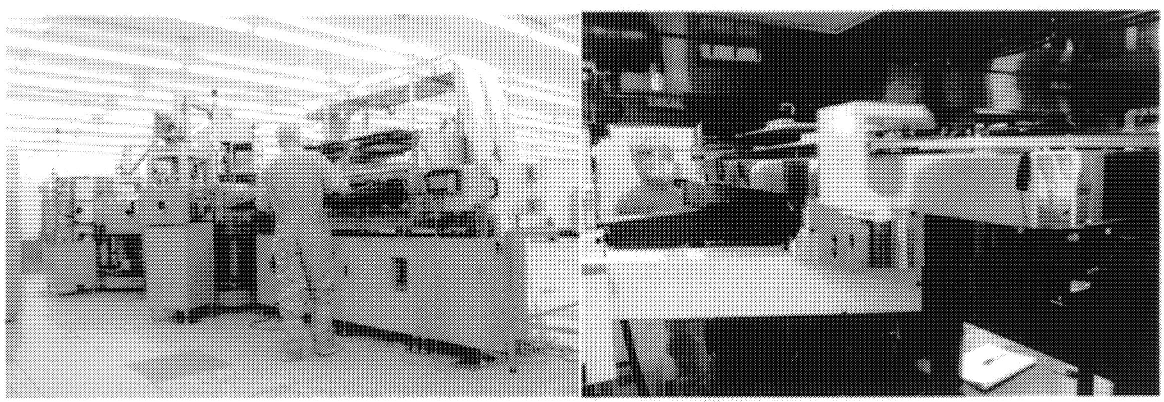

Figure 2. – Godmanchester Facility Equipment:
Left - Tokki Deposition Tool, and Right - Photolithography Tool

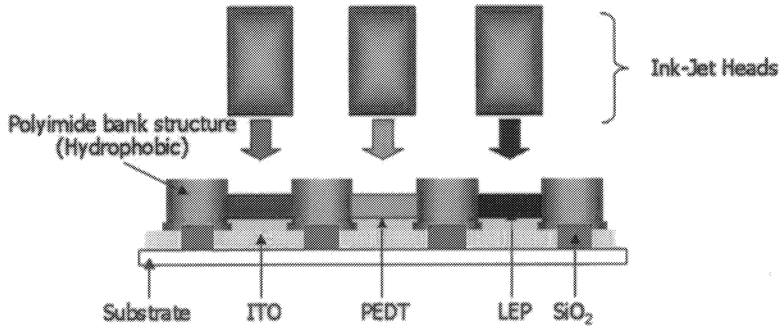

Figure 3. - Cross Section of Ink Jet Print LEP Display

Figure 4. - Toshiba Ink Jet Printed 17 in. Diagonal WXGA Format LEP Display

Figure 5. - Seiko Epson Ink Jet Printed Full Color 2.1 in. Diagonal 130 dpi. LEP Display

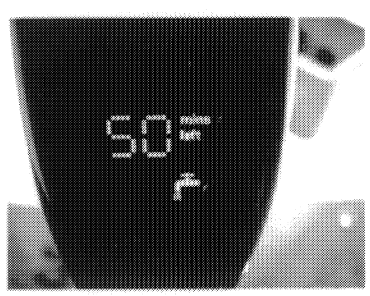

Figure 6. - Philips Norelco Electronic Shaver With LEP Display

Figure 7. - Delta Optoelectronics MP-3 Player With LEP Display

Figure 8. - Dupont Displays Plastic Substrate LEP Display

Figure 9. - TV Wristwatch Concept Product