

## 65.1: Invited Paper: An Overview of Display Interconnect Technology Trends: Technologies & Markets

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### Abstract

*This paper will address general technology and market trends for the assembly of display modules, concentrating on how the maturation of the display industry is affecting technology choices and market segmentation. The year 2007 promises to be one of great change in the world of flat panel displays, with non-LCD technology getting its first real foothold in mobile phone main screen applications, a continuing glut of glass manufacturing capacity, and the migration of display assembly factories into Eastern Europe and Mexico. This, coupled with double-digit percentage declines in the ASPs of almost every color display technology, means that manufacturers are continuing to squeeze out production costs wherever possible. As a result, companies are reviewing the back-end interconnect assembly portion of display manufacturing in a way that they have not done before now. The long-term end result is likely to be a higher level of segmentation in the display industry as it follows a path similar to the semiconductor industry before it. In the shorter term, companies will aggressively review technical requirements, assembly techniques, and material choices in their quest for lower costs.*

### 1. The Industry

2006 saw an explosion of flat panel television sales driven by a – at least from the manufacturers’ perspective – frighteningly rapid drop in prices. 47” LCD televisions with 1080i resolutions are now available for under USD2000, and forecasts show that by the end of 2007 prices will drop an additional 20-30% from their January 2007 prices. This reduction in prices has come from two areas: First and foremost has been an overinvestment in ever-larger motherglass. Simultaneously, however, has been a price reduction derived from a more efficient market segmentation into glass suppliers and display assembly houses. This holds true whether we talk about LCDs for large format applications such as TVs or whether we focus on small handheld applications such as mobile phones, but the effect on larger displays has been much more pronounced.

The ongoing segmentation of the LCD industry is broadly analogous to the specialization that occurred in semiconductor manufacturing years ago. In the early years of semiconductor manufacturing you had the leaders of the industry – IBM, Motorola, Philips, Intel, and Fujitsu among others – drive vertically-integrated operations where core research at internal labs led to proprietary chip designs that were fabbed on company lines and were used in company products. As understanding of the technology improved, these same companies began to sell their chips to third party end users. Soon after, they began outsourcing more and more of the chip manufacturing process. Today there are almost no instances where a chip is designed, fabbed, packaged, tested, and integrated into a final consumer-level product all within the same organization, let alone under the same roof.

The flat panel industry now finds itself following that same course of specialization and rationalization. Judging from the brand names found on displays around the world, we might be tempted to say that “fabless” display manufacturers abound. The reality is that just as we wouldn’t consider a company using an IC in a finished product to be a semiconductor manufacturer, we shouldn’t consider all manufacturers of flat panel TVs to be display companies. They are packagers of the display, not manufacturers.

Packaging specialists are increasing in number even as the major display manufacturers shift large-format display assembly out of Asia and into Eastern Europe or Mexico in order to capture savings from reduced labor or shipping costs. And while we have yet to see pure fabbing operations in the display industry, it is not too far-fetched to look at potential ways the industry could be rationalized and envision such a shift in the relatively near future.

Just as in the semiconductor industry, fabbing glass will remain a highly capital and knowledge-intensive operation, and the number of companies that will be able to succeed at the high end of the technology spectrum will be very limited due to these restrictions. On the back end of display manufacturing however, technological advances in equipment and materials are pushing down the barriers to entry, driving down overall costs. Specialist packaging houses can focus on reducing labor costs and increasing equipment utilization as a means to drive their competitiveness. Just as in the semiconductor industry, the ability to do this is highly dependent on the maturation of the industry and a growing range of options in both equipment and materials for assembly.

### 2. Technology

Five years ago if you were to have gone to one of the world’s top EMS houses and asked them to consider an ACF (Anisotropic Conductive Film) assembly project, the result would have likely been some polite shuffling of paper and a promise to get back to you. ACF was a specialty technology used only by display manufacturers. It was considered to be expensive, difficult to implement, and not part of the standard EMS repertoire. Today, that same inquiry would almost certainly result in a formal inquiry and proposal. Any company with several million dollars to spend and a reasonably good background in electronics assembly can now start up an ACF assembly line.

A good illustration of how stable and reliable ACF technology has become is seen in the construction of LCD TVs. Using several of the Sharp Aquos models in the 42-50” range we see that they have 14 flex components on the source side and 4 flex components on each of the gate sides. The source devices have outputs on a 72um pitch, while the gate devices are at 94um.

The first thing to consider is the sheer number of I/Os on the glass. With an HD 1080 display, that number is well over 5000. More instructive, however, is the fact that although the space around the edge of the display is more than enough to double the pitch, Sharp has chosen not to optimize for a wider pitch, but instead to optimize for a smaller component and the resulting

reduction in materials costs. The calculation is simply one based on manufacturing economics: The increased yield from using a wider pitch is more than offset by the reduced cost of the smaller drivers and their lower material content.

The lower total cost, however, is not simply based on the first-pass yield. Over the past three years, almost all LCD TV applications have switched from epoxy-based ACFs to acrylic-based ACFs. This has resulted in a two-fold improvement in costs for panel assembly houses. First, acrylic materials cure at a much faster rate than the epoxy materials they replace – typically in the range of 8-10 seconds at recommended temperatures. More importantly, these acrylic materials are much more reworkable than epoxy formulations, which has finally led to the widespread practice of reworking failed bonds at an economically viable cost.

Further work is being done on expanding the use of acrylic materials in ACF bonding, with widespread application now on the input side of driver components for flex-on-board assembly, as well as for peripheral devices in mobile phones, such as for camera modules, electroluminescent lamps, sidekey flexes, and other flex-to-flex interconnections. The extent that ACF is being used outside of its traditional role in display assembly can be seen in the fact that the top 5 mobile phone manufacturers as well as the top 5 pure display manufacturers all have “off-glass” ACF assemblies in mass production that replace traditional solder assemblies.

This “off-glass” assembly work is currently driving some of the latest innovations in ACF development, including ultra-low temperature products that will likely find themselves more widely used in displays as flexible displays on polymer substrates gain a wider foothold in the market. Additional developments in particle materials and sizes should also help increase even further the reliability of ACF in advanced rigid displays.

### 3. Conclusion

Display vendors are shipping more and more bare glass to outside assembly houses in a classic example of Adam Smith’s principle of the division of labor. The semiconductor industry provides a very good template for us to see how this will pan out in the future. The capital-intensive front end glass manufacturing and the much more labor-intensive back-end assembly process don’t easily fit within the same organization. Now that costs have dropped and technology has created a stable infrastructure on which to develop an assembly-oriented business model, we can expect the trend to do nothing other than accelerate over the next several years. As mentioned above, we are even seeing the larger general-purpose EMS houses moving into this segment as they attempt to capture business further and further upstream in the manufacturing operation. As they apply their size and expertise to display assembly, it is reasonable to assume that they will drive costs down even below their current level.

Finally, it remains to be seen whether the display industry will follow the last few steps outlined by the semiconductor industry before us and develop true fabless design houses and pure fab manufacturing operations. Fabless design houses built around proprietary technology can already be seen in how E-Ink and Citala have set up their businesses, but it will likely take a massive restructuring of current active matrix display manufacturing industry before a pure fab house can emerge from the wreckage with a capital cost able to support the concept in LCDs..