From Novelty to Ubiquity: Challenges & Strategies of Scaling the LCD Platform

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What is an active matrix LCD? What product did Corning sell?
TFT-LCD Panel Manufacturing

Source: Display Search; Applied Materials
Mid-1980’s – First commercial active matrix LCD devices

- Corning supplies substrates for company’s first commercial active matrix LCD product
- 3-inch TV made by Matsushita (known commercially as Panasonic) debuts in 1986
LCDs are ubiquitous today based upon the versatility of the platform
LCD platform success, far from assured in the late 80’s, is evidenced by 2013 substrate consumption of over 4 B ft²
Cumulatively...about 24 billion square feet of high-spec glass have been consumed by the LCD industry since 1987

This is enough glass to create a continuous ring of 100” LCD TVs circling the earth and the moon
The LCD glass demand developed through three successive waves of application growth:

- **viability**
  - notebook computer

- **practicality**
  - desktop monitor

- **ubiquity via versatility**
  - TV + everything else

The chart shows the increase in demand from 1997 to 2012, with milestones for TV, Monitor, Mobile PC, and Small devices.
Glass is just one component in the LCD value chain

*Our recipe for 20 years of sustained value*

**Advanced optical melting + fusion sheet forming process**

**Innovative aluminosilicate glass compositions**

- Molten glass
- Fusion Isopipe
- Sheet of glass
- Clean
- Stable
- Flat
LCD commercialization (approx. ‘89–’94) proved viability of the LCD platform via the notebook application.

LCD’s key attributes relevant to NBs: Thin, light, color & high resolution capable, low voltage operation (runs on batteries).
Understanding the core of glass value: What enabled scale was **surface**

Ground/Polished

[Image of ground/polished glass surface]

c. 1997 competitor polished glass

As Formed

[Image of as-formed glass surface]

Corning code 7059 non-polish glass
Early learning was that the finest sub-micron scratch can result in yield loss.
From 1995 – 2002 the LCD proved practicality by displacing CRTs in the computer monitor application.

LCD’s key attributes relevant to CRT displacement in monitors:
- Flat & scalable to larger sizes,
- green, non-fatiguing viewing (crisp digital screen)
LCD Ubiquity: 2003 - Present

LCD’s key to winning the display space is based upon the versatility of LCD & its technology extensions. The “legacy” performance issues are neutralized at the same time the platform is scaled.
Scaling the LCD substrate area: 100X

Substrate Generations

- Gen 10
- Gen 8
- Gen 7.5
- Gen 7
- Gen 6
- Gen 5
- Gen 4
- Gen 3
- Gen 2
- Gen 1

Year
- 2009
- 2006
- 2005
- 2004
- 2003
- 2002
- 2000
- 1995
- 1993

Typical size used in LCD pilot line in mid-80’s

3.1 meters

2.9 meters

LCD TV

Information Technology
Exponential Growth Industries
Where Technology enables Demand

① IC

- cost per transistor
  - 1980: 3μm, ~$330/Mb, ~3X10^{12} bits
  - 1994: 0.35μm, ~$3/Mb, ~7X10^{15} bits
  - Source: SIA, In-Stat, IC Insights

② LCD

- cost per area
  - 1999: 0.62 x 0.75m, $10,000/m^2, 1 million m^2
  - 2008: ~3 x 3m, $1,190/m^2, 84 million m^2
  - Source: Display Search, Nikkei BP, Applied Materials

③ SOLAR

- cost per watt
  - 2008: ~$4/Wp module, c-Si
  - ?: c-Si/TF/Other
  - 2008: $1-2/Wp module
  - ?: >50GW
  - Source: Applied Materials

Above data for DRAM

Source: Applied Materials
AKT PECVD System Family for Flat Panel Display Manufacturing

AKT-1600B CVD
< 400 x 500 mm

AKT-3500 CVD, AKT-4300 CVD
< 620 x 750 mm

1000x1000mm² Class
“Gen 5”
AKT-90K PECVD (Gen 10) System Overview

- Transfer Chamber w/ Dual-arm Vacuum Robot
- AKT-APX™ Process Chamber (x5)
- Triple Slot Load Lock

Foot print: ~14m x 14m  |  Weight: 273 metric tons
Equipment Cost Per Glass Area ($/m²)

Dramatic Improvement with Larger Substrates

Note: Equipment costs include equipment depreciation and gas costs
Glass Size Migration – Driving Cost Reduction

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Gen 2</th>
<th>Gen 5</th>
<th>Gen 8.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Application</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of panels</td>
<td>400 x 500mm</td>
<td>1.1 x 1.3m</td>
<td>2.2 x 2.5m</td>
</tr>
<tr>
<td>Notebook PC</td>
<td></td>
<td>PC Monitor</td>
<td>LCD TV</td>
</tr>
<tr>
<td>10.4&quot; x 4</td>
<td>22&quot; x 8</td>
<td>46&quot; x 8</td>
<td></td>
</tr>
</tbody>
</table>

**Generation Scaling and Cost Reduction Key to Growth**

Cost per Area ($\text{Thousand/m}^2$)

- Gen 2
- Gen 3
- Gen 4
- Gen 5
- Gen 6
- Gen 7
- Gen 8
- Gen 8.5
- Gen 10

**Generation Breakdown**
- Gen 2: 1993
- Gen 3: 1995
- Gen 4: 1997
- Gen 5: 2001
- Gen 6: 2003
- Gen 7: 2005
- Gen 8: 2007
- Gen 8.5: 2009
- Gen 10: 2011

**Substrate Area (M$^2$) vs. Cost per Area**

- Scale + Technology
- Cost Reduction
- Demand
The terminal Gen Platform: Sharp’s Gen 10 “Green Front Sakai” brought LCD to 3 meter scale
The terminal Gen Platform: Sharp’s Gen 10 “Green Front Sakai”

- Facility is the first of its kind in the display industry
  - Corning is one of 19 companies on site: mutual benefits in logistics, inventory and quality
- Complex is 314 acres, the equivalent of 240 football fields
- Environmentally advanced production
- Panel production capacity:
  - At full capacity, capable of over 1 million 40” LCD panels/month
Gen 10 efficiently produces wide range of panel sizes

### Comparison of Panelization: Gen 10 vs. Gen 8

<table>
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<tr>
<th>Panel Size</th>
<th>Gen 10</th>
<th>Gen 8</th>
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<tbody>
<tr>
<td>70-inch class</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>60-inch class</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>40-inch class</td>
<td>18</td>
<td>8</td>
</tr>
</tbody>
</table>
Corning moves Gen 10 glass directly into Sharp’s process

- Sharp’s inter-building transport system moves Gen 10 substrates directly to production floor, eliminating traditional delivery systems. Previously, transportation infrastructure has limited glass substrate size
Is there a Moore’s Law for Display? Kind of…

Large mother glass used for multiplicity of display panels + Higher resolution in small & intermediate mobile devices
Resolution trend: Moore’s Law for LCD manufacture

Gen 8 LCD - TV fabs used for mobile devices... Almost 1 Billion Pixels per Mother Glass!
This brings us up to the present…

LCD platform is continuing to grow…abundant opportunities for extending display functionality & performance…so the scaling of the LCD platform is a great success story, right?

WRONG! (for the participants…great for the consumer)

• LCD platform looks like a 25 year suicide pack for display manufacturers characterized by hyper-competition, over investment, periodic non-profitability but requiring sustained investment for product differentiation with poor return.

• The glass manufacturer remains the last material component supplier standing in terms of sustained value capture…but the pressure is ratcheted up continually.
One of the negative aspects of the economics of scaling LCD has been nationalism.
Flexible glass is an enabling technology that supports key trends in display devices & future breakthroughs.
Thin and flexible glass substrates for ultra-slim displays with promise for ultra-low-cost manufacture

- Corning® Willow® Glass is thin enough to be flexible while retaining its superior glass attributes

- Combines inherent benefits of glass with a mechanically bendable form factor, enabling continuous and cost-efficient processing

- Enables thinner, lighter, and potentially conformable electronic devices that deliver high performance at a lower cost

- Eventually, displays will be printed on a flexible web…but years of development are required to make this practical.
Flexible glass applications roadmap – optimistically viewed in 2011 – delayed largely by lack of ecosystem.

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<th>Initial commercial products</th>
<th>Next-generation technologies</th>
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<tr>
<td>HP Oxide TFTs</td>
<td>OLED or LCD Color Filter</td>
<td>Flexible display</td>
</tr>
<tr>
<td>WMU / CAMM Organic PV</td>
<td>ProCap Touch Sensor</td>
<td>E-Paper</td>
</tr>
<tr>
<td>ITRI-DTC</td>
<td>Flexible CIGS PV panels</td>
<td>Organic PV</td>
</tr>
<tr>
<td>Ch-LC display</td>
<td></td>
<td>Roll-to-roll displays</td>
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<tr>
<td>University of</td>
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<td>Stuttgart TFT-LCD</td>
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- **2010**: Lab-scale device demos
- **2011**: Initial commercial products
- **2012**: Next-generation technologies
My conclusions

• The scaling of LCD technology was effected through waves of application growth.
• Two of the key technologies that enabled this scaling were engineered glass substrates and PECVD/PVD platforms.
• Despite a successful technological scaling & innovation that neutralized LCD’s legacy performance issues, it has been a poor economic venture for panel makers and some brands.
  – Nationalism and tardy rationalization of manufacturing capacity has led to periodic over-supply and a pathological market dynamics.
  – Good for consumer…bad for many in the LCD value chain.
• The emergence of R2R manufacture, initially for display & lighting components, may be attractive for new applications such as micro PV.