The Past, Present & Future of LCDs: The Black Swan Matures & Prospers

Frederic J. Kahn, president

Kahn International ™
Palo Alto, CA
fjkahn@post.harvard.edu

Keynote
SID Bay Area - One Day Technology Conference
Sunnyvale, CA
March 24, 2016
World of 1967: Color TV gaining market share
Today’s LCD success
was a black swan* in 1967

* a high impact event that is extremely difficult to predict

http://lucaatalla.files.wordpress.com/2009
First Commercial LCDs – 1971

Current driven
Scattering mode
0.75” high
7-segment numeric

Product of
RCA Solid State Division

Courtesy of Dr. Sun Lu, Landmark Technologies
Vertically aligned nematic (VAN) LCD

Edge view

Conoscopic view (converging light)

F. J. Kahn, Appl. Phys. Lett. 20, 199-201 (1972)
VAN LCD photos - 1971*

Coupling agents align liquid crystals

Align LCs normal to surface

\[
\text{N,N-dimethyl-N-octadecyl-3-aminopropyltrimethoxysilyl chloride (DMOAP)}
\]
\[
\begin{align*}
\text{C}_{18}\text{H}_{37} & \quad \text{Cl}^- \\
\text{N} & \quad (\text{CH}_2)_3 \text{Si(OCH}_3)_3 \\
\text{CH}_3 & \quad \text{CH}_3
\end{align*}
\]

Align LCs parallel to surface

\[
\text{N-methyl-3-aminopropyltrimethoxysilane (MAP)}
\]
\[
\begin{align*}
\text{H}_3\text{C} & \quad \text{N} \quad (\text{CH}_2)_3 \text{Si(OCH}_3)_3 \\
\text{H} & \quad \text{H}
\end{align*}
\]

Laser (thermal) Smectic LC Light Valve Projector
12.25 Mpixel (1973)
The dark gray LCD swan
Demonstrated to William Hewlett and David Packard, May 1974
Precision alignment control for calculator LCDs

![Graph showing sequential oblique incidence evaporation](image)
The first HP calculators used LEDs
The first HP LCD calculator (1979)

“The alpha-numeric LCD screen of the HP-41C revolutionized the way a calculator could be used.” (Wikipedia)
“the oldest consumer electronic device still in production” and "still HP’s best selling calculator" (Hewlett-Packard, Jan. 2004)

Still selling today, 35 yrs after introduction, 42 years after tech demo to Hewlett & Packard. Amazon $63.85, March 2016)
On the future of LCDs (1985)

Advances “will occur sooner, with higher performance, and at lower cost, than most of us expect today.” (F.J. Kahn)

THE FUTURE OF LIQUID CRYSTAL DEVICES

- LARGER AREA
- HIGHER RESOLUTION
- FULL COLOR
- HIGHER SPEED
- MORE DIVERSIFIED APPLICATIONS SUCH AS DISPLAY, PRINTING, OPTICAL PROCESSING, OPTICAL STORAGE, AND OPTICAL COMMUNICATIONS

... WILL OCCUR SOONER, WITH HIGHER PERFORMANCE, AND AT LOWER COST, THAN MOST OF US EXPECT TODAY
Greyhawk Softplot (1986)
40”D, 7.5 Mpixels

Display of the Year, *Electronic Products Magazine*, 1986
Greyhawk Large Area Display (1988)
144 inch D, 37.5 Mpixels
Close-up view of “print-quality” image detail
Ilford/Greyhawk Digital Photolmager for short-run color printing

Prints up to 200 full-color 35 mm slides, overhead transparencies or 8.5x11” prints per hour.

35 mm slide example
DuPont/Greyhawk SeriFLASH printed circuit board exposure system
Two Earthquakes: October 1989

Loma Prieta quake shakes California.  

TFT LCDs from Sharp shake and transform display world.
TFT LCDs - The Great Market Enabler

Historical Review of our LCDs

- AQUOS (2001)
- Kameyama Plant 1 (2004)
- Kameyama Plant 2 (2005)
- 2008
- 2009 Sakai Plant

- UV²A
- LED-AQUOS

1989
- DSM-LCD
- TN-LCD (dot matrix)
- STN-LCD
- TFT-LCD

1999
- LCD-TV [AQUOS]
- Kameyama Plant 1
- 2000 VA-LCD
- 2004
- 2005
- 108-in
- 2007
- X51: 2.3cm²

1998
- PDA "Color Zaurus"
- LCD Desk-top PC
- Note-book PC
- Pocket Game
- DSC
- 1996
- 1995

1992
- Car navigation
- LCD-TV "Window"

1993
- PDA "Zaurus"

1998
- Mobile
- Game Boy

1989
- Rear PJ
- Cellular Phone
- Wrist Watch
- Word Processor
- Viewcam

1987
- STN-LCD
- TFT-LCD

1980
- Electric Translator [103000]

1979
- TN-LCD (dot matrix)

1973
- DSM-LCD
- DL-805 Calculator

SID International Symposium, 26th May, 2010
White LCD swan continues to ascend
HDTV comparison
(at constant pixel density)

Potential future HDTVs with Greyhawk “print-quality” definition (>37 Mpixels, wall-size, 8K class)

NHK Japan:
4K broadcasting, June 2014
8K test broadcasting, 2016
widespread, 2020 Tokyo Olympics

Today’s HDTVs (2 Mpixels)

2K: 1920x1080

~8K: 7680x4320
33 Mpixels
BOE (China) UHD 10K 82in LCD
Best of show – Display Week 2015

The World’s First and Largest 10K UHD Display
with the Highest Resolution — 82” 10K
AMLCD vs. AMOLED Structures

- Fundamentally Simpler Structure than TFT-LCDs
  - AMOLEDs should have **Lower Cost**

- Better display performance compared to TFT-LCDs
  - But they have not taken over ..., (at least, not yet!)

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S. Kim, Samsung, SID 2010
Samsung’s AMOLED-TV Vision

Targets mainstream technology for “Premium TVs” in Gen 8 production facility by 2015

S. Kim, Samsung, SID 2010
World wide TV market View 2010 (units)

S. Kim, Samsung, SID 2010
## Large Area TFT LCD/OLED Shipment Shares by panel makers, unit base

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Year</th>
<th>2014</th>
<th>2015</th>
<th>2016</th>
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<tbody>
<tr>
<td>AUO</td>
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Source: IHS

Sri Peruvemba, Marketer International
Quantum Dot LCD TVs: OLED performance, LCD prices

LCD TV with Quantum Dots

IDTechEx Research

Million Units


Sri Peruvemba,, Marketer International
2016 OLED Status: TVs struggle; Small area OLEDs succeed

LGD OLED TVs introduced but continue to struggle due to high price, low yields, low production volume. LGD operates Gen 8 OLED production facility. Others adding this capability. Panasonic’s impressive & pricey OLED TV uses LGD panels.

Major success: small area OLEDs for SmartPhones (Samsung) and watches (Apple).

Apple 2017 next gen iPhone: Samsung to supply flexible OLEDs says ETNews. LGD, Sharp/Foxconn, Japan Display, others are potential second sources.
4K LCDs dominate beyond 2020!
Total LCD Market Dominance Continues

• WW display market
  – 2015: $116B (Marketsandmarkets)
    • Mostly LCD TV panels (Research MOZ, Kahn Intl)
  – 4K displays, Major growth 2015 to 2020 (IHS)
    • Mostly 4K LCD TV panels (~$32B 2020) (IHS)

• WW OLED market (< LCDs through 2022)
  – 2015: $13B (LG/IHS)
  – 2022: $29.1B (LG/IHS)
Potential future improvements to extend LCD dominance

Evolutionary

Higher production throughput
Lower cost backlight structures and LEDs
Lower cost materials, e.g., thinner glass, polarizers
Higher image quality, e.g., QD LCDs
Higher information content
Larger area, lower weight per unit area

Revolutionary

New faster LC effects
Elimination of color filters: >3X brighter
Flexible and/or rollable substrates
Smart and interactive panels
Full wall displays
The LCD Black Swan is now a soaring, ascending White Swan. LCDs are the world’s most successful display industry. Continuous improvement & high R&D expenditures continue to protect LCD dominance.

OLEDs are the most likely potential competitor. OLED TVs sales now limited by price, production and yield. Major OLED markets: small area for SmartPhones, watches, autos. Potential mainstream competition with LCDs in 2021 - 2025.

I have enjoyed surfing the liquid crystal wave for 49 years. I thank the 1000s of people who have helped me stay afloat and you for your attention this morning.