PLANAR™

When image experience matters.

A History of Flat Panel Displays

Christopher N. King
Founder (Retired)
Planar Systems, Inc.
May 2009

Laying the Scientific Foundations 1960 - 1980

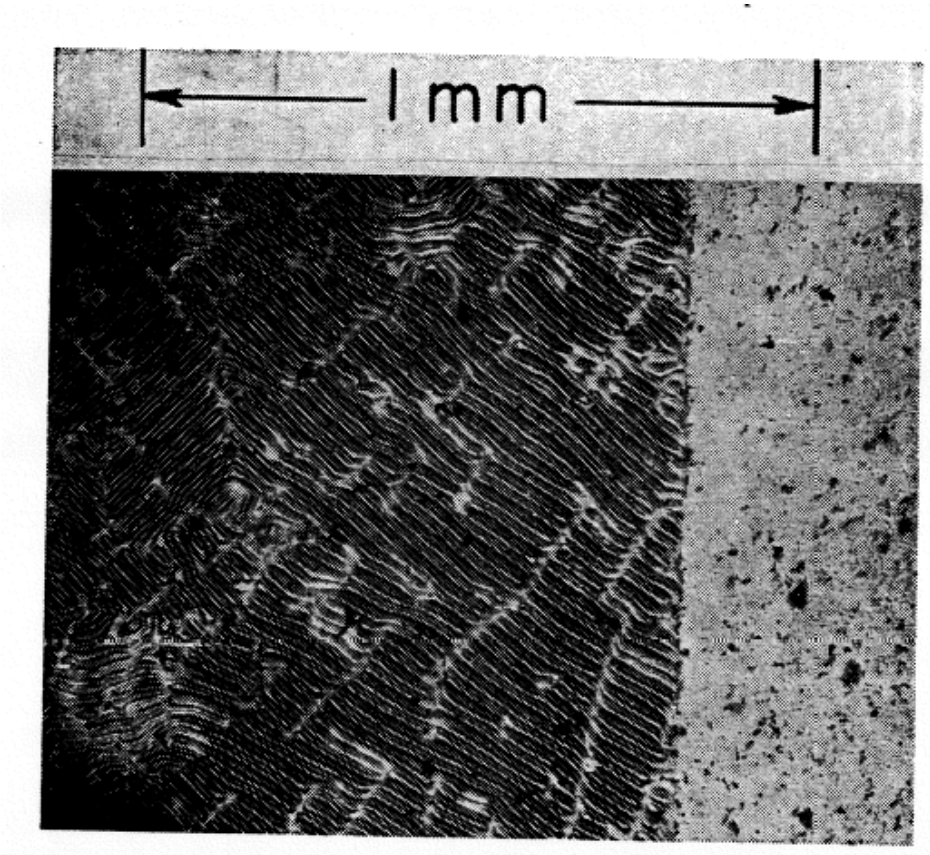
- Liquid Crystal Displays
- Plasma Displays
- Thin Film Electroluminescent Displays

PLANAR

The Birth of LCDs at the RCA Sarnoff Laboratories

- 1962 R. Williams discovers the phenomenon of “Williams Domains” in nematic liquid crystals.
- 1968 G. Heilmeir and his group develop first liquid crystal displays based on dynamic scattering effects

Williams Domains



Domains in liquid crystals with an applied voltage of 2,500 V/cm observed by Richard Williams in 1962.

PLANAR

R. Williams U.S. Patent 3,332,485(1967) applied for November 9, 1962

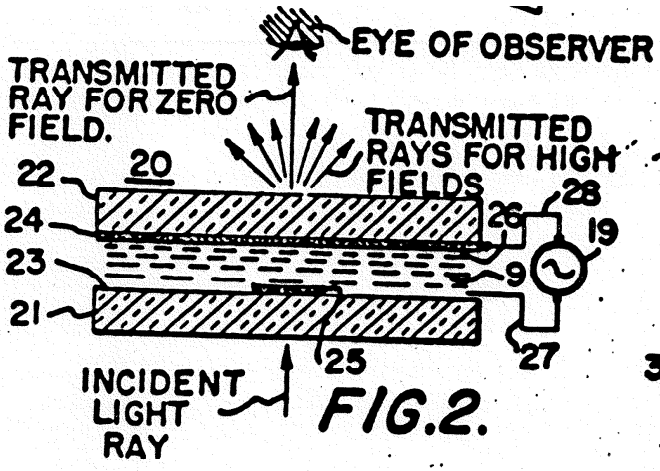


FIG.2.

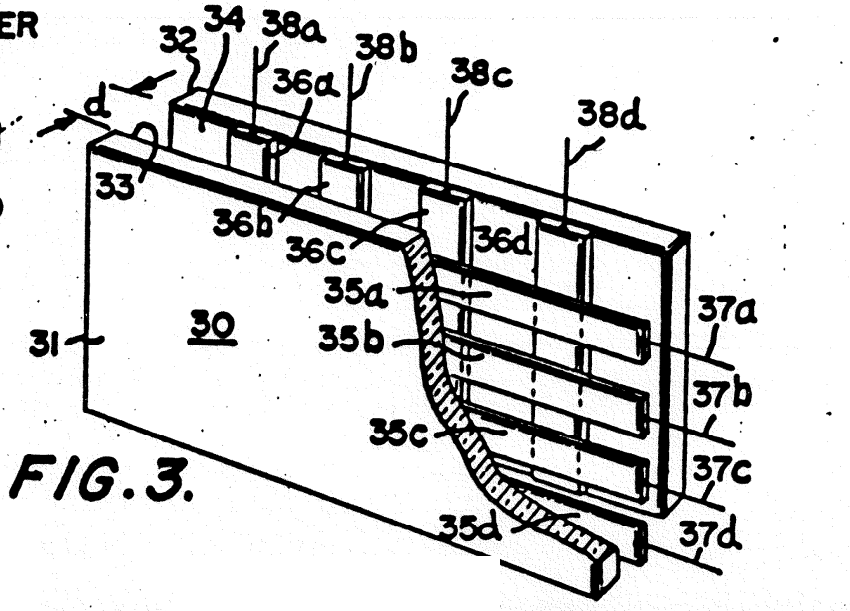


FIG.3.

PLANAR

RCA demonstrating Dynamic Scattering LCD Clock (1968)

PLANAR

First Digital LCD Watch Optel (1970)

PLANAR

First LCD Calculator Rockwell (1972)

PLANAR

VOLTAGE-DEPENDENT OPTICAL ACTIVITY OF A TWISTED NEMATIC LIQUID CRYSTAL

M. Schadt and W. Helfrich
Physics Department, F. Hoffmann-La Roche & Co. AG., Basel, Switzerland
(Received 8 December 1970)

A new electro-optical effect in twisted nematic liquid crystals is described which allows variations of the rotation of linearly polarized light continuously from 0° to 90°. It requires lower voltage than other electro-optic effects.

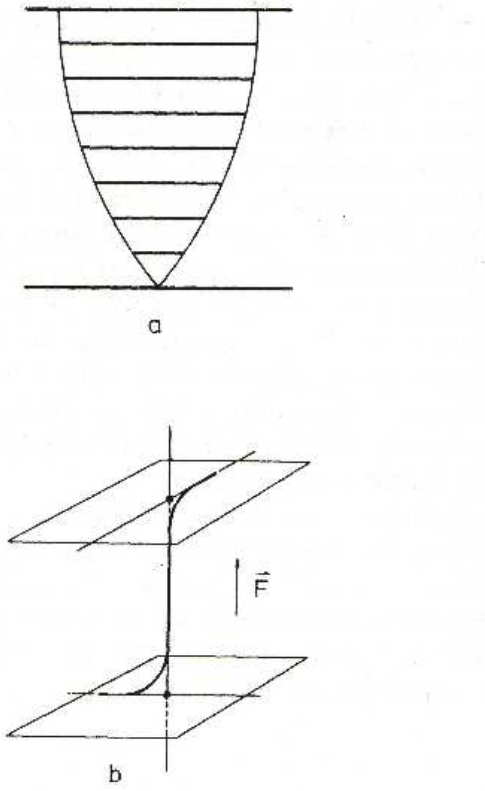
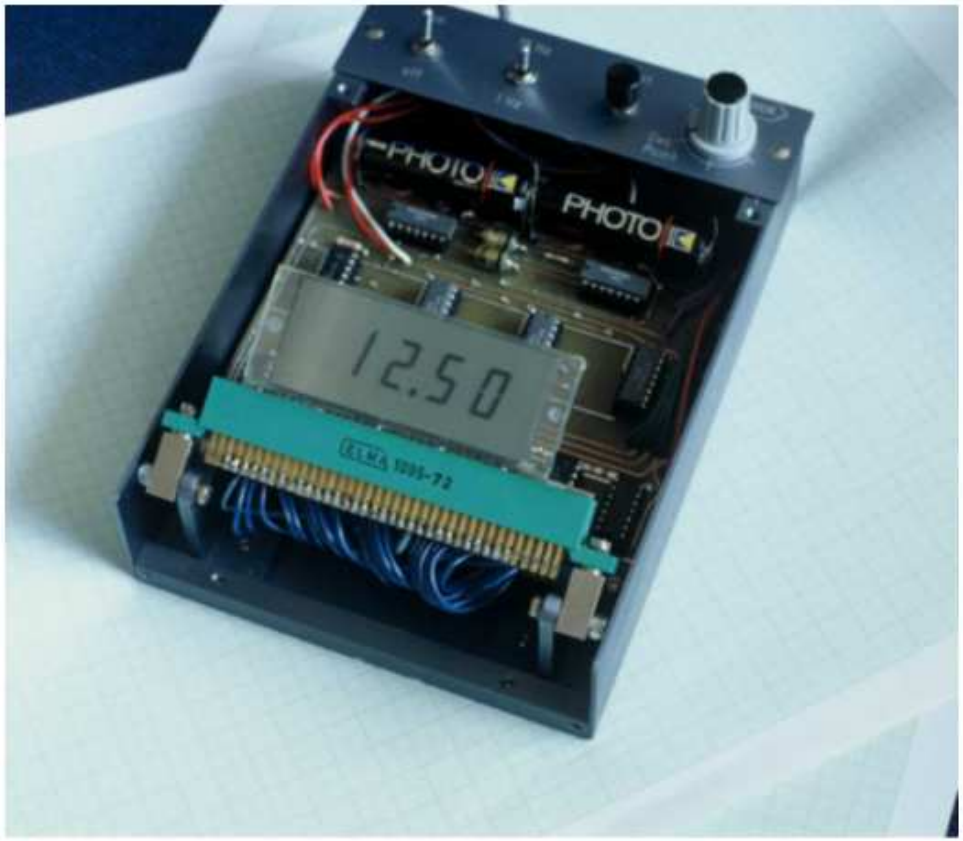


FIG. 1. (a) 90° twist in a nematic liquid crystal; (b) splay and bend instead of twist in a strong electric field $\vec{F}$.

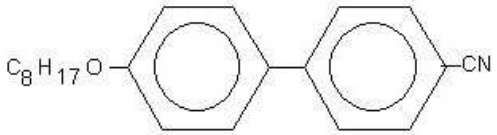
Twisted Nematic Liquid Crystal Display (TN-LCD)

Schadt and Helfrich; J. Appl. Phys. Lett. **18**, 127, (1971); Swiss Patent Nr. 532261, 4th Dec. (1970)

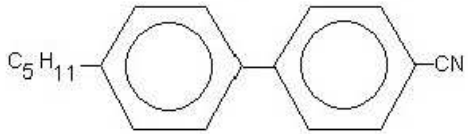


PLANAR

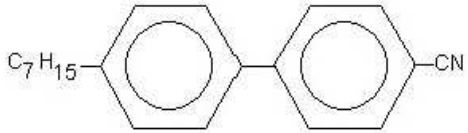
Cyanobiphenyls (1972)
G. Gray, J. Nash and K. Harrison



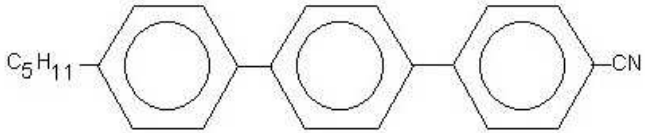
A - Nematic Range: 54 - 80 degrees C



B - Nematic Range: 22 - 35 degrees C



C - Nematic Range: 28 - 42 degrees C



D - Nematic Range: 130 - 239 degrees C

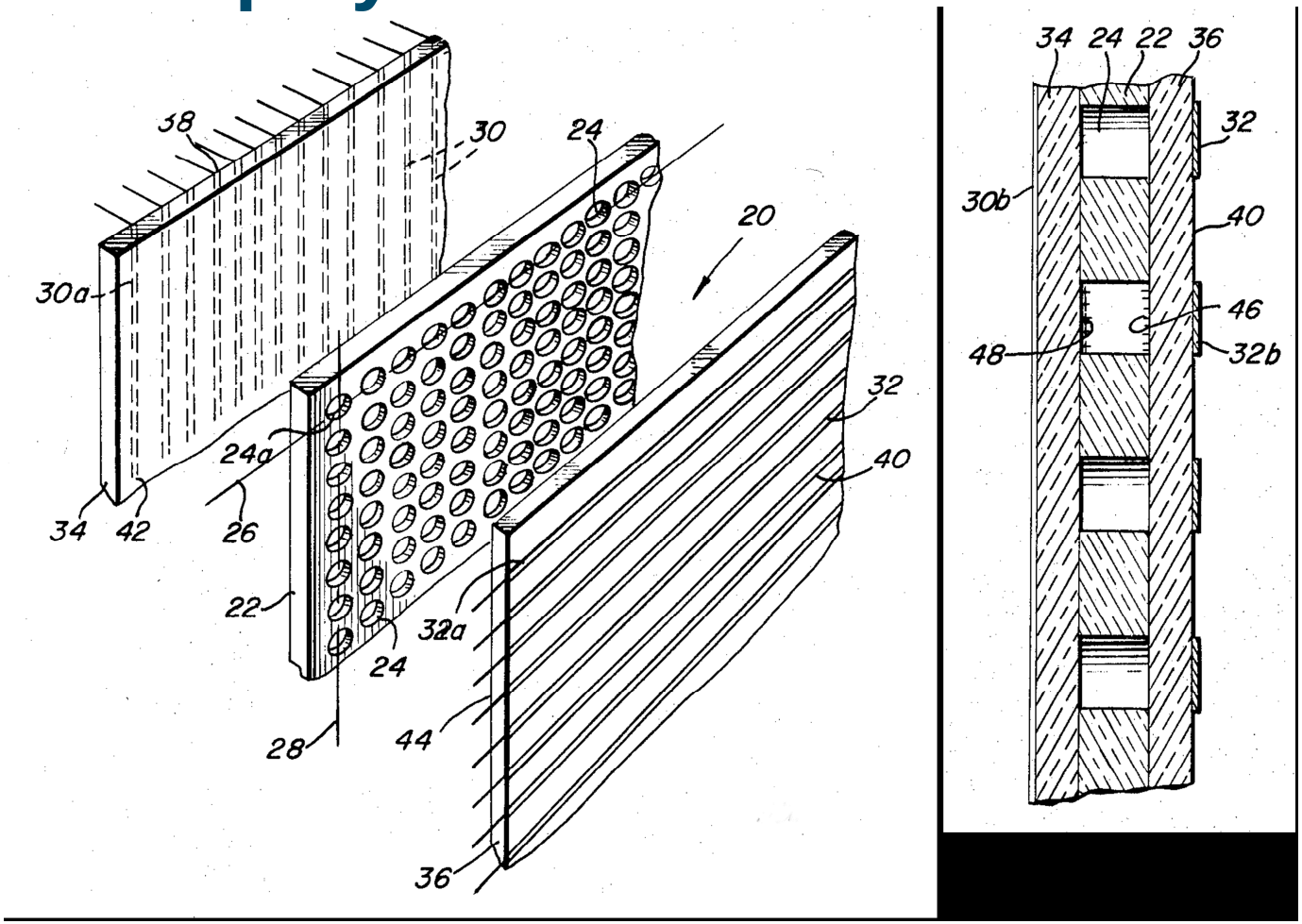
PLANAR

Invention of ac Plasma Display at the University of Illinois

- 1964 D. Bitzer, G. Slottow, & D. Wilson
- 1968 Owens-Illinois develops open cell structure
- 1971 12” diag. 512 x 512 Graphic Display product

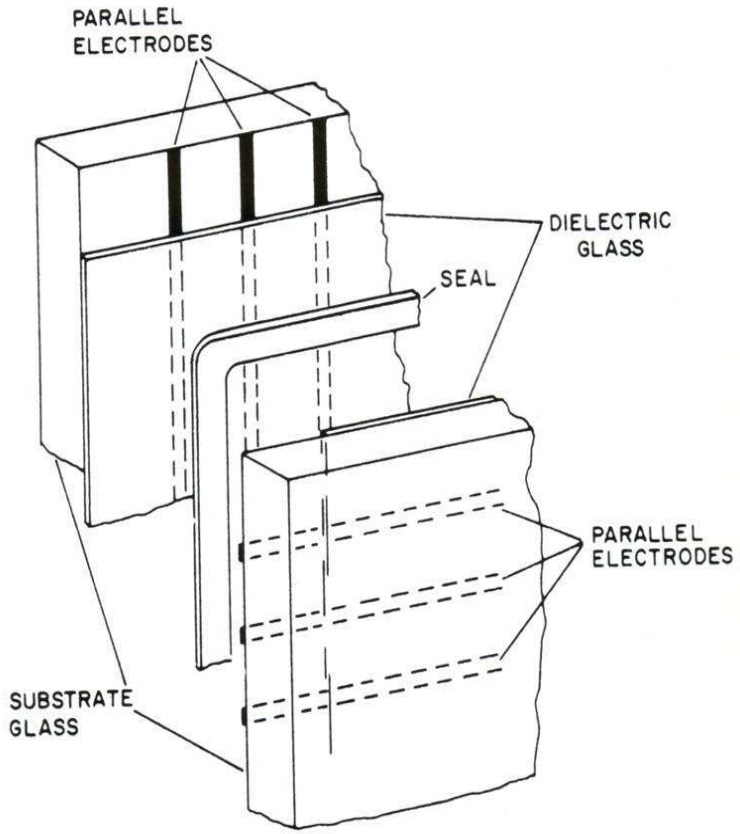
PLANAR

Original University of Illinois Plasma Display Patent



PLANAR

Open Cell Structure Developed by Owens Illinois(1968)



PLANAR

First ac Plasma Product
Owens Illinois (1971)

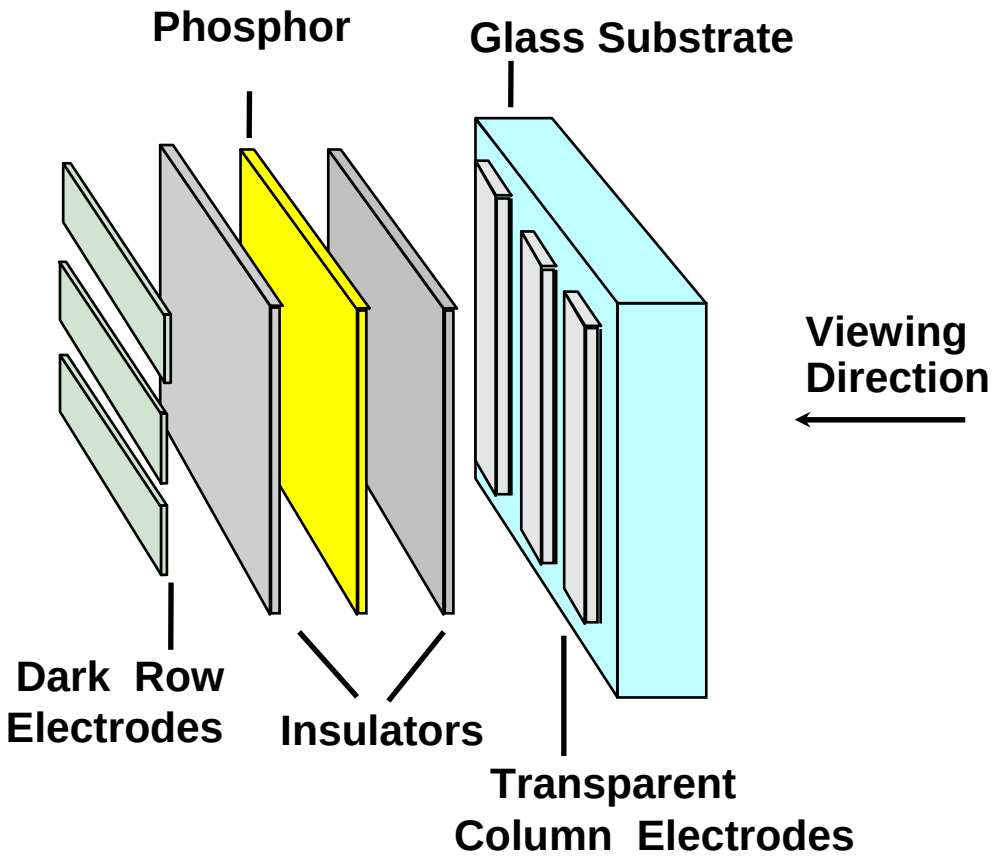
PLANAR

Thin Film EL Breakthrough by Sharp Laboratories

- 1974 T. Inoguchi and his group report a stable and high brightness TFEL Display
- 1975 Sharp demonstrates a 320x240 QVGA display
- 1983 Sharp introduces first commercial TFEL display product

PLANAR

Thin Film Electroluminescent (TFEL) Display Technology



- **Advantages**
  - High contrast
  - Wide operating temperature range
  - Emissive - excellent viewing angle
  - Fast response time
- **Disadvantages**
  - High voltage drivers

PLANAR

1980s :
The Quest for High Information Content

- The birth of the personal computer created a desire for a portable computer with a flat panel screen
- This market opportunity led to fierce competition between emissive and non-emissive display technologies

PLANAR

TFEL Prototype built at Tektronix

PLANAR

CALCULATED POWER CONSUMPTION FOR A TFEL 10.4” VGA WITH NO POWER REDUCTION CIRCUITRY

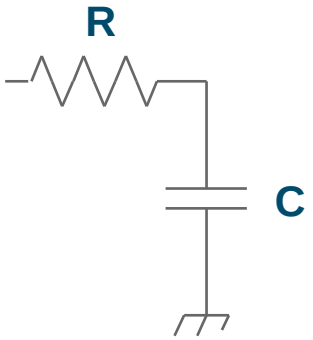
Power Component Watts	Typical Power m = 0.1 M	Maximum Power m = 0.5M
P Light	0.125	0.625
P Row Charge	2.59	2.59
P Column Charge	4.93	12.32
P Total	7.645	15.54

PLANAR

CAPACITOR CHARGING POWER CONSUMPTION

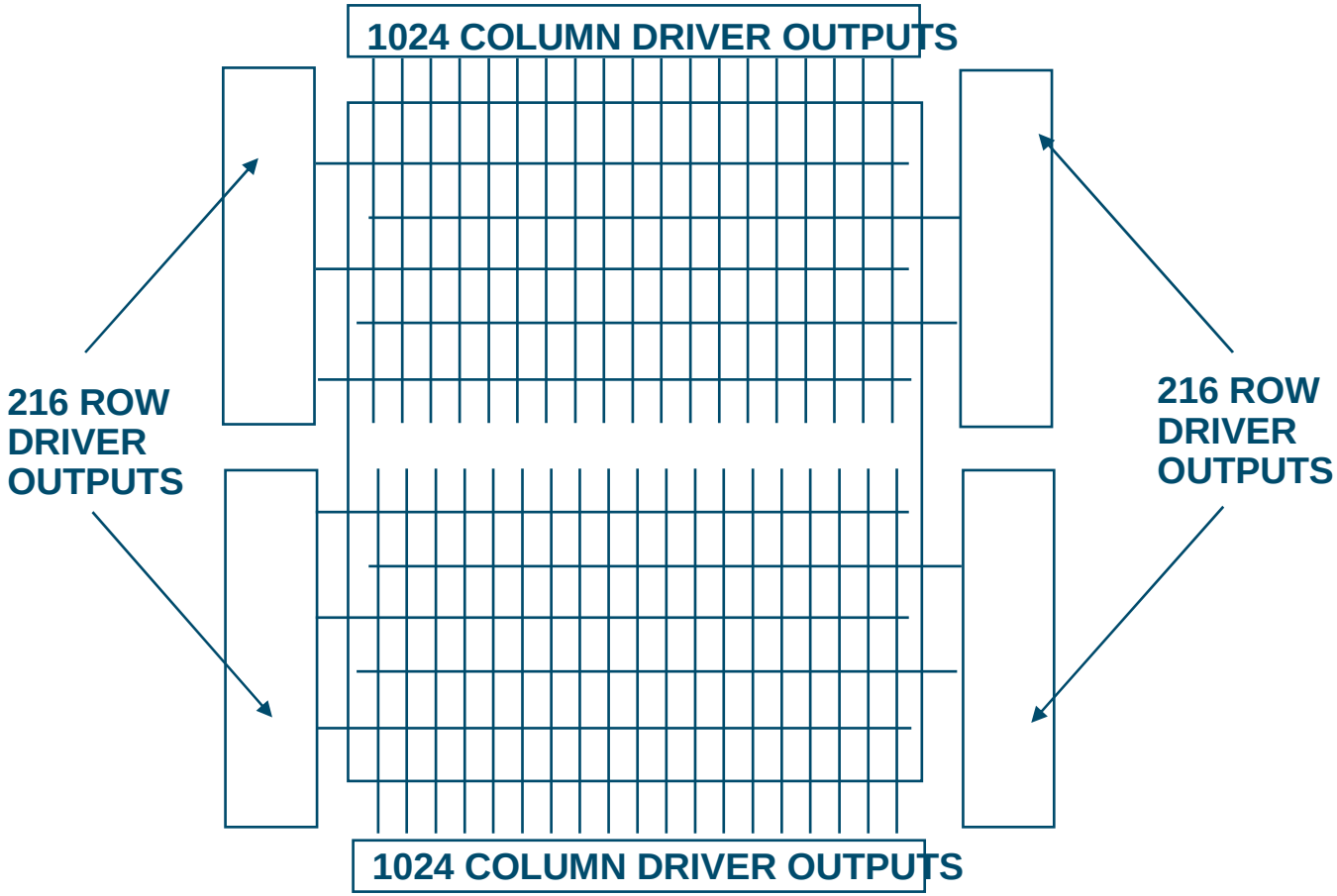
$$W_C = W_R = \tfrac{1}{2} CV^2$$

$$P = f * C * V^2$$



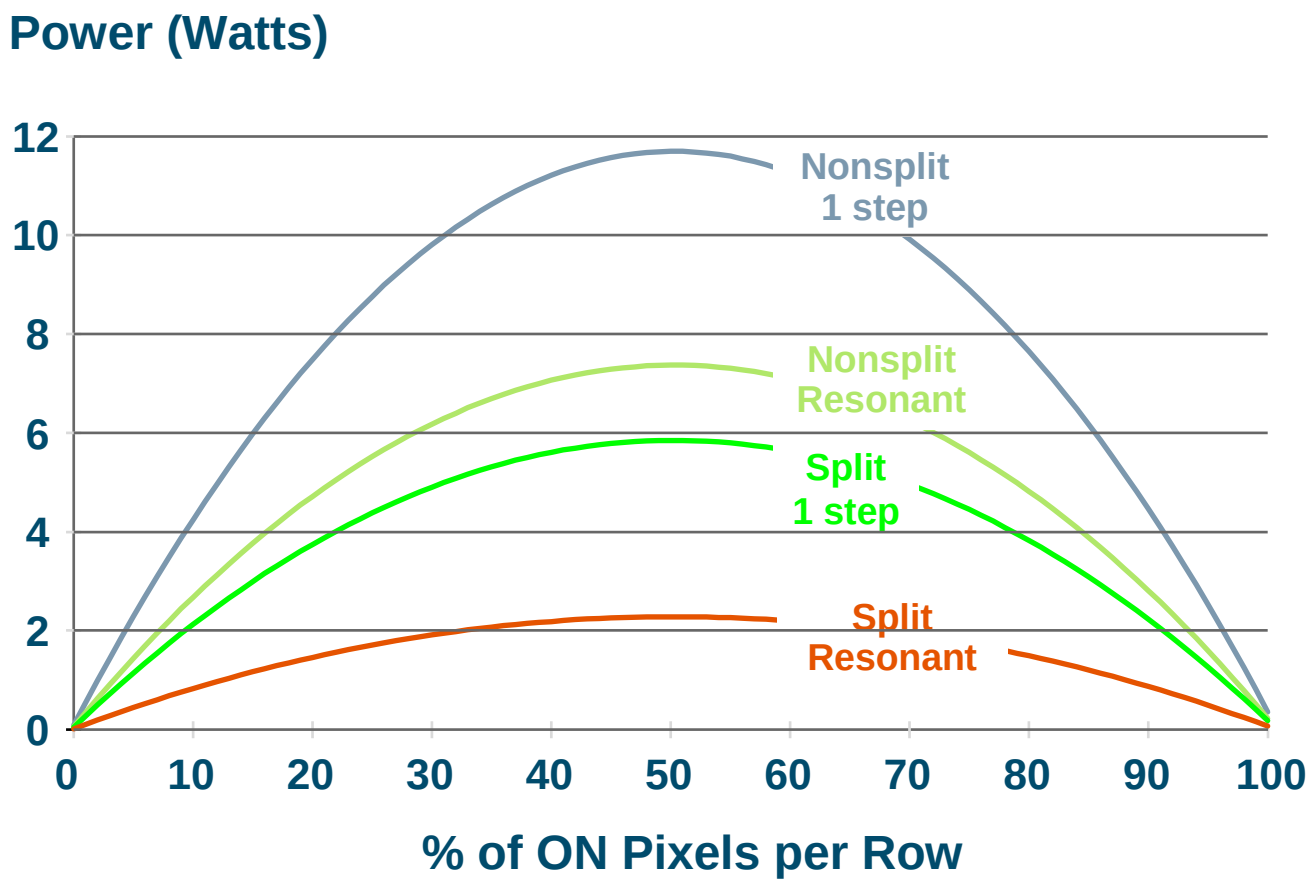
PLANAR

SPLIT COLUMN ELECTRODE STRUCTURE



PLANAR

POWER REQUIRED TO DRIVE THE COLUMNS
10" Diagonal, VGA TFEL Panel



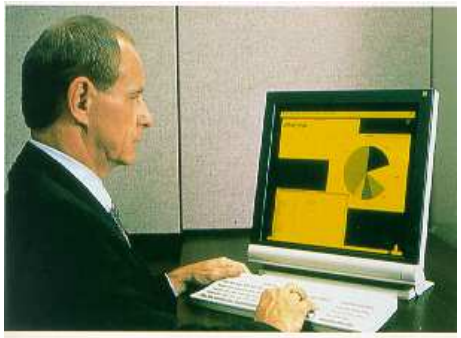
PLANAR

TFEL Computer Displays in the 1980's

Grid
1983

HP
1985

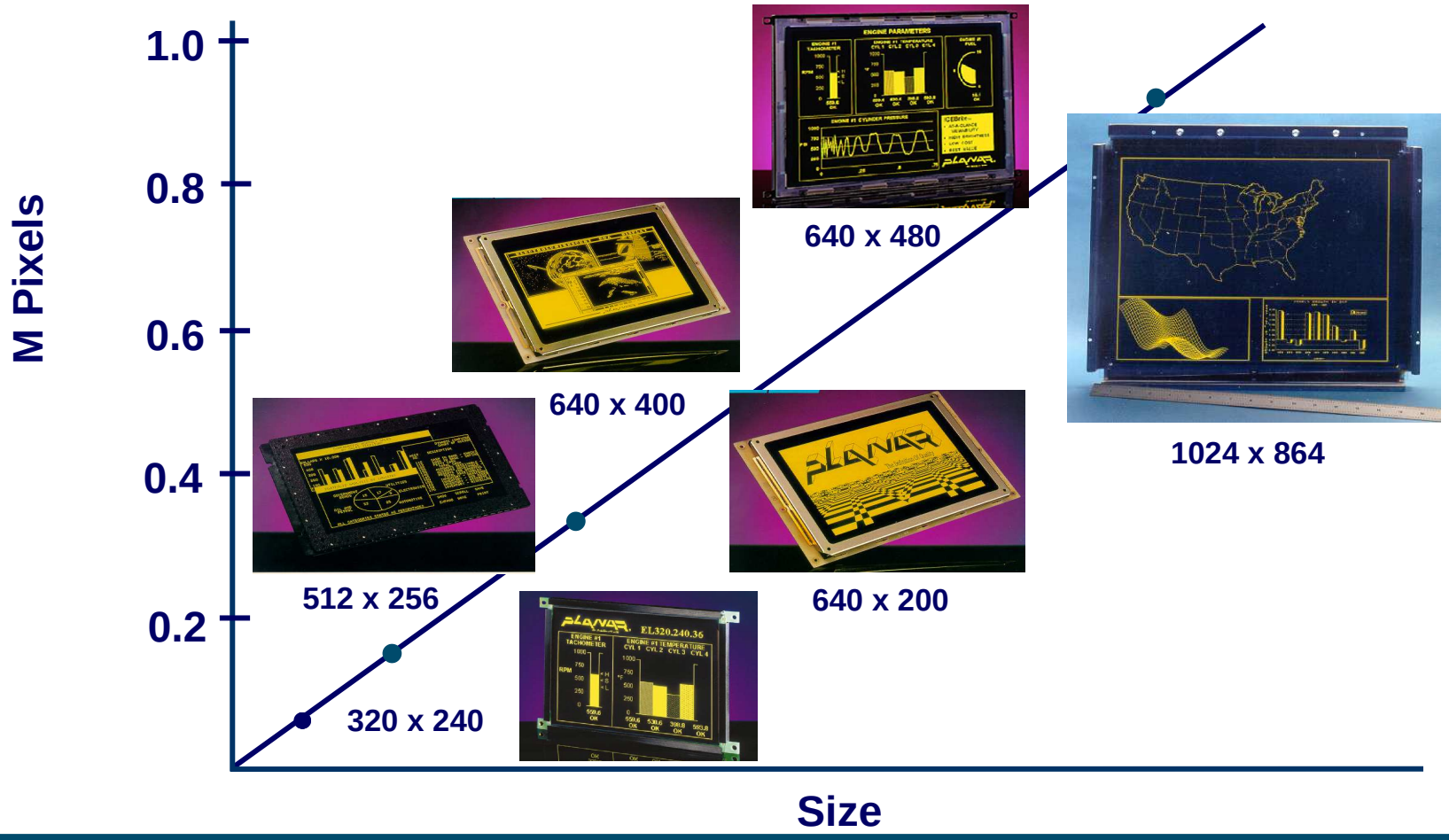
Data General
1986



DEC
1989

PLANAR

Progression of EL Display Information



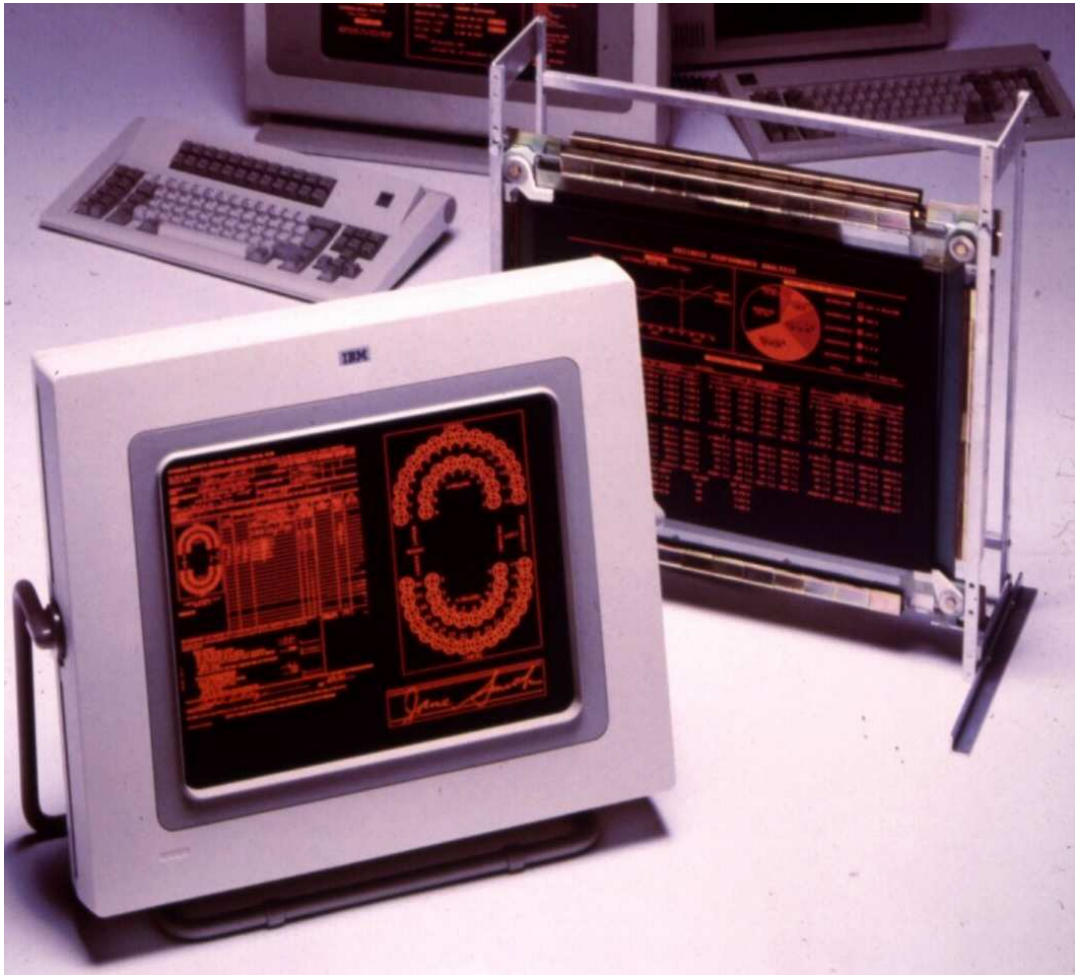
PLANAR

TWO STEP ENERGY SAVINGS

$$W_{2STEP} = \frac{1}{2} C (V/2)^2 + \frac{1}{2} C (V/2)^2 = \frac{1}{4} CV^2$$

PLANAR

IBM Plasma Display



PLANAR

The Development of the STN LCD

- 1983 T. Scheffer and Jürgen Nehring at Brown Broveri Co. discover the Super Twisted-Nematic effect
- 1985 Brown Broveri Co. demonstrates a 10.7 inch diag. 540 x 270 STN panel
- By the end of the 1980s the STN-LCD becomes the dominant flat panel display technology for portable computers

PLANAR

The 1990s: The Quest for Color

- All of the three major flat panel technologies needed to make significant changes to their device structures and materials to achieve color in the 1990s.
- Successful color development positioned flat panels to compete directly with the CRT.

PLANAR

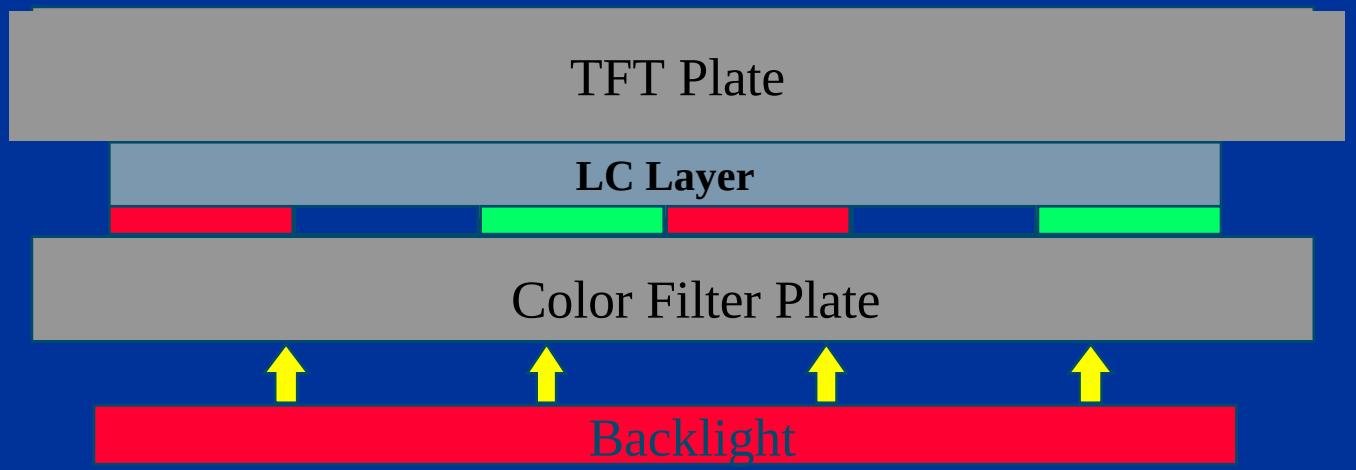
Active Matrix LCDs

- Although passive matrix addressed LCDs dominated the market for low power displays, emissive displays had superior performance in terms of brightness, contrast, viewing angle and response time.
- Active matrix addressed LCD with a-Si TFTs solved the basic materials limitations of liquid crystals and the addition of a mosaic color filter enabled color.

PLANAR

Color Reproduction

- Transmissive TN Mode
- RGB Color Mosaic Filter + Backlight
- Pixel Pitch and Viewing Distance



PLANAR

Early TFT Development

- 1968 P. Brody's group at Westinghouse builds TFT addressed EL display
- 1974 P. Brody builds first AMLCD using CdSe TFTs.
- 1979 P. Le Comber and W. Spear at the Univ. of Dundee demonstrate a-Si TFT
- 1983 S. Morozumi and his colleagues at Seiko Epson build first commercial hand held color LCD TV

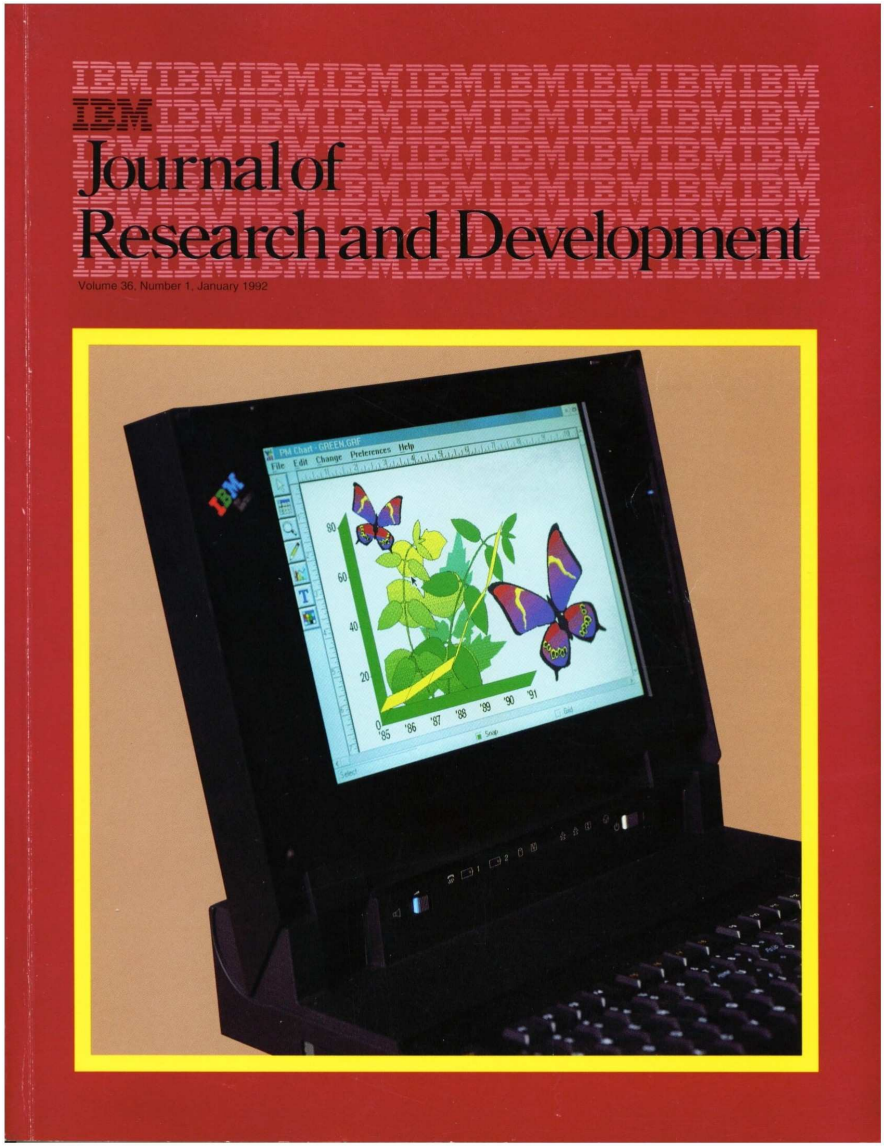
Seiko Epson Hand Held TV

PLANAR

Cost Competitive AMLCD

- The manufacture of small AMLCDs for the hand held TV market allowed Japanese companies to go down the manufacturing cost learning curve.
- In 1991 IBM and Toshiba formed a joint venture to manufacture color AMLCDs for portable computers.
- The IBM Think Pad portable PC was introduced in 1992.

PLANAR

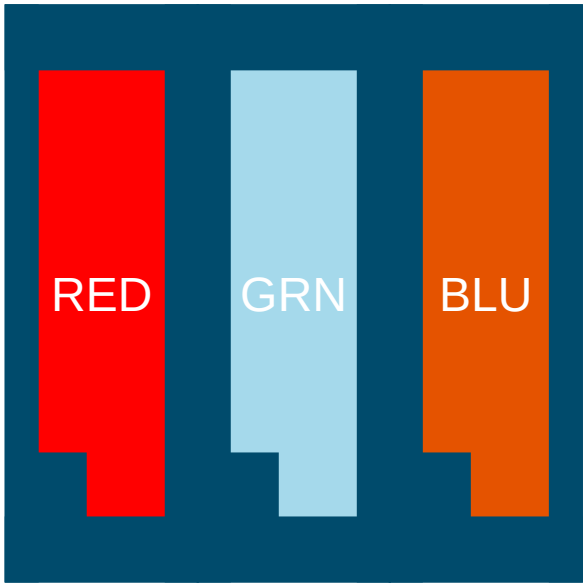

IBM
Journal of
Research and Development
Volume 36, Number 1, January 1992

PLANAR

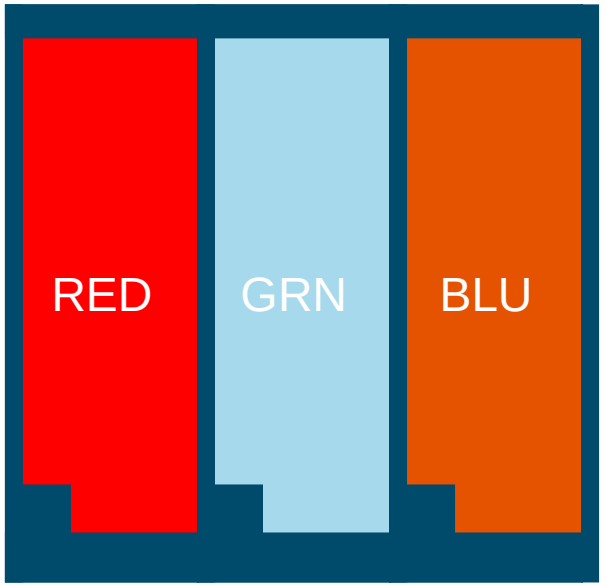
TFT Color LCD Power Consumption

- Initial 10.4” VGA consumed > 10W
- Power Reduction Actions
  - Improve Back Light and power supply efficiencies
  - Match Back Light spectrum to color filter transmission curves
  - Brightness Enhancement Films
  - Increase the TFT aperture ratio

APERTURE RATIO ENHANCEMENT



Conventional ~ 55 %

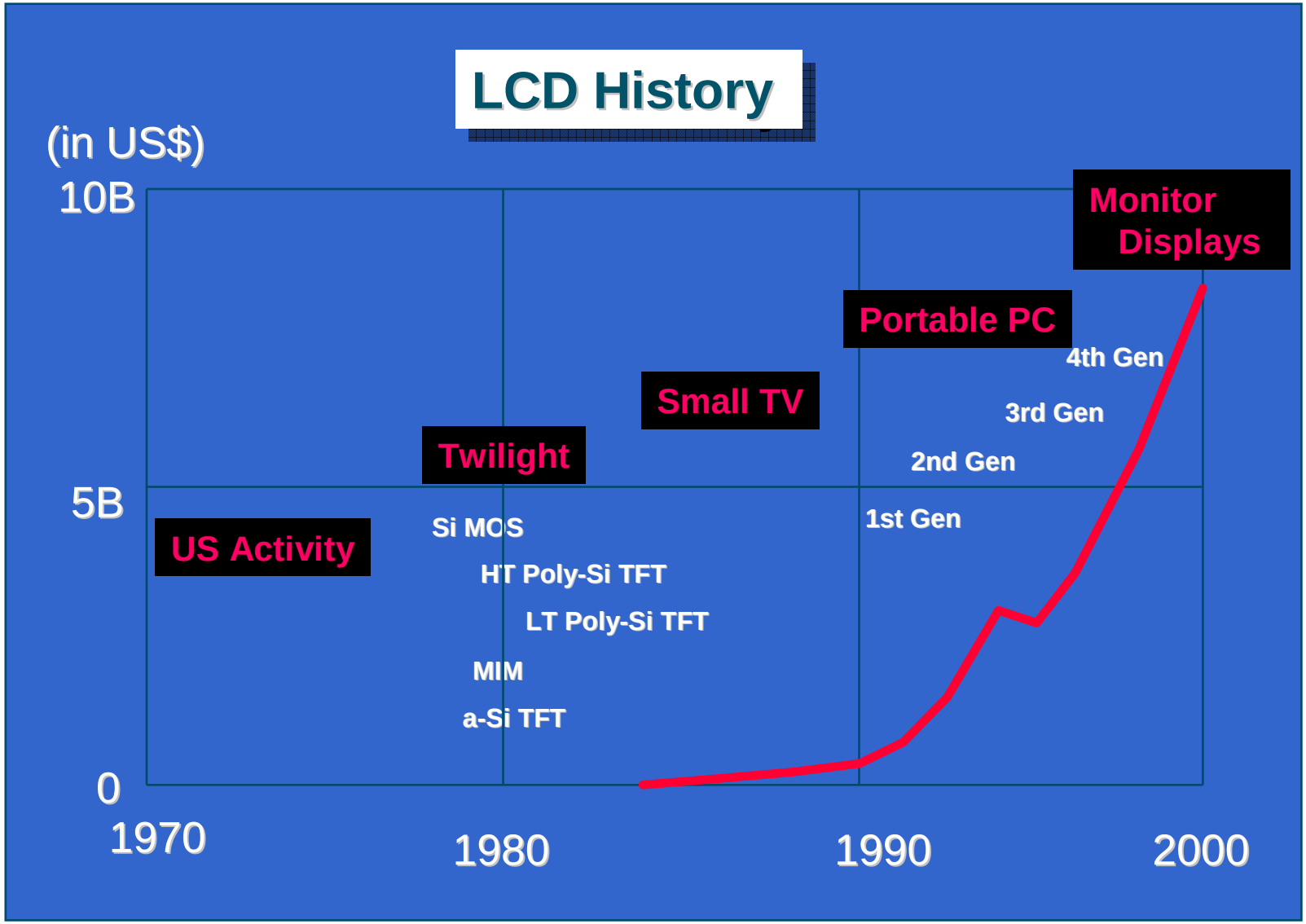


Super High Aperture up to 80 %

PLANAR

Power Reduction for 10.4” VGA by IBM

Date	Product	Display Power (W)
12/1991	PS/55	15
10/1992	ThinkPad 700C	8.5
9/1993	ThinkPad 750C	5.6
11/1994	ThinkPad 755CE	3.6

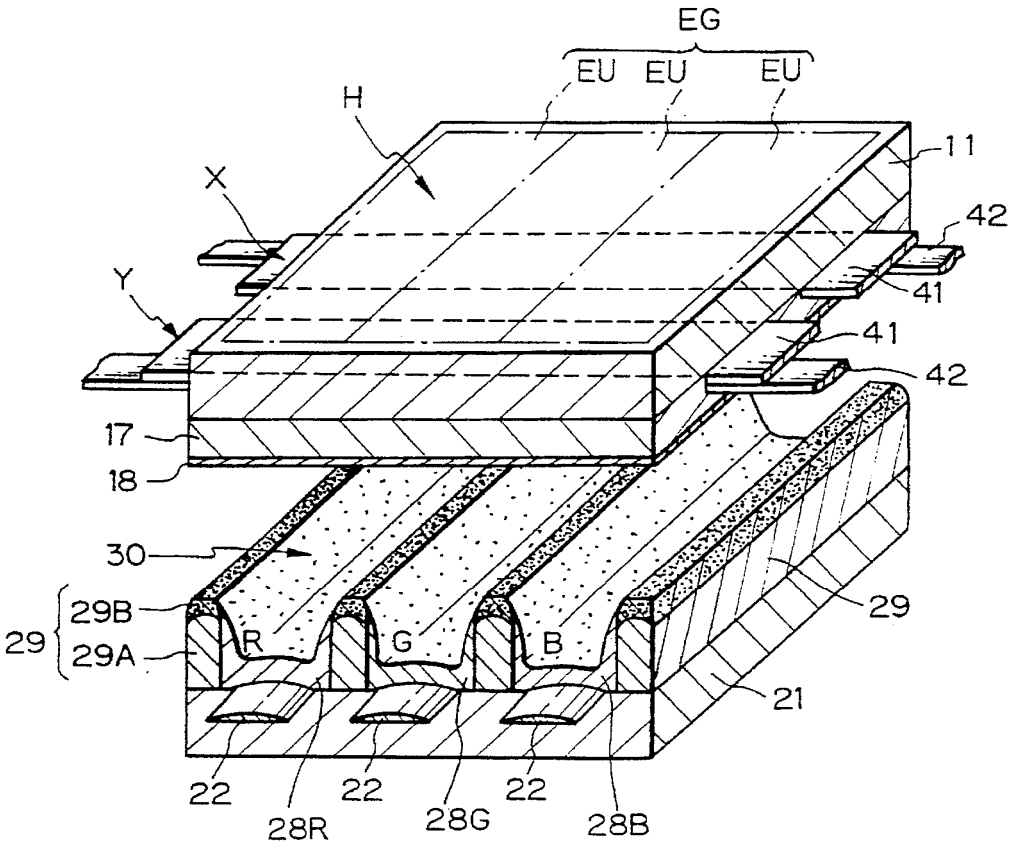

LCD History
(in US$)
10B
5B
0
1970
1980
1990
2000
US Activity
Twilight
Si MOS
HT Poly-Si TFT
LT Poly-Si TFT
MIM
a-Si TFT
Small TV
Portable PC
1st Gen
2nd Gen
3rd Gen
4th Gen
Monitor Displays

PLANAR

Color Plasma Displays

- 1990 T. Shinoda of Fujitsu invents the three-electrode panel with RGB phosphors excited by Xenon gas discharge
- 1992 Fujitsu 21 inch dia. Color PDP
- 1996 Fujitsu 42 inch dia. Color PDP
- By the end of the decade color PDP is the premium large flat panel TV screen

Color Plasma Display Structure



PLANAR

21” Diagonal Color Plasma Display

(1992)

Item	Performance
Display Area	422 x 316 mm
Aspect Ratio	4 : 3
Number of Pixels	640(R,G,B) X 480
Pixel Pitch	0.66mm X 0.66mm
Number of Colors	260,000
Luminance	180 cd / m2
Viewing Angle	> 160 degrees
Power Consumption	100 W max
Weight	4.8Kg

PLANAR

42” Diagonal Color Plasma Display

(1996)

PLANAR

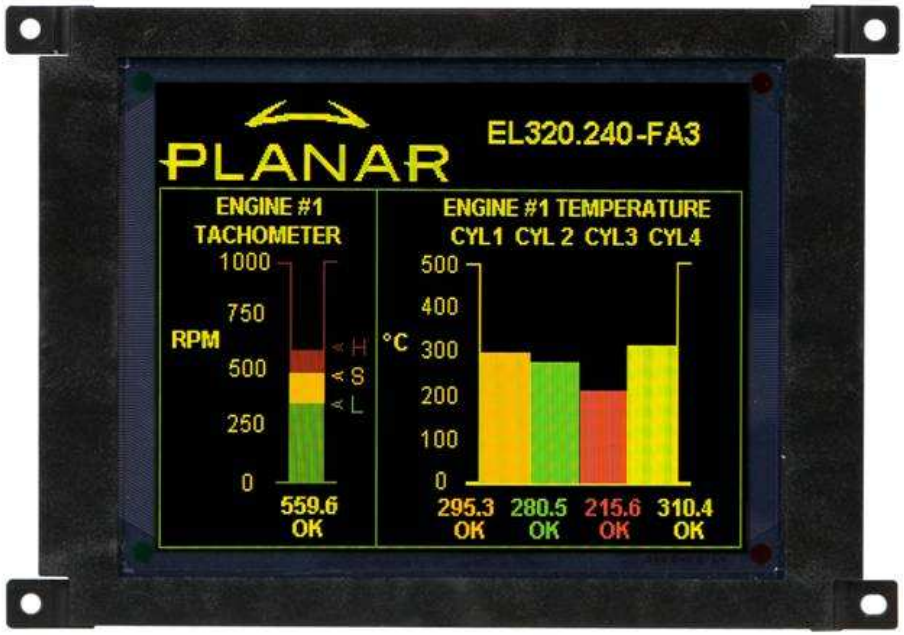
The Long Quest for Color Inorganic EL

- 1987 S. Tanaka & H. Kobayashi of Tottori University propose color by white structure
- 1993 Planar introduces Red-Yellow-Green TFEL product
- Planar demonstrates several RGB prototypes using SrS:Ce, SrS:Cu, or $SrGa_2S_4$:Ce for the blue phosphor

PLANAR

Red-Yellow-Green TFEL Products

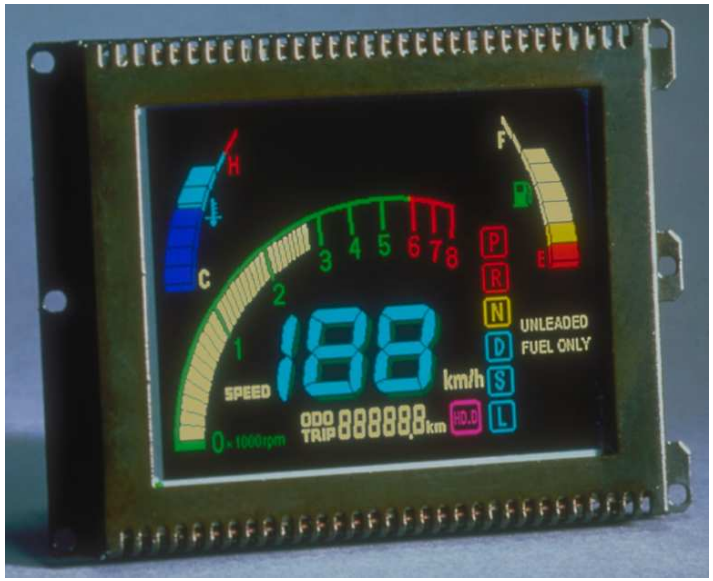
Multi Color VGA



Multi Color QVGA

PLANAR

Color Prototypes



Color QVGA TFEL

Color VGA AMEL

PLANAR

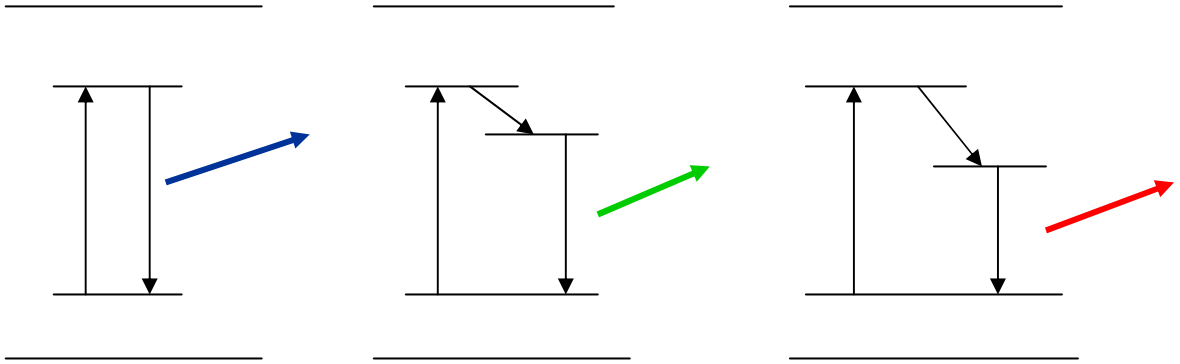
Blue EL Phosphor Breakthrough

- 1999 N. Miura of Meiji University discovered efficient blue EL in $BaAl_2S_4$:Eu
- 2004 X. Wu of iFire reports on Color by Blue structure using $BaAl_2S_4$:Eu
- 2007 iFire demonstrates a 34 inch dia. Color EL TV panel

PLANAR

Achieving Full Color (Color By Blue)

Based on the Physics of Photoluminescence



Blue EL Phosphor
- “Blue Pump”

Emits blue light

Green Conversion

Absorbs Blue
Emits Green

Red Conversion

Absorbs Blue
Emits Red

PLANAR

iFire 34” Diagonal Color EL

PLANAR

Organic EL Technology Milestones

- 1987 C. Tang and S. Van Slyke of Kodak report the development of an efficient OLED device.
- 1995 C. Hosokawa of Idemitsu Kosan develops an efficient blue emitter material.
- 1999 S. Forrest and M. Thompson develop efficient red & green electrophosphorescent materials.

PHOSPHORESCENT OLED PERFORMANCE

2009 UNIVERSAL DISPLAY CORP.

PHOLEDs	CIE Color Coord.	Luminous Efficiency (cd/A)	Luminous Efficiency (Lum/Watt)	Lifetime to 50% Lo (hrs)	Voltage (V)
Deep Red	**(0.67,0.33)**	21	15.3	80,000	4.3
Deep Red	**(0.66,0.34)**	22	19.6	200,000	2.8
Red	**(0.64,0.36)**	28	31.4	500,000	2.8
Green	**(0.36,0.60)**	58	65	100,000	2.8
Green	**(0.36,0.60)**	67	45	250,000	45

PLANAR

Organic EL Product Milestones

- 1996 Pioneer introduces first commercial monochrome OLED display
- 2003 Kodak and Sanyo introduce first color AMOLED product
- 2008 Sony introduces first color AMOLED TV

PLANAR

OLED Products and Prototypes

PIONEER
The Art of Entertainment

Pioneer Monochrome OLED display 256x64 pixels (FM radio sold only in Japan)

Sanyo Color AMOLED display - 852x222 pixels (prototype, 2.5” diag.) A 5-inch QVGA has also been shown

Pioneer Multicolor OLED display in a AM/FM CD changer sold worldwide

Pioneer Multicolor OLED display in a Cell phone product

Sony SVGA AMOLED Prototype

PLANAR

OLED Products - Kodak Digital Camera

KODAK EasyShare LS63 Zoom digital camera…

- Screen and camera made by Kodak
- Launched February 2003

PLANAR

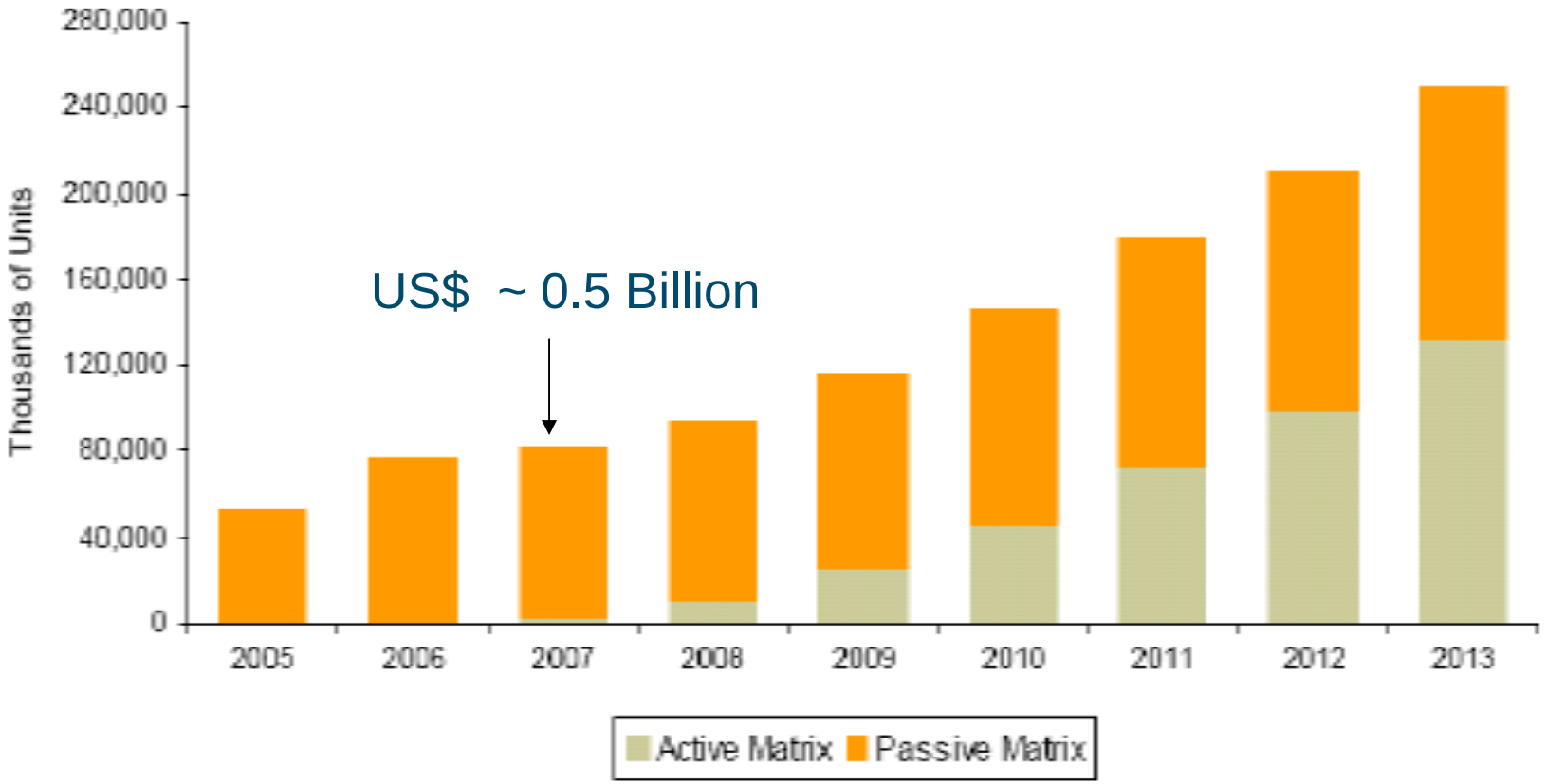
Sony AMOLED-TV – Model XEL1

- 11“ and 3mm thick
- Contrast ratio: 10^6 to 1
- View angle: 180 degree
- Resolution: 960 x 450
- Color gamut: 101% NTSC
- Power consumption: 45W

Contrast

PLANAR

AMOLED PMOLED Market Trend



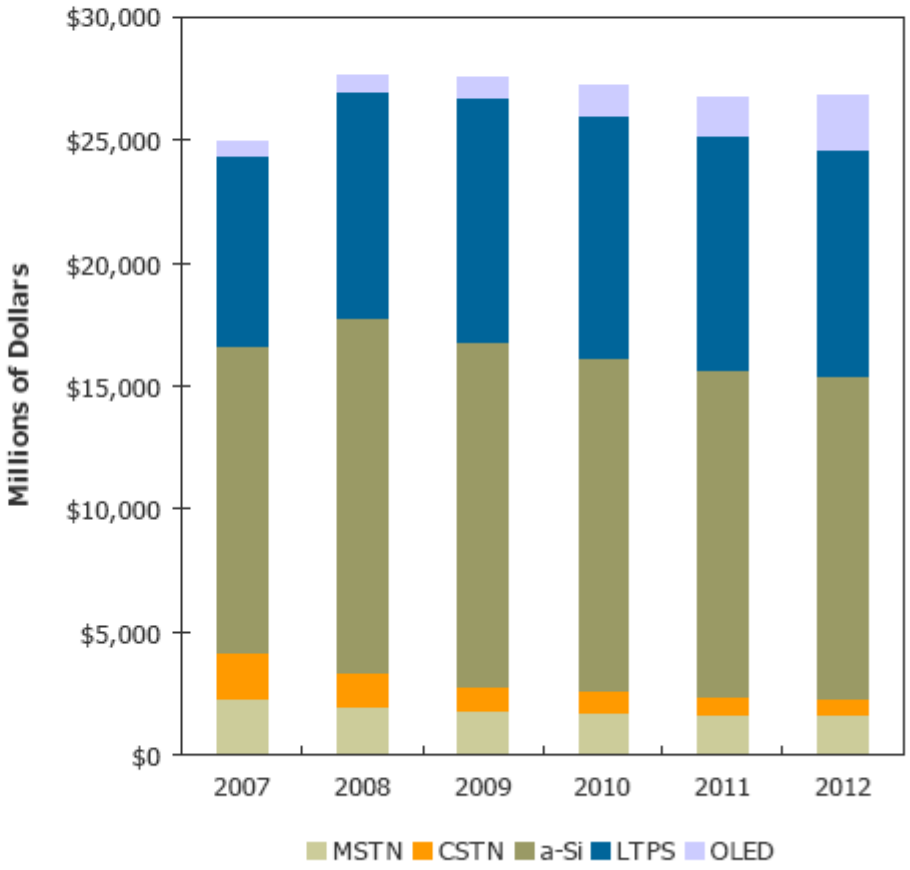
Source: iSuppli, August 2008

PLANAR

iSuppli

Coexistence of display technologies

- Market value will peak in 2008 and gradually decline due to continuous price drop
- Coexistence of display technologies, but AMLCDs lead, while PMLCDs used in low value applications
- OLED market will grow but will have a fairly small piece
  - OLEDs struggling with manufacturing to expand volume
- Low-end character and segmented MSTN displays continue in white goods:
  - Microwaves, coffee machines etc



PLANAR

Flat Panel Success Requirements

Components for Success	LCD	OLED
1. High Volume Entry Market	Watches, Calculators	Cell Phones
- Key Features	- Low Power Monochrome	Low Power Color
2. High Information Content Capability		
- Market	Computer Display	TV Screen ?
- Display Type	AMLCD	AMOLED
- Key Technology	a-Si TFT	**? TFT**
3. Full Color Capability		
- Market	TV Screen	TV Screen?
- Initial Competitors	CRT, Plasma	AMLCD
- Technical Issues		
- Viewing Angel	MVA & IPS	Excellent
- Response Time	Materials, addressing, backlights	Addressing Circuitry
- Color Gamut	Backlights	Color Filters
- Power Consumption	Dynamic Backlights	**Very Efficient Materials**
4. Costs		
- Panel Process	Low	Medium
- TFTs	Low	**High**
- Color Filter	High	High
- Back Light	High	None
- Driver ICS	Low	Low

PLANAR

Acknowledgements

LCD History

Hirohisa Kawamato, “The history of liquid crystal displays,” *Proc. IEEE* **90** (4), 460–500
(2002).

Joseph Castellano, “Liquid Gold,” World Scientific Publishing, Singapore (2005).

Plasma History

Larry Weber, “History of the Plasma Display Panel,” *IEEE Transactions on Plasma Science,”*
34 (2), 268–278 (2006).

EL History

Yoshimasa Ono, “Electroluminescent Displays,” World Scientific Publishing, Singapore(1995).

PLANAR

Sony First OLED Color TV

XEL-1

PLANAR