Light, Bright, and Flexible

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May 3, 2006

A Perspective

- OLEDs Yesterday
- OLEDs Today
- OLEDs Tomorrow

Milestones in OLEDs (1960-2000)

1963
Pope et al.
(NYU)
Organic EL in anthracene crystals

1977
Heeger, MacDiarmid, Shirakawa
(UCSB)
Conductive polymer

1983
Partridge
National Physical Laboratory, UK
EL from polyvinylcarbazole

1987
Tang & van Slyke
Eastman Kodak
Flourescent SMOLED

1990
Burroughes, Friend et al.
Cambridge University, (CDT)
Flourescent Polymer OLED

1996
UDC
IPO (PANL)

1997
Pioneer
1st commercial OLED
display: car audio display

1998
Pioneer
5.2" full color

1998
Forrest & Thompson
Princeton/USC/UDC
Phosphorescent OLED

1999
SK Displays
2.4" full-color AMOLED

2000
CDT\Epson
2.8" IJP PLED

1960 1970 1980 1990 2000

Milestones in OLEDs (2000-2005)

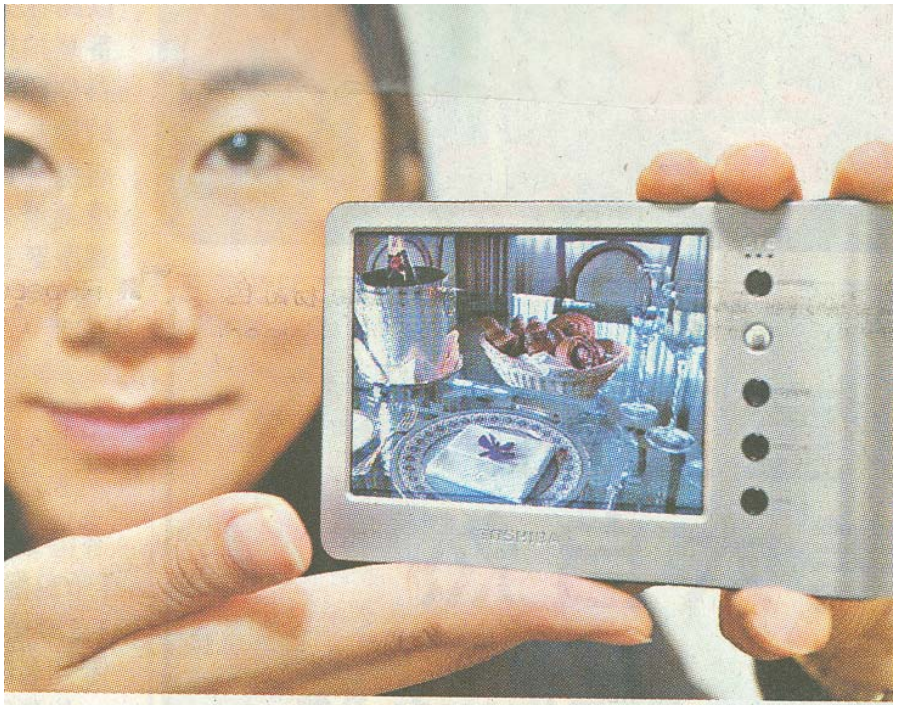
Samsung Electronics' 40" AMOLED at SID05

TV Screens Get Smaller

- **The New York Times: (February 15, 2005)**
  - **"Thanks to Cellphones TV Screens Get Smaller …** You've got half the population going out and buying 60-inch television screens, and the other half is pulling down content onto smaller and smaller devices like phone and P.D.A.'s and iPods …"

- **EETimes: (February 21, 2005)**
  - **"So many specs, such tiny screens …** Mobile industry *debates* how to beam TV to handsets … The mobile-phone industry has given itself a deadline for bringing TV to handsets: June 9, 2006, in time for the World Cup in Germany."

Portable Video– A Killer App Today?



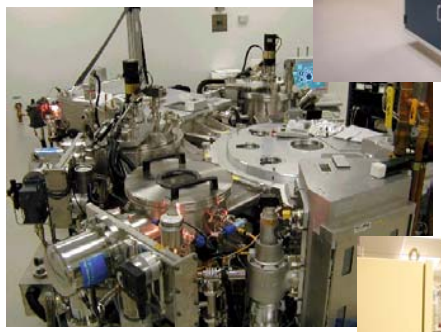
新一代手提 TV

日本東芝公司周三介紹研究中的 3.5 吋迷你手提屏幕，是新一代的「有機發光二極體」（OLED）顯示屏。OLED 每個像素都可自行發光，改善了以往液晶顯示屏（LCD）的缺點如可視角度及日光下顯示等問題。 法新社

Flexible Video– A Killer App Tomorrow?

Universal Display Corporation

- **Industry Pioneer** - Recognized as a leading OLED technology licensor and PHOLED material supplier
- **Strong Patent Portfolio** - Solid foundation in intellectual property and creative thinking with ~ 725 issued and pending patents worldwide
- **OLED Innovation** - World-class R&D team with more than 100 people including UDC researchers as well as those at Princeton University, USC and PPG Industries
- **Expanded state-of-the-art OLED facilities** - 40,000 s.f. headquarters with clean rooms for OLED development and prototyping, chemistry labs and analytical capabilities
- **Growing Market Opportunities** - Partnerships with world-class manufacturers for flat panel displays, lighting and future organic electronics
- **Solid Financial Position** - Strong cash position with growing revenue outlook



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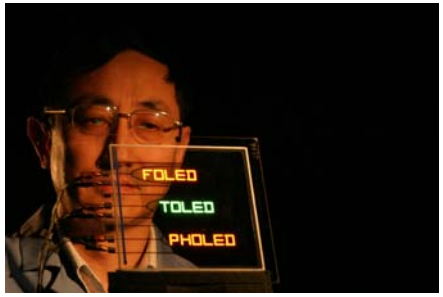
Key Technology Platforms

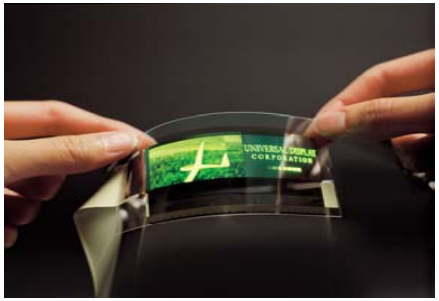
OLED Technologies

- PHOLED™ Phosphorescent OLEDs
- WOLED™ White OLEDs
- TOLED® Transparent and Top-emission OLEDs
- FOLED® Flexible OLEDs
- P²OLED™ Printable Phosphorescent OLEDs
- SOLED® Stacked OLEDs
- Encapsulation

Novel OLED Manufacturing Technologies

- OVPD™ Organic Vapor Phase Deposition
- Ink-Jet Printing
- Organic Vapor Jet Printing
- Stamping





Record PHOLED Efficiency Means….

- Phosphorescent OLEDs (PHOLEDs) have up to **4 times the efficiency** of traditional fluorescent OLEDs
- PHOLEDs provide reduced power consumption for **portable, battery-powered** devices
- PHOLEDs reduce display temperatures **extending operational lifetimes**
- PHOLEDs provide reduced power losses and heat dissipation issues for **large-area** displays
- PHOLEDs offer the potential to use existing low cost **amorphous-Silicon (a-Si)** backplane infrastructure in addition to emerging **poly-Silicon (poly-Si)** backplane technology

Passive-matrix OLED display
Courtesy of Tohoku Pioneer

AMOLED using poly-Si technology
Courtesy of Samsung SDI

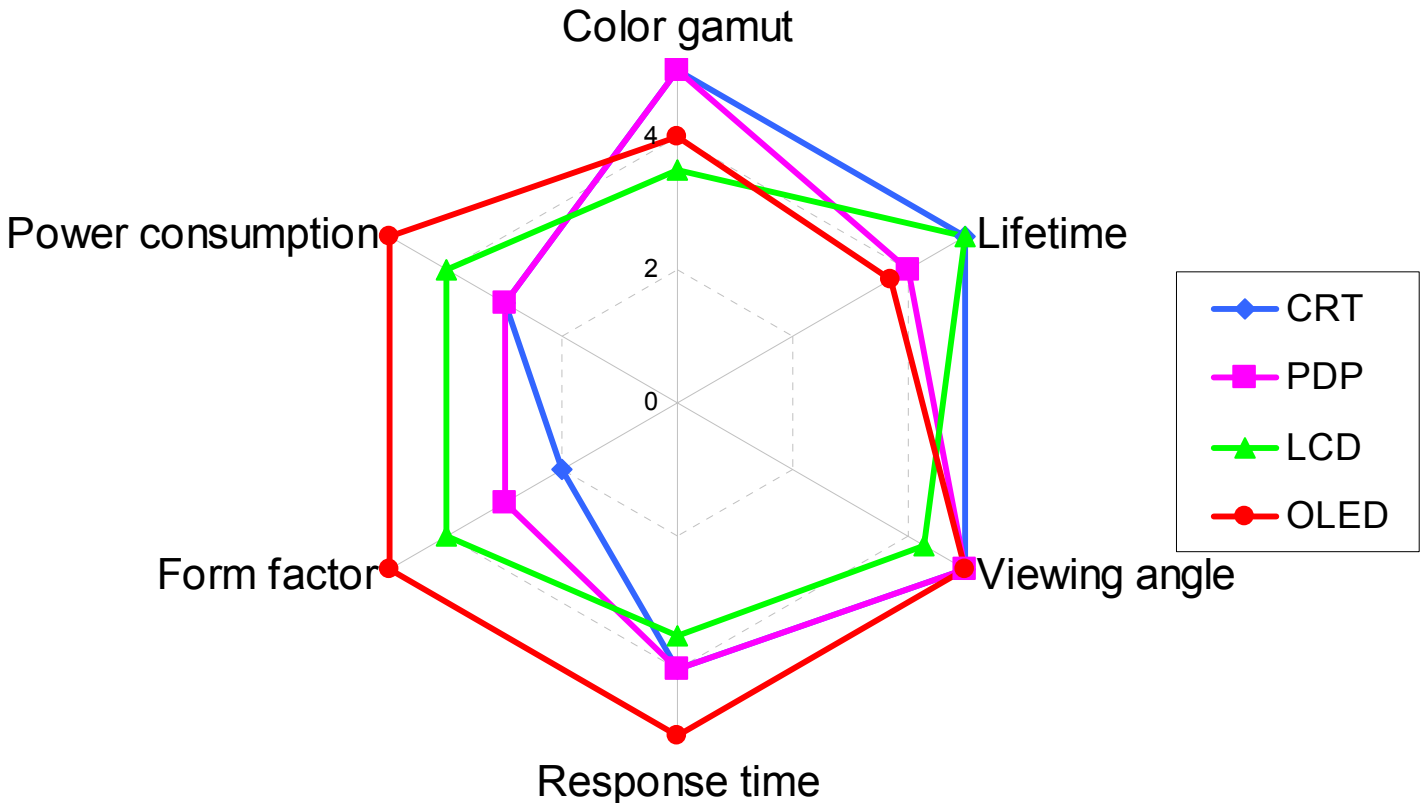
40” AMOLED using a-Si technology
Courtesy of Samsung Electronics

OLEDS Today……

Courtesy of T. Urabe

- CRT TV quality that is thin and light weight
- High power efficiency with PHOLED
- Potential for low manufacturing cost
  - Simpler structure
  - Fewer process steps
  - Lower materials cost

Display Technology Comparison



“FLAT-PANEL REPORT:Move Over LCDs, Here Comes AM OLED”

Tuesday March 21, 11:58 AM By Yun-Hee Kim Of DOW JONES NEWSWIRES

TAIPEI (Dow Jones)--While many makers of flat-panel displays are focusing on the TV segment to drive future growth, some companies are betting on what industry players dub as the next-generation display for cellular phones and music players: active matrix light emitting diodes.

The Flexible Display Vision

- **Information Display: (May 2005)**
  - **"The vision of the flexible flat panel display** (FPD) entered popular consciousness in late 2002 when a **prototype roll-up display from Universal Display Corp. was seen by millions** on the *CBS Evening News*, in *Time and Newsweek* magazines, and elsewhere. The age of the flexible FPD is not yet upon us, but it is the subject of an extraordinarily energetic quest by many companies and institutions worldwide."

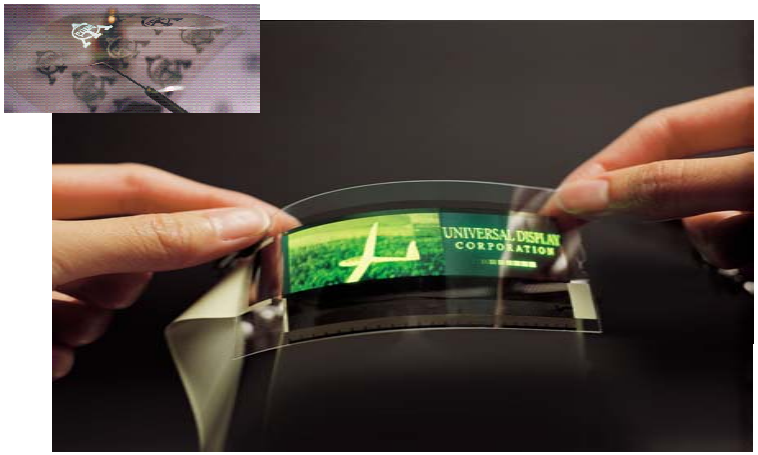
Conformable and Flexible Displays

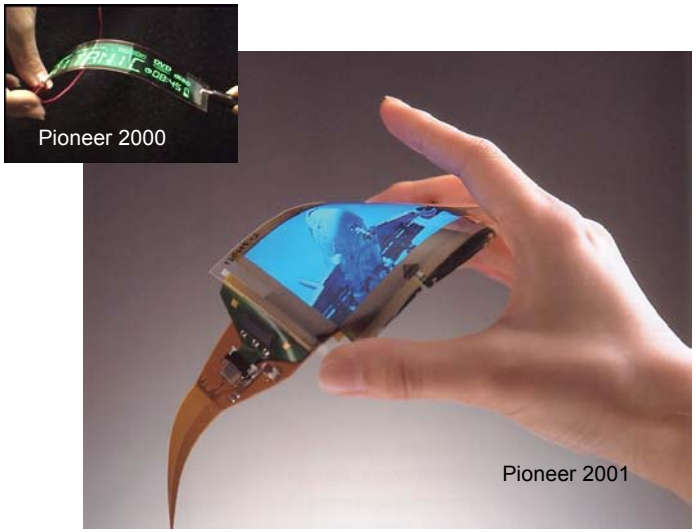
- Lightweight
- Thin
- Unbreakable
- Low cost processing potential, e.g. roll-to-roll
- New product possibilities

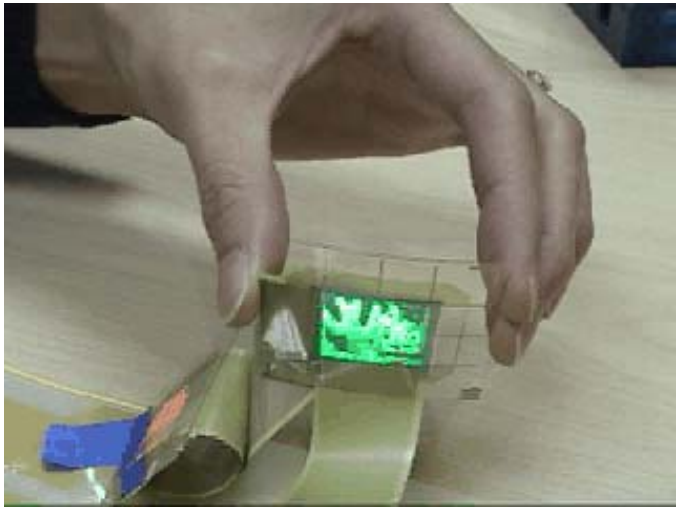
Universal Communication Device (UCD)

Advances in FOLED™ Technology

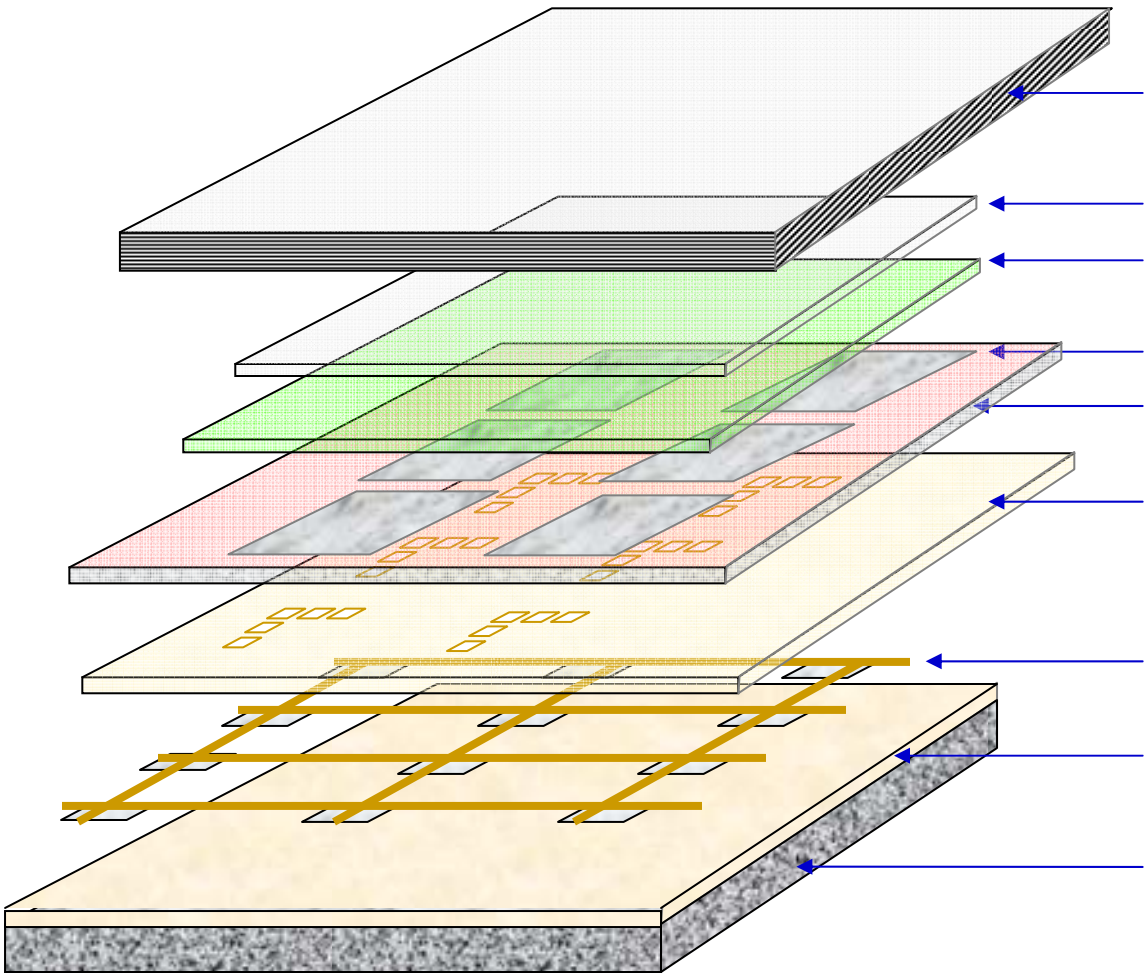
- Plastic Substrates







AM-TOLED Display on Steel Foil



VII. Drive electronics

VI. Encapsulation

V. Transparent cathode

IV. OLED stack

IIID. Grid

IIIC. Anode

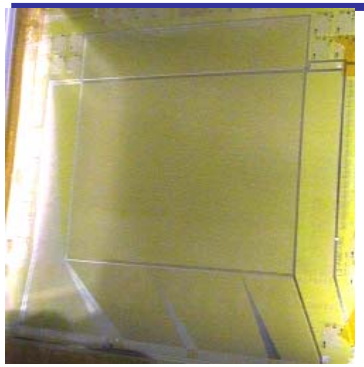
IIIB. TFT passivation with vias for anode contact

IIIA. PS TFTs

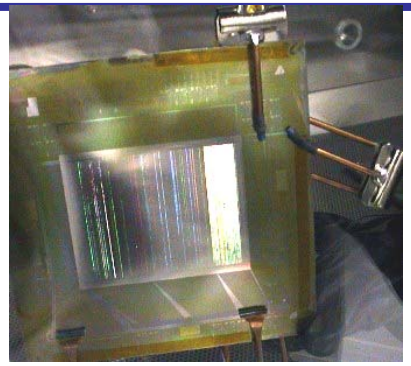
II. Substrate planarization layer

I. Steel foil substrate

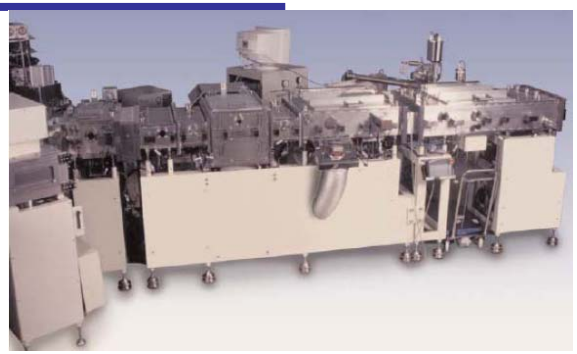
Process Flow Overview



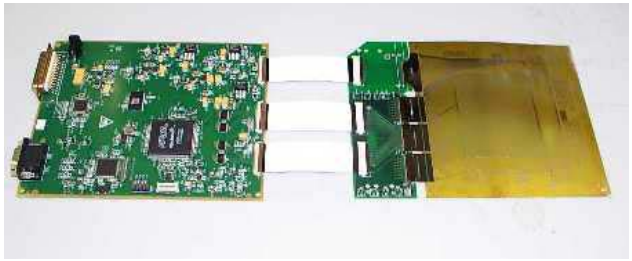
Poly-Si TFT backplanes are fabricated on 6”x6” steel foil substrates



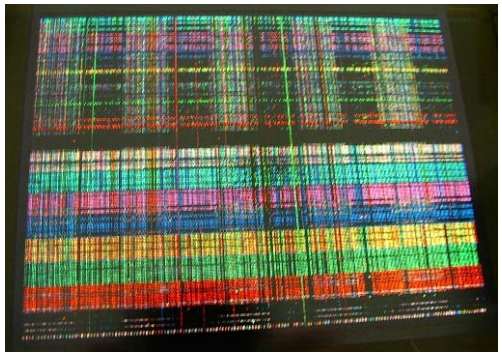
Arrays undergo full color OLED deposition and first light up



Completed displays are encapsulated with a conformal, multilayer thin film encapsulation



Encapsulated displays are integrated with the drive electronics

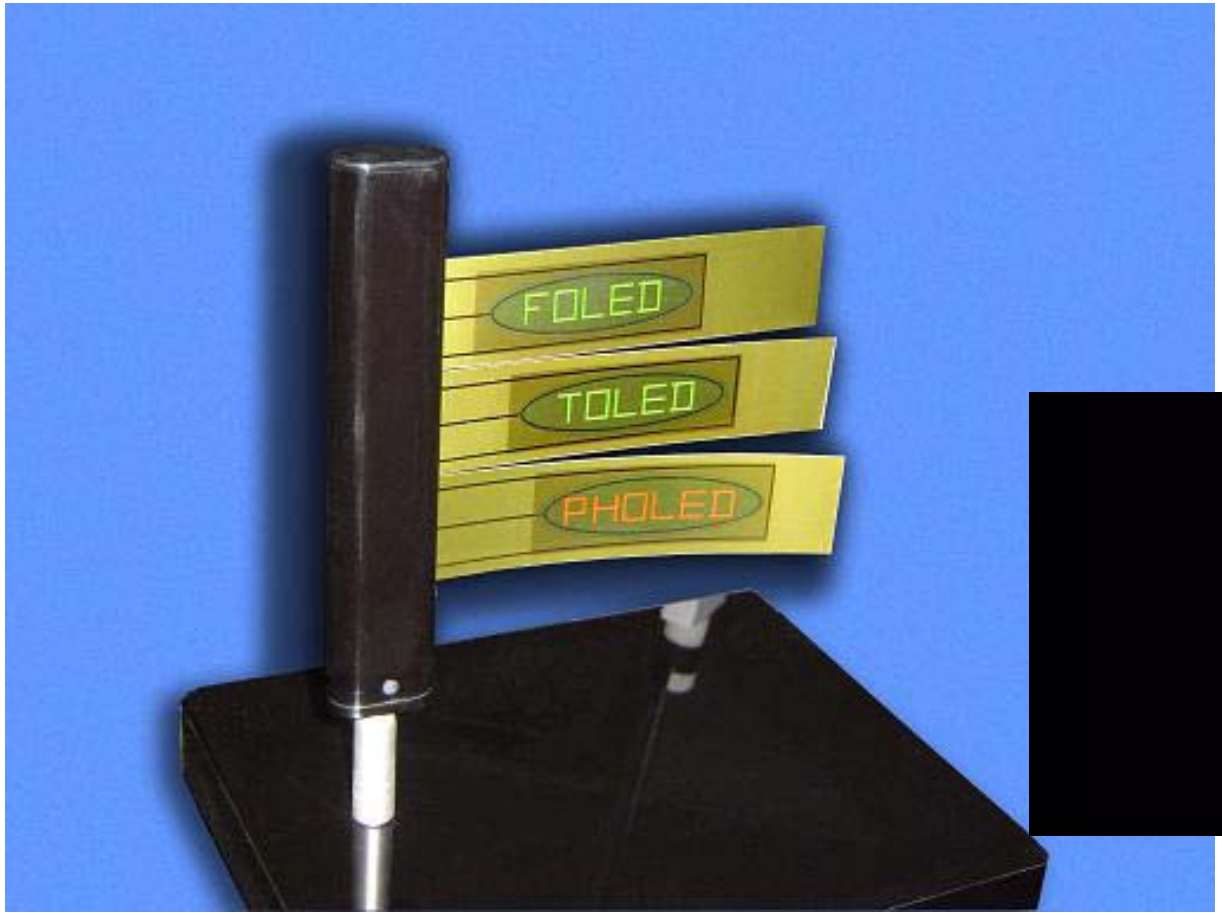


Completed displays are test driven.

Why Metallic Substrates Today for AM-OLEDs

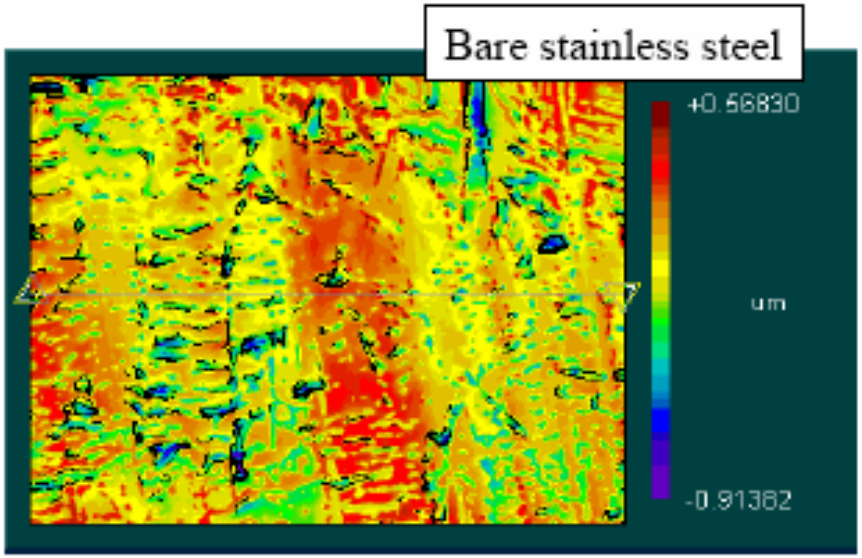
- High working temperature – compatible with LTPS TFT backplane process
- High dimensional stability
- No need for oxygen/water permeation barrier
- High thermal conductivity for heat dissipation during operation
- Rugged

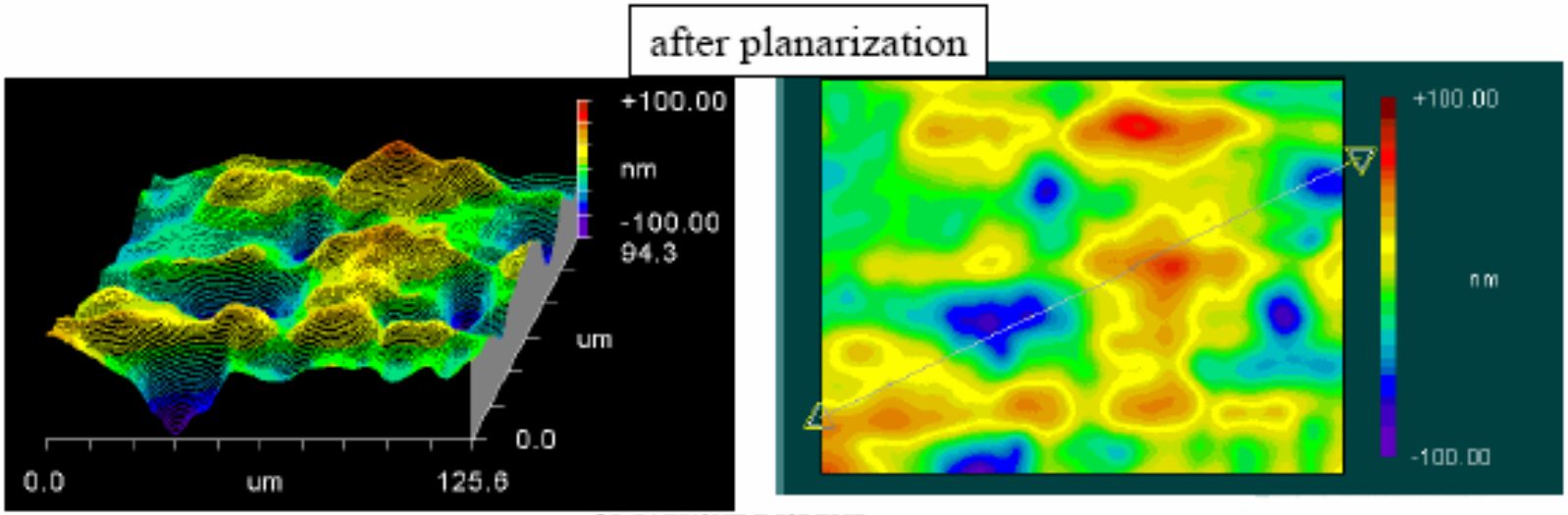
Metallic Substrate FOLED™ Technology



Substrate Planarization

- Polyimide as planarization layer
  - Reduces roughness from 180nm RMS to 25nm RMS
  - Increases roughness length scale
  - Insulating barrier

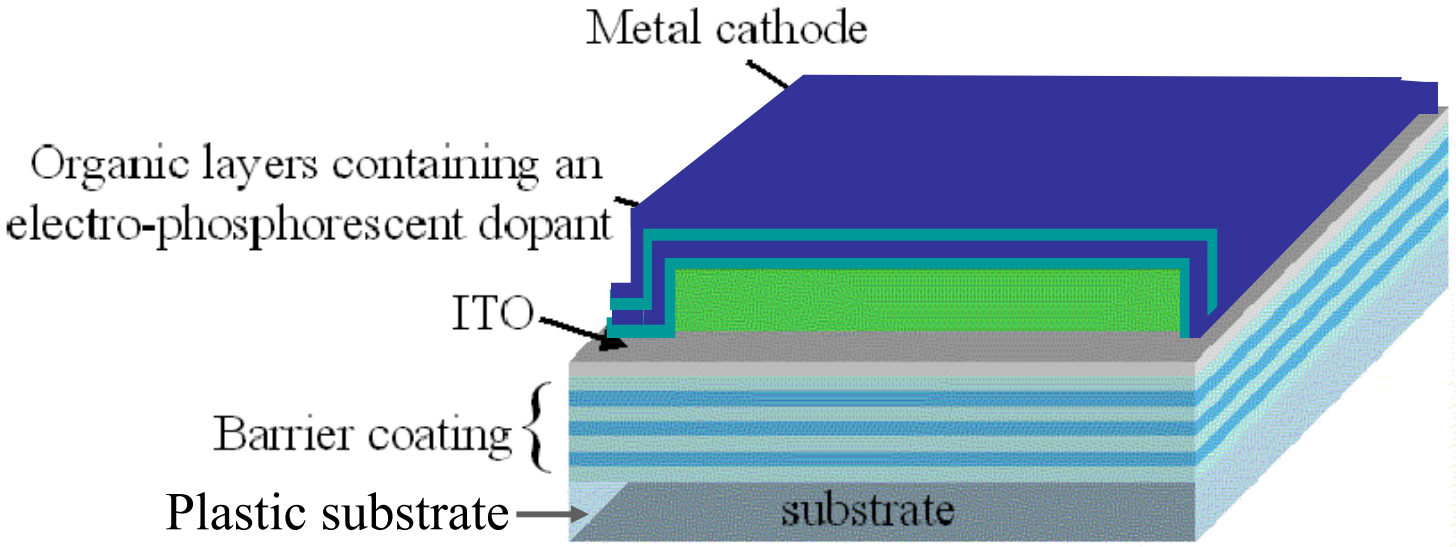




Multi-Layer Thin Film Encapsulation

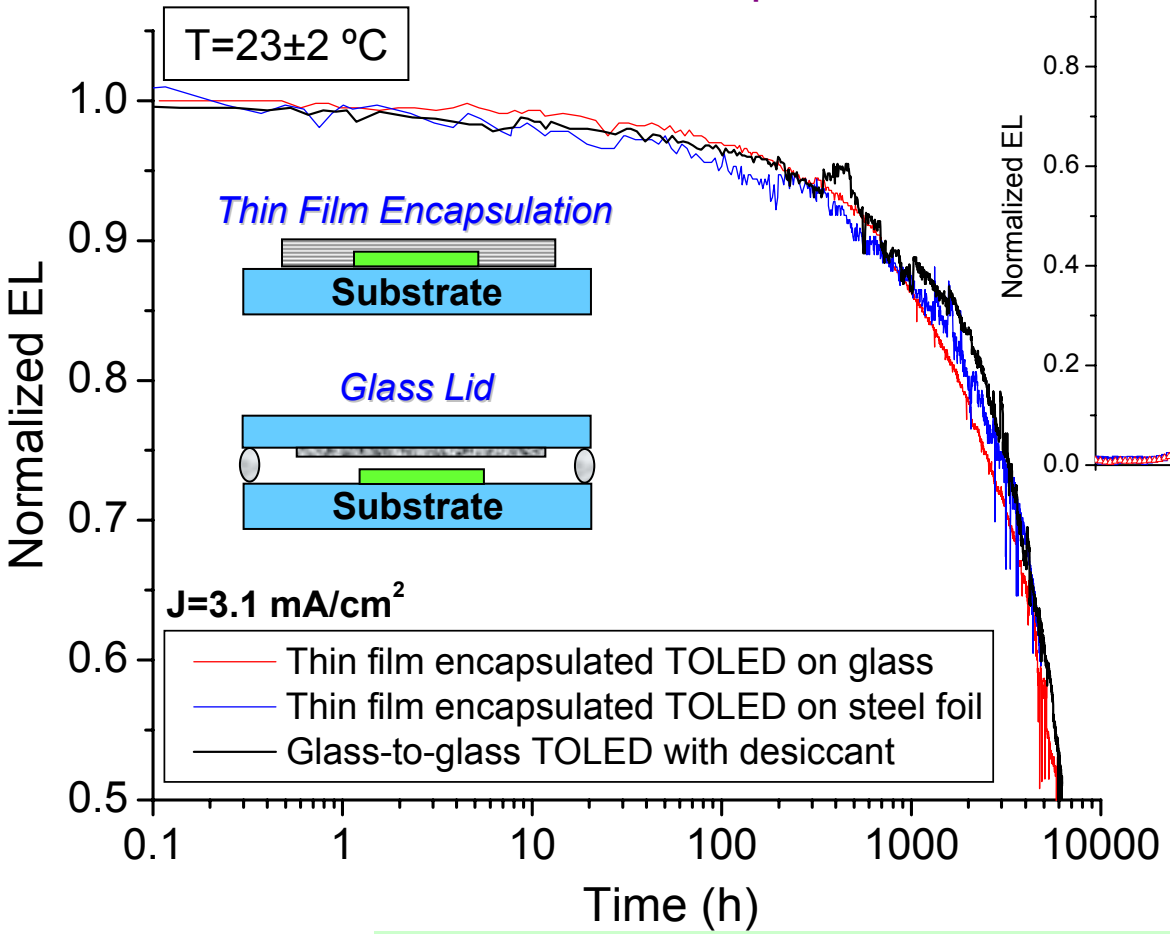
Barix™ Coating Technology

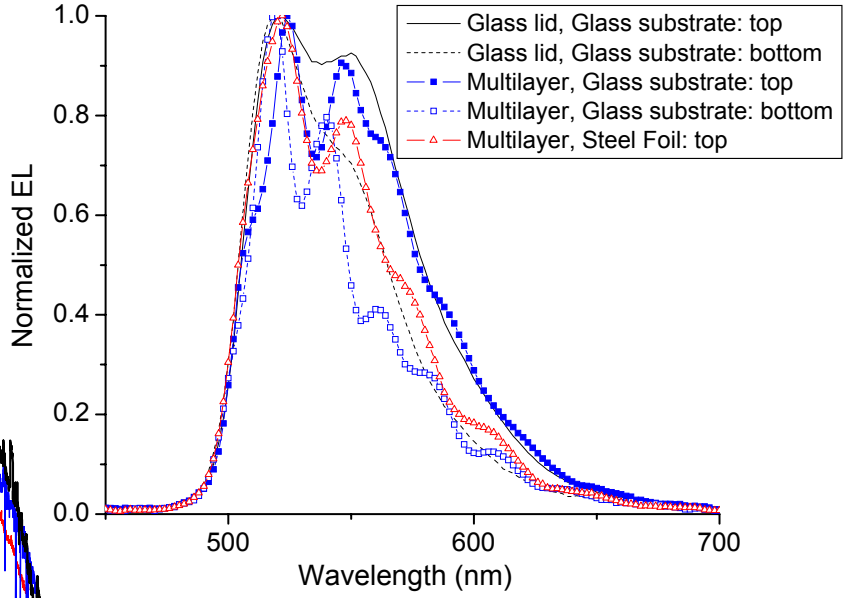
- Polymer film planarizes surface to reduce substrate defects
- Inorganic film provides barrier properties
- Organic film protects barrier layer from mechanical damage
- Multiple Barix layers yield an enhanced barrier by decoupling defects



Encapsulated TOLED Driven Lifetime

*Device structure not optimized





>5,000-h lifetime of TOLED pixel on steel foil is encouraging, demonstrates viability of approach

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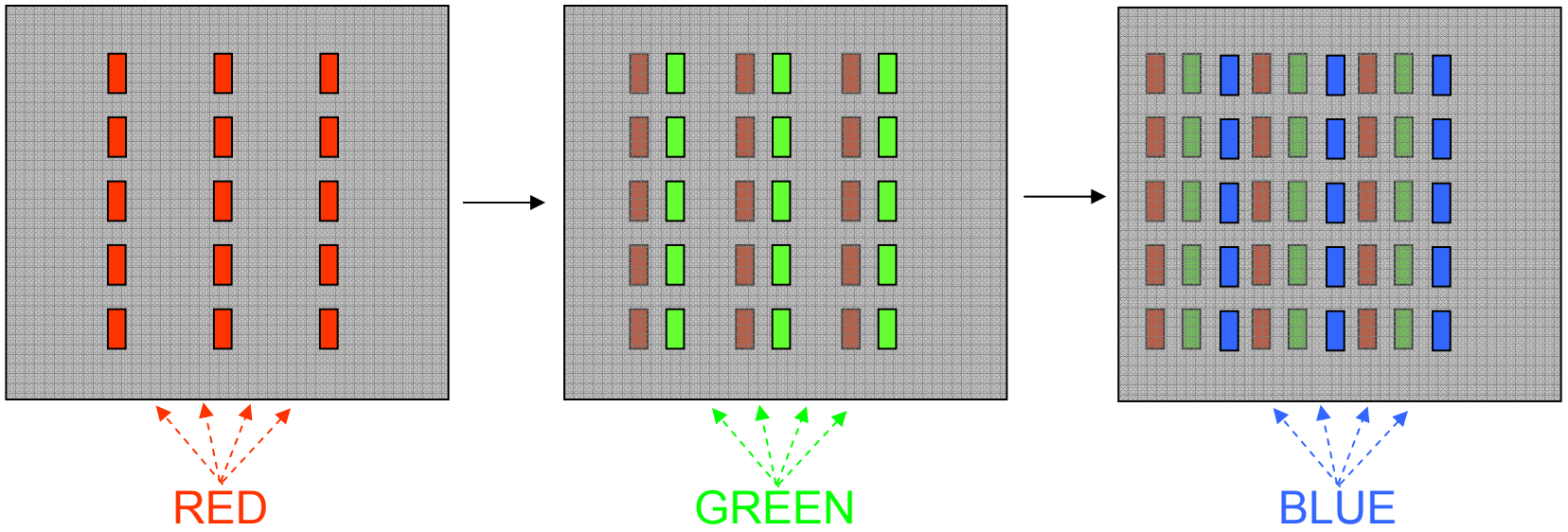
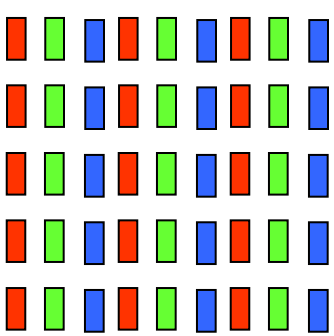
VITEX SYSTEMS

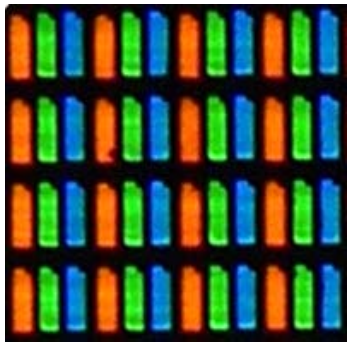
High Precision Alignment FOLED Display System

- *Manufactured by Tokki Corporation*

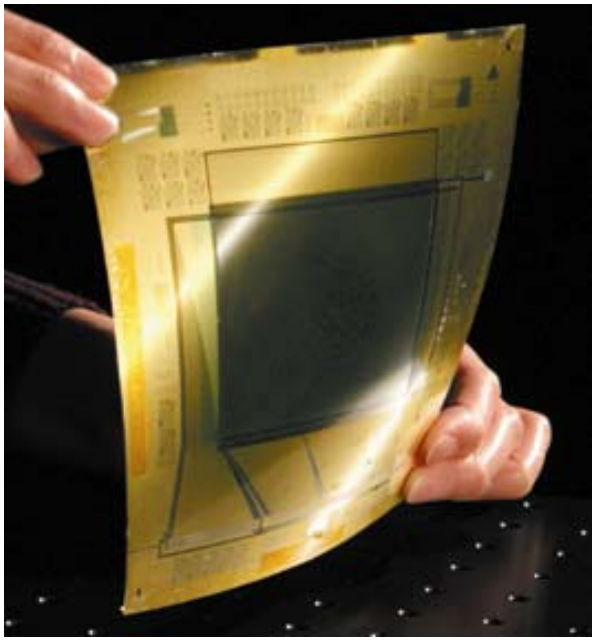
Full Color Deposition Through Shadow Mask

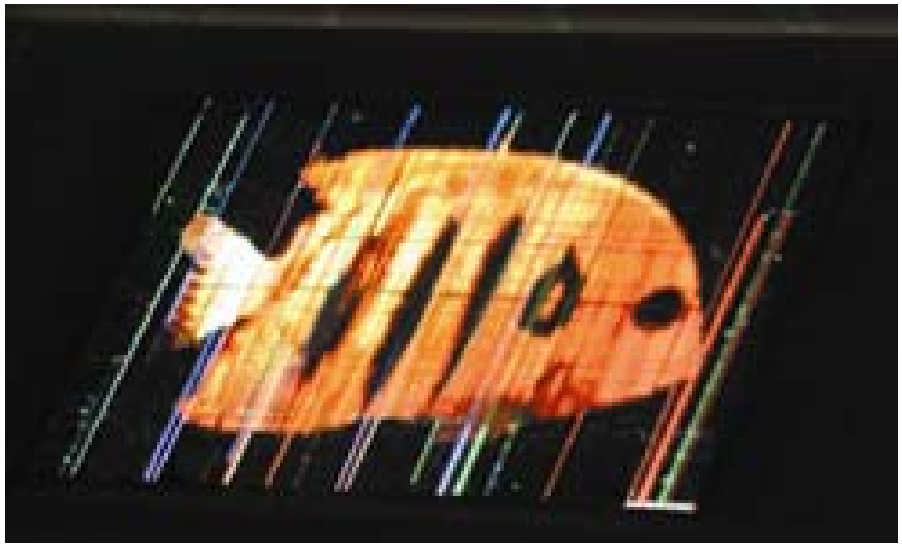






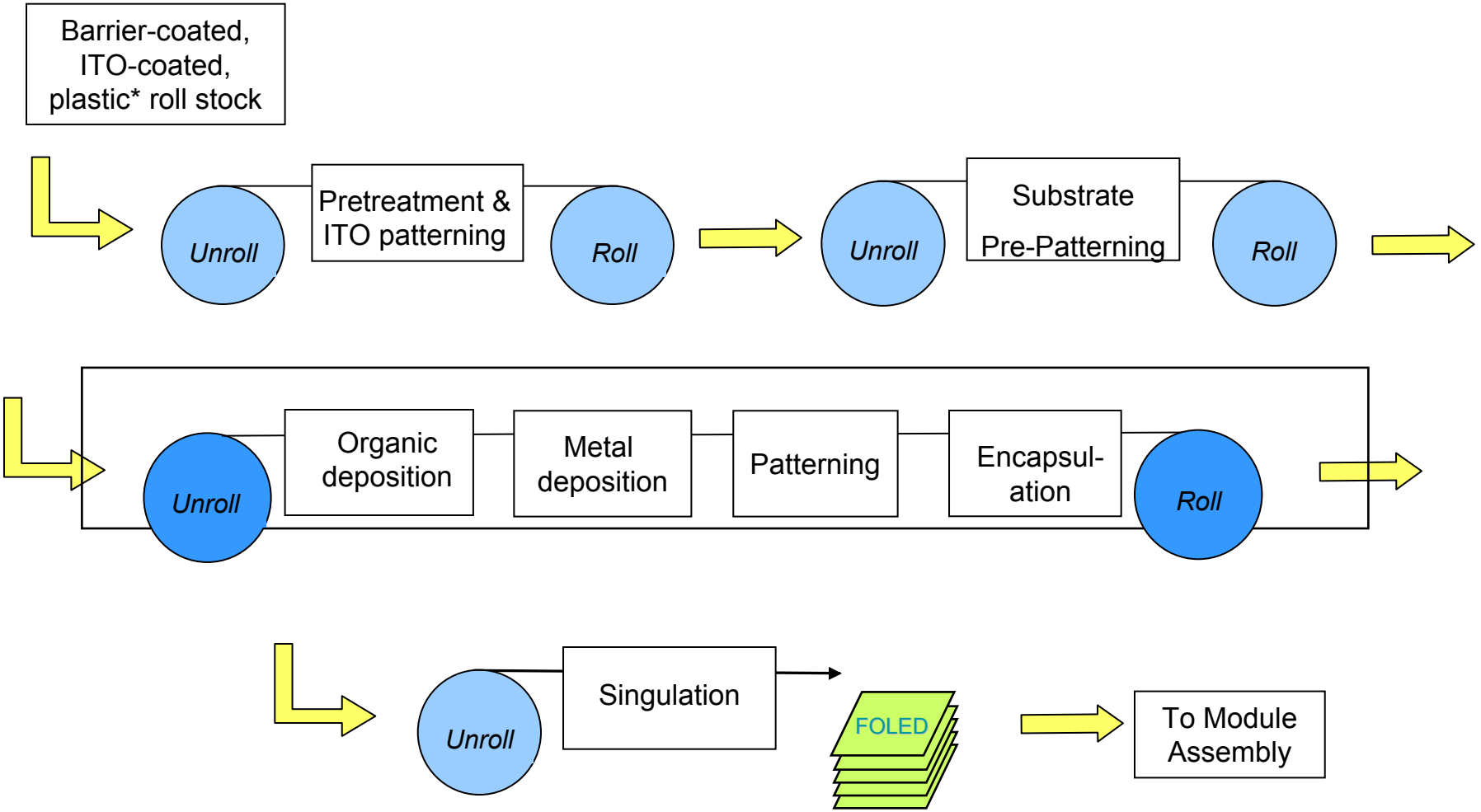
Full Color QVGA AMOLED Demonstration





- 320x3x240
- 60 Hz refresh rate
- 64 grayscale levels
- Full color
- 100 dpi (85 um sub-pixel pitch)
- Top emission
- Multilayer thin film encapsulation

FOLED Continuous Process Flow



OLED Roadmap: Now and Into the Future

1997

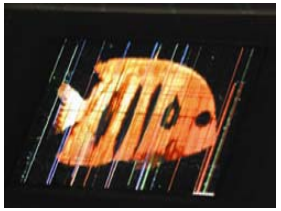
Small Area
Multi-color\Monochrome
OLED Products

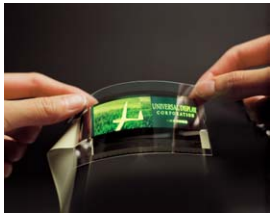
Full-color
Product
Prototypes

Small Area
Full-color
OLED
Products

Today

Large area
OLED TVs





Flexible OLEDs

Lighting

Increasingly demanding product targets
Requires PHOLED Technology to Enable

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Acknowledgements

- Flexible display team at UDC
- Technical teams at the Palo Alto Research Center, L3 Displays, and Vitex
- Profs. Steve Forrest and Mark Thompson
- Army Research Lab
- Air Force Research Lab
- CERDEC