Color Filter for TFT-LCD

W. T. Cheng

Dept. Ch. E./NCHU

Outline

• Introduction
• Color Principle
• Design of Color Pixel
• Fabricating Method
• Black Matrix
• Inspection & Test
• Future Trend
Introduction

Milestone of Color Displays (2-1)
Milestone of Color Displays (2-2)

- **1990s**
  - Analog Display
    - TV
    - Monitor

- **1990s**
  - Digital Display
    - TV
    - Laptop
    - Monitor
    - Mobile
    - Various Industrial Displays

- **2010s**
  - Ubiquitous Display
    - Wall Display
    - Large e-Paper
    - Electronic Newspaper & Magazine
    - Paper Display of Mobile Device
    - Information boards

TFT LCD Industry Supply Chain
TFT-array and Color-filter Substrates

Reduction of photo-induced leakage current in a TFT

Samsung Electronics
Color Principle

Generating Primaries (3-1)

Emissive Display
Generating Primaries (3-2)

Emissive Display

Generating Primaries (3-3)

Non-Emissive Display

Useless Light Energy
Color Mixing

Additive Color Mixing

Subtractive Color Mixing

Modulation of Primaries: Additive

Additive Color Mixing

By Light Generation
Modulation of Primaries: Subtractive

Additive & Subtractive Color System

Primary Color: using 1 Primary
Secondary Color: using 2 Primaries
Primaries Overlapped Color: using 3 Primaries
Base Color: using No Primaries
Design of Color Pixel

Color Pixel

<table>
<thead>
<tr>
<th></th>
<th>Stripe</th>
<th>Mosaic</th>
<th>Delta</th>
</tr>
</thead>
<tbody>
<tr>
<td>Array Design</td>
<td>Simple</td>
<td>Simple</td>
<td>Complex</td>
</tr>
<tr>
<td>C/F Fab.</td>
<td>Simple</td>
<td>Difficult</td>
<td>Difficult</td>
</tr>
<tr>
<td>Driving CKT</td>
<td>Simple</td>
<td>Complex</td>
<td>Simple</td>
</tr>
<tr>
<td>Color Mix</td>
<td>Poor/w/low res.</td>
<td>Good</td>
<td>Best</td>
</tr>
</tbody>
</table>

Samsung Electronics
How an LCD produces colors?

Representation of Color

A color = rR + gG + bB
- r = R / (R + G + B)
- g = G / (R + G + B)
- b = B / (R + G + B)
with \( r + g + b = 1 \)
CIE Color Coordinates

- Color Balance
- Color Reproducibility or Color Saturation
- Color Temperature

Color Reproducibility of Display (a) =
\[
\frac{\text{Area of } \Delta(a)}{\text{Area of } \Delta(NTSC)} \times 100\%
\]

Pixel Pitch vs. Diagonal Size of Screen
Pixel Size and Resolving Power of Human Eye

- 10.4 inch VGA : 0.110mm x 0.330mm (77dpi)
- 12.1 inch SVGA : 0.1025mm x 0.3075mm (83dpi)
- 15.0 inch XGA : 0.099mm x 0.297mm (117dpi)
- 17.0 inch SXGA : 0.090mm x 0.270mm (94dpi)
- 21.3 inch UXGA : 0.080mm x 0.270mm (94dpi)

Total # Colors

\[ \text{# of Color} = 2^n (R) \times 2^n (G) \times 2^n (B) = 2^{3n} \]

- n = # of data bits of LCD chip
- 3 bit = 8-gray/RGB = 512 colors
- 4 bit = 16-gray/RGB = 4,096 colors
- 6 bit = 64-gray/RGB = 262,144 colors
- 8 bit = 256-gray/RGB = 16,777,216 colors

Analog IC = Continuous gray-scale = full color
Gray Scale Generation

Consideration for Color Design

- Luminance, Efficiency
- Chromaticity, Purity
- Color Gamut, Gradation
- Cost, Implementation
- Application, Images
- Viewing Conditions
- Color Reproduction
Color: An Attribute for Image Quality

- Display Quality
- Color Quality
- Chromaticity Diagram

Fabricating Method
Color Filter Forming Methods (2-1)

Color Filter forming methods (2-2)

<table>
<thead>
<tr>
<th>Method name</th>
<th>Description</th>
<th>Features</th>
<th>Resolution</th>
<th>Color spectra</th>
<th>Reliability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gelatin dyeing method</td>
<td>Pigment molecules [P] Gelatin relief pattern</td>
<td></td>
<td>∅</td>
<td>∅</td>
<td>△</td>
</tr>
<tr>
<td>Patterned resin is dyed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pigment impregnation method</td>
<td>Pigment [P] Resin</td>
<td></td>
<td>∅</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Resin containing pigments made into a pattern</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Printing method</td>
<td>Color ink containing pigment [P] printed on substrate</td>
<td>∧</td>
<td>×</td>
<td>△</td>
<td>○</td>
</tr>
<tr>
<td>Electro-deposition method</td>
<td>Pigment with resin is electro-deposited on the substrate</td>
<td></td>
<td>△</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>
Pigmented Photosensitive Red, Green, Blue color filter resins

• Dyed Photosensitive Cyan, Magenta, Yellow color filter resins (materials in development)

• Dyed Photosensitive Red, Green, Blue color filter resins (materials in development)
PDCR Composition for CF

- Acrylic resin with multi functional group
- Reactive monomer
- Organic pigment
- Photo-initiator
- Solvent
- Additive
Electro-deposition Mechanism for CF

**Anionic Type**

- Pigment containing resin with negative charge

\[
\begin{align*}
2\text{H}_2\text{O} & \rightarrow 2\text{OH}^- + 2\text{H}^+ + 2e \\
2\text{OH}^- & \rightarrow \text{H}_2\text{O} + \text{O}_2^- \\
2\text{O}_2^- & \rightarrow \text{O}_2 \\
-\text{COO}^- + \text{H}^+ & \rightarrow -\text{COOH}
\end{align*}
\]

**Cationic Type**

- Pigment containing resin with positive charge

\[
\begin{align*}
2\text{H}_2\text{O} + 2e & \rightarrow 2\text{OH}^- + 2\text{H}^+ \\
2\text{H}^+ & \rightarrow \text{H}_2 \\
-\text{NR}_2^+ + \text{OH}^- & \rightarrow -\text{NR}_2 + \text{H}_2\text{O}
\end{align*}
\]

---

**Inverse Transfer Printing**

【印刷用法の特長】
- 1. 印刷用法の特長（細部の調和性発揮での高機能化）を兼ねることが可能です。
- 2. 印刷用法での細部の機能発揮で、印刷特性を増強することが可能です。
- 3. 録画・録音・録音などのプロセスがなく、点字数の印刷や録音などに興味が持たないことはありません。
- 4. 印刷用法での特性を活用することを模索しています。
- 5. 機能基板への適用の可能性があります。

【印刷用法の機能】

1. 印刷用法の機能を活用するため、機能基板への適用の可能性があります。
2. 印刷用法での特性を活用することを模索しています。
3. 印刷用法での特性を活用することを模索しています。

Toppan Printing Co. Ltd.
Pigment Dispersion (2-1)

Glass Cleaning
- Brush Cleaning
- IR-UV Drying

Black Matrix Film Formation Process
- Cleaning
- Spin Coating
- PRE-Bake
- Exposure
- Developing
- Etching
- Stripping

R. G. B Film Formation Process
- Cleaning
- Spin Coating
- PRE-Bake
- Exposure
- Developing
- Rinse
- Post-Bake

Over Coat Film Formation Process
- Cleaning
- Spin Coating
- PRE-Bake

Pigment Dispersion (2-2)

ITO Film Formation Process
- ITO Sputtering
- Spin Coating
- PRE-Bake
- Exposure
- Developing
- Etching
- Stripping

Glass Cutting
- PVA Coating
- Glass Cutting
- Dege Chamfering
- Final Cleaning

Final Inspection
- Dimension Inspection
- Color Inspection
- Optical Inspection
- Defect Inspection
- Reliability Inspection

Everest Tech. Co. Ltd.
Ink-jet Thermal transfer Printing (4-1)

1. Direct image black matrix from donor sheet onto glass.
2. Transfer colorant from donor (same process as step 1).
3. Repeat for the other two colors (same process as step 1).
4. Apply ITO common electrode and alignment layer.

Creo Inc., Canada

Ink-jet Thermal transfer Printing (4-2)

Top View

Side View

Creo Inc., Canada
The color line width is \( \sim 100 \mu m \) and the black matrix lines are \( \sim 20 \mu m \) wide.
Spin-less Coating Technology
(Slit/Patch Coating)

**Comparison of Pigment Dispersion and Ink Printing Methods for Large size CF**

<table>
<thead>
<tr>
<th>Color forming method</th>
<th>Film process</th>
<th>Mask process</th>
<th>Color layer uniformity</th>
<th>Degree of freedom</th>
<th>Saving material</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pigment Dispersion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. SC</td>
<td>3</td>
<td>3</td>
<td>○</td>
<td>○</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>2. SC+Slit</td>
<td>3</td>
<td>3</td>
<td>○</td>
<td>△</td>
<td>×</td>
<td></td>
</tr>
<tr>
<td>3. Slit (spin less)</td>
<td>3</td>
<td>3</td>
<td>×</td>
<td>○</td>
<td>○</td>
<td>◎</td>
</tr>
</tbody>
</table>

| Ink Printing         |              |              |                        |                   |                 |      |
| 1. Convex transfer   |              |              |                        |                   |                 | ○    |
| 2. Concave transfer  |              |              |                        |                   |                 | ○    |
| 3. Ink jet           | 1            | 1            | ×                      | ○                 | ○               | ○    |
| 4. Inverse transfer  |              |              |                        |                   |                 | ○    |

Toray Industries, Inc.

NCHU_Dept.CE/2005CF_notes/W. T. Cheng
Black Matrix

Cr Process for Black Matrix

Glass substrate
Cr deposition
Positive resist coating
UV exposure
Development
Etching & Striping
Process for Photosensitive BM Resin

Spin coating

Soft baking

UV Exposure

Development

Post baking

Process step | Critical parameters
Spin coating | Spin speed determines
Soft baking | Solvent baking affects
UV Exposure | Exposure dose affects
Development | Developing window

Photosensitive BM for CF (2-1)

TFT Color Filter with Brewer Science Black Matrix

Brewer Science, Inc.
### Properties of Various BM Processes

<table>
<thead>
<tr>
<th>Items</th>
<th>Photopolymer Ni plating</th>
<th>Lift off</th>
<th>Black resist</th>
<th>Black laser</th>
<th>Etch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of process</td>
<td>9</td>
<td>10</td>
<td>7</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Thickness (μm) at OD=3</td>
<td>1.0</td>
<td>0.4</td>
<td>1.0</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Reflection (%)</td>
<td>1~2</td>
<td>&lt;10</td>
<td>&lt;2</td>
<td>&lt;2</td>
<td>&lt;4</td>
</tr>
<tr>
<td>Reliability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shielding material</td>
<td>Nickel</td>
<td>Graphite</td>
<td>Carbon black</td>
<td>Carbon black</td>
<td>CrO/Cr</td>
</tr>
<tr>
<td>Cost</td>
<td>△</td>
<td>△</td>
<td>○</td>
<td>△</td>
<td>×</td>
</tr>
</tbody>
</table>

Brewer Science, Inc.

30 μm x 30 μm Pixels outlined with 10 μm wide Black Matrix

NCHU Dept.Ch.E./2005CF_notes/W. T. Cheng
Black Resist Composition

- Polymer with multi functional group
- Reactive monomer
- Carbon black
- Photo-initiator
- Solvent
- Additive

Inspection & Test
CF Defects (7-1)

Bumps

CF Defects (7-2)

White dents
**CF Defects (7-3)**

- Oil/EBR solvent
- Contaminates

**CF Defects (7-4)**

- Metal/Glass debris
- BM released
CF Defects (7-5)

- Scratch

CF Defects (7-6)

- Non-uniform Color
- Color layer peeling
CF Defects (7-7)

Contaminated scale

Requirements of CF

Display Quality
- Special transmittance
- Contrast
- Uniformity
- Flatness
- Non-defect

Compatibility with Post process
- Thermal resistance
- Chemical resistance
- Sealing property

Reliability
- Light resistance
- Thermal resistance (Long-run)
- Running
Spectral transmittance and Chromaticity of CF (Transmissive LCD TV)

LG.Philips LCD Co. Ltd.

Spectral transmittance and Chromaticity of CF (Transmissive PC Type)

LG.Philips LCD Co. Ltd.
Future Trend

Applications of LCD TV (2-1)

- AV Enjoyment Anytime Anyplace
  - In the gym
  - In the kitchen
  - In the car

- Easy to carry

- Free-Style Setting to Match Any AV Viewing Situation
  - Bedroom TV
  - Personal TV
  - AV Entertainment

Sharp Co. Ltd.
Applications of LCD TV (2-2)

In the living room
In the personal & dining room
In the bedroom

Applications of LCD TV (2-2)

Advanced Color Filter

- COA (Color Filter on Array)
- TOC (TFT on Color Filter)
- SOC (Spacer on Color Filter)
- ROC (Ribs on Color Filter)
- CF integrated LED
- CF integrated OELD
Super IPS

- Widest Viewing Angle

IPS technology allows viewers to see the same still or moving image at any vertical or horizontal angle without any substantial loss in picture quality, a factor that can be noticed even with the naked eye. The proof is indeed in the "eye".

CF on TFT Array

Source: Samsung Electronics – Display Search Conference April 2005
TFT Array on CF (5-1)

Upper glass substrate  Common electrode

TFT  BM2  Pixel  Cst

Buffer/overcoat  BM1  Lower glass substrate  CF

LG Philips LCD Co. Ltd., IDRC 2000

TFT Array on CF (5-2)

BCB (benzocyclobutene)  an organic insulation material as the passivation layer, provides more prominent higher Aperture ratio.

Conventional  BCB use TFT array

LG Philips LCD Co. Ltd., IDRC 2000
TFT Array on CF (5-3)

(a) Lower BM formation

(b) CF formation

(c) Planarization & Buffer SiN\(_x\) deposition

(d) Low temperature TFT fabrication

TFT Array on CF (5-4)

Drain electrode  Gate  Source electrode

SiN\(_x\)/Overcoat  Color filter

BM
**TFT Array on CF (5-5)**

**Spacer and Ribs on CF**

- Color filter complexity increasing
- Multi-domain viewing angle (MVA) technology requires patterned “ribs” to define domain zones
- Photo spacer replace spacer balls. Improves cell gap which improves contrast ratio and uniformity
CF Materials and Processes Development

• RBG color resist

• Photosensitive BM (Black Matrix) resin

• Color filter on array photo-resist to increase aperture numbers resulting in high definition mobile display (HDMD).

HR-Color TFT LCD
(Pixel Density >200ppi)

1. Micro Reflective Structure
2. Super High Aperture Ratio
3. High Contrast Reflection
**Needs of Photosensitive BM Resin**

- high optical density
- high volume resistivity
- low reflectivity
- high heat resistance
- light and chemical resistance
- high sensitivity and high resolution
- simple process
- aqueous alkaline development
- safer solvent based formulation
- uniform coating with no pinholes, striations or particles
- environmentally safe and low cost

---

**TFT-LCD Business Vision**

**Cost Reduction**
- Reduced material cost
- Higher throughput equipments
- Larger substrate with improved productivity

**Market Growth**
- Replacing CRT Products: Monitor, LCD-TV
- Creating new application area: Game, Web-Pad, PDA, HHP, GPS, PSP, Medical display, etc.

**Standardization**

**Evolution of Technology**

- Higher Performance
- CRT Compatibility
- Lower Cost
- Process