Multimedia – Electronic Displays: E-Paper

E-Paper & Flexible Displays

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Overview

• Introduction

• E - Paper Technologies

• E - Paper Applications

• Flexible Displays

• Summary
Definition of “Advanced Paper”

Softcopy Type

**PLD**
(Paper Like Display)

- Near display, but display
- Holds data without power
- Rewritable without printer

Hardcopy Type

**RWP**
(Re-Writable Paper)

- Near paper
- No power supply needed
- Rewritable by printer

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RECO-View™ Monochrome RWP

---

**here**

e-Book
Paper Like Displays (PLD) as Electronic Paper System

Merits
- Bi-stable
- Thin & light
- Flexible
- Design free
- Readability
- Low cost
- Ease of use

+ Display (System) + = E-Paper (System)
- Rewritable
- Re-use
- Portable
- Storage
- Data access
- Moving images

Shortcomings
- Re-use
- Data access
- Static content
- Bi-stable
- High cost
- Rigid & heavy

Shortcomings of e-paper displays?
Electronic Paper

• **Idea**: Replacement of paper (books, price tags, billboards, ...)

• **Advantage**: 'Re-write' within seconds

  • Bi-stable and reflective
    → Lowest power consumption

  • Small pixel size
    → High resolution (... 200 dpi)

  • Flexible possible
    → Requires plastics and organic electronics
E-Paper Display Market Revenue Forecast

Million USD per year

Source: DISPLAYBANK, May 2009

E-book is a large but not the only market
Main Optical Issue for E-Paper Displays: Readability

- High Whiteness (close to paper, eye adaptation)
- High reflectivity (reflectance > 40%; newspaper, magazines >80%)
- Black & white Contrast Ratio > 10:1 for readability
- Good color reproduction – the challenge for E-Paper displays
- High resolution (> 150 ppi for personal devices)
- Response time moderate if no video required

All R&D (beside materials and processes) focus on optical performance
Display Technology vs. Ambient Light: Sunlight Outdoor

Transmissive color AM LCD

Reflectivity of paper > 80%

Display is ON!

Reflective E-INK EP

E-Paper is closest to paper

Reflective b/w PM LCD

Transflective Color AM LCD

Reflective MUX LCD
Why Is Color Performance of E-Paper So Poor?

100% white

Each color filter absorbs statistically 33% (1/3)

Ideal reflector: 100%

Eo-layer: 30%

What is not drawn: color filter and eo-layer is passed twice. This is taken into account via %-values.
### Reflectivity & Color Performance of E-Paper Technologies

<table>
<thead>
<tr>
<th>Monochrome</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>White Reflectance</strong></td>
<td><strong>Lateral</strong></td>
</tr>
<tr>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>40%</td>
<td>20%</td>
</tr>
<tr>
<td>Monochrome</td>
<td><strong>Stack</strong></td>
</tr>
<tr>
<td><strong>RGB (additive)</strong></td>
<td><strong>CMY (subtractive)</strong></td>
</tr>
<tr>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td><strong>ADT</strong></td>
<td>50%**</td>
</tr>
</tbody>
</table>

(typical values, *: MAGINK, **: ADT)
# Color Prototypes 2009

## RGBW additive

- **Top view**
  - High reflectivity & good color reproduction!

## CMY subtractive

### Side view
- Limited color reproduction!

### Top view
- RGBW additive:
  - K, W, R, B, G

- CMY subtractive:
  - K, W, R, B, G

### Side view
- RGBW additive:
  - 2009

- CMY subtractive:
  - 2009
Reflectivity & Color Performance of E-Paper Technologies

- **LG EPD @ IMID 2010**
  
<table>
<thead>
<tr>
<th>Reflectance</th>
<th>Mono 45.0% / Color 26.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contrast Ratio</td>
<td>Mono 15:1 / Color 10:1</td>
</tr>
<tr>
<td>Color Saturation</td>
<td>2.9% of NTSC</td>
</tr>
</tbody>
</table>

- **AEG MIS ChLCD RGB stack**
  
  Reflectivity white: 17%
  Contrast Ratio**: 5:1
  Color Gamut: 10% NTSC
  (values from spec)

- **ADT EW CMY stack**
  
  White reflectance (color): > 50%
  Color gamut (but CMY): 70% NTSC
Contrast Ratio vs. Color Gamut of E-Paper Displays

Today

\[ C_R = 8:1 \]

Needed for color e-paper

\[ C_R = 20:1 \]

\[ C_R = 100:1 \]

• Saturated colors only with high \( C_R \) for reflective RGBW achievable
• \( C_R = 20:1 \) including ambient light reflections is very challenging
Trimode TN LCD by PIXEL QI

- **Trimode** = transmissive + transflective + reflective in one display

- **Benefit**: compromises power consumption and sunlight readability

- Best color in transmissive mode

- Monochrome (incl. grey levels) for reflective mode

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### Specification

<table>
<thead>
<tr>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>10.1” diagonal 222.72 x 125.28 mm active area</td>
</tr>
<tr>
<td>Display modes</td>
<td>Transmissive, transflective, reflective</td>
</tr>
<tr>
<td>Pixel count</td>
<td>1024 x 600 color 1024 x 3 x 600 black and white</td>
</tr>
<tr>
<td>Pixel Pitch</td>
<td>0.2175(h) x 0.2088 (v) mm</td>
</tr>
<tr>
<td>Pixel density</td>
<td>220 ppi</td>
</tr>
<tr>
<td>White-state reflectance</td>
<td>24%</td>
</tr>
<tr>
<td>Contrast ratio</td>
<td>&gt;100:1</td>
</tr>
<tr>
<td>Field of view</td>
<td>±45°</td>
</tr>
<tr>
<td>Color gamut</td>
<td>45% NTSC</td>
</tr>
<tr>
<td>Refresh rate</td>
<td>25 – 60 Hz</td>
</tr>
<tr>
<td>Power consumption</td>
<td>0.4W – 0.8W, reflective (30Hz, 60Hz) 1.3W – 1.7W, transflective (30 – 60) 2.2W – 2.6W transmissive (30 – 60 Hz)</td>
</tr>
<tr>
<td>Colors</td>
<td>262,144</td>
</tr>
<tr>
<td>Brightness</td>
<td>150 nits</td>
</tr>
</tbody>
</table>
Trimode TN LCD by PIXEL QI vs. E-INK

**E-INK** : monochromie & no video, “no” power
**PIXEL QI** : monochromie (low power) or color (high power), video

**Indoor**

**E-INK** without frontlight but readable

**PIXEL QI** excellent & color (video) but high power (transmissive)

**Outdoor**

**E-INK** higher white reflectivity

**PIXEL QI** monochromie & low power (reflective)
Trimode TN LCD by PIXEL QI

Contrast Ratio

(measurements performed @ Display Lab)

Transmissive (color)

Reflective (monochrome)

Illuminance (diffuse) /lx
Power Consumption vs Display Technology

(typical values)

- Standard AMLCD
- AMLCD + FSC + 2DD
- AMOLED 80% black
- AMOLED 80% white
- E-Paper day
- E-Paper night

Power consumption

- LCD savings depend strongly from content and ambient light
- Black background not good for e-books
- Lack of multimedia
- Most e-paper technologies are not transparent

Low power consumption is crucial for many applications!

iPad 10h
KINDLE 300h

Low power consumption is crucial for many applications!
Overview

- Introduction

- **E-Paper Technologies**

- E-Paper Applications

- Flexible Displays

- Summary
E-Paper Display Fundamentals

Cross section of a typical e-paper display

Front plane
- Substrate incl. barrier layer
- Color filter (option)

eo-layer
Here focus on eo-layer as panels are similar

Back plane
- Matrix drive, x-Si, electronics
- Substrate incl. barrier layer, reflector as option

(not to scale)
Reflective Electro - Optic Layer Technology Overview

**Electrophoretic**

- **Wet**
  - (E-INK, SIPIX, PVI, POLYMER VISION, PLASTIC LOGIC, ...)

- **Dry**
  - (BRIDGESTONE)

**Reflective LCDs**

- **Bistable TN Nematic**
  - (NEMOPTIC, ZBD, ...)

- **Reflective TN**
  - (PIXELQI, watches, ...)

- **Smectic**
  - (POLYDISPLAY, ...)

- **Guest Host**
  - (AEGMIS)

- **PDLCD**
  - (SHARP, SAMSUNG, ...)

- **ChLCD**
  - (KENT, AEGMIS, FUJITSU, ...)

**Other**

- **Electro Chemical**
  - - Electro-Chromic
    - (NTERA, SAMSUNG, ...)
  - - Electro Deposition
    - (KONICA MINOLTA, ...)

- **Electrowetting**
  - (LIQUAVISTA*, ADT, GAMMA DYNAMICS*, ...)

- **MEMS**
  - (QUALCOMM MIRASOL*, PIXTRONIC, ...)

*: low power but not fully bistable
Nomenclature for Electronic-Paper Technologies

**Electrophoresis** is the movement of an electrically charged substance under the influence of an electric field. This movement is due to the Lorentz force.

**Electrochromism** is the phenomenon displayed by some chemical species of reversibly changing color when a burst of charge is applied.

The **electrowetting** effect was originally defined as "the change in solid electrolyte contact angle due to an applied potential difference between the solid and the electrolyte". from WIKIPEDIA
Electrophoretic Displays: Charged Microcapsules

- **E-INK**
  Opposite charges in one microcapsule

- **SIPIX**
  Colored liquid in microcups

- **BRIDGESTONE**
  Air $\Rightarrow$ fast speed
Cholesteric LCDs (ChLCD)

- **Principle**: Special liquid crystal, no polarizer, PM
- **Color by dedicated LC reflection**

![Diagram of ChLCD](image)

Reflectivity (%) vs Wavelength (nm)

- AEGMIS, MAGINK
- KENT
- FUJITSU
### Other Reflective & Bistable LCD Technologies

<table>
<thead>
<tr>
<th>Bistable Nematic</th>
<th>Zenithal Bistable</th>
<th>Smectic A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BiNem by NEMOPTIC</strong></td>
<td><strong>ZBD</strong></td>
<td><strong>PolyDisplay, Kent, ...</strong></td>
</tr>
</tbody>
</table>

#### 2009: Shelf labels in mass production
- BiNem by NEMOPTIC

#### 2010: ~ 1 Mio electronic shelf labels sold
- BiNem by NEMOPTIC
- ZBD
- PolyDisplay, Kent, ...
E-Paper Display Technologies Forecast

Source: DisplaySearch 2009
Electrophoretic Wet-Type PLDs: E-INK

- **Principle:** Microcapsules with black and white, opposite charged particles
- **Color by RGB(W) filter**

**Light State**

- Electrode

**Dark State**

- Electrode

- Most advanced technology, in mass production
- E-INK eo layer is used by many panel makers
RGB + White (RGBW) square subpixel:

The white subpixel enhances the brightness and dynamic range with minimal impact on color saturation.
**Electrophoretic Wet-Type PLDs:** Microcup by SIPIX

- **Principle:** Similar E-INK but only one sort of charged particles
- **Color by colored fluids**

SIPIX microcups enable R2R production
# Electrophoretic Wet-Type PLDs: SIPIX Microcups

## Specifications

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>SPXF040</th>
<th>SPXF015</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Reflectance</td>
<td>25%</td>
<td>25%</td>
</tr>
<tr>
<td>Contrast Ratio</td>
<td>10:1</td>
<td>8:1</td>
</tr>
<tr>
<td>Response Time</td>
<td>300 ms</td>
<td>700 ms</td>
</tr>
<tr>
<td>Thickness *</td>
<td>150 μm</td>
<td>150 μm</td>
</tr>
<tr>
<td>Bistability **</td>
<td>&gt;&gt; 1 month</td>
<td>&gt;&gt; 1 month</td>
</tr>
<tr>
<td>Bending Radius</td>
<td>&lt; 2 cm</td>
<td>&lt; 2 cm</td>
</tr>
</tbody>
</table>
Electrophoretic Wet - Type PLDs: GYRICON

- **Principle**: Charged (dipole) beads, only one sort of charged particles
- **Color by color filters or beads**

- **Light State**

- **Dark State**
Electrophoretic Dry - Type PLDs: BRIDGESTONE

- **Principle:** Similar E-INK but air gap instead of fluid
- **Color by colored powder or color filters**

480x384 Passive Matrix  
4096color, 80ppi

Flexible QR-LPD  
(320×192, 80ppi)

- **Short response time:** 200 μsec, no T-dependency
- **Passive Matrix driving** (low cost) for < VGA
Electrophoretic Dry-Type PLDs: BRIDGESTONE

Color Approaches

Colored Liquid Powder

- Appearance like a printed image
- Bright colors
- Low cost (no color filters, simple manufacturing process)
- Many colors are available

Color Filter

- Utilizing matured technology
- Good color resist
- High resolution with conventional process
- Good reproduction of color image
Cholesteric LCD (ChLCD) PLDs

- **Principle**: Special liquid crystal, no polarizer
- **Color by dedicated LC reflection**

- **Reflective RGB stack without color filters etc.**
- **Passive Matrix driving (low cost)**

AEG MIS, KENT DISPLAYS, MAGINK (billboard), OPTREX, …
Other LCD-based PLDs: **Smectic A**

- **Principle:** Special liquid crystal, no polarizer, transparent possible
- **Color not yet demonstrated**

![Image of stack of liquid crystals]

*E.g. by PolyDisplay, Kent*
Other LCD-based PLDs: Bi-Stable Nematic

- **Principle:** Special liquid crystal
- **Color by RGB(W) filters**

- Contract for MP with SEIKO since 2007
- Bankrupt in 2010, maybe recovered
Other LCD-based PLDs: Polymer Dispersed LCDs

- **Principle**: Standard liquid crystal in droplets, no polarizer, not bistable
- **Color by filters**

96x96 PDLC by SHARP (SID 2009)
monochrome 50%, color 20% reflectance
Electrochromic PLDs: NTERA

- **Principle**: Color changes charging, PM and AM
- Color by liquids but limited

**Function:**

- Reversible color change depending on charging state
- Electrolyte provide a passage for charge transfer
- Here viologen molecules turn deep blue when charged at 1.2V and become colorless when discharged (viologen with reversible redox reaction)
**Electrochromic Displays: HP**

- Nematic LCD based on a novel orientational effect with solid nanoparticles

- Controlled by the optically “hidden” electrophoretic effect

- Bistable/multistable switching in a conventional LC structure

- Multistability, provided by the electrophoretically controlled birefringence effect, allows multistable color switching

- Standard LCD fabrication technique for low power high information displays

- Flexible, passive matrix drive even for large area displays possible
Membrane PLDs: Interferometric Modulator (IMOD)

- **Principle**: Electro-mechanical modulation of optical cavity
- **Color**: by optical interference of reflected light

- **High reflectivity** as no color filters or polarizers are needed

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**QUALCOMM (MIRASOL)**
Electrowetting Displays: Selected Prototypes

- **LIQUAVISTA**
  - 6.2” SVGA AM
  - 8.5” XGA AM

- **ADT**
  - Indicator

- **GAMMA DYNAMICS**
  - ~100 DPI prototype, ~10,000 pixels

(source = company)
Electrowetting PLDs: LIQUAVISTA

EW by area

Not bi-stable

‘Analogue’

Water

Reflectivity at 550 nm (%)

Contrast at 550 nm

Voltage (V)

Voltage response

- Demonstrators up to VGA
- SID 2009

Pixel: 500 x 500 µm²
Wall height: 50 µm
Black walls
15 µm magenta oil
0.8 µm fluoropolymer
**Electrowetting Display: Droplet Moving (ADT)**

- **Principle**: Droplet moving
- **Color by fluids, CMY stack**

- True ‘No Power’ display
- Passive Matrix driven (low cost)
- Pixel size 0.5 … 10mm
- High reflectivity, backlight-able
# Backlight & Ambient Light for Electrowetting by ADT

<table>
<thead>
<tr>
<th>Mode</th>
<th>Transmissive</th>
<th>Transflective</th>
<th>Reflective</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Principle</strong></td>
<td>D: Display</td>
<td>T: Transflector</td>
<td>B: Backlight</td>
</tr>
<tr>
<td></td>
<td>D T B</td>
<td></td>
<td>OFF</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Photo of 8-Segment ADT’s EW</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="8-Segment ADT’s EW" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low level light like night (low power)</td>
</tr>
<tr>
<td>Low level indoor (low backlight power)</td>
</tr>
<tr>
<td>Brighter indoor and outdoors (no power)</td>
</tr>
</tbody>
</table>
### Comparison of Major Bistable E-Paper Technologies (typical data)

<table>
<thead>
<tr>
<th>Feature</th>
<th>E-INK</th>
<th>SIPIX</th>
<th>QR-LPD</th>
<th>EC</th>
<th>EW</th>
<th>xLCD</th>
<th>MEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>B/W reflectivity*</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Backlight-able</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>++</td>
<td>- … O</td>
<td>-</td>
</tr>
<tr>
<td>Contrast ratio</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>O</td>
<td>+</td>
</tr>
<tr>
<td>Color</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Response time</td>
<td>0</td>
<td>0</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Pixel scale-ability</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Drive</td>
<td>AM</td>
<td>AM</td>
<td>PM</td>
<td>AM</td>
<td>PM</td>
<td>PM</td>
<td>AM</td>
</tr>
</tbody>
</table>

---

Too many technologies (~12) with different merits and issues

*: Data by Heikenfeld, NATURE PHOTONICS, VOL 3, MAY 2009 / other sources: Pala, DENSO, V&V
Overview

• Introduction

• E-Paper Technologies

• E-Paper Applications

• Flexible Displays

• Summary
E-Paper Applications Overview for Replacing Paper

High content & function

Small size

Watch
Smart cards
Status control

Low cost

Smart phone
E-book
Laptop?
Signs

Low content & function

Price tags

Large size

Billboards

High cost
Indicators: ADTs ‘No Power’ Electrowetting

Saving green house gases by replacing LEDs by no power indicators!

Today:
LED indicators
draw ~ 50mW each,
resulting in MW in Europe.
EU: Stand-by ≤ 0.5 W
⇒ 1 LED ≡ 10%

Tomorrow: ADT LED replacement

2s of power, lasts for ‘years’

Other applications

Household ‘true white’ display
Design:
White display even with no power

Wireless switch
Meters ... Watches basing on E-INK’s EO-Layer

The latest designs from Phosphor Watches use displays based on E Ink technology

Lowest power & reflectivity enables new designs and functionality

Feasible but yet limited acceptance

Sources = names
Smart Cards

Main requirements:

- Durability
- Bendable
- No power
  (change only when in reader or limited power to change for RFID)

Smart cards like money card or with various applications would be pushed if having a display!

Amount of money if the display fails e.g. 8888.88?

Sources = names
Electronic shelf labels

Main requirements:

- No or lowest power
- Good readability
- Low cost
- Control system enabling integration into business process

- Replace paper tags
- Business case for wireless price updates

Sources = names

- Replace paper tags
- Business case for wireless price updates

Sources = names
PDAs & Smart Phones

Main requirements:

- Foldable or rollable
- Good readability also for color

Slim line mobile device with large screen but potentially low acceptance without color

POLYMER VISION READIUS with E-INK

Sources = names
E-Book Readers Overview (not all listed)

- Jinke Electronics: Hanlin eBooks versions V8, V2, V3,
- Sony Portable Reader PRS-500, Libre EBR_1000, PRS-505
- IReX Technologies: iLiad ER-0100
- Hon Hai Precision Industries: Amazon Kindle
- ERead: STAReBOOK STK101, Bookeen
- Frontech-Fujitsu: FLEPiA A4, FLEPiA A5
- Booken: cybook
- Polymer Vision: Readius
- IRiver: Iriver e-Book
- NeoLux of South Korea: NUTT
- Ricavision: Home E-Reader
- Apple: iBook
- …

• Larger size for newspapers (eases ‘distribution’)
• E-books compete with netbooks and smart phones
• Advantage is sunlight readability and battery life
• Is this ‘enough’ to buy an additional device?
  (because of limited multimedia performance)

“monochrome”

Color prototype(s)

not all are sold in Europe
Signs

Main requirements:

• Large(r) size

• Sunlight readability

• System integration incl. wireless data transmission and solar powered

Many advantages but potentially limited acceptance without color for some applications

Sources = names
Billboards

Main requirements:

- Large size (10 m²)
- Sunlight readability
- Mullion-free
- Excellent color reproduction
- Wide viewing angle

Large market with only LED-walls as competitor
## Applications for Major Bistable E-Paper Technologies

<table>
<thead>
<tr>
<th>(typical data)</th>
<th>E-INK</th>
<th>SIPIX</th>
<th>QR-LPD</th>
<th>EC</th>
<th>ADT</th>
<th>xLCD</th>
<th>MEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicators</td>
<td>+</td>
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<td>O</td>
<td>+</td>
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<td>-</td>
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<tr>
<td>Watches</td>
<td>+</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>O</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Smart Cards</td>
<td>+</td>
<td>+</td>
<td>O</td>
<td>O</td>
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<tr>
<td>Shelf Labels</td>
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<td>+</td>
<td>+</td>
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<tr>
<td>Mobile multimedia</td>
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<td>E-Books</td>
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<td>Newspaper</td>
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<td>-</td>
<td>O</td>
<td>+</td>
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<tr>
<td>Signs</td>
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<td>O</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Billboard</td>
<td>O</td>
<td>-</td>
<td>O</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Electrophoretic is suitable for many applications but other technologies outperform EP in some markets like signs!
Overview

• Introduction

• E-Paper Technologies

• E-Paper Applications

• Flexible Displays

• Summary
**What means ‘Flexible’?**

<table>
<thead>
<tr>
<th>Conformal</th>
<th>Bendable</th>
<th>Rollable</th>
</tr>
</thead>
</table>

- Conformal
- Bendable
- Rollable

... also that

... or foldable?
Flexible Displays for Innovative Devices

Today’s Prototypes

Vision
Technical Challenges For Flexible Displays

- Process temperatures for plastic substrates (as many PLD require AM)
- Transparent semiconductors for electrodes (PEDOT, …)
- Substrate quality incl. planarization layer
- Encapsulation (barrier to moisture, … mainly OLEDs)
- Mechanical stress & strain (keeping the two substrates together)
- Manufacturability at reasonable cost
- Interconnects for flexible substrates
- Glass based infrastructure mass production

- Active Matrix on flexible substrates (next slide)
What are the Requirements for ‘Flexible’?

- Substrates have to be thin and light weight
- Display material must be able to work under strain
- Most display technologies need an Active Matrix, but Passive Matrix makes the transition from glass to polymeric substrates much simpler

Core issues that typically come up:
- Lifetime
- Keeping the two substrates together
- Fabrication
- Flexible interconnects

What about the electronics system?

What are the new applications, customers …?
Producing Displays like Printing Paper (BRIDGESTONE)

Production

Example of roll-to-roll manufacturing equipment (Rib developing system)

High speed R2R with micron accuracy!

Metal electrode PET base back plane manufactured by roll-to-roll process
Electrophoretic Wet - Type PLDs: SIPIX Microcups

Roll-to-roll process feasible, inkjet printing only for color displays
Flexible Active Matrix Technologies

- Thin glass (TOSHIBA) Easy to adapt for displays but not very flexible
- Stainless steel (E-INK, PHILIPS, …) Easy but expensive
- High T\(_g\) plastic (SAMSUNG, SHARP, …) Prototypes but manufacturability?
- Silicon transfer process (SONY, SEIKO-EPSON, …)
- Organic TFT
  - Mask based (POLYMER VISION, …)
  - Print based (XEROX, PLASTIC LOGIC, …)

Why not silicon TFT backplane on flexible plastic substrates?

Silicon is
- Smooth (easy to process on)
- Do not distort with changes in temperature or by solvent absorption
Organic TFTs Overview

Organic semiconductors are

- Inherently flexible
- Solution processing
- Deposition at room temperature

However

- New technology so materials and processes are under development
- Stability can be poor, depending on the materials
- Low current, low conductivity (~1/1,000) and low mobility compared to a-Si
Organic TFTs Manufacturing Overview

• **Mask based processes** (POLYMER VISION)
  - Semiconductor deposited at low temperature
  - Low cost PEN substrate
  - Very flexible
  - Limitations on size and ppi (caused by mask)
  - 5 mask steps → high cost

• **Print process** (PLASTIC LOGIC)
  - Solution processing, printing and laser patterning (low temperature)
  - Local alignment of patterning head
  - Multilayer pixel architecture
  - Few steps without mask alignment
Why Inkjet Technique for Displays?

<table>
<thead>
<tr>
<th></th>
<th>Lithography</th>
<th>Inkjet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>Huge</td>
<td>Compact</td>
</tr>
<tr>
<td>Investment</td>
<td>Heavy</td>
<td>Moderate</td>
</tr>
<tr>
<td>Resources</td>
<td>Massive</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

AM FPDs are getting larger and larger
→ Inkjetting could solve lithography problems

Drawbacks of printing
- Conductors (for AM) are critical (Ni is a candidate)!
- OLED material more feasible but still some issues
Requirements for Inkjet Printing

- Maintenance of head
- Alignment accuracy (nozzle position)
- Jetting angle
- Ink (formulation, coffee cup, …)
Examples of Inkjet Printers

LITREX

DIMATIX
for lab use

ITI

Inkjet printing of LCD spacers
SID 2006 UEDA
Ink jet printing to pattern polymers for full colour displays

Spin coating is used for monochrome LEP devices
Inkjet Printed S/D and Gate Electrodes

All electrodes can be accurately formed using inkjet process!
Inkjet Printed OLEDs

Screen printing also demonstrated for OLEDs

Advantages

• High resolution demonstrated
• Higher material utilisation than spin coating
• Scalability to large-size glass
• Versatile digital printing process

Challenges

• Demonstrate high yield process
• System complexity scales with throughput
• Materials development required
• Equipment development required

DUPONT DISPLAYS
Producing Displays like Printing Paper (BRIDGESTONE)

Production

Example of roll-to-roll manufacturing equipment (Rib developing system)

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Metal electrode PET base back plane manufactured by roll-to-roll process
Electrophoretic Wet-Type PLDs: SIPIX Microcups

Roll-to-roll process feasible, inkjet printing only for color displays

1. Coating
   - Plastic Substrate
   - Transparent Conductor

2. Microembossing
   - Sealed Microcup®

Lamination  Adhesive  Filling & Sealing  Inkjet printing
Overview

• Introduction

• E - Paper Technologies

• E - Paper Applications

• Flexible Displays

• Summary
Vision : Living Room with Flexible E-Paper Displays
## E-Paper Panel Strategies

<table>
<thead>
<tr>
<th></th>
<th>Today</th>
<th>Current Target</th>
<th>Future Target</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electro-optic Layer</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B/W</td>
<td></td>
<td>Color</td>
<td>Moving Picture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(reflectivity)</td>
<td>(response time)</td>
</tr>
<tr>
<td><strong>Back Plane</strong></td>
<td></td>
<td>Printed</td>
<td>All printed</td>
</tr>
<tr>
<td>a-Si, p-Si</td>
<td></td>
<td>O-TFT</td>
<td>back plane</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(manufacturability)</td>
<td>incl. drivers</td>
</tr>
<tr>
<td><strong>Panel</strong></td>
<td></td>
<td>Flexible</td>
<td>(current target will need long time)</td>
</tr>
<tr>
<td>rigid</td>
<td></td>
<td>R2R</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(manufacturability)</td>
<td></td>
</tr>
</tbody>
</table>
E-Paper is Green: Saving Materials & Preserving Nature
Green: Saving Space and Energy with New Displays

From 100 W via 10 W to nearly zero power!
E-Paper Prototypes with Enhanced Touch Capabilities

11.5" Flexible E-Paper with In-Cell Touch

- Display Type: EPD (Electrophoretic Display)
- Touch Type: Photo Sensing Type
- Active Area: 233.6 mm (W) x 175.2 mm (H)
- Panel Thickness: 0.601 mm (with *PS)
  0.3 mm (without *PS)
- Weight: 82 ± 5 g
- Display Resolution: 1600 X mono X 1200
- Touch Resolution: 2 Sensor / 10 X 12 pixel
- Pixel Density: 174 ppi
- Colors: Monochrome (4 Gray)
- Reflectance: 35%
- Contrast Ratio: ≥ 6:1
- Viewing Angle: 70°/70°/70°/70° (U/D/R/L)
- Driving Voltage: ±15V
* PS = Protect Sheet

LG with E-INK

Touch Writing Tablet by Kent Displays (ChLCD)
Designers' Visions

Foldable interactive display with stylus input

Carnegie Mellon University, SMART Technologies, Alberta

Long term visions since years but still many years to go

Roll-up Laptop

Wireless system integration

Electronic Newspaper

Source: V&V
Summary

E-paper has the potential to revolutionise mobile computing

(Too ?) Many technologies for e-paper today

There are many applications beside e-readers for e-paper displays

To do: color reproduction, switching speed and flexible (AM) substrates

Flexible displays enable new products and roll-to-roll manufacturing

What is your idea for a striking e-paper application?
Case Study / Questions to think about

• Reasons why E-paper will revolutionise mobile computing

• Arguments why this would not happened for many applications

• How can we select (invest) today in the most promising candidates

• Flexibility will give (bi-stable) displays break-through applications

• Flexible technology enables roll-to-roll manufacturing – but what is about cost and benefit for high resolution displays?

• Compare today’s notebooks vs. (future) e-readers

• E-Paper applications for the industry
Case Study: E-Reader

Kindle eReader, Wi-Fi, 15 cm (6 Zoll) E Ink Display, deutsches Menü
von Amazon

EUR 99,00 Kostenlose Lieferung. Details

Like paper but comfort for mobile reading?

- Compare price to laptops!
- Business model similar to mobile phones?
Case Study: E-Reader

German laws vs. US

Print List Price: $26.95
Kindle Price: $9.99
You Save: $16.96 (63%)
(includes FREE wireless delivery)
## Case Study: E-Reader

<table>
<thead>
<tr>
<th>Display</th>
<th>15 cm (6 Zoll) E Ink-Display, optimiert mit geschützter Waveform- und Font-Technologie, Auflösung von 600 x 800 Pixel bei 167 dpi, 16 Graustufen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abmessungen</td>
<td>166 mm x 114 mm x 8,7 mm</td>
</tr>
<tr>
<td>Gewicht</td>
<td>170 Gramm</td>
</tr>
<tr>
<td>Systemanforderungen</td>
<td>Keine, der eReader funktioniert drahtlos und benötigt keinen Computer</td>
</tr>
<tr>
<td>Geräte-Speicher</td>
<td>2 GB intern (ca. 1,25 GB stehen für Nutzerinhalte zur Verfügung)</td>
</tr>
<tr>
<td>Cloud-Speicher</td>
<td>Unbegrenzt für Amazon-Inhalte</td>
</tr>
<tr>
<td>Akku-Laufzeit</td>
<td>Ein vollgeladener Akku hält bei ausgeschalteteter Wi-Fi-Funktion bis zu einem Monat, wenn Sie täglich bis zu einer halben Stunde lesen. Mit dauerhaft eingeschalteter Wi-Fi-Funktion hält er bis zu 3 Wochen. Die Akku-Laufzeit variiert je nach Nutzung, z. B. ob Sie im Kindle-Shop einkaufen, den Browser benutzen oder Inhalte herunterladen.</td>
</tr>
<tr>
<td>Ladezeit</td>
<td>Lässt sich mithilfe des mitgelieferten USB 2.0 Kabels über einen Computer in 3 Stunden voll aufladen. Optionales Netzteil separat erhältlich.</td>
</tr>
</tbody>
</table>
**Case Study: E-Reader**

| **Wi-Fi / WLAN** | Unterstützt öffentliche und private Wi-Fi-Netzwerke und Hotspots, die einen folgender Standards nutzen: 802.11b, 802.11g oder 802.11n (im b- oder g-Kompatibilitätsmodus). Kindle unterstützt die Sicherheitstechnologien WEP, WPA und WPA2 mit Kennwortauthentifizierung; er verbindet sich nicht mit WPA- und WPA2-gesicherten Netzwerken mit 802.1X Authentifizierungsmethoden; unterstützt keine Ad-hoc (oder Peer-to-Peer) Wi-Fi-Netzwerke. |
| **USB-Anschluss** | USB 2.0 (Micro-B USB) |
| **Unterstützte Formate** | Kindle (AZW), TXT, PDF, ungeschützte MOBI, PRC nativ; HTML, DOC, DOCX, JPEG, GIF, PNG, BMP nach Konvertierung. |
| **Dokumentation** | Kurzanleitung (im Lieferumfang enthalten); Kindle Benutzerhandbuch (auf dem eReader vorinstalliert). Weitere Informationen sind online erhältlich. |
| **Garantie** | 1 Jahr Herstellergarantie. 2 Jahre Extragarantie kann für Kunden aus Deutschland optional von Squaretrade erworben werden. Die Benutzung des Kindle unterliegt der Lizenzvereinbarung und Nutzungsbedingungen. |
| **Lieferumfang** | Kindle eReader, USB 2.0 Kabel, and Kurzanleitung. |
Case Study: E-Reader

And color??

E.g. for internet, multimedia, …

Technical Details

<table>
<thead>
<tr>
<th>Display</th>
<th>7” multi-touch display with IPS (in-plane switching) technology and anti-reflective treatment, 1024 x 600 pixel resolution at 169 ppi, 16 million colors.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (in inches)</td>
<td>7.5” x 4.7” x 0.45” (190 mm x 120 mm x 11.4 mm).</td>
</tr>
<tr>
<td>Weight</td>
<td>14.6 ounces (413 grams).</td>
</tr>
<tr>
<td>Battery Life</td>
<td>Up to 8 hours of continuous reading or 7.5 hours of video playback, with wireless off. Battery life will vary based on wireless usage, such as web browsing and downloading content.</td>
</tr>
</tbody>
</table>

It has an LCD!

(AMAZON has announced over the years that they will come up with color E-INK display!)
Case Study: E-Reader

- Will monochrome e-book readers survive?
  (additional device for commuting, travel, etc. as smartphone is a must)

- Will color e-book readers survive with “dedicated” hardware or will they be replace by tablets?

- What is the business model of the future?
  Hardware, content for various devices, …
Thank you for your attention!

Further information & sources:
- Conferences on (flexible) E-Paper
- Society for Information Display www.sid.org
- Veritas et Visus Flexible Substrate www.veritasetvisus.com/