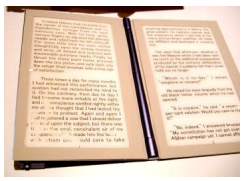

Technical Advances in E-Paper

Karlheinz Blankenbach

Pforzheim University, Germany

ETSI Green Agenda Seminar, Cannes, 26th Nov. 2009

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Overview

„Substituting bits for materials by advanced displays“

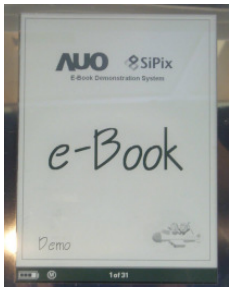
Definition of "Advanced Paper"

Softcopy type

PLD
(Paper Like Display)

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

here



Hardcopy type

RWP
(Re-Writable Paper)

- Near paper
- Rewritable by printer

【RECO-View™ Monochrome RWP

Paper Like Displays (PLD) as Electronic Paper System

Paper + **Display (System)** = **E-Paper (System)**

Merits

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

+

- Rewritable
- Re-use
- Portable
- Storage
- Data access
- Moving images

→

Short-comings

- Re-use
- Data access
- Static content

- Bi-stable
- High cost
- Rigid & heavy

Overview

„The optical challenges for e-paper are reflectivity and color“

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

Reflective b/w PM LCD
Transmissive color AM LCD

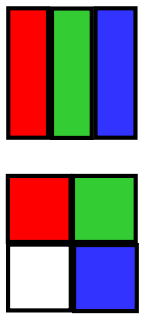
Transflective
Color AM LCD

Reflective E-Paper
Reflective MUX LCD

How to Achieve Color for E-Paper Displays

White Reflectance

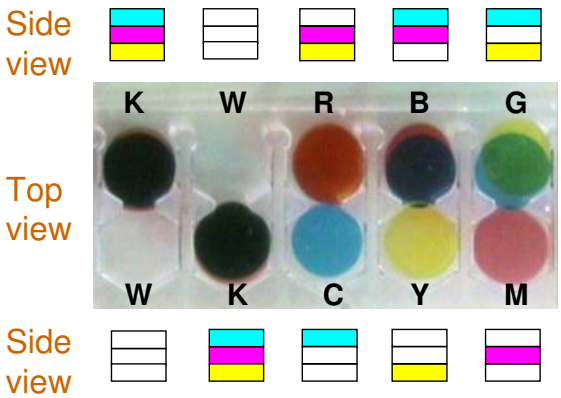
- **Additive**
  - Conventional RGB
  - RGBW for higher reflectivity but lower color gamut
  - Stacked RGB-reflective (ChLCD)



☹

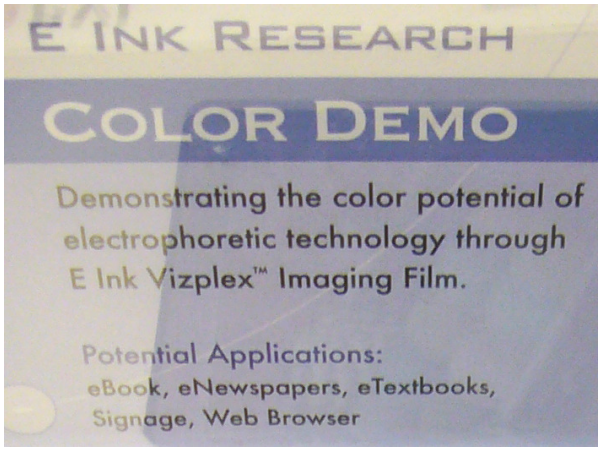
😐

- **Subtractive**
  - 3 panels CMY (printer-like)
  - Issue: parallax, only good for large pixel size



☺

Color Prototype 2009 : E-INK

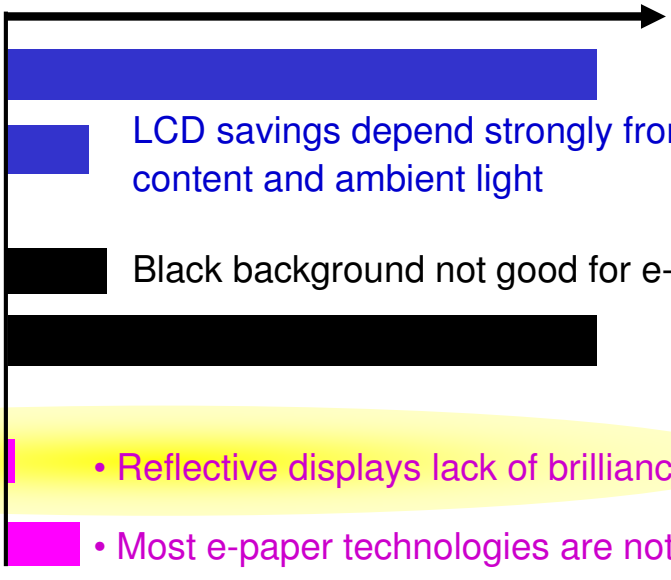


Color reproduction until today (2009) very limited !

Energy Consumption & Power Saving Strategies

(typical values)

Power consumption



Standard AMLCD

AMLCD + FSC + 2DD

LCD savings depend strongly from content and ambient light

AMOLED 80% black

Black background not good for e-books

AMOLED 80% white

E-Paper day

• Reflective displays lack of brilliance

E-Paper night

• Most e-paper technologies are not transparent

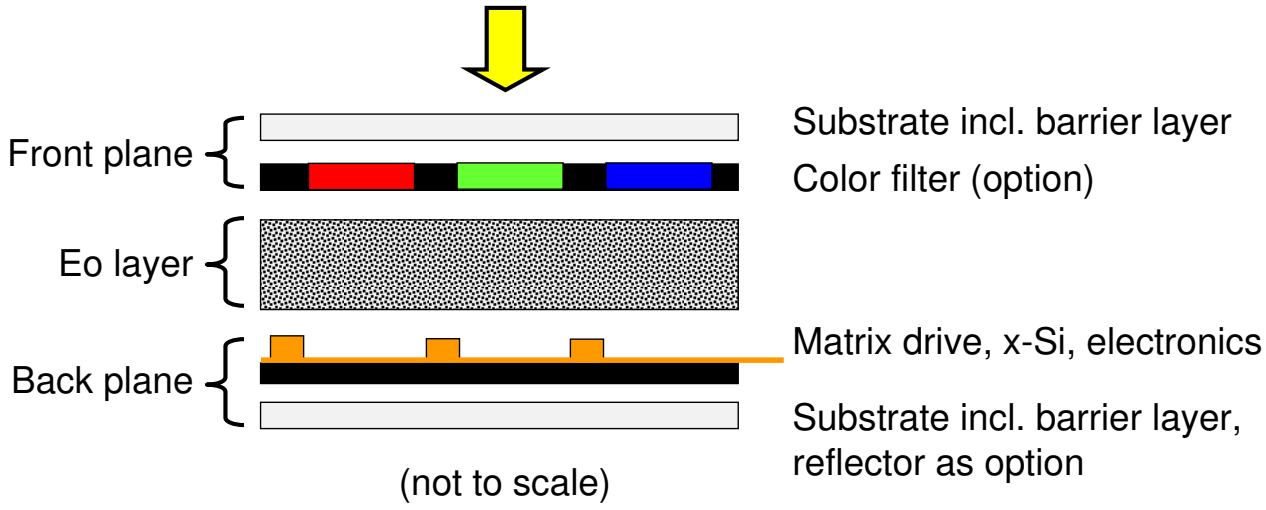
Low power consumption is the only way for many applications !

Overview

„There exist more bistable e-paper technologies than E-INK“

E-Paper Display Fundamentals

Cross section of a typical e-paper display



Topics of R&D are on materials, electronics and processes !

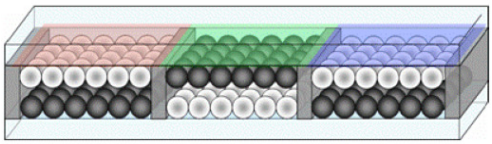
E-Paper Panel Strategies

	Today	Current Target	Future Target
Electro-optic Layer	B&W	Color (reflectivity)	Moving Picture (response time)
Back Plane	a-Si, p-Si	Printed O-TFT (manufacturability)	All printed back plane incl. drivers
Planel	rigid	Flexible R2R (manufacturability)	(current target will need long time)

Bistable E-Paper Technologies Overview

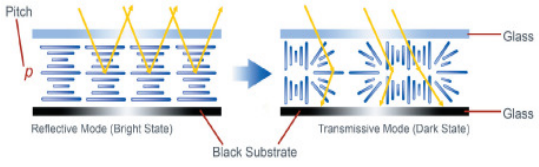
Electrophoretic

RGB(W) color, flexible, QR-LCD fast



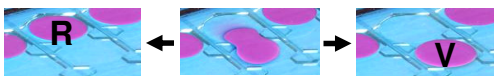
Cholesteric LCD (ChLCD)

RGB reflective color stack, slow T_R



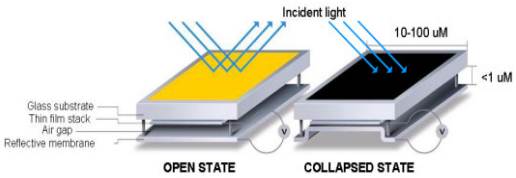
Electrowetting (ADT)

CMY color stack, no power



MEMS (MIRASOL)

RGB(W) color



Comparison of Major Bistable E-Paper Technologies

(typical data)	E-INK	SIPIX	QR-LPD	EC	ADT	xLCD	MEMS
B/W reflectivity*	+	+	+	++	++	+	+
Contrast ratio	+	+	+	+	++	o	+
Color	o	+	o	-	+	+	+
Response time	o	o	++	-	-	o	+
Pixel scale-ability	+	-	-	+	+	+	-
Drive	AM	AM	PM	AM	PM	PM	AM

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

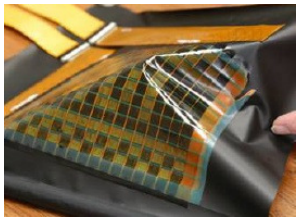
*: Data by Heikenfeld, NATURE PHOTONICS, VOL 3, MAY 2009 / other sources: Pala, DENSO, V&V

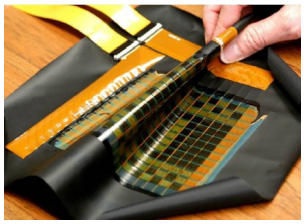
Overview

„Overcoming today's limited rigid square design“

What means 'Flexible' ?

Conformal	Bendable	Rollable
		

… also that 

… or foldable ? 

Technical Challenges For Flexible Displays

- Process temperatures for plastic substrates
- Transparent semiconductors for electrodes (PEDOT, …)
- Substrate quality incl. planarization layer
- Encapsulation (barrier to moisture, … mainly OLEDs)
- Mechanical stress & strain
- Manufacturability at reasonable cost
- Active Matrix on flexible substrates

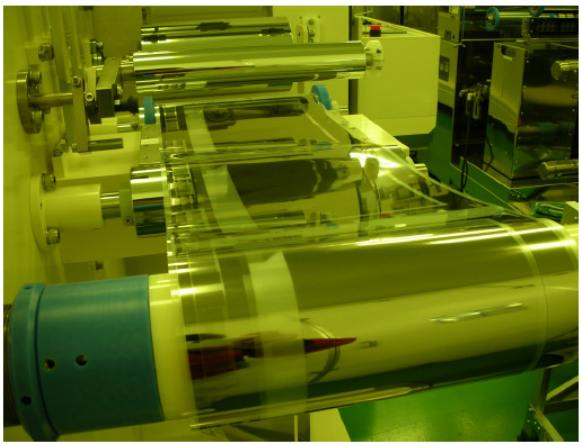
  e.g. **OTFT**
  - Mask process (POLYMER VISION)
  - Print process (PLASTIC LOGIC)

Red brick wall symbolizes limitations

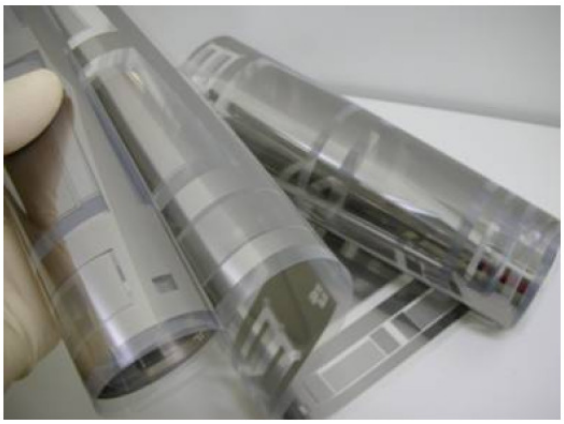
Electrophoretic Dry - Type PLDs : BRIDGESTONE

Production

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



Brick wall:
High speed R2R with micron accuracy!

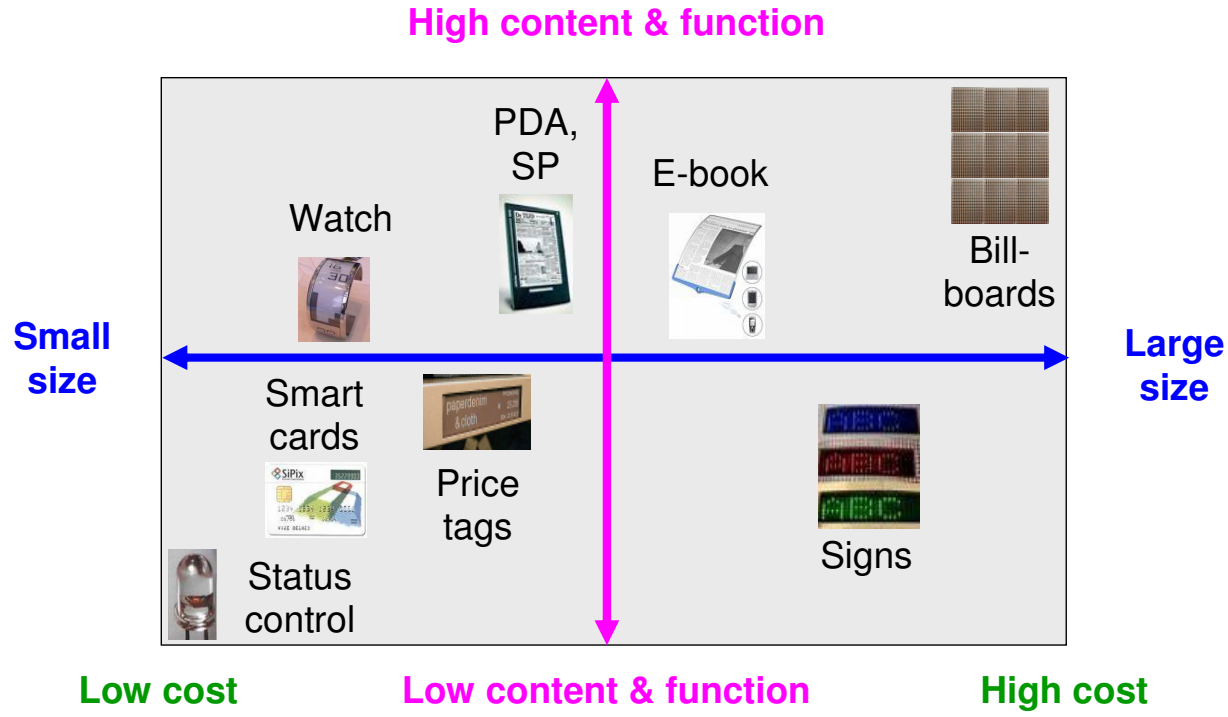


Metal electrode PET base back plane manufactured by roll-to-roll process

Overview

„There are more applications for e-paper than e-readers“

E-Paper Applications Overview



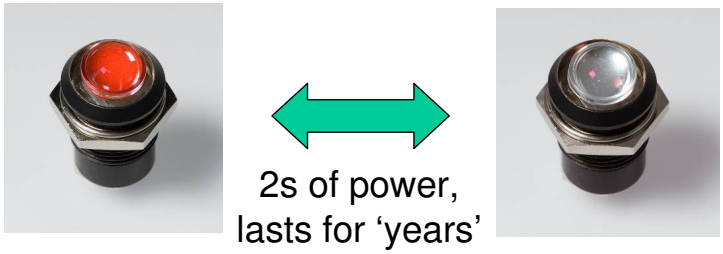
Indicators : ADTs 'No Power' Electrowetting

Saving x atomic power plants by replacing LEDs by no power indicators !

Today:

LED indicators
draw ~ 50mW each
Results in MW in Europe

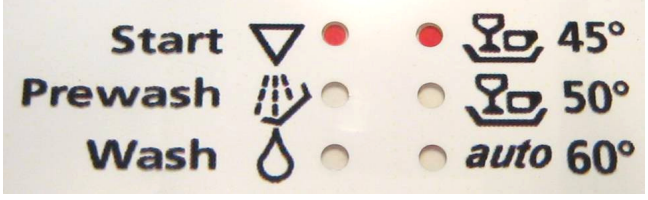
ADT LED replacement



Other applications

Design:
White display
even with
no power

Household 'true white' display



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

Feasable but yet limited acceptance

Sources = names

Smart Cards

Main requirements:

- Durability
- Bendable

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

SIPIX EP
MICROCUPS

SIEMENS EC
(quitted)

Smart cards with various applications need display like money card

Sources = names

Electronic shelf labels

Main requirements:

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

Source: Bridgestone

Source: Pricer - Sipix

Source: NCR
STN-based shelf label

Source: ZBD Displays

Business case for wireless price updates

Sources = names

PDAs & Smart Phones

Main requirements:

- Foldable or roll able
- Good readability also for color

POLYMER VISION
READIUS with E-INK

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

Sources = names

E-Book Readers Overview (not all listed) all monochrome

- 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
- …


iLiad


Kindle

cybook

not all are sold in Europe

Color only prototypes

E-books compete with netbooks and smart phones
Advantage is sunlight readability and battery life.
Is this enough to buy an additional device?

Signs

Main requirements:

- Large(r) size
- Sunlight readability
- System integration

POLYDISPLAY Smectic A

AEGMIS ChLCD

SAMSUNG E-INK

Many advantages but potentially low acceptance without color for some applications

VOSSLOH E-INK

Sources = names

Billboards

Main requirements:

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

MAGINK tiled ChLCD reflective RGB stacks

Large market with only LED-walls as competitor

Applications for Major Bistable E-Paper Technologies

(typical data)	E-INK	SIPIX	QR-LPD	EC	ADT	xLCD	MEMS
Indicators	+	+	o	+	+	-	-
Watches	+	o	o	o	o	+	+
Smart Cards	+	+	o	o	-	-	-
Shelf Labels	+	+	o	-	-	+	+
Smartphone	+	o	+	-	-	o	+
E-Books	+	o	+	-	o	+	-
Signs	+	o	+	-	+	+	-
Billboard	o	-	o	-	+	+	-

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

Overview

„Enabling mobile computing by advanced displays“

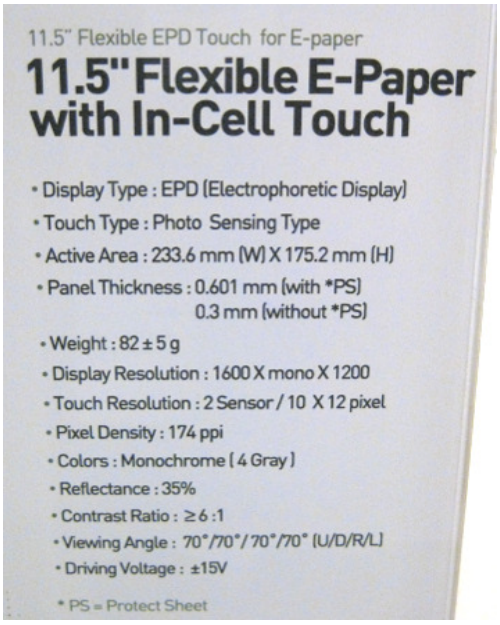
Green: Saving Materials & Preserving Nature

Go green

Green: Saving Space and Energy with New Displays

From 100 W via 10 W to nearly zero power !

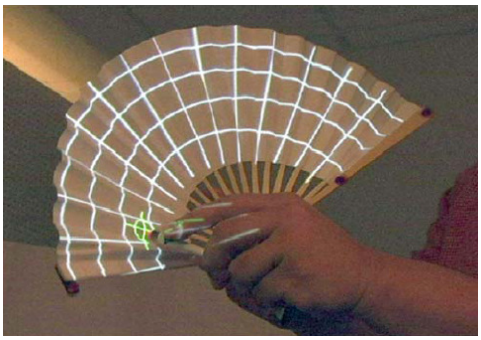
2009 Prototypes with Enhanced Touch Capabilities



LG with E-INK

Touch Writing Tablet by Kent Displays ChLCD

Visions



Foldable interactive display with stylus input

Carnegie Mellon University, SMART Technologies, Alberta

Long term vision since years but still years ahead

Roll-up Laptop

Source: V&V

Electronic Newspaper

Source: V&V

Summary

- E-paper would / will revolutionise mobile computing
- (Too ?) Many candidates for e-paper today
- There are many applications beside e-readers for e-paper displays
- To do: enhance color reproduction and switching speed, flexible substrates
- Flexible technology enables roll-to-roll manufacturing
- New products require new standards

What is your idea for a striking e-paper application ?

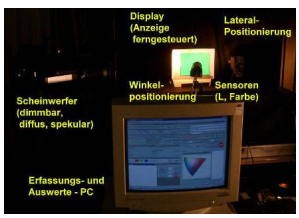
Further information & sources:

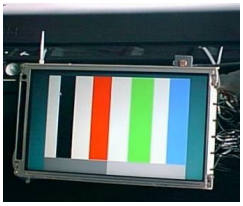
- Conferences on (flexible) E-Paper
- Society for Information Display
  www.sid.org
- Veritas et Visus Flexible Substrate
  www.veritasetvisus.com/

Prof. Dr. K. Blankenbach

- Chairman of ED electronic displays Conference
- Member of the board of DFF (German Flat Panel Forum) DFF
- Chairman adria. steering committee

Bildschirmexperte Blankenbach (r.)*: Pixelfehler, falsche Farben, unscharfe Kanten



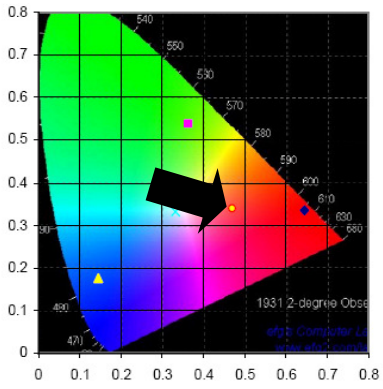


Display systems

- R&D 'around' displays (HW & SW)
- Funded by BMBF, BMWI, industry, …
- Many references, large projects, …
- Prototypes, evaluation, workshops, …

Contrast Ratio vs. Color Gamut of E-Paper Displays

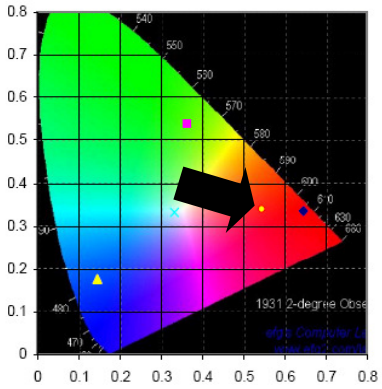
Today



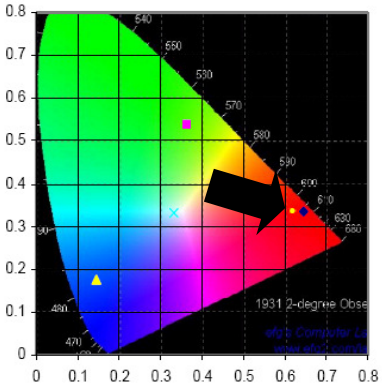
C_R = 8:1

Needed for color e-paper

iRex Techn.



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

Reflective E-Paper Display Technologies Overview

- **Electrophoretic**
  - Wet (E-INK, SIPIX, PHILIPS, GYRICON, …)
  - Dry (BRIDGESTONE)
- **Electro Chemical**
  - Electro-Chromic (NTERA, SAMSUNG, …)
  - Electro Deposition (KONICA MINOLTA, …)
- **LCDs**
  - Bistable TN Nematic (Nemoptic, ZBD, …)
  - Smectic (POLYDISPLAY, …)
  - Guest Host
  - PDLCD* (SHARP, …)
  - Cholesteric Crystal Displays (KENT, AEGMIS, …)
- **Electrowetting** (LIQUAVISTA*, ADT, GAMMA DYNAMICS, …)
- **MEMS** (QUALCOMM MIRASOL, …)

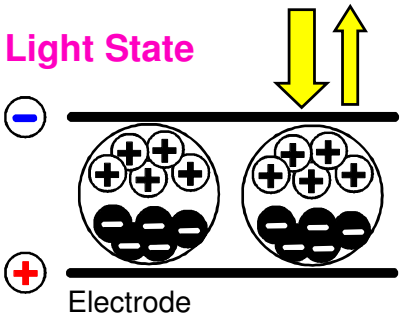
Too many ?

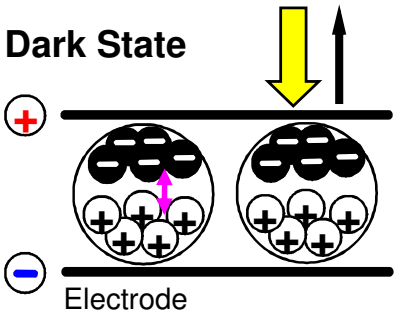
(also in terms of time for this talk – not all will be presented)

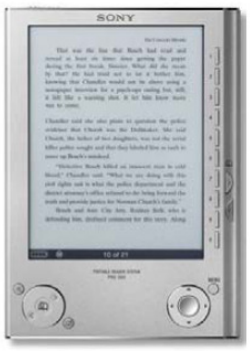
*: not bistable

Electrophoretic Wet - Type PLDs : E - INK

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



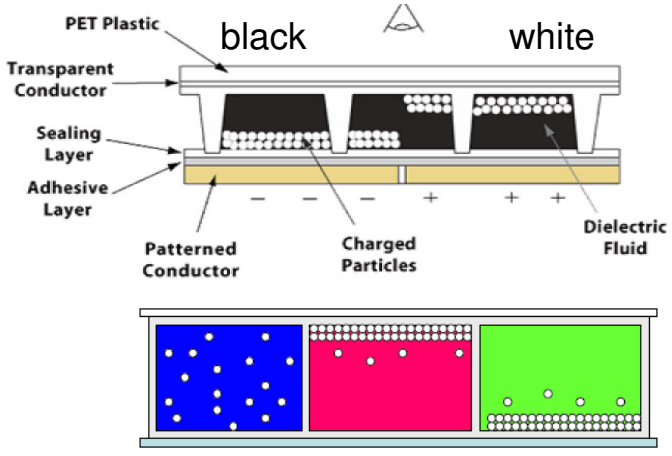


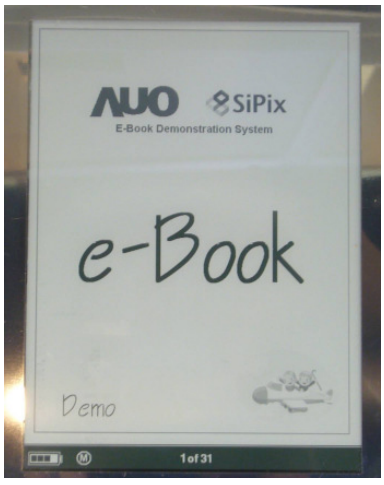


- **Most advanced technology, in mass production**
- **E-INK eo layer is used by many panel makers**

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 Dry - Type PLDs : BRIDGESTONE

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

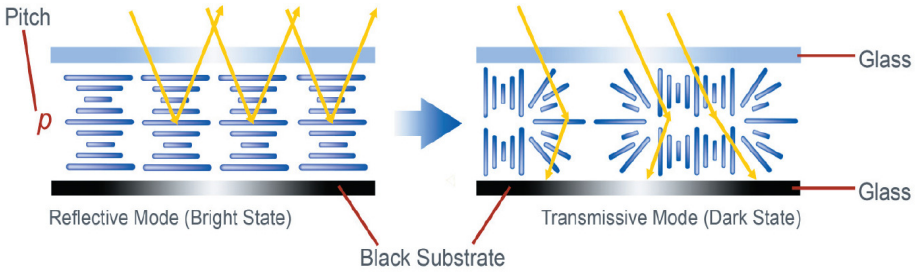
PET base flexible QR-LPD
(320×192, 80ppi)

480x384 Passive Matrix
4096color, 80ppi

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

Cholesteric LCD PLDs

- Principle: Special liquid crystal
- Color by dedicated LC reflection

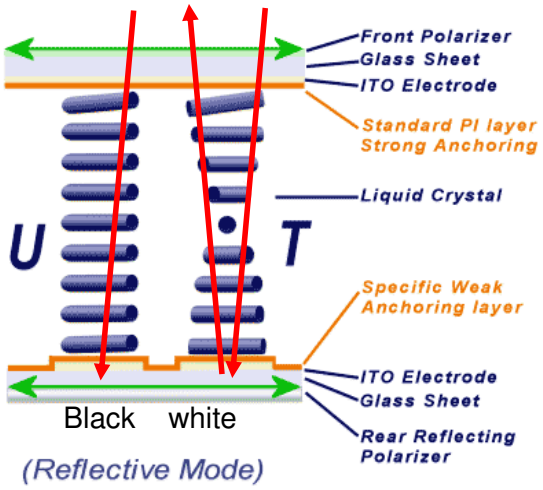


OPTREX,
AEG MIS,
KENT DISPLAYS,
MAGINK
(see billboard), …

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

Other LCD - based PLDs : Bi - Stable Nematic

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

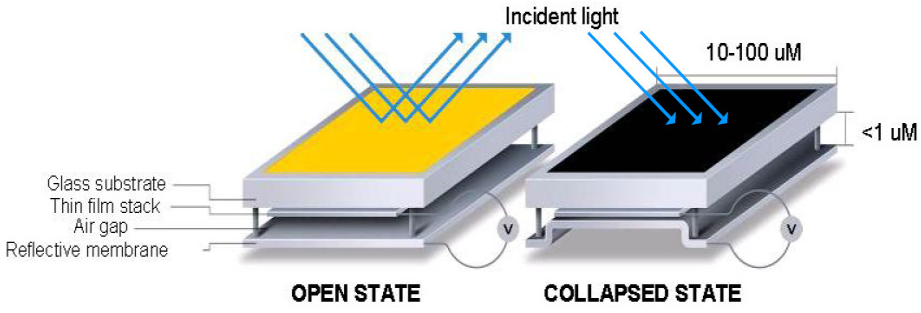


NEMOTPIC

- **Contract for MP with SEIKO since 2007**

Membrane PLDs : Interferometric Modulator (IMOD)

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

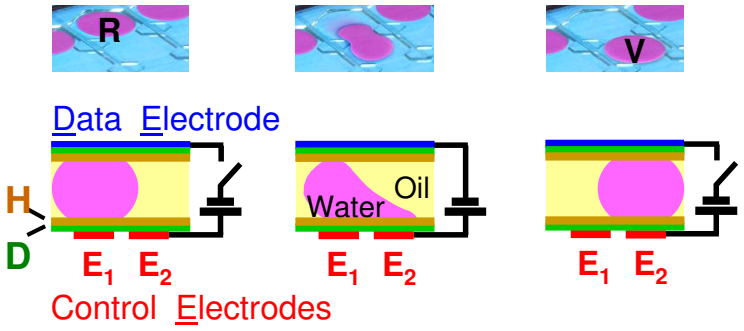


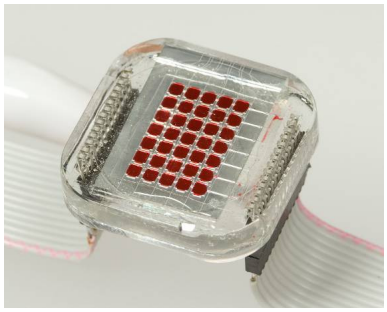
QUALCOMM (MIRASOL)

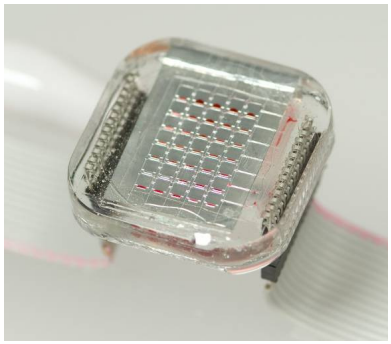
- **High reflectivity as no color filters or polarizers are needed**

Electrowetting Display : Droplet Moving (ADT)

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



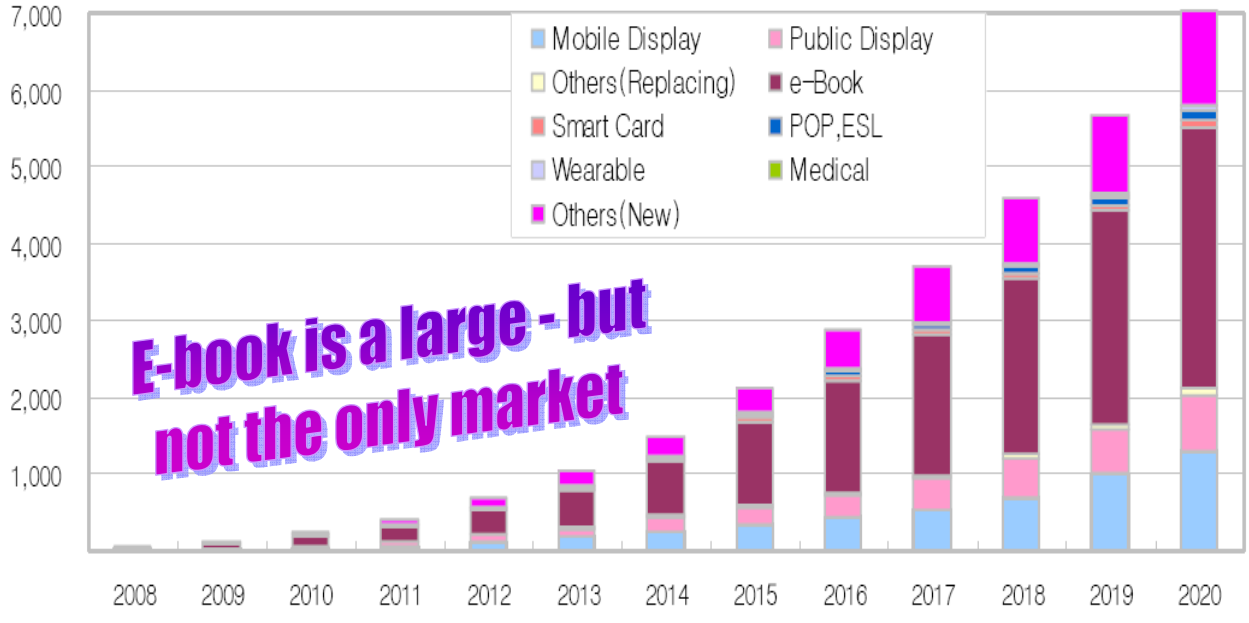




- **True 'No Power' display**
- **Passive Matrix driven (low cost)**
- **Pixel size 0.5 … 10mm**
- **High reflectivity, backlight-able**

E-Paper Display Market Revenue Forecast

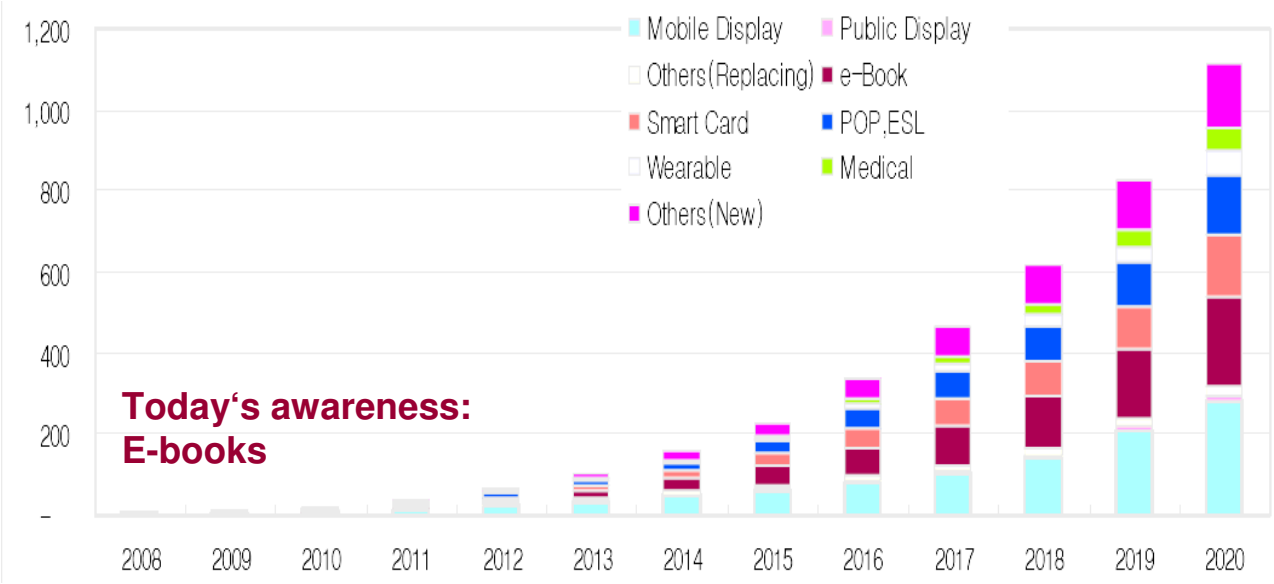
Million USD per year



Source: DISPLAYBANK, May 2009

E-Paper Market Forecast by Volume

Million pieces per year



Source: Displaybank, May 2009

Mobile displays are supposed to have higher volumes than e-books in 2020