1. Next Generation Display Technology
Next Generation Displays?

(1) Jumbo Interactive Screen Displays

(2) Super High Resolution Display
   \[ FHD \rightarrow UHD \rightarrow \text{Super High Vision} \]

(3) Flexible Display
   \[ \text{Bendable} \rightarrow \text{Foldable} \rightarrow \text{Wearable / True Flexible} \]

(4) Transparent Display

(5) Low Cost OLED-TV Manufacturing
   \[ \text{Printed OLED TV} \]
(1) Jumbo Screen Displays

- Large-format multi-touch applications

- Education
- Gaming Tables
- Advertising
- Digital Signage
- Industrial Control
- Vending

Source: Zytronic
Education Displays with Interactive Sensors

- **e-Board**
  - Large size touch screen
  - Writing capability

- **e-Desk**
  - Sensor imbedded in display
Video Wall with Narrow Seam

7.3mm → 5.7 mm → 5.3 mm →
(46")   (55")   (46")

5.3 mm

Samsung 46” x 4
Narrow bezel Video Wall

184” Video Wall   (46”x 16)
(2) Super High Resolution Displays

[ FHD $\rightarrow$ UD $\rightarrow$ Super Hi-Vision ]

2M       8M       32M pixels
Super Hi-Vision Theater at the World Expo

Surround sound (22.2 Ch) + 3D Super Hi-vision Jumbo Screen

⇒ Maximum Reality (最大臨場感)

Shanghai World Expo Theme Pavilion
(3) Flexible Displays

- Current Market Replacement (Thin & light panel)
- New Market Creation (Color OLED Color EPD)

### New Market Creation
- Plastic B/W EPD (14.3” 180ppi)
- Plastic Color EPD
- Roam

### Replacement Current market
- Plastic Color EPD
- 10.1” WSVGA
- Philips
- CF Plastic 0.07t
- TFT Plastic 0.07t
- BLU 0.3t
- Plastic Substrate (0.5t)

- Polishing panel → Using the Thin plastic Substrate
- Design Freedom
- Nokia
- Flexible Displays
New Concept Mobile Electronics

- Mechanical flexibility
- Transparency
Wearable Displays
Tomorrow’s True Flexible OLED

- Foldable
- Wearable

LG could Soon Be Supplying Flexible OLED Screens to Apple ‘iWatch’

(source: LGE)
Flexible Displays Market Size (estimated)

Source: Displaybank (2011)

Unit: 100 M$
Technologies for Flexible Displays

**Substrate**
- Materials:
  - thin metal foil, polymer, flexible glass
- Key issues:
  - mechanical stress (shrinkage, thermal expansion, gas permeation, temperature, optical transmittance, etc.)

**Display mode**
- Display type:
  - LCD, OLED, electronic ink
- Key issues:
  - stability, performance, flexibility, etc.

**Switching device**
- Semiconductors:
  - a-Si, LTPS, organic, oxide, oxynitride
- Key issues:
  - mobility, stability, fabrication process, transparency

**Barrier (Reliability)**
- Materials
- Key issues:
  - barrier property, flexibility, process time
Flexible Electronics for Flexible Displays

- Flexible TFT
- Flexible Circuit
- Flexible Cover glass, Flexible Touch Screen

Flexible and Stretchable Electronics

Fig. 1. (a) Schematic image and photograph of the graphene FETs using hybrid electrode, (b) the relative resistance changes versus tensile strain of the FET arrays on flexible substrate.
**TFT Requirements for Displays**

- **Unit**: mobility (cm²/Vs)

**Organic**
- Polymer TFT
  - Small molecules Organic TFT
  - Amorphous, Crystalline

**Inorganic**
- a-Si
  - LTPS
  - c-Si
  - Oxides

**AMOLEDs**
Photo-annealed Flexible IGZO TFT & Circuit

- $V_{DS} = 10\, V$
- $W/L = 100/10\, \mu m$
- $\sqrt{I_D}$ vs. $V_G$

- $f > 340\, kHz$
- delay $<210\, ns$ stage$^{-1}$

$V_{DD} = 15\, V$, $f = 341\, kHz$

Output Voltage (V) vs. Time ($\mu s$)
(4) **Transparent Displays**

- *Real time Information anytime*
- *Enhance Office Productivity*
- *Augmented Reality*
(5) Low Cost OLED-TV Manufacturing

Retrying Printing  OLED-TV

OLED TV with Inkjet Printing method
Requirement for Next Generation Displays

(1) Jumbo Interactive Screen Displays

(2) Super High Resolution Display
   \[ FHD \rightarrow UHD \rightarrow Super \ High \ Vision \]

(3) Flexible Display
   \[ Bendable \rightarrow Foldable \rightarrow Wearable \ / True \ Flexible \]

(4) Transparent Display

(5) Low Cost OLED-TV Manufacturing
   \[ Printed \ OLED \ TV \]

- Flexible Substrate
- Flex Encapsulation
- Flex TFT
- Flex Transparent Touch Screen
- Flex Electronics
Touch Screen Tomorrow
ITO Replacement

Why ITO Replacement?

ITO
- High Temp. processing
- Not Flexible
- Rs typical ~100 ohm/□
  min. 40 ohm/□

ITO Replacement

Metal mesh Advantages
- Roll to roll patterning
  Rs is much lower than ITO
- Flexible

[Candidates]
- Metal Mesh
  - Roll to roll printing
    - Sputtered Cu
    - Sputtered Al
- Silver nanowire
- Silver nanoparticle ink
- Conductive polymer
ITO Replacement

**Silver Nanowire**

Cambrios is first-mover and leader

**Advantages**
- High conductivity (10 Ω/□ at 94% transmission)
- High transparency
- Can be spin-coated or slit-coated

**Disadvantages**
- Increased haze at < 30 Ω/□

**Metal mesh**

- Roll to roll printing → **low cost**
- **Flexible**, applicable to larger panels
- Resistivity <10 ohm/□
- Slightly visible

4~6um Cu line width

Source: Uni-Pixel

Source: Cambrios
Tomorrow’s “To-be” Touch Screen

1. **Z-axis sensing, “Hover”**
   - Hover to position, then touch to select
   - Alternatively-

2. **True pressure sensing**
   - Press lightly to a point, then press hard to select
   - True pressure sensing PCap does not exist today
   ① Pressure-sensing using an array of organic transistors where pressure changes the gate current
   ② Pressure-sensing capacitors (3M material)
   ③ Piezo

3. **Pen input w/ any Passive Pen**
   → Eliminate Active Pen (Wacom Pen)

4. **Plastic cover sensor** for Flexible display
   (instead of Cover Glass)

Use finger to hover in the browser, just like with a mouse

Apple’s hybrid touch input invention, “depressible button”
**Touch screen Evolution Path**

**Yesterday**
- Resistive
- Surface Cap
- PCap
- Optical/Acoustic

**Today**
- PCap dominant
- Multi touch / Soft touch
- Active Pen input

**Tomorrow**
- Pcap on Large Format Display
  - Signage, Education displays
- Hovering or True Pressure Sensing
- Pen input with Passive pen
- Sensor on Plastic cover

Hovering Z-touch
- select & press

True Pressure sensing
Large Displays with Touch screen

- Larger Format Displays with Touch Screen
- Metal mesh Touch Sensor

- Large-format multi-touch applications

- Education
- Gaming Tables
- Advertising
- Digital Signage
- Industrial Control
Sheet Resistivity Requirement vs Screen Size

Illustrates trends; details depend on required performance, noise environment, substrate materials, thickness, optical requirements, etc.

These numbers based on maintaining same time constant as sensor scales in size

30” : 8 Ω/
17” : 25 Ω/
13.3” : 42 Ω/
10” : 75 Ω/
5” : 300 Ω/

Source: Synaptics (unmodified)
Future Displays
Displays for Watching

Displays that can *Interact* with Human & give *Maximum Reality*
Future Jumbo Screen Displays

Immersive & Realistic image

Jumbo screen, Super Hi Vision

Video Wall
Autostereographic 3D Display
(Without 3D Glasses)

- Natural 3D without Glasses
  - Multi Viewpoints >18 pts
  - SHV 4K8K ➞ Flat 3D

- Super Hi Vision (SG)
  (8K x 4K)

- UD 240Hz(SG)
  (2K x 4K)

- UD 3D with SG

- 3D with SG

- FHD 240 Hz (SG)
Holography

- Holography in Movie (Minority Report, 2002)