JDI’s Business and Core Display Technology

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Agenda

• Market Trend and JDI’s Business Development
• JDI’s Core Strategy
• Technology Strategy
  – Core Display Technology: LTPS
  – Smartphones
  – Automotive Electronics
  – Reflective Displays for Wearables/Outdoor Use
Market Trend and JDI’s Business Development
Size Forecasts for Target Market

Growth forecasts for the entire target market

(Trillion yen)


New market
Signage
Industrial
Automotive electronics
Smartphones

Source: JDI’s estimates based on research company data
Create 3 Business Pillars to Provide a Solid Business Base

Mobile business reaching maturity; grow auto business & nourish new 3rd pillar; move to 30% non-mobile sales ratio

- **Mobile business**: Volatile demand
- **3rd business (Reflective)**: Business building
- **Auto business**: Stability
- **4th business (OLED)**

- **Volume (# of sheets)**
  - Smartphones
  - Top: High-res HUD
  - Bttm: Curved displays

- **Margin**
  - Wearables
  - (reflective)
  - Digital signage
  - (reflective)
  - e-POP
  - (reflective)

Earnings

Year

2020

Auto business reaching maturity, grow auto business & nourish new 3rd pillar; move to 30% non-mobile sales ratio.

- **Mobile business**: Volatile demand
- **3rd business (Reflective)**: Business building
- **Auto business**: Stability
- **4th business (OLED)**

- **Volume (# of sheets)**
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- **Margin**
  - Wearables
  - (reflective)
  - Digital signage
  - (reflective)
  - e-POP
  - (reflective)
JDI’s Core Strategy
LTPS is the basis for various types of displays

LTPS: Low Temperature Polycrystalline Silicon
LCD: Liquid Crystal Display
OLED: Organic LED
JDI is the lead global supplier of LTPS devices

LTPS-LCD capacity as of end-FY16

K sheets / Months (G4.5 equiv.)

JDI produces all CMOS-LTPS.

Source: JDI estimates based on research firm reports.
JDI’s Technology Growth Strategy

LTPS is the core technology for JDI’s product development

**Smartphones, Tablet PCs**

- High resolution/Low power consumption/In-cell touch
- Design improvement: Mass production of sheet OLED in CY18

**Automotive Electronics**

- High resolution/in-cell touch/curved displays/rapid response time displays (no delays)

**Reflective**

(Industrial devices/electronic shelf labels/signage, etc.)

- Ultra low-power consumption display with MIP (Memory-in-Pixel)

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Technology Strategy
Basic Principles of Display Technology

An image is shown with pixels arranged in a matrix.

Changing images numerous times each second results in picture motion.

Changing the brightness of each sub-pixel reproduces every color in a pixel.
JDI’s core technology: LTPS

LTPS is used in display panels as TFTs (Thin Film Transistors).

LTPS TFTs on glass substrate

LTPS TFTs on film substrate
(For sheet display)
LTPS and Devices

LTPS is a basic technology for various devices

Front-plane
- LCD

Back-plane
- LTPS
- Backlight

Transmissive LCD
Reflective LCD
OLED
Device X
Display uses multiple TFTs. LTPS, one TFT solution type, is JDI’s core technology.
Reflective LCD Structure and TFT

- Reflective electrode
- Memory circuit
- Substrate
- Liquid crystal
- Polarizer
- Light
- Reflective electrode, Memory circuit
- Color filter (R/G/B)
- Common electrode
- Drive circuit
- Cross-sectional view
- Expanded overhead view
- SRAM memory circuit
OLED Structure and TFT

Cross-sectional view

- Substrate
- Organic light emitting layer (R/G/B)
- Electrode, TFT
- Drive circuit

Expanded overhead view

- Display area (pixels)
- Border (drive circuit)
Transistor Technology Comparison

- LTPS has higher electron mobility than other TFT technologies

Voltage and Electrical Current Characteristics

<table>
<thead>
<tr>
<th>Mobility, $\mu$ cm²/Vs</th>
<th>Technology / Architecture</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-16}$</td>
<td>Crystal Si (Ref.)</td>
</tr>
<tr>
<td>$10^{-15}$</td>
<td>LTPS</td>
</tr>
<tr>
<td>$10^{-14}$</td>
<td>CMOS</td>
</tr>
<tr>
<td>$10^{-13}$</td>
<td>NMOS</td>
</tr>
<tr>
<td>$10^{-12}$</td>
<td>a-Si</td>
</tr>
<tr>
<td>$10^{-11}$</td>
<td>LTPS</td>
</tr>
<tr>
<td>$10^{-10}$</td>
<td>a-Si</td>
</tr>
<tr>
<td>$10^{-9}$</td>
<td>LTPS</td>
</tr>
<tr>
<td>$10^{-8}$</td>
<td>a-Si</td>
</tr>
<tr>
<td>$10^{-7}$</td>
<td>LTPS</td>
</tr>
<tr>
<td>$10^{-6}$</td>
<td>a-Si</td>
</tr>
<tr>
<td>$10^{-5}$</td>
<td>LTPS</td>
</tr>
<tr>
<td>$10^{-4}$</td>
<td>a-Si</td>
</tr>
</tbody>
</table>

LTPS TFT functions in small sizes.
LTPS realizes high resolution, low power consumption

→ Since a large aperture ratio enables more use of light power consumption can be lower (or brightness enhanced).
LTPS realizes narrow border

LTPS enables small-size TFT & fabrication of smaller gate circuits

Border width (mm)

Resolution (ppi)

200 400 600 800

LTPS

a-Si

5” Full-HD (443ppi)

Bigger display, impressive design quality

Narrow border
Evolution of Productivity (Mother Glass Size)

G6 Glass Substrate

- No. of transistors (FHD)
  6.22mn pixels per smartphone x 320 units
  = 2bn transistors

- Processing accuracy
  Long side of substrate:
  approx. 1.8m
  Processing accuracy:
  several μm

Substrate accuracy = 1ppm
JDI’s Technology Growth Strategy

LTPS is the core technology for JDI’s product development

**Smartphones, Tablet PCs**

- High resolution/Low power consumption/In-cell touch
- Design improvement: Mass production of sheet OLED in CY18

**Automotive Electronics**

- High resolution/in-cell touch/curved displays/rapid response time displays (no delays)

**Reflective**

- Ultra low-power consumption display with MIP (Memory-in-Pixel)

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High Resolution ··· LTPS
Resolution (Ergonomic Evaluation)

Up to 800 ppi recognizable (Visual range 22 cm)

**Resolution (ppi)**

Limits of pixel detection by eye

Human eye cannot detect the pixels.

LTPS can support >800 ppi displays

**Conditions**

- Viewing distance: 25 cm
- Viewing angle: normal to the display
- Subjects: 5 females and 17 males
- Luminance: 200 cd/m² (L* = 100%)

Y. Hisatake et al., P-145, SID 2012

Making characters legible requires high resolution

Character height*:
- Main text: 3 mm (9 points)
- Footnotes: 2 mm (6 points)

*Standard text height of Japanese paperback
Smartphone Display Trends

- Rapid evolution of display size, no. of pixels, resolution, etc.

**2012 Oct. MP start (Full-HD)**

- Display technology: Transmissive IPS, LTPS TFT
- Screen size: 5.0-inch (12.6cm) diagonal
- Number of pixels: 1080 x 1920
- Pixel density: 443 ppi
- Contrast ratio: 1000:1
- NTSC ratio: 71%
- Luminance: 500 cd/m²
- Dimensions: 64.3mm (W) x 118.8mm (H) x 1.4mm (D)
- Side border: 1.2mm

**Development (4K2K *1)**

- Display technology: Transmissive IPS, LTPS TFT
- Screen size: 5.5-inch (13.9cm) diagonal
- Number of pixels: 2160 x 3840 *1
- Pixel density: 806 ppi *2
- Contrast ratio: 1000:1
- NTSC ratio: 93%
- Luminance: 500cd/m²
- Dimensions: 69.8mm (W) x 128.9mm (H) x 1.9mm (D)
- Side border: 0.9mm

*1: 2160x3840 with sub pixel rendering (Image resolution based on ICDM standard)
*2: Vertical
# Application Product of High Resolution Technology for Smartphone

## 8K4K Display for professional use

### Specifications

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Screen size</strong></td>
<td>17.3 inch</td>
</tr>
<tr>
<td><strong>Resolution format</strong></td>
<td>7,680 x RGB x 4,320</td>
</tr>
<tr>
<td><strong>Pixel density</strong></td>
<td>510 ppi</td>
</tr>
<tr>
<td><strong>Luminance</strong></td>
<td>250 cd/m²</td>
</tr>
<tr>
<td><strong>Contrast ratio</strong></td>
<td>2,000:1</td>
</tr>
<tr>
<td><strong>Color gamut</strong></td>
<td>70%</td>
</tr>
<tr>
<td><strong>Frame rate</strong></td>
<td>120Hz</td>
</tr>
<tr>
<td><strong>LCD drive system</strong></td>
<td>IPS-NEO</td>
</tr>
</tbody>
</table>

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Image: Courtesy of NHK

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Joint development with NHK
Low Power Consumption

・・・ Low Frequency Drive
# Advanced LTPS Low Frequency Drive

**Advanced LTPS**: LTPS technology which reduces current leakage

<table>
<thead>
<tr>
<th></th>
<th>FY2015</th>
<th>FY2016</th>
<th>FY2017</th>
<th>FY2018</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Drive frequency</strong></td>
<td>60Hz</td>
<td>30Hz</td>
<td>15~5Hz</td>
<td></td>
</tr>
<tr>
<td>LTPS (Gen.1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>advanced LTPS (Gen.2)</td>
<td>MP</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>advanced LTPS (Gen.3)</td>
<td></td>
<td>MP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Circuit electricity**

Power $\propto f \times V^2$

- Gen.1: 200 mW
- Gen.2: 140 mW
- Gen.3: 80 mW

**Flicker (15Hz)**
In-cell touch Technology
Sensor electrodes (Tx & Rx) are formed in LCD cells and controlled by an LTPS circuit.

Advantages: thin, high sensitivity, low cost
“Pixel Eyes” has advantages over other in-cell touch technology & can support next-generation touch interfaces.

<table>
<thead>
<tr>
<th>Pixel Eyes™</th>
<th>Other type in-cell touch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cover glass</td>
<td>Cover glass</td>
</tr>
<tr>
<td>Color filter sub.</td>
<td>Color filter substrate</td>
</tr>
<tr>
<td>TFT substrate</td>
<td>TFT substrate</td>
</tr>
<tr>
<td>Rx</td>
<td>Rx/Tx</td>
</tr>
<tr>
<td>Tx</td>
<td></td>
</tr>
</tbody>
</table>

- ✓ High immunity to external noise thanks to the shield layer on color filter glass.
- ✓ Lower touch power in sleep mode
- ✓ Touch FPC required

- ✓ Vulnerable to external noise because the sensor electrodes are electrically floating.
- ✓ Higher touch power in sleep mode
- ✓ Touch FPC not required
“Pixel Eyes” continues to evolve

Gen. 2
Narrow boarder
Real Black
Water tracking
Multi-touch
Stylus pen input
Brush Writing

Gen. 3
Next generation UI
Curved
Frameless
Low power by new driving method
Edge display
Hovering

Gen. 4
Sensing function
and more . . .
OLED Technology
## LCD vs OLED  Structure and Display Principles

<table>
<thead>
<tr>
<th></th>
<th>LCD</th>
<th>OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Display principles</strong></td>
<td>【Transmission type・voltage driving】&lt;br&gt;LCD uses the light modulating properties of liquid crystal.</td>
<td>【Light emission type・current driving】&lt;br&gt;Excitation formation by electron-hole recombination</td>
</tr>
<tr>
<td><strong>Structure</strong></td>
<td><img src="image" alt="LCD diagram" /></td>
<td><img src="image" alt="OLED diagram" /></td>
</tr>
</tbody>
</table>

**Front plane**  
- **Liquid crystal**  

**Back plane**  
- **TFT (LTPS)**  

**Substrate**  
- **Mainly glass**  

**Backlight**  
- **Required for transmissive LCD**  
- **Unnecessary**
# LCD vs OLED

- LCD suitable for high pixel density; OLED suitable for flexibility
- Advanced LTPS technology realizes low-power OLED

<table>
<thead>
<tr>
<th></th>
<th>LCD</th>
<th>OLED</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>LTPS</td>
<td>Advanced LTPS</td>
</tr>
<tr>
<td>Pixel density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(600ppi)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power consumption</td>
<td>Fair</td>
<td>Excellent</td>
</tr>
<tr>
<td>Design “Flexible”</td>
<td></td>
<td>Poor</td>
</tr>
<tr>
<td>(need backlight)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Narrow Border</td>
<td></td>
<td>Excellent</td>
</tr>
<tr>
<td>In cell touch technology</td>
<td></td>
<td>Excellent</td>
</tr>
<tr>
<td>(currently on cell or film method)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reliability</td>
<td></td>
<td>Excellent</td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td>Excellent</td>
</tr>
</tbody>
</table>
Prototype OLEDs using flexible film substrate

- **Notebook type**
- **Bangle type**
  - With touch function
- **Projection type**
# JDI’s Technology Growth Strategy

LTPS is the core technology for JDI’s product development

<table>
<thead>
<tr>
<th>Smartphones, Tablet PCs</th>
<th>Advanced LTPS technology</th>
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<tr>
<td>• High resolution/Low power consumption/In-cell touch</td>
<td></td>
</tr>
<tr>
<td>• Design improvement: Mass production of sheet OLED in CY18</td>
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<tr>
<th>Automotive Electronics</th>
<th>Curved &amp; rapid response displays with LTPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>• High resolution/in-cell touch/curved displays/rapid response time displays (no delays)</td>
<td></td>
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</tbody>
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<table>
<thead>
<tr>
<th>Reflective</th>
<th>LTPS memory technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Industrial devices/electronic shelf labels/signage, etc.)</td>
<td></td>
</tr>
<tr>
<td>• Ultra low-power consumption display with MIP (Memory-in-Pixel)</td>
<td></td>
</tr>
</tbody>
</table>
A variety of display types in automobiles

Automotive market needs for low-power consumption and narrow borders will drive the technology shift toward LTPS.
Curved panel technology for automobile
Curved or non-rectangular shape automotive displays

Integrate in-cell gate drive circuits using LTPS technology
Easier to make curved or non-rectangular shapes

Concave  Convex  S shape  Non-rectangular shape

Driver IC location only on one side → Easier to make curved or non-rectangular shapes

LTPS  S-Dr  LTPS  S-Dr
Quick response system technology for digital mirrors
Digital Mirrors

- LTPS technology supports a higher frame frequency (60Hz → 240Hz) to eliminate blurring & increase safety

<table>
<thead>
<tr>
<th></th>
<th>Conventional</th>
<th>Prototype</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Image</strong></td>
<td><img src="image1.png" alt="Conventional Image" /></td>
<td><img src="image2.png" alt="Prototype Image" /></td>
</tr>
<tr>
<td><strong>Blurring</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>LC response speed</strong></td>
<td>20ms</td>
<td>8ms</td>
</tr>
<tr>
<td><strong>Frame frequency</strong></td>
<td>60Hz</td>
<td>240Hz</td>
</tr>
<tr>
<td><strong>Signal delay from camera to display</strong></td>
<td>100ms</td>
<td>4ms</td>
</tr>
</tbody>
</table>
JDI’s Technology Growth Strategy

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**Reflective**
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  - Ultra low-power consumption display with MIP (Memory-in-Pixel)

**Advanced LTPS technology**

**Curved & rapid response displays with LTPS**

**LTPS memory technology**
Ultra-low power consumption Reflective LCD

- Backlight power consumption unnecessary
- Memory in Pixel (MIP) saves more power

- Each pixel has build-in-memory (SRAM)
- Data writing to memory for each frame unnecessary as each pixel holds data.
- Uses LTPS-CMOS technology

Power consumption of reflective LCD and MIP
Outdoor Visibility (Photo)

Photos of same outdoor menu illuminated by 50,000 lux

Reflective color LCD

Transmissive color LCD

25-inch FHD

Brightness: 270cd/m²
Reflective Color LCD Applications

Wearable devices
- 1.34"
- 1.2"
- 1.39"
- 0.99"

Special-purpose PC monitors/readers

Industrial devices

Digital signage

ESL*・POP

*ESL: Electronic shelf label
Just between you and the world