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)

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

**Volume (# of sheets)**
- **Smartphones**: ESL reflective MIP displays (color)
- **Automotive**: Signage reflective MIP displays
- **Wearables**: e-POP (reflective)
- **Digital signage (reflective)**

**Year**
- Mobile business reaching maturity
- 2020: Move to 30% non-mobile sales ratio

**Earnings**
- **Mobile business**
- **Auto business**
- **3rd business (Reflective)**
- **4th business (OLED)**

**Margin**
- Top: High-res HUD
- Bottom: Curved displays
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

Front-plane
- Transmissive LCD
- Reflective LCD
- OLED
- Device X

Back-plane
- LTPS
- Backlight

OLED

Something new
JDI is the lead global supplier of LTPS devices

LTPS-LCD capacity as of end-FY16
K sheets / Months (G4.5 equiv.)

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)
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
  - LTPS
  - Backlight
- **Back-plane**
  - LTPS
  - Reflective LCD
  - Transmissive LCD
  - OLED
  - LTPS
  - Something new
  - Device X

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Structure of Transmissive LCD and TFT

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
- Color filter (R/G/B)
- Common electrode
- Drive circuit
- Reflected light

Cross-sectional view

Expanded overhead view

SRAM memory circuit
OLED Structure and TFT

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

Cross-sectional view

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>Technology / Architecture</th>
<th>Mobility, ( \mu ) cm(^2)/Vs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal Si (Ref.)</td>
<td>1000</td>
</tr>
<tr>
<td>LTPS</td>
<td>100</td>
</tr>
<tr>
<td>a-Si</td>
<td>10</td>
</tr>
<tr>
<td>NMOS</td>
<td>1</td>
</tr>
<tr>
<td>CMOS</td>
<td>0.1</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).
Transistor Tech. Comparison (Border)

- **LTPS realizes narrow border**

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

![Graph showing border width vs. resolution (ppi)]

- **Graph**
  - **Border width (mm)**: 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6
  - **Resolution (ppi)**: 200, 400, 600, 800
  - **Legend**:
    - a-Si
    - LTPS
  - **5” Full-HD (443ppi)**

- **Key Points**
  - Narrow border
  - Bigger display, impressive design quality
  - Gate circuit
  - Display area

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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

G6 1500X1850mm
  320 smartphone panels

G5.5 1300X1500mm

G4.5 730X920mm
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Advanced LTPS technology
Curved & rapid response displays with LTPS
LTPS memory technology

(Japanese: ジャパンディスプレイ技術成長戦略
LTPSはJDIの製品開発の核となる技術です)

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High Resolution ••• LTPS
Resolution (Ergonomic Evaluation)

Up to 800 ppi recognizable (Visual range 22 cm)

Limits of pixel detection by eye

Making characters legible requires high resolution

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%)

*Standard text height of Japanese paperback

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

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

Character legibility requires high resolution

Resolution (ppi)

Limits of pixel detection by eye

Sight distance (cm)

LTPS can support >800 ppi displays
## Smartphone Display Trends

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

### 2012 Oct. MP start (**Full-HD**)  
![Image](image1.png)

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

### Development (**4K2K **\(^1\)**)

![Image](image2.png)

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

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\(^1\): 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

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

Joint development with NHK

Image: Courtesy of 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>15~5Hz</td>
</tr>
<tr>
<td>LTPS (Gen.1)</td>
<td>MP</td>
<td>MP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>advanced LTPS (Gen.2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>advanced LTPS (Gen.3)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Circuit electricity

- **Power ∝ f x V²**

### WQHD

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

### Flicker (15Hz)

- Reference
- Gen.3
In-cell touch Technology
In-cell touch LCD

Pixel Eyes ™ Advantages: thin, high sensitivity, low cost

Sensor electrodes (Tx & Rx) are formed in LCD cells and controlled by an LTPS circuit.

Side view

Bird’s-eye view
**Advantage of “Pixel Eyes”**

“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><img src="#" alt="Diagram" /></td>
<td><img src="#" alt="Diagram" /></td>
</tr>
<tr>
<td><strong>Cover glass</strong></td>
<td><strong>Cover glass</strong></td>
</tr>
<tr>
<td><strong>Color filter substrate</strong></td>
<td><strong>Color filter substrate</strong></td>
</tr>
<tr>
<td><strong>TFT substrate</strong></td>
<td><strong>TFT substrate</strong></td>
</tr>
<tr>
<td>Rx/Tx</td>
<td>Rx/Tx</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

<table>
<thead>
<tr>
<th>Gen. 2</th>
<th>Gen. 3</th>
<th>Gen. 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narrow boarder</td>
<td>Next generation UI</td>
<td>Sensing function and more . . .</td>
</tr>
<tr>
<td>Real Black</td>
<td>Curved</td>
<td></td>
</tr>
<tr>
<td>Water tracking</td>
<td>Frameless</td>
<td></td>
</tr>
<tr>
<td>Multi-touch</td>
<td>Low power by new driving method</td>
<td></td>
</tr>
<tr>
<td>Stylus pen input</td>
<td>Edge display</td>
<td></td>
</tr>
<tr>
<td>Brush Writing</td>
<td>Hovering</td>
<td></td>
</tr>
</tbody>
</table>

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

Next generation UI Curved Frameless Low power by new driving method Edge display Hovering
OLED Technology
# LCD vs OLED  Structure and Display Principles

<table>
<thead>
<tr>
<th>Display principles</th>
<th>LCD</th>
<th>OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td>【Transmission type・voltage driving】</td>
<td>LCD uses the light modulating properties of liquid crystal.</td>
<td>【Light emission type・current driving】</td>
</tr>
<tr>
<td>Excitation formation by electron-hole recombination</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>LCD (Front plane)</td>
</tr>
<tr>
<td>LCD (Back plane)</td>
</tr>
<tr>
<td>Substrate</td>
</tr>
<tr>
<td>Backlight</td>
</tr>
</tbody>
</table>
**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>
</thead>
<tbody>
<tr>
<td></td>
<td>LTPS</td>
<td>Advanced LTPS</td>
</tr>
<tr>
<td><strong>Pixel density</strong></td>
<td><strong>Excellent</strong></td>
<td><strong>Fair</strong></td>
</tr>
<tr>
<td><strong>Power consumption</strong></td>
<td><strong>Fair</strong></td>
<td><strong>Excellent</strong></td>
</tr>
<tr>
<td><strong>Design “Flexible”</strong></td>
<td>Poor</td>
<td><strong>Excellent</strong></td>
</tr>
<tr>
<td><strong>Narrow Border</strong></td>
<td><strong>Excellent</strong></td>
<td><strong>Fair</strong></td>
</tr>
<tr>
<td><strong>In cell touch technology</strong></td>
<td><strong>Excellent</strong></td>
<td><strong>Fair</strong></td>
</tr>
<tr>
<td><strong>Reliability</strong></td>
<td><strong>Excellent</strong></td>
<td><strong>Fair</strong></td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td><strong>Excellent</strong></td>
<td><strong>Fair</strong></td>
</tr>
</tbody>
</table>
Prototype OLEDs using flexible film substrate

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

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

Advanced LTPS technology

Curved & rapid response displays with LTPS

LTPS memory technology

(Industrial devices/electronic shelf labels/signage, etc.)
LCDs for Automobiles Market Trends

- 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
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></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Blurring</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>
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LTPS is the core technology for JDI’s product development

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**Reflective**
- (Industrial devices/electronic shelf labels/signage, etc.)
- Ultra low-power consumption display with MIP (Memory-in-Pixel)
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

*JDI estimates
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
- 0.99”
- 1.2”
- 1.34”
- 1.39”

Special-purpose PC monitors/ readers

Industrial devices
- 2~4”
- 6~25”

Digital signage
- 25”~

ESL*・POP
- 2~3”
- 4”~

*ESL: Electronic shelf label

Page dimensions: 780.0x540.0

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