Metal Mesh: Enabling Thin, Light and Flexible Devices

2016 IHS Korea Display Conference

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Vice President, Marketing

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UniPixel Introduction

- A leader in metal mesh Touch Sensors (XTouch) and hardcoat technology (Diamond Guard)
- Acquired key XTouch IP from in 2015 (Atmel’s XSense)
- Gaining momentum with multiple design wins in 2016
- Over 1.5 million sensor units shipped to date
- 70+ employees; 5 PhDs
- 60 issued patents (34 US) + 141 pending patents (71 US)
- Headquarters in Santa Clara, CA; Manufacturing in Colorado Springs, CO; R&D in Houston; Sales offices in Taiwan, Houston, and Santa Clara.
- NASDAQ: UNXL
Flexible metal mesh sensor material enables innovative product designs

Copper-based mesh
~90% light transmission*
-For brighter display

Thin borders
-For reduced weight and size

Advanced Sensor Pattern
-Low Sheet Resistance (<10 Ω/□)
for Finger Touch and Stylus Performance

Narrow Bond Area
-For low cost and high reliability

(* With anti-reflective coating or optical bonding)
XTouch Design Wins in 2016 Portend Growth of Metal Mesh

Multiple Announced Design Wins Across Multiple Categories
Industry Analysis Predicts Growth of ITO-replacement Technologies

“The ITO-replacement industry has made good progress in the touch panel and other applications in the past two years ...”

“We forecast that ITO-replacement will become the major transparent conductor for touch panels after 2021. ITO will be the minor transparent conductor for touch panels.”

- Dr. Jennifer Colegrove, CEO and principal analyst of Touch Display Research Inc.

<table>
<thead>
<tr>
<th>Units (000s)</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal Mesh</td>
<td>5,802</td>
<td>6,650</td>
<td>7,334</td>
<td>7,919</td>
<td>8,406</td>
</tr>
<tr>
<td>Nanowires</td>
<td>959</td>
<td>1,578</td>
<td>1,719</td>
<td>1,794</td>
<td>1,873</td>
</tr>
<tr>
<td>Grand Total</td>
<td>6,761</td>
<td>8,228</td>
<td>9,053</td>
<td>9,714</td>
<td>10,279</td>
</tr>
</tbody>
</table>


Source: IHS Q12016 Touch Panel Tracker.
Market Driving Towards Thinner, Lighter & Pen-Input Devices

- **HP Spectre Pro 13.3”**
  - 3.1 lb
  - 0.61”

- **Dell Latitude 12” 7000**
  - 2.7 lb
  - 0.76”

- **Lenovo LaVie 13.3”**
  - 1.9 lb
  - 0.7”

- **MacBook 12”**
  - 2.0 lb
  - 0.5”

- **Surface Pro 4 12”**
  - 1.7 lb
  - 0.4”

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Low Effective Resistance is an enabler of superior touch and stylus performance, thin bezel width, reduced Z-height, and lighter weight.
Effective Resistance: Sheet Resistance

• Two key factors in Effective Resistance
  • Bulk material sheet resistance
  • Sensor electrode pattern

• Typical bulk sheet resistance
  • ITO GFF: 150Ω/□
  • OGS: 50Ω/□

• XTouch metal mesh: <10Ω/□
Effective Resistance: Sensor Electrode Pattern

Diamond: $>6 \square$/node or more
Single node (OGS) = $\approx 320 \ \Omega$
More $\square$/node = higher total electrode resistance

XTouch: 1-2 $\square$/node
Single node = 20 $\Omega$

Lower R = Better Sensor Performance
Fastest Touch Performance

Fast XSense charge time offers multiple benefits including improved noise immunity, lower power consumption, and faster responsiveness.

4.3" XTouch sensor charge time is <100ns

4.3" ITO sensor charge time is 1300ns

Measurements taken using a signal generator
Narrow Borders for Thin Bezel

Low Effective Resistance enables Single Routing

*XTouch*

Variable Pitch Tracking
• As thin as 20/20µm today with opportunity to go thinner

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Overcome Re-transmission to Enable Thin Cover Lenses

- Retransmission reduces touch sensor signal and causes multi-touch failure with thinner cover lenses.
- Moisture performance is related to retransmission.
Re-transmission Challenge for Thin Cover Lenses

Cover Lens = ≤0.4mm

Touch

Anti-Touch
“Ghosting”
Very High

Poor multi-touch
XTouch has low Retransmission

Cover Lens = \leq 0.4\text{mm}

Excellent SNR & Multi-touch

Minimal Anti-Touch “Ghosting”
Metal Mesh Sensors Well Suited for Flexible Displays

• ITO sensors will have difficulty supporting bendable displays.

• Copper-based metal mesh touch sensors, being made of a ductile metal, will be well-suited to support the bendability and thin cover lens requirements of flexible displays.
Bend Test Conditions

- 3mm bend radius
- 90,000 cycles
- 120 cycles/min
Test Sample and Bending Direction

- Sample: 15.6” XTouch sensor bonded to passive FPC
- Bend testing performed on short axis
- Test Software used to measure Reference Level (related to resistance change)
Reference Level Measurement

- Reference Level measured at 90k cycles with no failures.
- Additional testing at increased cycles and smaller bend radius to be performed.
Thin Plastic Cover Lens
Flexible Display Likely to Require Thin Plastic Cover Lens

• Cover Lens for Flexible Display likely to be thin plastic film, perhaps 0.100mm or less.

• UniPixel has two technologies to address challenges of thin plastic cover lens material:
  • Proprietary XTouch sensor pattern to overcome challenge of re-transmission
  • Diamond Guard hardcoat resin to increase hardness and abrasion resistance of plastic cover lens while maintaining flexibility
Diamond Guard™ Hard Coat

Optically Clear
- >90.5% Transmission on PET
- <0.6% Haze on PET

Glass like smooth surface – Rq = 13.9 n

Hard, scratch & abrasion resistant surface
- ASTM 6H+ pencil hardness on PET; 9H on PMMA
- Taber – CS-10 wheel – 500 cycles – 500g - Haze – no change
- Wyzenbeek – Denim – 1000 cycles – 500g - Haze – no change
- Bayer – Luminous Transmission – post Bayer – no change

Diamond Guard™ Film/Sheet Layers
- PET/PC/PMMA Film or Sheet
- 2 mil to 1mm thickness
- Diamond Guard Coating – 5 to 25 um thick
- Protective Film (optional)

Rq = 13.9nm
Diamond Guard Key Features

- High Scratch Resistance
- Great Optical Quality – High transmission/Low Haze
- Die cutting compatible
- Flexible and formable
- Very smooth surface
- Stain Resistant
- Chemical resistant
- Easily cleaned surface
- UV resistance
Diamond Guard on Substrates

Actual Diamond Guard pencil hardness measurements on various substrates at varying single layer thicknesses
# Surface Abrasion Test: Diamond Guard vs. Polarizer

<table>
<thead>
<tr>
<th>Abradants</th>
<th>Test Condition</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Polarizer Films</td>
</tr>
<tr>
<td>Steel-Wool</td>
<td>250 g</td>
<td>Obvious Scratch after 10 cycles (Pic 1)</td>
</tr>
<tr>
<td>Denim</td>
<td>250 g &amp; 500 cycles</td>
<td>Obvious Scratch</td>
</tr>
<tr>
<td></td>
<td>500 g &amp; 500 cycles</td>
<td>Obvious Scratch</td>
</tr>
<tr>
<td></td>
<td>750 g &amp; 500 cycles</td>
<td>Obvious Scratch</td>
</tr>
<tr>
<td></td>
<td>1000 g &amp; 500 cycles</td>
<td>Obvious Scratch</td>
</tr>
<tr>
<td>Paper Towel</td>
<td>250 g &amp; 500 cycles</td>
<td>Obvious Scratch</td>
</tr>
<tr>
<td></td>
<td>500 g &amp; 500 cycles</td>
<td>Obvious Scratch</td>
</tr>
<tr>
<td></td>
<td>750 g &amp; 500 cycles</td>
<td>Obvious Scratch</td>
</tr>
<tr>
<td></td>
<td>1000 g &amp; 500 cycles</td>
<td>Obvious Scratch</td>
</tr>
</tbody>
</table>
## Diamond Guard coated PET Cover Lens: Pencil Hardness

### Stack-up

<table>
<thead>
<tr>
<th>Cover Lens</th>
<th>OCA1</th>
<th>OCA2</th>
<th>H</th>
<th>2H</th>
<th>3H</th>
<th>4H</th>
<th>5H</th>
<th>6H</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack 1</td>
<td>195µm</td>
<td>50µm</td>
<td>50µm</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>-</td>
</tr>
<tr>
<td>Stack 2</td>
<td>50µm</td>
<td>175µm</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Stack 3</td>
<td>250µm</td>
<td>50µm</td>
<td>50µm</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>Stack 4</td>
<td>50µm</td>
<td>175µm</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
<td>Pass</td>
</tr>
</tbody>
</table>

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Enabling Thinner, Lighter Touch Panels

GFF

XTouch Thin Glass

XTouch Glass Cover Lens Diamond Guard Bottom Hardcoat

XTouch Plastic Cover Lens Diamond Guard Bottom Hardcoat

XTouch Diamond Guard Top and Bottom Hardcoat

- GFF: 0.55mm Glass
  - OCA 1
  - ITO 1
  - OCA 2
  - ITO 2
  - 850-1000µm

- XTouch Thin Glass: 0.4mm Glass
  - OCA 1
  - XTouch
  - OCA 2
  - HCPET
  - 625µm

- XTouch Glass Cover Lens Diamond Guard Bottom Hardcoat: ≤0.4mm Glass
  - OCA 1
  - XTouch
  - 550µm

- XTouch Plastic Cover Lens Diamond Guard Bottom Hardcoat: ≤0.2mm Plastic
  - OCA 1
  - XTouch
  - 350µm

- XTouch Diamond Guard Top and Bottom Hardcoat: ≤70µm
Conclusion

• Growing market momentum for metal mesh touch sensors.

• XTouch and Diamond Guard help enable thin, light and flexible devices.

• XTouch supports narrow bezel, thin cover lens, and is future-ready for flexible displays.

• Diamond Guard enables improved abrasion resistance for thin cover lenses that will be required for flexible displays.

• The future is curved and flexible, and UniPixel looks forward to contributing to make it happen!