Touch Panel Industry III
Emerging touch technologies - Metal Mesh, Silver Nanowires, and Carbon Nanotubes

Most of the touch-enabled electronic devices available today are using indium tin oxide (“ITO”) based solutions. However, due to the Chinese government’s restriction on the production of indium, it has been difficult to lower the costs for ITO. Hence, the touch panel industry has been trying to lower touch panel costs particularly for large-sized touch panels with alternative solutions such as metal mesh, silver nanowire, carbon nanotube (CNT), or graphene in the past few years. These technologies have also made it easier to adapt to different form factors (i.e. flexible display, 2.5D, 3D surface). In this report, we provide an introduction to these emerging technologies and attempt to analyze the impact on the touch panel industry. We also identify potential winners and losers.

- **Metal mesh is the first in mass production** – Although theoretically, the material costs of metal mesh could be only 1/3 of ITO-based touch panels, the current pricing for metal mesh appears to be similar to the ITO-based solutions. Atmel (Not Covered, ATML.US) was the first company to announce the successful mass production of metal mesh film sensors. We expect more mid-to-large touch panels will use metal mesh in 2H13, but its market share might remain insignificant unless prices come down further. The main issue with metal mesh is the lower optical transmittance than ITO-based touch, and the low production yield rate that might need time to resolve.

- **Silver nanowires have gained industry tractions** – Contrary to metal mesh, silver nanowires have superior optical transmittance whereas its drawback lies in difficulties in manufacturing the silver nanowires ink. Cambrios (Unlisted) appears to be the sole provider of silver nanowire ink at present. Many industry heavyweights have contracted with Cambrios either as strategic investors (Samsung and TPK) or as sensor providers (ShinEtsu, Hitachi Chemical, Nissha Printing, DIC, Toray, etc.). Carbon nanotubes, on the other hand, demonstrate superior stability under different temperature/humidity conditions, but it is in an early stage of development.

- **Winners & losers** – Atmel (Not Covered, ATML.US) is the first to put metal mesh in mass production, whereas early movers to work with Cambrios such as Samsung (OW), TPK (OW), Nissha Printing (OW), etc. could enjoy first mover advantage when the technology takes off in 2H14 or later. ITO replacement technologies could be a risk in the longer term to Nitto Denko (OW), which has been the dominant leader on ITO film but not focused on these emerging technologies.

Source: Bloomberg. Share price as of July 3, 2013

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Industry Trend

With the release of smartphones, tablets, and Windows 8-based touch-NBs, demand for touch panels has been surging. Most of the smartphone/tablet/touch-NB available today use indium tin oxide (“ITO”) based solutions. However, due to the Chinese government’s restriction on the production of indium, it has been difficult to lower the costs for ITO, which accounts for about 40% of the touch panel sensor material costs (See “Touch Panel Industry II: ITO film supply tightness favors Tier-1 players”, published on March 20, 2013). Hence, the touch panel industry is trying hard to gain price competitiveness particularly for large-sized touch panels with alternative solutions such as metal mesh, silver nanowire, carbon nanotube (CNT), or graphene in the past few years.

ITO is a ceramic material processed using vacuum deposition at high temperatures, making production quite costly. Currently the industry has turned to ITO since it offers low resistance. Nevertheless, this option has its major limitations on (1) further room for cost-cut and (2) flexibility in design. ITO is mostly indium, a rare, volatile, and geopolitically sensitive material. Most of the world’s indium is a byproduct of zinc mined in China. Commissioning a new mine to produce zinc and indium takes several years, and a sudden rise in demand is always accompanied by a period of shortage coupled with high prices. Besides, ITO cannot withstand repeated bending or rolling as it is brittle and prone to cracking, limiting truly flexible devices.

Several new technologies such as metal mesh, silver nanowire, and carbon nanotube are projected to emerge as the technologies to replace the ITO film particularly in the mid- and large-sized touch panels. As the mobile device industry advances, ITO’s limitations are becoming increasingly evident and device makers are transitioning to a new generation of transparent conductive materials and displays to enable thinner, stronger, and better performing mobile devices. Among ITO alternatives, silver nanowire and metal mesh have emerged as the most promising solutions. As a result of their flexibility and low cost points, these two materials also present the greatest opportunity for device makers looking to develop mobile devices with flexible, curved, and foldable screens, as well as devices that are completely bezel-free, with touch capabilities wrapped around their edges.

Metal Mesh

What is metal mesh?

Comprising interwoven “grids” of thin copper or silver, roll-to-roll metal mesh technology is one of the available ITO alternatives. Suggested applications of this technology include “edgeless” touch screen devices without bezels or designs in which the touch interface wraps around the sides of the device. Metal mesh is typically made either by printing or through a photographic development process on an optically clear substrate such as polyethylene terephthalate (PET) or, in a rare case, glass.

It has a low resistivity like any other metals but it also has a very low light transmittance. As a result, the key challenge with metal mesh is the visibility of the
metallic grids and optical interaction with the underlying display. To achieve invisibility, the touch sensor circuit lines must be printed in sizes smaller than 5 microns. (As an illustrative comparison, a human hair is 40 to 120 μm wide.) Both UniPixel and Atmel are the first companies to claim to have achieved printed circuit lines under 5 μm in size on transparent film. UniPixel manufactures the UniBoss touch sensor and Atmel manufactures the xSense touch sensor.

The metal mesh film that can replace ITO film is not only price competitive but also applicable to flexible display touch panels, which ITO could not be applied to as it cracks. Thus metal mesh is considered to be one of the next-generation conductive film materials.

Copper pattern is built on the film by etching. Suitable for large-scale displays including digital signage and PC monitors as its resistance level is lower than ITO.

From a raw material standpoint, the price for metal mesh could be significantly cheaper than ITO. The material cost for metal mesh is supposed to be 1/3 that of ITO film, but currently given limited availability the metal mesh solution is priced similar to ITO-based solutions (roughly USD1-1.5 per inch diagonal). The technology is applied to several products in the market including Asus Eee Pad Transformer.

**Pros and cons**

**Pros:**

- Lower resistance/Better conductivity – Metal mesh touch sensors are superior to ITO touch sensors as metal mesh has less electrical resistance than ITO; this improves latency and battery life.

- Adapted to different shape – The sensor can be used on curved surfaces or even wrapped around the edges of the device, allowing for a sleeker and edgeless touch interface.

- Lower cost – Removes BOM cost by 20-30%. Copper (and other metals) are readily available and much cheaper than Indium, a rare earth metal.
Cons:

- Low light transmittance/Weak optical performance – Metal mesh creates moiré patterns (visible lines). This reduces the resolution/display quality and has been the biggest problem for metal mesh. Developers are looking into ways to make the lines finer and invisible, but when it goes into roll-to-roll process, the pattern will be easily broken, causing a low yield rate.

- Possible oxidation – depending on the metals it is using. Silver and copper have been the most popular materials to try on metal mesh given the excellent conductivity. However, the metals could be easily oxidized, hence creating a shorter life-time. This issue may need time to prove.

- Yield rate - Manufacturing yield rate remains a challenge especially during the roll-to-toll process, where the lines could be broken.

Manufacturing Process

The manufacturing process to fabricate metal mesh touch sensors consists of drawing the touch sensing circuit with a special catalytic ink on transparent film. The touch sensing circuit is drawn with lines and structures under 5 μm in size. The film is then submerged into a plating bath where the metal grows on the catalytic ink by autocatalytic deposition forming the printed metal circuit. The end result is a printed circuit on film that is virtually invisible.

Silver Nanowire

What is Silver Nanowire?

Silver nanowire is a nanostructured inorganic material that produces a transparent conductor coating. Silver nanowire technology has excellent electrical and optical properties coupled with outstanding flexibility. Single-crystal silver nanowires can be coated onto various substrates, including glass, polycarbonate, and PET film. Film-based touch sensors made with silver nanowires are light, thin, and shatterproof. The nanowires also create a flexible transparent conductive layer that is conducive to bendable and curved form factors, or devices with touch capacities wrapped around their edges. Already a leading ITO competitor for large-area touch applications including ultrabooks and all-in-one computers, durable silver nanowires are ideal for emerging mobile technologies.

Cambrios Technologies Corporation “Cambrios” is a California, U.S. based company that is the leader and the sole provider of the silver nanowire ink nowadays. The company has strategic investors like Samsung and TPK. It supplies transparent ink to its contracted partners such as Nissha Printing, Hitachi Chemical, ShinEtsu, DIC, Toray, etc. The “ink” is then coated onto the film and then shipped to sensor makers for patterning and back-end lamination. The technology is already used in commercially available mobile products including Huawei’s Ascend smartphone and NTT Docomo NEC N-07D Medias X smart phone.
Pros and cons

Pros:

- Higher conductivity – Although the unit cost of indium is comparable to the cost of silver, the conductivity of silver is far superior than indium (silver is 50 to 100 times more conductive), requiring a small fraction of silver relative to the amount of indium needed for the same surface area.

- Advanced manufacturing process – Silver nanowire is applied to material using a wet chemical solution and does not require the expensive vacuum application required by ITO.

- Better optical transmittance – Contrary to metal mesh, silver nanowire does not create moiré patterns (visible lines). The optical transmittance could be better than ITO OGS, therefore consuming less battery.

- Outstanding flexibility – Silver nanowire creates a flexible transparent conductive layer that is conductive to bendable and curved form factors.

Cons:

- High material costs – The unit cost of silver is comparable to ITO, but higher than copper metal mesh.

- Sole provider – Cambrios appears to be the sole provider of the silver nanowire ink in the market.

Manufacturing Process

The silver nanowire material consists of a wet processable dispersion of high-aspect-ratio silver nanowires. Starting from silver salts, twinned-crystal silver nanowires are grown via the polyol process. By carefully controlling the process parameters, high aspect ratio silver nanowires can be synthesized at high yield, with an average diameter in the low tens of nanometers and an average length in excess of 10 μm. Independent control of nanowire length and diameter is possible, allowing the tailoring of morphology-dependent optical and electrical properties for specific applications. These nano-structures are then purified and formulated into a coatable suspension that is compatible with industry standard coating methods such as roll-to-roll slot die coating or spin coating.

The transparent conductive layer is created by coating the formulated suspension of nanowires on the surface of a substrate such as glass or plastic. Upon drying of the solvent, the nanowires form an interconnected, two-dimensional mesh on the surface. Controlling the sheet resistivity of the layer of interconnected nanowires is accomplished by changing the number density of nanowires on the surface.
Figure 2: Silver nanowire manufacture process

Source: J.P. Morgan

Figure 3: Silver nanowire supply chain

Silver nanowire ink
- Cambrios

Film makers
- Okura, Toray, DIC, Hitachi Chemical, ShinEtsu
- LGE and other Korean suppliers
- China and US based suppliers

Touch sensor makers
- LGE
eTurboTouch
- CNi
- Nissha Printing
- Shin-Etsu
- TPK

Source: J.P. Morgan
Carbon Nanotubes

What is Carbon Nanotubes?
Carbon Nanotubes (CNT), a unique form of carbon, exhibit remarkable electrical, optical and mechanical properties. One result of those properties is the fact that specific types of Single–Walled Carbon Nanotubes (SWCNT), when printed in very thin films, are both highly electrically conductive and highly transparent to visible light. This makes them important candidates for applications, such as touch panel sensors, that require a transparent conductive film (TCF). Compared with the currently used ITO films, CNT has higher durability, increased accuracy, higher sensitivity, flexible, better transmittance, and capability of higher resolutions. There is also cost savings associated with CNT due to cheaper raw materials and no requirement for glass etching, which equates to a more price competitive final product.

Pros and cons
Pros:
- Lower manufacturing costs – There is cost savings associated with CNT due to no requirement for glass etching, which equates to a more price competitive final product.
- Increased accuracy/higher sensitivity – The conductivity is better than ITO
- Flexible – It could be applied to flexible substrates without damaging the pattern.
- Better transmittance – Similar to silver nanowire, it provides strong optical performance.
- Stable in conditions of high/low temperature and humidity.

Cons:
- Difficult in impurity and morphology control
- High material costs – CNT is not particular much cheaper than ITO

Manufacturing process
CNT has been formulated into inks which are printable by standard commercial processes such as screen, gravure and flexography. Because these are relatively inexpensive processes, and because the desired pattern is built into the printing screen, plate or cylinder, CNT based inks print a transparent conductive film on a substrate in precisely the required pattern. No subsequent etching or other film removal steps are required. This is referred to as additive patterning.
Table 1: ITO-substitute touch panel technologies

<table>
<thead>
<tr>
<th>Base Material</th>
<th>Advantage vs ITO</th>
<th>Issue</th>
<th>Maker</th>
<th>Material</th>
<th>Deposition/Patterning</th>
<th>Development Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal Mesh</td>
<td>Lower material cost</td>
<td>Thinning</td>
<td>3M</td>
<td>Silver Mesh</td>
<td>Hexagonal mesh pattern printing</td>
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<td></td>
<td>Deposition by wet process</td>
<td>Invisibility</td>
<td>Atmel</td>
<td>Metal Mesh</td>
<td>Wet process patterning</td>
<td>MP in 2H12</td>
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<tr>
<td></td>
<td>Superior electrical conductivity</td>
<td></td>
<td>DNP</td>
<td>Silver Mesh</td>
<td>Wet process patterning</td>
<td>Ag patterning</td>
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<td></td>
<td></td>
<td>Fuji Film</td>
<td>Silver Halide</td>
<td>Silver halide photography</td>
<td>Capability to less than 10 μm</td>
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<td></td>
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<td></td>
<td>GUNZE</td>
<td>Silver Ink</td>
<td>DTP(Direct printing) screen printing</td>
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<td></td>
<td>Hitachi Chemical</td>
<td>Silver Mesh</td>
<td>Wet process patterning</td>
<td>Etching patterning</td>
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<td></td>
<td>Poly IC</td>
<td>Silver Mesh</td>
<td>Wet process patterning</td>
<td>Thin metal line patterning</td>
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<td>Toppan</td>
<td>Metal Nano Wire</td>
<td>Wet process patterning</td>
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<td></td>
<td></td>
<td>Toray</td>
<td>Copper Mesh</td>
<td>Wet process patterning</td>
<td>Etching patterning</td>
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<td>Silver(Ag) Nanowire</td>
<td>Leading mass production</td>
<td></td>
<td>Cambrios</td>
<td>Silver ink sales</td>
<td></td>
<td>Some models in MP</td>
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<td>Flexibility</td>
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<td>Hitachi Chemical</td>
<td>Wet process patterning</td>
<td>Sell Deposition film</td>
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<td>High transmittance</td>
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<td>ShinEtsu</td>
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<td></td>
<td>DIC</td>
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<tr>
<td>Carbon Nano Tube</td>
<td>High tensile strength</td>
<td></td>
<td>Unidym</td>
<td>Wet process patterning</td>
<td></td>
<td>Co-develop with Samsung and LG</td>
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<td>Durable to keystroke</td>
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<td>Canatu</td>
<td></td>
<td></td>
<td>Developing</td>
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<tr>
<td></td>
<td>Moisture/temperature resistance</td>
<td></td>
<td>Innolux and Funatouch</td>
<td></td>
<td></td>
<td>Track record on adopted in touch panel</td>
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<td></td>
<td></td>
<td></td>
<td>Toray</td>
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<td></td>
<td>Two layer CNT</td>
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<tr>
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<td>Samsung</td>
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<td>Developing</td>
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<td>Flexibility</td>
<td></td>
<td>Fujitsu R&amp;D Institute</td>
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<td></td>
<td>Developing</td>
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<tr>
<td>Conductive Polymer</td>
<td>Lower cost on wet process</td>
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<td>NOF</td>
<td>Wet process patterning</td>
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<td>Sample</td>
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<tr>
<td></td>
<td>Flexibility</td>
<td></td>
<td>Agfa</td>
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<td></td>
<td>Transparency</td>
<td></td>
<td>H.C. Starck Clevios</td>
<td></td>
<td></td>
<td>Sample</td>
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<td></td>
<td>Attain conductivity to film</td>
<td></td>
<td>Nagase &amp; Co</td>
<td></td>
<td></td>
<td>Sample</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Lyntec</td>
<td></td>
<td></td>
<td>Sample</td>
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</tbody>
</table>

Source: Display Search, J.P. Morgan
Takeaways from supply chain visits:

- **Atmel (Not Covered, ATML.US)** – Atmel’s xSense is already in mass production. It targets US$15-20 million revenue contribution from metal mesh in 2013. This essentially translates into around 1-2 million units of 10” touch panels. Currently Atmel has designed in some of the products available in the market including ASUS Eee Pad Transformer. Atmel claims comparing ITO-based touch panels with metal mesh touch panels is similar to comparing Coke with Pepsi – the difference could be negligible. It also targets US$100 million revenue contribution from xSense for 2014. The price could be similar to ITO-based solution at US$1-1.5 per inch diagonal at present (sensor), therefore the cost advantage has not been evident.

- **O-Film (Not Covered, 002456.CH)**. According to the company, it is ready to manufacture metal mesh for tablet panels and below. O-Film has already done customer certification for its metal mesh products and is preparing to start production in 2H13.

- **Nissha Printing (OW, 7915.JP, covered by Itaya Masashi)** – The company has been working on silver nanowire. Nissha supplied this to smartphone customers in the past. However, it requires meaningful investment on the raw material (silver nanowire ink) if trying to turn it into mass production level. Cambrios is the main supplier developing silver nanowire ink and a contracted supplier to Nissha Printing. Cambrios supplies silver nanowire ink (a transparent liquid), whereas Nissha Printing does patterning. Nissha Printing reckons that silver nanowire is still difficult in mass production. CNT is the best for flexibility but not as transparent.

- **Nitto Denko (OW, 6988.JP, covered by Itaya Masashi)** – Nitto Denko recognizes the advantages and disadvantages of these ITO replacement technologies but currently focusing on ITO films. The company thinks at the current stage ITO replacement materials manufacturing costs remain high, partially due to small volume.

- **Fujifilm (N, 4901.JP, covered by Moriyama Hisashi)** – The company is targeting JPY 5 billion revenue in FY13 vs FY12 J.P. Morgan assumption of JPY 1 billion. It is also supplying the films to touch module makers like Young Fast (Not Covered, 3622.TT).

- **Toray (Not Covered, 3402.JP)** – Similar to Nissha Printing, Toray also contracted with Cambrios to acquire silver nanowire ink. Cambrios supplies the silver nanowire ink to Toray’s subsidiary and Toray makes the film. Toray’s subsidiary has the know-how of coating/spattering. The company is not actively involved in copper metal mesh manufacture.

- **TPK (OW, 3673.TT, covered by Narci Chang)** – TPK set up JV with Cambrios back in June 2012. TPK’s wholly owned subsidiary TPK HK obtained 80.1% of the share in the joint venture, TPK Film, and the remaining 19.9% is owned by Cambrios. TPK HK and Cambrios invested US$12,015 thousand and US$2,985 thousand, respectively, to found TPK Film. TPK also strategically invested in Cambrios. The company believes possible mass production could be no earlier than 2014.

- **J-touch (Not Covered, 3584.TT)** – J-touch is scheduled to set up metal mesh production lines and complete certification in 3Q13. Potential mass production could be 4Q13 or later. The company develops both copper metal mesh and silver metal mesh and claims its metal mesh lines could be as thin as 3 micron. The company plans to do the coating by itself rather than purchasing from other vendors.

- **Melfas (Not Covered, 096640 KS)** – The company is in early development stage and working with Mirae Nanotech (Not Covered, 095500.KQ). The company thinks metal mesh film based touch
solution is not ideal for visibility especially for outdoor activity, hence major usage application in near-term would be PC rather than smartphone/tablet. Mirae Nanotech is commercializing large size 20"+ metal mesh touch panels in joint development with Melfas which will be doing sensor patterning.

- **ELK (Not Covered, 094190.KS)** – The company is developing tablet touch solution using metal mesh replacing current "ITO films". Initial target volume seems minimal (won 1 order targeting 3Q13 launch). ELK is a touch panel vendor in Korea and it is supplying to new Samsung tablet using metal mesh material (8" size tablet likely) for 3Q13 market launch. Although there are some vendors mentioning metal mesh, the majority of Korean touch panel makers claim metal mesh would not replace or be perfect substitute to ITO film.

- **Ilijin Display (020760.KS)** – Ilijin Display thinks metal mesh may take place only in 2014 or later. It would be used for large-size only as it is not suitable for outdoor activity and visibility.

### Table 2: Global touch panel peer valuation comparison

<table>
<thead>
<tr>
<th>Company</th>
<th>Ticker</th>
<th>Rating</th>
<th>Price (LC)</th>
<th>Market cap (US$ M)</th>
<th>P/E (x) FY12</th>
<th>P/BV (x) FY13E</th>
<th>ROE (%)</th>
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<td>3673 TT</td>
<td>OW</td>
<td>460.0</td>
<td>5,002.7</td>
<td>10.4</td>
<td>8.1</td>
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<td>ATML US</td>
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<td>106.9</td>
<td>23.2</td>
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<td>Unipixel</td>
<td>UNXL</td>
<td>NC</td>
<td>13.6</td>
<td>134.4</td>
<td>(12.3)</td>
<td>21.4</td>
<td>34.0</td>
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<td>Youngfast</td>
<td>3622 TT</td>
<td>NC</td>
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<td>244.1</td>
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<td>17.1</td>
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<td>n.a.</td>
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<td>Mirae Nanotech</td>
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<td>68.9</td>
<td>55.1</td>
<td>25.6</td>
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**Source:** Bloomberg, J.P. Morgan. Consensus estimates for Not-Covered (NC) companies, J.P. Morgan estimates for all others. Prices and valuations are as of July 3, 2013.
Companies Recommended in This Report (all prices in this report as of market close on 03 July 2013)
FUJIFILM Holdings (4901) (4901.T/¥2,284/Neutral), Nissha Printing (7915) (7915.T/¥1,928/Overweight), Nitto Denko (6988) (6988.T/¥6,450/Overweight), Samsung Electronics (005930.KS/W1,301,000/Overweight), TPK Holding Co., Ltd. (3673.TW/NT$460.00/Overweight)

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Source: Bloomberg and J.P. Morgan; price data adjusted for stock splits and dividends.

Initiated coverage Oct 17, 2006.
### Nissha Printing (7915) (7915.T, 7915 JT) Price Chart

Source: Bloomberg and J.P. Morgan; price data adjusted for stock splits and dividends.
Initiated coverage Jan 26, 2009.

### Nitto Denko (6988) (6988.T, 6988 JT) Price Chart

Source: Bloomberg and J.P. Morgan; price data adjusted for stock splits and dividends.
The chart(s) show J.P. Morgan's continuing coverage of the stocks; the current analysts may or may not have covered it over the entire period. J.P. Morgan ratings or designations: OW = Overweight, N= Neutral, UW = Underweight, NR = Not Rated

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**Park, JJ:** LG Display (034220.KS), LG Electronics (066570.KS), Panasonic (6752.T), SK Hynix (000660.KS), Samsung Electronics (005930.KS), Sony (6758.T), TSMC (2330.TW)
J.P. Morgan Equity Research Ratings Distribution, as of June 28, 2013

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<th>J.P. Morgan Global Equity Research Coverage</th>
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<th>Neutral (hold)</th>
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*Percentage of investment banking clients in each rating category.

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