Flexible & Printed Electronics
Fields of Research Activity

Founded in 1998, Yole Developpement is a global market, technology and strategy consulting company involved in:

- Power Electronics
- Advanced Packaging
- Photovoltaics
- MEMS & Image Sensors
- Microfluidic & Medical Technologies
- HB LED, LED & LD
- Wafers and Substrates

Our research is performed by in-house personnel conducting open-ended discussions based on interviews.

- 32 full time analysts with technical and marketing degrees
- Primary research including over 3,500 interviews per year
30% of our business is in North America

40% of our business is in EU Countries

30% of our business is in Asia

Our Global Activity

- Yole Inc.
- Yole Paris
- S+C
- Yole Développement Lyon HQ
- Yole Korea
- Yole Japan
- Yole Taiwan
Mission Statement
Knowledged Based Company

• Help our customers develop their business through specific analysis and reports by providing:
  • Accurate market data, market segmentation and marketing analysis
  • Technical evaluation and technology cost and COO analysis
  • Patent portfolio analysis and freedom to operate analysis
  • Strategic analysis to enhance company and business unit performances
  • Support strategic development: find growth opportunities, support M&A and find new investors
  • Advertising opportunities in YOLE magazines, via webinar and specific events

• Help them get operational results from our actions
Yole Activities

Technology & Market Reports
Report/Database/Reverse Costing/Tools

Custom Studies
Market Research
Technology & Strategy

Media business
Website / Magazines / Webcasts

Yole Finance
M&A / Due Diligence / Fund raising services

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Research Products
Content comparison

Custom analysis scope is defined with you to meet your information and budget needs.
### Some of Our Customers

#### Financial investors & industry advocates
- BainCapital
- Booz Allen Hamilton
- Applied Ventures
- SMH Capital
- Scottish Enterprise

#### Suppliers (equipment, wafers, materials)
- DARPA
- Applied Materials
- EVG
- Dalsa
- ASML
- Air Liquide
- TEL
- SOSS.MicroTec
- STS
- Lam Research
- Multitest
- ASM
- Despatch Industries
- ASEI
- Set.

#### Component manufacturers
- Aime
- Infineon
- E2V
- Philips
- Analog Devices
- MicroParts
- Freescale
- Labs of America
- Sharp
- Bosch
- TOSHIBA
- OSI
- Siemens
- AMI
- Kyocera
- NXP
- Honeywell

#### Integrators, system suppliers & end users
- Apple
- Seagate
- TOYOTA
- Mitsubishi
- STMicroelectronics
- DoCoMo
- Danfoss
- ABB
- France Telecom
- OLYMPUS
- STMicroelectronics
- Nippon Sheet Glass
- Sony
- Bridgestone
- Panasonic
- ALSTOM
- SONY
- LG
- DENSO
- Continental

#### R&D Organizations
- ETRI
- LETI
- IME
- CMC Microsystems
- HSG
- IMIT
- KOREA Institute for Basic Science
- KIMM
- Continental
Definitions

- **Flexible electronics**: Partly or completely flexible electronic devices. Manufacturing process can include evaporation, MOCVD, solution printing etc.

- **Printed electronics**: Electronic devices using solution-based manufacturing processes (screen printing, roll-to-roll, inkjet etc.). Although we do not consider as printed devices products with only one printing step such as screen-printed PV devices. Only the devices which have an active part made by printing techniques are considered as “printed”. Therefore, for instance crystalline silicon cells with screen printed metallization are not considered here.

- **Polytronics**: Formerly “Polymer Electronics”. They are devices mixing printed electronics, flexible electronics, and inorganic electronics (standard Si ICs, thin film technologies and so on...).
APPLICATION LANDSCAPE
Application landscape (1/3)

Flexible
Application enabling / Function enabling

- Small OLED Displays
  - Mobile phones / tablets
- Conformable OLED Lighting
  - Automotive / luxury lighting
- Conformable Organic PV
  - Energy harvesting

Printed
(Potentially) Large volumes / Low cost

- Electronic paper
  - e-readers
- Systems on foil
  - Smart systems, polytronics
- Gas sensors
  - Wireless sensors
- Large OLED Displays
  - TV
- OLED Lighting
  - General lighting
- Large / high volume
  - Organic PV
  - PV farms / grid electricity
Market drivers for flexible and printed electronics are different, even though manufacturing processes and end applications share similarities.

Main market drivers for flexible electronics are:

- The possibility to add new functionalities:
  - Conformability for OLED lighting (for the automotive industry),
  - Conformability for OPV (energy harvesting)
  - Robustness for small OLED displays (for smart phones & tablets)
- The possibility to create new applications:
  - Wearable electronics.
- Flexible electronics is NOT meant to be low-cost, and usually uses expensive processes (MOCVD, evaporation)

The main market driver for printed electronics is:

- Cost reduction thanks to high volume (Roll-to-roll) manufacturing or to the fewer use of expensive manufacturing processes (MOCVD, evaporation):
  - Potentially lower cost OLED TVs can be built if solution based manufacturing is mastered, potentially low cost OPV can appear if technical challenges are leveraged
## Application landscape (3/3)

<table>
<thead>
<tr>
<th>Technology</th>
<th>Application</th>
<th>Development driver</th>
<th>Manufacturing focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displays</td>
<td>Small OLED Display</td>
<td>Smart phone &amp; tablets displays; PMP displays etc.</td>
<td>Robustness</td>
</tr>
<tr>
<td></td>
<td>Large OLED Display</td>
<td>TV screens</td>
<td>Lowering costs</td>
</tr>
<tr>
<td></td>
<td>Electronic paper</td>
<td>E-readers; auxiliary screen for cellphones</td>
<td>Low power consumption</td>
</tr>
<tr>
<td>Lighting</td>
<td>Conformable OLED lighting</td>
<td>Automotive indoor lighting; luxury lighting</td>
<td>Conformability</td>
</tr>
<tr>
<td></td>
<td>Large panel OLED lighting</td>
<td>General lighting</td>
<td>Lighting homogeneity</td>
</tr>
<tr>
<td></td>
<td>OPV</td>
<td>Energy harvesting; conformable solar panels</td>
<td>Conformability</td>
</tr>
<tr>
<td></td>
<td>Large volume OPV</td>
<td>Solar farms; building powering</td>
<td>Lowering costs</td>
</tr>
<tr>
<td>Sensing</td>
<td>Printed sensors</td>
<td>Chemical sensing; printed touchscreens</td>
<td>Lowering costs</td>
</tr>
<tr>
<td></td>
<td>Systems on foil / Smart sensors</td>
<td>RFID sensing; medical, cosmetic, packaging, etc…</td>
<td>Enabling the “Internet of Things”; low cost smart systems</td>
</tr>
</tbody>
</table>
PLAYERS LANDSCAPE
Players landscape (1/3)

Flexible
Application enabling / Function enabling

Small OLED Displays
Conformable OLED Lighting
Conformable Organic PV

Electronic paper
Systems on foil / polytronics
nextinput

Gas sensors

Large OLED Displays
OLED Lighting
Large / high volume Organic PV

Large OLED Displays

Printed
(Potentially) Large volumes / Low cost

Electronic paper

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Printed electronics and Flexible electronics share most of their manufacturing processes
Printed electronics and Flexible electronics share the same manufacturing materials
Each Printed Electronics Segment Has Very Complex Supply Chains

Example of ThinFilm Electronics NVRAM supply chain Unique to ThinFilm

If you want to play in Printed Electronics, you have to put your own infrastructure together!
Printed electronics applications

- **peDisplays: OLEDs & ePaper**
  - Various flexible display designs

- **peSolar Applications – 2012+**
  - Energy harvest
  - Short product lifetimes
  - Flexible applications
  - Small power needs

- **OLED Lighting**
  - Various lighting applications

- **peLogic, Memory & Sensors 50+ Applications**
  - Different electronics products and applications
Former YOLE Printed Electronics Forecast by Application

Printed Electronics By Applications

<table>
<thead>
<tr>
<th>Year</th>
<th>peLMS</th>
<th>peSolar</th>
<th>peLighting</th>
<th>peDisplay (peOLEDs &amp; ePapers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>$18</td>
<td>$25</td>
<td>$4</td>
<td>$153</td>
</tr>
<tr>
<td>2011</td>
<td>$33</td>
<td>$29</td>
<td>$16</td>
<td>$266</td>
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<tr>
<td>2012</td>
<td>$59</td>
<td>$34</td>
<td>$70</td>
<td>$430</td>
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<tr>
<td>2013</td>
<td>$107</td>
<td>$40</td>
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<tr>
<td>2014</td>
<td>$194</td>
<td>$47</td>
<td>$448</td>
<td>$665</td>
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<tr>
<td>2015</td>
<td>$351</td>
<td>$55</td>
<td>$810</td>
<td>$765</td>
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</tbody>
</table>

“pe” represents “printed electronics”

Must use traditional "printing" manufacturing techniques

Must be "electronic" and not simply electrical

These two definitions separate out new and interesting technological advancements from simply old technologies that may be flexible or use organic polymers

Substrates may be flexible or not, transparent or not, organic or inorganic

peLMS = Logic, memory & sensors and includes 50+ applications
Technology needs always more time to come to the market…”

“pe” represents “printed electronics”

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pelMS = Logic, memory & sensors and includes 50+ applications
2013-2020 Flexible & Printed Electronics Market

- Printed & Flexible Electronics is expected to be close to $1B market by 2020 with a 27% CAGR over 2013-2012

TOTAL Flexible & Printed Electronics (US$M)

<table>
<thead>
<tr>
<th>Year</th>
<th>US$M</th>
</tr>
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<tbody>
<tr>
<td>2013</td>
<td>$176</td>
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<tr>
<td>2014</td>
<td>$181</td>
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<tr>
<td>2015</td>
<td>$189</td>
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<tr>
<td>2016</td>
<td>$257</td>
</tr>
<tr>
<td>2017</td>
<td>$338</td>
</tr>
<tr>
<td>2018</td>
<td>$534</td>
</tr>
<tr>
<td>2019</td>
<td>$749</td>
</tr>
<tr>
<td>2020</td>
<td>$959</td>
</tr>
</tbody>
</table>

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PRINTED ELECTRONICS CHALLENGES:
TECHNICAL LIMITATIONS
Technical Limitations

- **Materials performances**
  - High-performance materials are required for most applications such as OLED displays for example.
  - Solution materials have to keep from mixing with each other.
  - They have to stay contained in a pixels area for displays.
  - Etc...

- **Appropriate equipment**
  - Appropriate printing equipment must be developed and affordable.
  - Printed electronics requires smaller pitches than what can offer current printing pieces of equipment: graphic industry does not need a precision under 40 μm.

- **High Volumes!**
  - For printed solutions to become affordable, high volumes have to be reached, and this will not be the case at short / mid term.
Solar cells lead the raised amounts in printed electronics, even though they will not be the first to reach actual volumes, if-ever they can reach high volumes…

Amount Raised - Applicative Breakdown
TOTAL US$1,35B
Dow Jones Venture Source
FLEXIBLE ELECTRONICS CHALLENGES
Challenges for flexible electronics

• **Flexible barriers**
  – The main challenge is on materials for encapsulation
  – Current technologies are not so good when used on flexible devices
  – Current options such as flexible glass or multi-layer technologies are expensive
  – Active materials are required for higher performance applications such as OPV or flexible OLED. No such material yet exists

• **Some companies start to build production lines for flexible OPV in 2016+. Nevertheless these companies are betting on the hope that a suitable barrier material will exist by the time the line is operational.**
PRINTED ELECTRONICS CHALLENGE: FINANCIAL INCOHERENCE
2013 Financial analysis

- In last report, we tracked 24 companies for a total of US$1.35B raised over 2000-2010 (we did not get the information for 3 companies).

- Two years later, 1 companies out of the 3 that had raised > $100M did bankrupt:
  - Konarka (photovoltaics).
  - Nanosolar starts layoffs in February 2013
  - And PlasticLogic is currently trying to find new applications outside the e-readers market!

![Amount raised over 2000-2011(USD)](Dow Jones Venture Source)
EVOLUTION OF PRINTED ELECTRONICS: POLYTRONICS
Polytronics (Polymer Electronics) is the “evolution” of printed & flexible electronics. We assimilate it to the also called “hybrid printed electronics”, it is the integration on a flexible foil of different technologies:

- Printed devices (printed sensors, OPV)
- Si ICs
- Thin film technologies
- Etc…

The main purpose of Polytronics is to develop smart systems with a potential low cost, thus enabling larger visions such as “the Internet of Things” and even more.

The global interest in polytronics is born from the difficulties faced by the flexible & printed electronics industry. It is an alternate way to come to similar results while trying to avoid some of the main challenges.
Printed electronics, Flexible electronics & Polytronics history

80’s
- Highly conductive polymers start to be investigated.
- Printed electronics promises: New applications
- Flexible electronics is being investigated

90’s
- Beginning of the hype
- Printed electronics promises: New applications, Low costs
- Flexible electronics is being investigated

2000’s
- In the hype!
  - Tremendous amounts of money are being invested. First working prototypes are demonstrated.
  - Start-ups are popping-out
- Printed electronics promises: New applications, Low costs, Infinite potential
- Flexible electronics is being investigated

2010’s
- Time for disillusion:
  - No killer applications
  - Huge technical challenges
  - Low market pull
  - Restructuration of the market (companies close)
- Printed electronics promises: Only a few potential applications (OLED displays, touchscreens)
- Flexible electronics is being investigated

2020’s
- First high volumes in printed & flexible electronics, in a few applications only
- Actual polytronics challenges are being revealed
- Polytronics starts to be investigated

Legend:
- Printed electronics
- Flexible electronics
- Polytronics

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Several building blocks are being investigated by polytronics. Some building block already exist, but most of them must exist to build a marketable devices.

Some companies have already developed commercial products, but are now in “advance of phase” and are techno-pushing

### Projects & players:
- Interflex, Chip2Foil, SmartEC, PRIAM etc...
  - Bosch
  - NXP
  - VTT
  - Fraunhofer
  - CEA LITEN
  - Etc…

<table>
<thead>
<tr>
<th>Energy harvesting</th>
<th>Thin film battery</th>
<th>Printed sensors</th>
<th>Small/thin inorganic electronics</th>
<th>Printed antennas</th>
<th>Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Disasolar, Eight 19, Armor, (Heliatek), etc…</td>
<td>- EnFuCell, Infinite Power Solutions, etc…</td>
<td>- KWJ Engineering</td>
<td>- NXP</td>
<td></td>
<td>- DuPont Teijin, Agfa, Heraeus, Etc…</td>
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<td></td>
<td></td>
<td></td>
<td>- Prelonic technologies</td>
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The Pasteur project aims at creating a printed RFID – wireless sensor tag for which enables monitoring the environmental conditions of perishables in the cold chain.

Many industrials and research centers are involved in this project: NVC, Inkoa, KUL, WageningenUP, Verhaert, Philips, TU/e, NXP, Prelonic, TU Delft, CNM, IMEC, NTC, TNO, Catrene, Boschman.

RFID – wireless sensor tag demonstrators:
Polytronics current stage

- Pilot facilities are being developed, mixing roll-to-roll processes and pick & place for inorganic components: VTT, Fraunhofer Institute, CEA LITEN, etc…

- Prototypes and start-ups start to appear:
  - VTT and EnFuCell: biosensor coupled with electronics for cosmetic applications like monitoring lotion penetration into the skin
  - Fraunhofer EMFT: polytronics based Lab-on-a-chip

BUT

- Only niche applications have been identified. The only killer application could be RFID if costs manage to go lower than Si-based RFID
- The technology is still at basic development stage
- Practical questions start to arise:
  - Smart packages: How to recycle it? It cannot go into standard recycle bins…
  - Smart clothing: Will it be trend-dependent and never last more than one season?
  - Smart sensing: Is there an health issue if my kid tries to eat the sensor I put in my refrigerator?
Late 90's: beginning of the hype for printed electronics  
Start-ups start to be created

2000's: beginning of the hype for flexible electronics  
Start-ups start to be created

2005-2008: In the hype for printed electronics  
Large investments in R&D / large investments in start-ups

2010's: In the hype for flexible electronics  
Large investments in R&D / large investments in start-ups

2012: End of the hype for printed electronics  
Industry restructuring / companies start to close

2013: beginning of the hype for polytronics  
Start-ups start to be created

Legend:  
- Printed electronics  
- Flexible electronics  
- Polytronics  
- Interest and investments
PE “At-a-glance”

- Yole defines Printed Electronics as using some kind of printing technology AND requiring a “semiconductor effect” such as “electron donor acceptor” or “electron-hole” type activity
  - Yole sees the printed electronics segment as very different from printed wires and other electrical devices
  - The semiconductor junction effect separates printed electronics from printed wires (e.g. RFID antennas) and printed batteries etc.

- The industry is highly fragmented and needs to coalesce around 1-2 manufacturing techniques in each application or the efficiencies of industry will not lower prices for equipment and material supply channels to make many applications economical.
  - This is however not the case today as many manufacturing techniques can be used for different applications.
  - PE transistors can be printed by various means: Inkjet, Gravure, Roll-to-roll, Flexography, Nano-imprint, Screen printing, Spin coating
  - Overall the printed electronics industry need more “killer applications” (none today) and
DISCUSSION