Impact of printed electronics on graphic arts industry

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According to a Pira report, RFID and printed electronics will have a big impact on the printing and publishing industries. Several developments pushed the burgeoning printed electronics industry along in 2005 but, asks Pira International, what will the industry grow into over the next 10 years?

Pira's Ten-Year Forecast of Disruptive Technologies in Printing and Publishing has identified the 25 potentially most disruptive technologies that will affect the printing and publishing industries up to 2015. The report also analyses these technologies and forecasts how they are likely to evolve, examine the impact these technologies will have on printing and publishing markets, and forecast how printing and publishing industries will evolve over the next 10 years.

To produce the report, initial discussions and soundings were taken among various industry experts in printing, publishing, paper, packaging, IT and material science to develop a list of potential technologies that could influence printing and publishing supply chains. This original list was circulated and developed into a refined choice of 72 in the fields of IT, prepress, printing materials, media and other more general technologies. Many of the technologies in this original list were found to be related, and so where appropriate were grouped together, leading to a final selection of 36 distinct potential disruptive technologies that were considered and scored.

The disruptive technologies considered are summarised using a standard technology scorecard. This covers a range of factors at the current time and forecasts how the technology might develop and the impact it will have by 2010 and 2015.
Scoring

During the research period the table was filled in for each of the disruptive technologies, with a commentary for each of the qualitative fields. A quantitative scoring system was used for the likelihood of adoption and the impact that widespread adoption would make on the printing and/or publishing sectors. This used a simple scale from 0 (unlikely or no impact) to 9[?] (very likely, high, widespread impact).The Delphi market research technique was employed to moderate the findings. This technique was originally developed by the Rand Corporation for predicting future events and testing possible future scenarios. The initial tables (without any scores) were distributed to a panel of authorities in print, publishing and materials for their comment and scoring. This provides a considered response not subject to the inhibiting factors of an interview or round-table discussion.

The technique is widely regarded as being especially useful in technical markets. The well-informed and up-to-date experts included senior Pira consultants (thanks to John Birkenshaw and Dr Graham Moore), and senior industry figures in Europe and the US (special thanks to Frank Romano at the Rochester Institute of Technology [RIT]). This panel is qualified to provide expert opinion on future outcomes for print and publishing and their input was used to prepare the final scores presented in the report, including the nanotechnology section, used in this article.
What is a disruptive technology?Disruptive technology is a term coined by Harvard Business School professor and bestselling author Clayton M Christensen to describe a new, emerging technology that unexpectedly displaces an established one. Christensen categorises new technology into two areas, either sustaining or disruptive. Sustaining technology relies on incremental improvements to an already established technology while disruptive technology lacks refinement, often has performance problems because it is new, appeals to a limited audience, and may not yet have a practical application.

Novel material properties are being exploited by large industrial companies with proven track records and start-ups, many spun off from university and research labs. Developments in material science will increase the range of substrates that can be printed, will widen the materials to be printed and coated beyond coloured inks and extend the range of products that result from the printing.

These will open new opportunities for printers to become specialist manufacturers, using precision coating, lithography and inkjet to produce new layered material and devices. General printers will change their production to incorporate new tags and labels, many RFID, on the printed material.
RFIDs and printed electronics in 2015

The first and potentially breakthrough market for printable organic semiconductors is likely to be in the emerging radio frequency identification (RFID) technology market. These intelligent tags and labels are growing in the logistical planning and operation of supply chain processes in manufacturing, distribution and retail industries. They are also being used in services such as security and access control, tracking and monitoring/management.

The three RFID components include the tag (a digital memory chip with integrated transponder), a reader (senses the presence of tags, receives and processes tag level data) and a host computer (aggregates data from tag readers and passes RFID data via middleware to core business systems).

An RFID tag consists of a microchip and an antenna, often in the form of a tiny ribbon that can in turn be packaged into many forms, such as a label, or embedded in between the cardboard layers in a carton. On the microchip is stored information about the product that the tag is affixed to, which can then be 'read' when the tag passes within proximity of an RFID 'reader', with that information being relayed back to a computer system that updates the location status of the associated product. This enables great efficiencies and cost reductions with respect to inventory management and control in a physical product environment, and enables innovative applications in locating and tracking people and assets in a services environment.

The use of RFID to capitalise on data flow in global supply chains could be one of the most significant developments in business strategy since companies first recognised the importance of information flow. High capital costs, imperfect read-rates, unproven systems and uncertainty around standards will all need to be addressed before retailers can adopt and benefit from the technology. This means that over the next 10 years, retailers will continue to use barcodes and gradually introduce RFID tagging, creating an environment of coexistence.

A major boost came from Wal-Mart, which announced a pilot programme in April 2004 that would require its top 100 suppliers to be RFID-compliant. It would also require tags on cases and pallets for Wal-Mart stores (and Sam's Club locations in the Dallas/Fort Worth area) by January 2005. Wal-Mart reported 100 per cent compliance.

This high-profile trial and others (Metro in Germany, M&S in the UK) are being watched by major retailers, and it is likely that the technology will spread. As powerful enterprise-wide computing has grown, the tools to process the information have developed, and retailers will try to make their processes more efficient in that very competitive marketplace. Moving out to the supply chain makes using RFID technology more complicated, but that is where great gains can be made.

Well before 2015, RFID technology will have the ability to track and monitor every product and part at each stage in the manufacturing process, from parts made in Korea and China, packaged in Japan, shipped through Europe, and distributed throughout the US. At every point along that chain there is opportunity for the process to break down and for errors to happen. Setting up RFID technology to track and monitor the entire process will be a killer application for logistics and retail.

Increasing information can be added to the RFID tag, such as best-before dates for perishable items helping shelf stackers use the products in the correct order to minimise waste. The other benefit to retailers is being able to measure consumer behaviour, although there are privacy implications that must be overcome.

Potential uses of RFID are growing. The airline industry is exploring the use of RFID to keep track of luggage, hopefully to cut down on the number of lost bags as air travel grows.Printable electronic devices

Organic semiconductor technology is being applied to make thin-film, flexible electronic devices based on transistors, opening up new markets for low-cost electronic devices. Inorganic semiconductors, such as silicon and gallium arsenide, are essential for countless applications from computers to CD players. Although offering unrivalled computational speed today, they suffer from rigidity and brittleness, and so cannot be used in applications where flexibility is required.

Semiconducting polymers bring together the virtues of plastics and semiconductors in materials of emerging technological importance and outstanding potential. Their enormous potential comes from the fact that they combine novel semiconducting electronic properties with the scope for easy shaping and manufacture of plastics. There is a nearly infinite variety of these organic materials that have been developed by research groups and companies; their properties can be tuned by changing their chemical structure, making them very versatile.

The combination of novel properties opens many new potential applications. They can be used to make a wide range of semiconducting electronic devices, such as transistors, OLEDs, transmitters, solar cells and lasers, but with simpler manufacture than conventional inorganic semiconductors. Organic semiconductors provide the opportunity for the development of flat and flexible electronics. The other key advantage from the perspective of the print industry is that it is possible to deposit semiconducting polymers onto a range of substrates, including paper and board, by a range of printing techniques.

For practical applications all necessary components should be printable. Liquid-phase processable organic semiconductor inks need to be developed for printing via silkscreen, inkjet, gravure and litho methods. The first screen-printed transistor was demonstrated in the mid-1990s. In those transistors, only the electrodes (gate, drain and source electrodes) were printed separately on each side of a polyester film, which acts as the dielectric layer. This film with electrodes was then taped to a plastic substrate followed by vacuum deposition of an organic semiconductor layer.

High-performance plastic transistors have been produced in which all the essential components are printed directly onto plastic substrates using screen printing. An indium tin oxide (ITO)-coated PET film is used as the plastic substrate on which the ITO layer acts as the gate electrode. A polyimide layer is printed through a screen mask onto the ITO surface. An organic semiconductor layer consisting of region-regular poly (3-hexylthiophene) is then put down by spin coating, casting or printing, using chloroform as the solvent. Finally, the device is completed by printing the drain and source electrodes using a conductive ink through another screen mask. By using this procedure, many devices with different shapes or geometries can be obtained in large quantities by printing through suitable screen masks.

The finest feature size that can be obtained by screen printing is still relatively large, in the range of 75-100 microns. Inkjet printing has great potential for the patterning of organic electronics. The technique does not suffer from any fundamental limitations. The only issues are related to further refinement of the process to meet the demands of the materials and the performance of the final product. These include:
- Producing inkjet droplets with uniform thickness;
- Improving the reproducibility of the shapes and sizes of printed droplets;
- Eliminating pinholes in printed layers;
- Expanding the range of viscosities of solutions that can be printed.Where the resolution required cannot be achieved with screen or inkjet printing, use of high-resolution lithographic techniques is an alternative. Such methods are attractive because they are low-cost, can be used directly with many organic materials, and have demonstrated resolution that comfortably satisfies the requirements for many applications of organic electronics.

Organic devices need several key innovations to achieve their market potential. First, ongoing improvement in raw materials is necessary. Improved conductivity and carrier mobility would increase the range of available applications. Improved chemical and mechanical stability would simplify packaging and allow use of organic devices in harsh environments. Predictable and consistent material properties are necessary for commercialisation. Organic solar cell materials in particular require significant fundamental improvements.

Development of high-efficiency organic solar cells would be the single most important factor in the emergence of ultra-portable applications like electronic textiles. A device that must accommodate a battery pack can easily include silicon circuitry as well. Integrated solar cells would allow organic semiconductor devices to achieve their full flexibility and potential. Solar cells are a major potential market.

By modifying the basic OLED device architecture, developers can produce organic photovoltaic devices that convert light energy into electricity. Printing can be used with these to commercialise low-cost web printed sheets of plastic photovoltaics that could be used as roofing materials on homes and businesses to act as a clean, renewable source of energy. Others would be used as power sources integrated into many specialist devices such as active tags.

Product applications that have been created, together with other conceptual ideas formed from such technology developments, include:

- RFID labels and tags;
- Flat-panel displays;
- Dot-matrix displays;
- Batteries;
- Solar cells;
- Transducers.Many of the developments and concepts considered for smart paper products evolve around the premise of laying down electronics onto paper and board substrates using printing technologies, modified in line with needs of the inks and polymer systems required for the electronic circuitry.

The rate of development for such products will be dependent on the market needs, the evolution of the technology and a competitive cost structure. Around the start of 2005 there were the following significant developments:

- A range of ink is being produced and polymer systems made available for the laying down of electronics onto a range of substrates.
- Many of the conductive inks - these are based around silver and copper, as well as a variety of other metal and oxide compositions - can be applied to a range of substrates, including paper and board, by conventional printing processes.
- Polypyrrole and polyaniline are the most commonly used conducting polymers, and are used commercially in a number of applications, including battery electrodes, capacitor electrolytes etc. Long-term stability of such polymer systems remains an issue, and improved stability of the highest conductivity materials is the major technical milestone.
- Organic semiconducting polymers are of emerging technological importance. There is a nearly infinite variety of these materials, and their properties can be tuned by changing their chemical structure. They can be used to make a wide range of semiconducting electronic devices, such as transistors, light-emitting diodes etc., with novel properties and much simpler manufacture than conventional inorganic semiconductors.
- Many of the conventional printing processes can be used to lay down the ink and polymer systems. The principal issue relates to resolution, which has required development work.
- Inkjet printing has great potential for the patterning of organic electronics, and is the subject of development and commercialisation by a number of companies. The technique is well suited for use with many different ink or polymer systems, and does not suffer from any fundamental limitations. The only issues relate to further refinement of the process to meet the demands of the materials and the performance of the final product.
- Gravure printing has not been widely investigated for the printing of electronics. It has good potential in that a wide

range of ink systems could be used and a reasonably thick ink film can be produced, especially at low speeds.
 - Flexo printing is well suited to printing electronics. It is capable of printing quite fine line work if the plates are made with the latest techniques and thin plates are used.
 - Litho printing is ideal for the printing of circuits, as it offers excellent dimensional control and registration with substrate patterns. Litho-printed circuits exhibit sheet resistivities comparable with thick film circuits produced by standard means.
 - Reel-to-reel printing is the subject of continuous development, and a number of successful trials have been undertaken. The development of a successful process will open up further product opportunities and potential reductions in unit costs.Company offerings

There are many companies that offer the printing of flexible circuits using inks and polymers, and these are finding use in cameras and other portable devices, for example. The scope of potential applications for printed electronics is wide. Many will use a plastic base as the substrate, but others use paper and board substrates.

The packaging sector is the dominant end-use sector for smart paper products and this is expected to continue. The principal product application is RFID. Such usage is being driven by retailers and brand owners seeking improvements in the supply chain. In addition to RFID, other opportunities revolve around the development of intelligent packaging.

Batteries screen-printed on a range of substrates are available commercially. These are printed, pasted or laminated onto paper, plastic and other media. Smaller batteries printed with inkjet technology have also been developed. Though little research has yet considered integration of organic semiconductors with conventional printing methods, the two technologies seem basically compatible. If this promise is achieved, organic semiconductors will offer electronics capability at costs far below those of inorganic semiconductors.

MAN Roland is a foundation member of the Organic Electronics Association (OEA), established in December 2004 with the aim of developing an infrastructure for the production of synthetic electronic components. MAN Roland is working closely in this field with the Technical University of Chemnitz, in Germany, where operable transistors using conductive polymers have already been printed on the LABORMAN.

Other companies include Degussa, Merck and Siemens, while the involvement of graphic arts companies and universities such as Felix Böttcher GmbH, Kieser Print Service, or the Technical Universities of Chemnitz and Darmstadt suggest the sector is drawing attention. The group believes that organic electronics is moving out of the laboratory and into the manufacturing stage.

Apart from RFID tags, areas of application also include sensors, solar cells, medical technology and simple consumer products. The OEA now wants to play its part in developing the process technology for mass production and get the first products onto the market as quickly as possible, with the involvement of forward-thinking print companiesTakeaways
 - In Pira's Ten-Year Forecast of Disruptive Technologies in Printing and Publishing, RFID and printed electronics were ranked fifth out of 25.
 - The Delphi technique was used to moderate the findings, from experts including Pira consultants and other printing experts.
 - Harvard Business School professor Clayton M Christensen defines a disruptive technology as one which initially lacks refinement, often has performance problems at the beginning, appeals to a limited audience and may not have proven practical applications.
 - The first breakthrough application for printable organic semiconductors will be RFID, a wireless information technology that enables the tracking of virtually any item, from consumer goods to baggage in airports.
 - Thanks to high-profile trials from large retailers, such as Wal-Mart, Tesco and Metro, RFID technology is likely to be a stalwart of most retail/manufacturer supply chains over the coming years.
 - However, widespread adoption of RFID is being held back in part by the cost of the RFID tags, which prohibits many manufacturers and retailers from applying them to all but the most expensive goods sold in a store such as electronic goods, CDs and clothing, so printable electronic materials could make the fabrication of RFID tags a much cheaper exercise.
 - Organic semiconductors are versatile, so they can be used to make other devices including OLEDs, transistors, solar cells and lasers.
 - Organic semiconductor inks can be applied using a variety of print techniques, although inkjet is showing the most potential because of its precision and flexibility.
 - We are still some way off from a fully functioning organic RFID tag, yet the work of individual companies and more importantly their participation in industry groups and consortiums is helping to take the technology out of the lab and into the marketplace.
This article includes research from the report Ten-Year Forecast of Disruptive Technologies in Printing and Publishing published by Intertech-Pira. To find out more, or to buy a copy, contact Mr Rav Lally on tel: +44 (0)1372 802271 or email: ravl@pira.co.uk