FLEXING ITS POWER

Dr Matthew Dyson explains why printed electronics, including wearable technology and smart packaging, is gaining traction across multiple application sectors and could be appearing in many more products and devices over the next few years

Printed electronics is a rapidly emerging approach to manufacturing electronics that is poised to displace conventional electronics in many applications. Rather than etching the circuit onto a laminated sheet of copper on a rigid board, conductive traces are instead printed from conductive ink, often onto flexible substrates. Furthermore, additional functionality such as sensors, photovoltaic cells and even batteries can also be printed.

This alternative manufacturing methodology brings many advantages. Utilising additive rather than subtractive manufacturing means that less material is used, potentially enabling cost savings. Circuits can be lightweight and flexible/conformal, eliminating the form factor constraint of a conventional rigid printed circuit board (PCB). Circuits can be directly printed onto flexible substrates using roll-to-roll (R2R) manufacturing techniques, facilitating both integration into conventional packaging lines and cost-effective manufacturing over large areas. All in all, printed electronics offers many advantages over the incumbent approach, and is being adopted in many applications including flexible displays, packaging, automotive interiors, and wearable healthcare.

"Smart packaging has huge potential to add value to the customer experience and improve supply chain efficiency

FLEXIBLE HYBRID ELECTRONICS

Despite the benefits of printed/flexible electronics outlined here, a key challenge has been the addition of processing/memory. While printed logic is technologically viable, it is essentially impossible to compete with conventional silicon integrated circuits (ICs). As such, most applications are best suited by a hybrid approach that combines printed functionality and placed components. Termed flexible hybrid electronics (FHE), this is perhaps best described as 'print what you can, place what you can't'.

Figure 1 shows a prototypical FHE substrate, comprising a wide range of printed functionality but with logic and memory made separately and mounted (although they can still be flexible). This combination of attributes opens a wide range of application possibilities, across many different industries. Indeed, IDTechEx finds that this could be a $3 billion market by 2030.

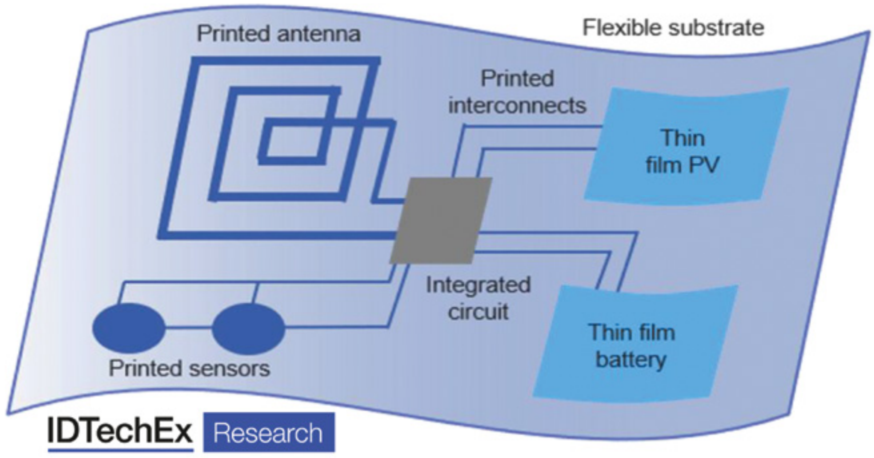
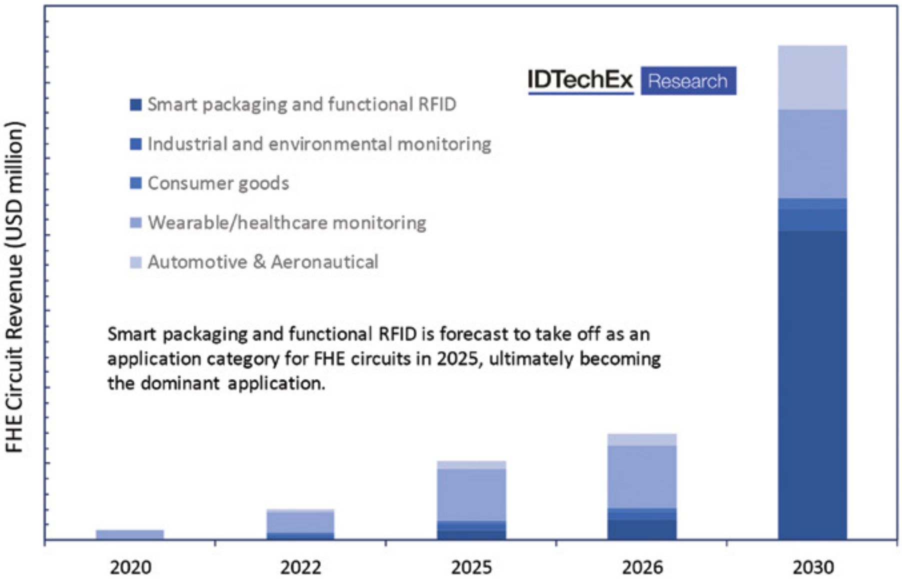


Figure 1: A prototypical flexible hybrid electronics circuit. Source: IDTechEx Research, 'Flexible Hybrid Electronics 2020-2030: Applications, Challenges, Innovations and Forecasts' www.IDTechEx.com/FlexElec

HIGHLY PROMISING APPLICATIONS

Especially promising applications for printed/hybrid electronics are wearable technology and smart packaging, both of which utilise the key benefits of low weight, flexibility/conformality, and potential for high-throughput low-cost manufacturing.

Wearable technology generally involves deploying sensing functionality either as skin patch or within an e-textile, enabling parameters such as heart rate and temperature to be recorded in real time and then transmitted wirelessly. This should enable continuous healthcare monitoring, reducing the need to visit a hospital or doctor's surgery. With such a clear benefit IDTechEx estimates that the wearable skin patch market for healthcare applications



Market forecast (by revenue) for the adoption of FHE for various applications. Source: IDTechEx Research, 'Flexible Hybrid Electronics 2020-2030: Applications, Challenges, Innovations and Forecasts' www.IDTechEx.com/FlexElec

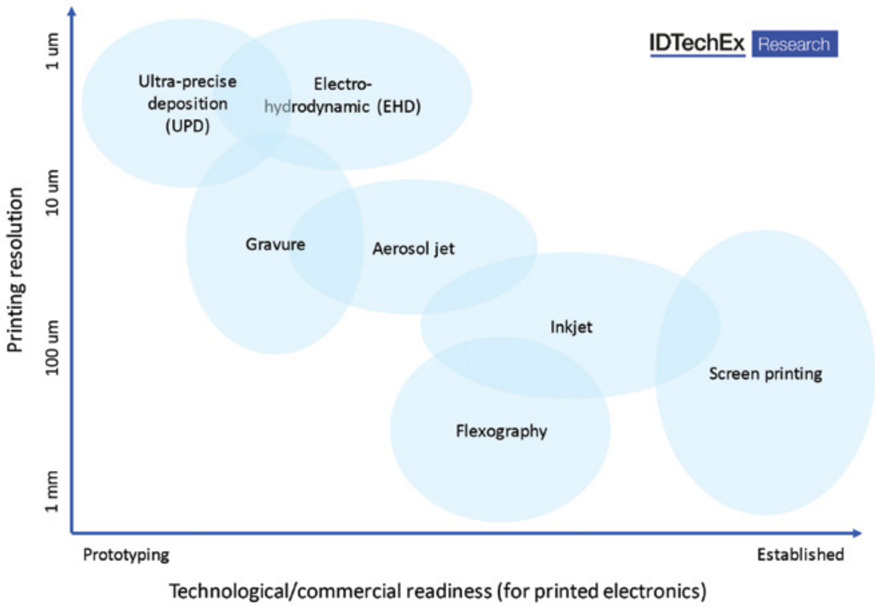


Figure 2: Assessment of various printing technologies used in printed electronics. Source: IDTechEx Research, 'Flexible Hybrid Electronics 2020-2030: Applications, Challenges, Innovations and Forecasts www.IDTechEx.com/FlexElec

will reach around $4 billion by 2030.

Smart/intelligent packaging can be regarded as dramatically extending the capabilities of conventional RFID tags. This can either involve electronic functionality being incorporated during the main packaging process or added afterwards using a functional sticker. It will enable the sensing of gases, temperature, movement, broken security seals, etc. The main challenge in commercialising smart packaging is that many applications, such as monitoring product condition throughout the supply chain, require entering the market at scale to be cost effective. However, smart packaging has huge potential to both add value to the customer experience and improve supply chain efficiency, and thus arguably presents one of the most promising long-term applications of printed electronics.

NEW PRINTING TECHNOLOGIES

In terms of printing technologies, screen printing is still by far the dominant method for conductive inks. This is due to its simplicity and compatibility with viscous flake-based conductive inks (no nozzles to clog) along with multiple substrate types including textiles. An additional, less commonly cited benefit is scalability, since screen printing can be used for very low-volume prototype printing as well as high volume continuous manufacturing using a rotary screen printer. Although the equipment will obviously need upgrading, the similarity in deposition method reduces the extent of ink reformulation that is required.

> *"Electrohydrodynamic printing can produce 1-micron resolution features"*

However, other printing methods are gradually gaining traction, with wide variation in technologies at different stages of development (see **Figure 2**). Longstanding graphics printing methods such as flexography are best suited to high volume applications such as smart packaging that don't require high resolution. The challenge here is ensuring that the desired properties of the printed conductive/functional materials are fully translated when scaling up from laboratory to prototype to production scale. Indeed, this is one of the central challenges for printed electronics, since attributes such as conductivity and more complex sensing/optoelectronic properties can be strongly influenced by slight changes in processing parameters.

> *"Covid-19 has provided substantial impetus for healthcare monitoring, with functional skin patches an ideal application for printed electronics"*

At the other end of the length scale, there is considerable technological innovation in enabling high resolution printing of conductive inks. These include aerosol jet printing, in which a collimated jet of material can be applied to 3D surfaces with a resolution as low as 20 microns. Other emerging techniques are ultra-precise deposition (UPD), in which 1-micron wide lines are produced by forcing a viscous conductive ink though a very fine glass nozzle, and electrohydrodynamic (EHD) printing, which can produce 1-micron resolution features by using an electric field to expel very small droplets.

Despite these impressive capabilities, high resolution printing technologies have arguably yet to find their perfect product market fit. The main challenge is throughput, which is broadly inversely proportional to resolution. As such, with a few exceptions high resolution printing systems have been sold for academic and R&D purposes rather than mass manufacturing. However, throughput can be increased by using multiple nozzles in parallel, with applications such as advanced electronics packaging and repairing TFT backplanes the most promising.

KEY TRENDS IN PRINTED ELECTRONICS

In summary, printed electronics continues to progress, with an increased focus on establishing product market fit. Especially notable is the development of flexible hybrid electronics (FHE), which is becoming established as the dominant approach to incorporate greater functionality in flexible electronic devices. Additionally, Covid-19 has provided substantial impetus for continuous healthcare monitoring, with functional skin patches an ideal application for printed electronics. At IDTechEx we expect printed/flexible/hybrid electronics to be increasingly adopted in commercial applications including smart packaging, wearables, automotive interiors, and consumer goods over the next few years.

IDTechEx offers a wide range of technical market research reports covering most aspects of printed/flexible electronics, building on the company's long history of analysing these technologies, markets, and applications. Reports especially relevant to this article include *Flexible Hybrid Electronics 2020–2030, Flexible Electronics in Healthcare 2020–2030,* and *Smart and Intelligent Packaging 2020–2030.* All reports include detailed analysis of established and emerging technologies, their potential adoption barriers and suitability for different applications, and an assessment of technological and commercial readiness. These reports also include multiple company profiles based on interviews with early-stage and established companies, along with 10-year market forecasts. A full list of IDTechEx's reports can be found at www.IDTechEx.com. ■

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