About this guide
The aim of this guide is to highlight the UK’s capabilities in the Plastic Electronics sector. Sponsored by the Plastic Electronics Leadership Group and supported by the Electronics, Sensors, Photonics Knowledge Transfer Network, it is designed to be used by commercial and academic groups, both within the UK and overseas, that may be looking for development partners or suppliers. We are keen to promote collaboration between UK universities as well as with inward investors.

We hope that the guide will be a useful source of reference for all people working in the sector and that it will encourage broader interactions and more active networking between those interested in this vital field of expertise.

The guide is available on the website http://ukplasticelectronics.com

The UK Plastic Electronics Capability Guide was compiled by Logystyx UK Ltd and edited and designed by Meeting Deadlines Ltd. Front cover image by courtesy of Conductive Inkjet Technology Ltd

The PELG is a volunteer group representing the UK plastic electronics community. Its mission is to promote the development of a successful Plastic Electronics sector in the UK.

ESP KTN is the UK’s fastest growing network spanning the fields of electronics, photonics, sensors and much more - click www.espktn.org to find out more.
Plastic electronics – also known as printed or organic electronics - is a technology that enables circuits to be printed onto a range of surfaces. This technology will lead to the creation of a whole new generation of innovative products that can be produced more cheaply and in a more environmentally-friendly way than previously viable.

New products will include large area ultra-thin and ultra-efficient display and lighting panels; low-cost solar cells that can be integrated into buildings; and intelligent packaging that provides protection against counterfeiting or responds to changes in products that have exceeded their shelf life. The potential for manufacturing is huge – the global market for plastic electronics is forecast to rise from £1bn today to £25bn by 2020.

The new technology has grown from expertise in various disciplines – thin film technology, organic chemistry, printing and circuit design. They are all areas in which UK universities and companies have particular experience, so it is not surprising that many of the early manifestations of the plastics electronics potential is coming from British researchers and entrepreneurs.

This publication reflects the depth and breadth of expertise of UK companies and organisations in this field. I am sure you will find the information here interesting, and I hope it will lead to new collaborations and joint ventures.

The UK is the number one destination for foreign direct investment into the European Union, with a growing proportion coming in high technology sectors. We want to facilitate new investment in plastic electronics, particularly in the creation of R&D and manufacturing facilities, and this publication should help here too.

This is an exciting area with significant future potential. I strongly encourage you to make use of the contacts we have provided and to grasp the opportunities that are available.
## Contents

3  **Introduction**  
3  Moving from the old to the new  
5  The plastic electronics platform  
6  Material sets  
6  Manufacturing processes  
7  Where does the market lie?  
7  Why use plastic electronics?  
8  UK expertise – a brief history  
9  Delivering the future - establishing the supply chain  
9  The UK’s plastic electronics community  

10  **Vision 2020: seven views by industry leaders**  
10  Plastic electronics and the Fast-Moving Consumer Goods sector  
  by Avijit Das  
11  Plastic electronics in the IT sector  
  by Adrian Geisow  
12  The future of portable hand-held devices  
  by Mike Banach  
13  Printed electronics and security printing  
  by Philip Cooper  
14  The changing face of lighting  
  by Geoff Williams  
15  Substrate materials for plastic electronics  
  by Stephen Langstaff  
16  An overview of the supply chain  
  by Taku Sato  

17  **Universities directory**  
36  **Centres of Excellence directory**  
44  **Companies directory**  
71  **General contacts**
The term ‘Plastic Electronics’ is becoming widely used within the electronics, printing and scientific communities to differentiate between the ‘old’ electronics’ manufacturing materials and processes used around the globe since the 1950s and the ‘new’ technology platform of materials, device architectures and additive manufacturing processes that are emerging currently.

Moving from the old to the new
Conventional semiconductor electronic systems such as those used in TVs, brown and white goods, computers and mobile phones are mostly based around discrete passive electronic circuit devices (such as resistors, capacitors, inductors etc) and active devices (diodes, transistors, integrated circuits). They are securely mounted onto rigid or flexible printed circuit substrate materials, usually by high-temperature soldering. The semiconductor elements are derived from crystalline wafers on which the circuits are fabricated then ‘sliced and diced’ and individually mounted into discrete plastic moulded, metal-leaded carrier devices.

The conventional semiconductor electronics market is characterised by needing high-cost design and fabrication processes to create the very high market volumes of complicated, high-resolution, high-density semiconductor devices, resulting in a few, high-investment, high-value companies manufacturing the vast bulk of global demand for semiconductor devices.

After initial manufacture, these packaged semiconductors, together with the simpler and smaller passive circuit devices required to create functional electronic circuits, are mounted onto their pre-patterned metallised printed circuit substrates using solder paste that is then reflowed at high temperature to make solid, low impedance, mechanically sound connections. These substrate materials are usually rigid printed circuit boards or flexible, high-temperature metallised and patterned plastic films. In both cases the electrical circuit traces onto which discrete components are to be mounted were usually created using a metal coating followed by photolithography and acid etching to remove the unwanted areas of metal.

Conventional electronics manufacturing can be summarised by the following:

- High-temperature processes required for individual component manufacture and subsequent circuit assembly
- Subtractive ‘coat, pattern and etch back’ processes used to manufacture electrically conductive substrate materials, resulting in excessive waste materials with environmental implications
- High-investment manufacturing cost resulting in a limited number of global manufacturers dominating the production of electronic devices.

Plastic electronics introduces a new, exciting platform of organic and inorganic material sets that can be matched with a new paradigm in manufacturing processes.

The revolutionary impact of plastic electronics is that individual circuit devices, whether passive elements (resistors, capacitors) or active elements (diodes, transistors, transistor arrays, etc) can now be fabricated at the point of circuit manufacture using new solution-processed materials and delivery methods. Active circuit elements can be printed using carbon-based semi-conductive inks, offering different performance criteria as an alternative to the use of old, conventional, discretely-packaged silicon wafer-based devices.

For the first time since the very early days of electrical and electronic laboratory experimentation in the first half of the 20th century, the electronic
circuit designer can now design the basic architecture of the components he or she wishes to use. He or she can modify the designs to adapt to the performance levels achievable from the available functional inks and pastes required in the new, simpler manufacturing processes. Existing designs can be easily updated as higher performance materials become available. For total design flexibility, he or she can place the electrical circuitry exactly where the functions are required on the substrate material. Plus, previous limitations on available substrate size can be considerably relaxed for the simpler circuit requirements, allowing functional electrical and electronic circuits to be fabricated on very large sheets of suitable material, and even in continuous fabrication using large area roll-to-roll manufacturing techniques.

Plastic electronics is a wide-ranging technology platform that radically challenges how electrical and electronic circuits in the future could and should be designed and fabricated. The technology platform offers early adopters the opportunity to dramatically reverse the decades-old business trend that has led to most high-volume electronics manufacturing of components and equipments being centred around a small number of off-shore companies. The cost of entering volume manufacturing of plastic electronic devices is very modest compared to that of comparable large-area silicon-based electronic systems.

The manufacturing processes that are required to implement plastic electronics, whether used at its simplest to create basic, low-resolution functional circuits or when taken to its revolutionary extreme as a method of in-situ fabrication of very large matrices of electrically or electronically active circuit devices, can be readily used by existing non-electronic manufacturers as well as dedicated electronics companies.

For the first time, printing companies, packaging companies and other product industries can ‘import electronics’ into their existing production lines to add electronic circuit functionality and end-user value to their existing portfolio of (non-electronic) products and devices. For example:

- **Printing companies** will be able to add interactive electronic cartoon elements to paper greetings cards and printed colour posters. Design examples already exist from UK companies where interactivity to a colour graphics printed card is created by an integral, solution-processed electrical circuit, printed switch element, and various electric circuit devices.

- **Using the same basic principles as the card printing companies**, packaging manufacturers will be able to incorporate dynamic product tracking functionality into their existing card- and plastic-based products. This will facilitate more re-use and recycling of existing packaging materials, as well as helping with location services.

- **Pharmaceutical companies** can add electronically-functional anti-counterfeiting elements to variants of their existing product packaging. A further development will allow the integration of timing and display functionality to product packaging, offering drug users an in-built time clock function to indicate when the next dose should be taken.

- **Construction companies** will be able to:
  - Fully integrate electrical monitoring and sensing circuits to existing materials such as concrete beams and wooden assemblies. This will allow multiple parameters such as temperature, humidity and stress to be remotely monitored as part of advanced structural maintenance programmes.
Manufacture building materials (roofing sheets, wall assemblies) with integral solar photovoltaic modules assembled into the base materials themselves. Buildings with large roof and solid façade areas can then have an in-built renewable energy source capable of offsetting the grid-connected power requirements.

Clothing and textile manufacturers will be able to manufacture ‘wearable electronics’ using woven materials and fibres that can perform different electrical functions such as low-power generation and storage, as well as lighting and display functions. This will create new market opportunities in fashion design, as well as improving safety in products such as illuminated jackets for emergency workers use at night. There is also considerable interest within military circles for ‘electronic camouflage’ that can cover people and equipment, and which is capable of dynamically changing to reflect its current environment.

The UK has become a hotbed of activity at all levels in plastic electronics.

Many of the UK’s universities, industrial companies and government-funded centres of excellence are at the forefront of international activity in plastic electronics, from the fundamental research, development and pilot production of new materials and devices through to commercial exploitation and full volume manufacturing of materials and products.

The plastic electronics platform

Plastic electronic devices can vary in design and fabrication complexity from being extremely simple to exceptionally complex.

In the simplest design case, where a few circuit elements are to be attached to a substrate to form the finished electrical circuit, the conductive traces are printed onto the substrate material to create the required circuit layout. Discrete passive elements (sensors, resistors, capacitors, inductors, switch elements) can then be printed as required. Active circuit elements such as discrete conventional diodes, LEDs, transistors and integrated circuits can be directly attached to the substrate using conductive adhesives.

Alternatively, where limited low-power active circuitry is required, a fully plastic electronic design can be considered whereby the active circuit elements are fabricated as thin film (diodes or transistors) by depositing additional layers of organic solution-processed materials directly onto fine-resolution conductive traces printed on the substrate, with the architecture of the active device created by a printing or stamping process.

In the more complex cases, such as is the case with large area active matrix backplanes fabricated on plastic, the final device may contain millions of micron-sized switching transistors that are themselves part of an additional device such as a sensor array or flat panel display. Here, it is usually the case that there must be better than 95% uniformity of physical size and electrical performance across the breadth and depth of the array of transistors. This requirement for uniformity and repeatability is relatively easy to achieve when fabricating thin film transistors on rigid substrates such as glass, but it continues to be extremely challenging when seeking to use flexible substrates such as plastic.

For example, for plastic electronic thin film transistors to deliver a switching performance that is suitable to drive a liquid crystal or electrophoretic display element subsequently integrated onto the active matrix array, the gate width of the conducting channel - which is the width of the spacing between adjacent conductive traces that form the drain and
source contacts - needs to be five micrometres or less. For comparison, state-of-the-art gate width in conventional semiconductors is now approaching twenty-two nanometres, more than two orders of magnitude higher resolution.

Achieving a narrow gate width on plastic substrates is one of the most challenging aspects. Inkjet printing will routinely deposit droplets with a positional accuracy better than ten microns, and has been demonstrated at machine manufacturers to deliver accuracy down to one micron with the sacrifice of placement speed. Most other higher-speed direct printing methods such as gravure, flexographic etc will at best deposit materials with a positional accuracy of order twenty five to fifty micrometres. To compensate for these limitations on placement accuracy, academic and industrial pioneers in the device architecture field such as Cavendish Laboratory, Plastic Logic, and PragmatIC Printing have each developed alternative approaches to fabrication that allows device fabrication to overcome the limitations of current commercially-available printing techniques.

Material sets
Over the last two decades of the 20th century, new organic and inorganic materials were invented in the UK’s universities that have now been licensed for commercial exploitation in production volumes. The key benefits offered to users with these new materials are that many of them can be solution-processed at low temperatures using various printing and coating techniques, whereas others are suitable for deposition by multiple alternative methods.

These new material sets include high-performance organic and inorganic transparent and opaque conductive materials, organic semiconductor materials and both organic and inorganic dielectric materials. For many of these organic and inorganic material sets, UK companies and academic institutions have shown that careful stoichiometric control at the point of manufacture can vary the materials performance from highly conductive, through semiconductive, to resistive and be used to fabricate in-situ resistors, capacitors, inductors and sensor elements. A major cost-saving implication of this feature is that simple chemical control of the material sets used at point of device fabrication allows the same functional material to perform different electrical circuit functions.

Manufacturing processes
To fabricate plastic electronic electrical and electronic circuitry on traditional rigid substrates or any of the lower-cost innovative new substrate materials, many evolutionary manufacturing processes have had to be re-developed from mature older technologies, in order to deliver the new paradigm for production capability.

An excellent example of this evolution is the radical development of vacuum-based deposition equipments, conventionally used to deliver materials onto substrates held at high temperatures, to be suitable for creating comparable, and even improved-performance thin films on substrates that can only safely be processed at room temperature.

Examples developed in the UK for global use include both remote plasma sputtering systems and atomic layer deposition systems. These manufacturing developments lend themselves to sheet-fed batch processing as well as the implementation of innovative, new higher-volume roll-to-roll manufacturing.

In addition, the plastic electronics platform offers a number of revolutionary manufacturing processes, specifically developed to offer solution-processing alternatives for materials deposition that overcome the resolution limitations of conventional printing techniques.
Combining some or all of these unique platform technologies promises to deliver new generations of electronically-functional devices assembled onto conventional or totally unique substrate materials.

Where does the market lie?
Plastic electronics does not primarily seek to replace conventional ‘silicon’ electronics. The visionary pioneers in plastic electronics see the technology platform supplementing and complementing existing silicon-based solutions to expand product functionality in areas where conventional electronic devices have failed to secure market traction. Plastic electronics in its truest form, with thin film organic active circuits fabricated on large-area flexible substrates, will deliver to market product concepts that could never have been realised using conventional electronics.

However, various of the plastic electronics platform technologies (metal oxide transparent conductors and semiconductors, organic semiconductors and organic light emitting devices, for example) are already beginning to replace ubiquitous conventional electronic materials in use at OEM companies around the world by offering improved performance or lower unit costs.

ID TechEx, the UK-based market research company, estimates that over the last two decades global investments into plastic electronics technologies exceed US $10 billion, and predict that this will grow to almost US$25 billion by 2020.

The vast bulk (estimated at ~94%) of the products around which these predictions are based for 2012 – OLED mobile displays, photovoltaic cells, sensors, e-paper displays, inorganic electro-luminescent displays and other miscellaneous products will be fabricated on glass or other rigid substrates, and the PE materials are used for cost and performance improvements.

It is estimated that more than 70% of the devices made are based on existing fabrication techniques used at the companies, with only 30% having additive printing as a primary manufacturing activity, so further improvements are likely as new deposition and patterning technologies are adopted.

By 2020, a much higher percentage of the global production of products will be exclusively based around the new PE platform manufacturing processes as these move into the commercial domain, with estimates of greater than 40% being predominately printed, and greater than 33% being fabricated on non-rigid substrates, with the overall plastic electronics market predicted to rise to a value in excess of US$ 45 billion.

Why use plastic electronics?
The commercial and ecological motivation to adopt the PE platform of technologies is compelling:

- **Energy savings in production.** Most production processes developed to deliver PE material sets are able to do so at much lower temperatures than used by conventional materials when deposited onto traditional substrates such as FR2, FR4 or glass. Many material sets can be deposited at, or near to, room temperature, facilitating the use of a much wider range of lower-cost substrates.

- **Material savings in production.** The development of high-resolution printing processes to deliver functional materials as inks or pastes, or by using a printed precursor material prior to electro-less plating or some other deposition enhancement process, means that the amount of material used in production can be greatly reduced by only placing material where it is needed, rather than coating a complete substrate and then etching back to deliver the required patterning.
Cost savings in establishing production capacity. Although the most complicated PE circuits under development today, such as the flexible, large area organic backplanes developed for use in e-readers, may continue to be made using batch production processes for some considerable time, many of the simpler functional circuits will lend themselves to be suitable for part- or full assembly on roll-to-roll (R2R) production lines. Leaning heavily on the knowledge available within the UK’s comprehensive printing industry, processes have been developed that will deliver high-volume production capacity for manufacturing plastic electronic circuits. The use of R2R processes as part of the assembly process will greatly increase production capacity at a modest cost.

Reduced cost of entry for development and early stage manufacturing. The combination of reduced operating temperatures for conventional processes, coupled with the increased use of additive printing to fabricate PE devices, broadens the range and reduces the cost of appropriate products. This will offer a unique opportunity to price-sensitive markets, such as fast-moving consumer goods, and both medical and environmental sensor applications, to integrate PE technology into their existing portfolios of products to deliver enhanced supplier and end-user benefits.

At a time of global austerity, it is clear that the introduction of plastic electronics into both new and existing product areas offers companies the opportunity to drive new technology forwards into cost-sensitive areas.

UK expertise - a brief history
Many of the current activities in organic semiconductors around the world have developed from the research and inventions that took place in the 1980s at the Cavendish Laboratory in Cambridge. In 1989, Jeremy Burroughes, Donal Bradley and Richard Friend showed that conjugated polymer diodes could emit light when electrically stressed. Their 1989 patent underpinned the 1992 founding of Cambridge Display Technology Ltd and, together with a pivotal 1990 *Nature* paper, launched the field of plastic electronics - this paper remains the most cited in the whole field of organic semiconductors.

Through the rest of the ’90s, the early research activities were mostly academic, supported by EPSRC and companies such as Dow Chemical, Sharp and Merck Chemicals. Early industrial interest around the UK was supplemented by spin-out companies from the Cavendish Laboratory, with both CDT Ltd (1992) and Plastic Logic Ltd (2000) being examples of the growing trend of academic teams looking to exploit commercially their own intellectual property. Another early example was Molecular Vision (2002) spun out of Imperial College London.

The former Department of Trade and Industry (DTI) recognised the potential of this field, and from the late ’90s onwards, supported the area with collaborative research funding. This early stage funding then developed into a wider range of programmes in the first decade of the 21st century, as various of the early developments showed clear promise to deliver world-leading materials, processes and device opportunities that would potentially generate wealth and employment creation opportunities.

The DTI evolved through stages into its current form as the Department for Business, Innovation and Skills (BIS) and, as part of this process, responsibility for delivering innovation programmes was transferred to a new Agency created for that purpose, namely the Technology Strategy Board...
(TSB). The TSB has continued to fund programmes in the wider area of plastic electronics, and as a result the UK now has a superb infrastructure to offer support to companies who wish to enter this space for the first time.

Government funding through EPSRC and the TSB has established a number of centres of excellence around the UK. Described later, these facilities are equipped to help companies explore how plastic electronics can benefit them. Between them, the different centres cover the ability to design and develop proof-of-concept samples, early stage prototypes, and follow through with production process development to demonstrate the robust, repeatable volume production of end-user ready devices.

**Delivering the future – establishing the supply chain**

No commercial exploitation of a new technology can be firmly established without first ensuring a solid supply chain for all necessary materials, equipments, metrology and end user device assemblies.

The focus on building the supply chain has been a key priority in the UK for the last few years, and the success of these efforts is now coming to the fore.

Achieving this success has required manufacturers of materials and equipments to identify the future commercial opportunities presented by plastic electronics, and then focus their research and development activities to deliver commercially viable production quality products.

**The UK plastic electronics community**

The visionary projections outlined in the Vision 2020 accounts following this introduction indicate a clear roadmap for commercial exploitation over the coming years. The members of the burgeoning network that comprises the UK’s plastic electronics community, led by the Plastic Electronics Leadership Group (PELG), share these pioneering views.

Chaired by Dr Jeremy Burroughes of CDT Ltd, PELG co-ordinates networking between the various companies involved across the UK’s PE community. This activity generates considerable feedback for the TSB to ensure that they are aware of the emerging opportunities for commercial exploitation within the UK and beyond.

By operating with this ‘joined up’ thinking, the PELG and TSB ensure that the UK remains at the forefront of global research and development activity across the multiple application areas of plastic electronics, both for domestic exploitation here in the UK, for export sales of UK-manufactured materials, equipments and PE devices, and for overseas licensing of the UK’s intellectual property.
One of the main aims for Fast-Moving Consumer Goods (FMCG) is to delight consumers in all possible interactions with an everyday product. It is much easier said than done. How could an everyday product possibly delight consumers? How could it add value with every interaction? The FMCG sector is in a constant quest to answer these questions through a portfolio of offerings including new breakthrough technologies. Printed electronics can contribute immensely in this pursuit.

Normally FMCG products touch consumers at five different points: (1) When a consumer first gets to know about the product or during an advertisement, (2) when he or she first experiences the product while shopping, (3) when it is used for the very first time, (4) during the regular usage and (5) disposal. Printed electronics can play critical role in each of these touch points to delight consumers.

Printed electronics has the potential to revolutionise the way advertisements are currently run, by bringing in more interactivity, engagement and fun. The same is correct for getting consumers attention on a crowded shelf in a supermarket. It can add unique ‘pick me up’ appeal while strengthening the relation with the brand and better communicating the product benefits. The main opportunity for the technology, however, comes when a product is being used by consumers. A memorable first usage followed by sustained value addition during its life has the most significant impact. Printed electronics technology providers have to work with the FMCG industry and come up with concepts and products with significant functional, sensorial and emotional benefit to consumers, which could not be provided otherwise at an affordable price point. Real benefits need to be differentiated from gimmicks and be delivered in such a manner that the usage is intuitive and delightful. Finally, disposal of a product with printed electronics should be easy and should support consumers to help the environment and sustainability.

Printed electronics technology is in its formative days in the UK. Now is the time to give it direction to ensure that it assimilates well and becomes a part of FMCG products by the end of the decade. The challenge is to look for the immediate opportunities while keeping a firm eye on the future consumer needs.

About the author:

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Plastic Electronics offers a number of key potential opportunities to the IT sector. These include weight reduction, robustness, flexibility of form factor, and lower set-up costs for design changes. These benefits are most obvious in the mobile/portable product sector, which increasingly overlaps with part of the consumer electronics sector. Mobile products clearly benefit from weight reduction and robustness – a major cause of product returns is breakage from dropping.

Whilst flexibility of the product receives a lot of attention, particularly in the displays field, it is more likely that (non-rectangular) shape options and conformability are of higher initial benefit - fully rollable/foldable products require the entire system to be very thin, and probably have niche value at least initially. Plastic displays may also enable significant energy savings - thin plastic substrates are more suitable for the stacked cyan/yellow/magenta colour architecture which is probably necessary to deliver adequate reflective colour – the backlight or light emission is the major consumer of power in an illuminated display, and because of this the display is one of the major power drains in smart phones and tablets.

Plastic electronics also offers potentially disruptive options outside displays themselves – close to the display technologies we have ideas such as colour changing skins for products, so that they can be electronically customised to the user’s taste or fashion requirements; beyond this is a range of sensor and actuator opportunities to enrich the interface to the user and the environment. We may well see further encroachment of what are currently IT/consumer electronics products into neighbouring sectors - just as the cellphone/tablet has become much more capable with the addition of camera, position and accelerometer sensors, the further addition of e.g. chemical and biological sensors could see portable IT products grow to cover a range of health and diagnostic functions – human, animal and environmental.

Beyond the portable/personal sector, we see big opportunities in electronic signage – from small scale such as the perennial shelf-edge price label opportunity to large-scale billboard displays. Plastic electronics’ robustness, low weight, and lack of fragile glass enables easier, safer deployment in a wider range of locations than current display technologies, and the potential for integration of other sensor/actuator functions to enhance the signage capabilities further increase the value.

Finally, there will also be opportunities in corporate IT infrastructure - data centres and server farms – by enabling the use of light to replace the copper wiring of today. Printed electronics will help deliver low-cost, micro-replicated photonic interconnect for fast and power efficient transfer of data between large arrays of compute elements in these environments.

About the author
Adrian Geisow is a Senior Research Manager with Hewlett Packard Laboratories
Consumers have been buying portable electronics for decades, but the landscape changed dramatically when the first mobile phone call was made in 1973. Since then customers have shown an insatiable appetite for smaller, sexier, more connected handheld devices. Today the most popular product classes are the smartphone, which experienced a 50% market growth in 2011, and the tablet, which tripled its sales in 2011. Even in these uncertain times, Gartner estimates the growth trends will continue with smartphone sales expected to double and tablet sales expected to increase by an astonishing seven times by 2015. The market appetite for portable devices has yet to be satisfied.

Over the next few years conventional electronics and displays will still be the workhorse technology for these devices. However, as handheld devices become more ubiquitous in everyday life, the demands on their durability and portability will increase. Plastic is a wonderfully light and robust material that can add value by replacing traditional components. For example, at Plastic Logic we are making it possible to replace heavy and fragile glass backplanes with a plastic alternative. However, it is clear that success in the near term will require plastic electronics firms to integrate their technology with conventional technologies in traditional product concepts.

As we move to the second half of this decade I envision plastic electronics enabling truly unique form factor products. Flexible electronics and displays have been the dream of handheld device designers for decades, but it will only be possible if we break from the paradigm defined by silicon and glass. For this vision to be realised, providers of plastic electronics technology will need to partner to create integrated devices. The UK will have a large part to play with PLED technology from CDT, flexible printed circuit boards from MFlex, backplanes from Plastic Logic, and others.

Finally, as we head into the next decade, the plastic electronics firms developing innovative manufacturing concepts based on printing and roll-to-roll techniques will begin to merge with those making highly-functional portable devices. At this point our industry will not only be challenging the form factor paradigms that have been set by silicon and glass, but we will also be challenging the business model paradigms. Low-volume highly-differentiated products will no longer come with compromise of either low functionality or high cost ushering in a new era of personalised electronics.

About the author

Mike Banach is the research manager at Plastic Logic
The security printing industry has to anticipate and respond to constant and unremitting attack from counterfeiters. This has always been a problem but latterly, with the advances in production technology and techniques, counterfeiters have increased their attacks very significantly.

The task facing the security print industry is to introduce a range of technology hurdles to deter or mitigate such attacks. Typically security products include a range of protective technologies including forensic or DNA-based features as well as technologies using covert machine-read systems. The main technology defence area, however, is the overt or interactive features which draw the consumer’s attention to the product – which is where we believe that printed electronics offers significant potential.

Many printed products - from brand certificates to security packaging - are very price-sensitive and cannot support the cost of conventional electronics. The potential for a printed electronic version that offers good anti-counterfeiting protection while being cost-efficient would be attractive to businesses whose valuable brands are constantly challenged. Printed electronics also has at its core that it can be readily manufactured in the UK and be competitive worldwide. It thus offers an effective alternative which cannot be achieved in any other way.

End-users are constantly engaged in producing products and packaging which differentiates them from the competition and encourages consumers to buy their product. At the same time they are also seeking to protect their identity. The issue has been that end-users will not usually pay a premium for technology features alone since they represent an increase in cost without direct evidence of return. The approach we believe the printed electronics industry should adopt is to combine brand enhancement with protection features. Enhancement techniques could, for example, combine printable displays and logic to produce flashing or blinking brand symbols that appear to move and draw the eye to the product - making instant recognition possible. The protection comes from several key areas. We make the actual printable micro-technology difficult to replicate without resorting to expensive conventional options and we combine or register the printed electronics with other secure printed features.

Another area of interest is printable electronic track and trace. This offers additional functionality over bar or QR codes, but at only moderate additional premium, and allows the consumer to check quickly with their mobile phones if the product is what it claims to be. While this ambition is still some way away, there is evidence that the technology has the potential to achieve moderate success within several years.

From our perspective, the embryonic plastic or printed electronics industry is growing up and starting to deliver on some of its initial promise. The early hype has given way to solid achievement and we look forward with true excitement to working with the new printable technologies and the energetic companies who will supply them.

About the author

Philip Cooper is a Consultant with De La Rue plc.
Since the introduction of artificial incandescent electric lighting in the early 1880s, there have been few new lighting technologies - just fluorescence in the 1930s, and the induction lamp (electrodeless) in late 1960s. As we enter the second decade of the 21st century, migration away from fluorescent lighting in the commercial sector and incandescence/compact fluorescence in the domestic environment towards light emitting diode technology is happening. By the end of this decade, how we light our homes and new-build workplaces will be different. But why, and how, will the technology be different?

Today, globally electric lighting accounts for almost 20% of all electricity generated, which in turn translates to 2,000 million tonnes of CO₂ emissions. Therefore, there is a political will as well as an environmental drive towards ever more efficient sources of artificial lighting. LED luminaire technology is beginning to challenge the efficiencies of the best-in-class fluorescent luminaires and will during this decade surpass them. This offers a clear opportunity in office environments to drive the lighting power densities down and building efficacies up.

Presently almost 50% of office electric use is accounted for by lighting, with average power densities of the order 13Wm⁻² installed lighting, the drive with leds is towards 5Wm⁻²: more than halving the power consumed.

On the back of LED market growth will be the other emerging solid state lighting technologies - OLED (organic led), and POLED (polymer oled) - in which there is industrial global technology strength in the UK, with the potential for a complete UK-based component supply chain to exist for POLED luminaire manufacture. Organic LED technology is trailing LED in performance, cost and the presence of international standards but is learning from the LED experience. POLED and OLED luminaires offer area illumination without sophisticated controlling optics and - with worry concerning glare control - their slimness and opportunity to be conformal opens new design freedoms for designers, lighting designers and architects.

Opportunities to incorporate added value also exists for solid state lighting over fluorescence, with high-frequency modulation of the light output to carry high speed data communications (LiFi) an active research topic, with university groups in Oxford, Edinburgh and Strathclyde leading the way. Presently the technology is one-way communications but - as the technology matures - two-way communications will emerge, with the ability to 3D map spaces, allowing for truly interactive lighting schemes. The lit area will be optimised against the room furniture layout, change that and the lighting will duly follow, optimised lighting plus optimised lighting efficiency! This will become available during the 2020s, and almost certainly in conjunction with imagine recognition, the demise of the presence sensor operating at 10.6µm!

About the author

Geoff Williams
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The challenges for substrates in plastic electronics are many and varied and predominantly depend on the end application. However, it is not just the end application that will dictate the selection of materials. Getting a material to function through the different process stages of the supply chain is also critical.

A good example of this is in the production of OLED displays. Here, the excellent optical properties and ‘pixel perfect’ performance are pre-requisites but a level of high-temperature stability is also required during manufacture. Despite significant efforts to develop alternatives, ITO coating remains the favoured technique for producing clear conductive substrates suitable for OLED displays (or DSSC). Currently this coating technique requires high-temperature processing which leads to PET or glass being the materials of choice, although techniques to produce conductive films at lower temperatures are under development in the UK.

In the case of glass, excellent barrier properties prevent the ingress of oxygen or moisture that would significantly reduce the life of the OLED. Work in the UK is being undertaken to improve the barrier properties of PET and other films for such applications thus allowing truly flexible displays. Development in flexible glass is another area of focus with the same aim of producing fully functional and flexible OLED displays.

A further advantage of fully flexible substrates is the ability to produce components via a roll-to-roll process. The consequence of this is a very significant reduction in the final cost of any article due to the potential for high productivity.

The influence of substrate and production cost is unlikely to jeopardise the growth of large-format OLED displays in the short term. However, for printed electronics to gain a foothold in the area of smart packaging cost per pack is a critical parameter. In the packaging arena polypropylene is the material of choice and significant work is being undertaken to build ‘smart’ functionality on this family of products. One challenge that has recently been overcome is the ability to print and sinter functional inks on these materials. This could trigger the dawn of truly interactive packaging.

Environmental awareness is of growing importance in all areas so it is natural to link this to printed electronics in the development and selection of substrates. Here, paper holds a strong position and linked to its cost structure makes it a focus for development. Other biopolymers such as NatureFlex™ offer superior environmental credentials, high transparency and high temperature stability. The development of technically suitable, cost effective substrates is of vital importance to the success of the UK printed electronics industry. Cross-functional links between industry and academia are helping drive this critical area.

About the author

Stephen Langstaff is Product Manager for polypropylene films at Innovia Films’ R&D Centre.
UK plc is strategically positioning itself within the plastic electronics industry, providing full supply solutions from materials development (Merck, SmartKem, Intrinsiq Materials Ltd, etc), industrial manufacturing platforms (M-Solv Ltd, Oxford Lasers, Carbonlite, etc) and end users (Eight19, BAE Systems, Airbus, etc). The PE industry is seen as a growth area and R&D is being driven by both government funding, such as TSB and EPSRC, and industry.

The UK is building on its world-renowned reputation as conducting state-of-the-art research and pushing forward the Technology Readiness Level of infant processes and device architecture. Examples of UK industrial partners leading the way in the PE industry include Intrinsiq Materials Ltd which currently manufactures the world’s leading copper based inkjet ink with laser curing capabilities making on the fly processing on a reel-to-reel platform possible.

SmartKem are leading the way with their proprietary polymer organic semi-conductor that is not only air stable, but can also be inkjet printed. Merck at Southampton are developing novel materials systems for organic photovoltaics and flexible displays. Meanwhile CDT has long had a reputation for making the best-in-class P-OLED materials with over 300 patents filed in the PE area.

It is important that laser patterning and processing platform suppliers and developers keep up with the fast developments occurring in PE materials. M-Solv Ltd have been highly successful in producing state-of-the-art ‘dry etch’ laser patterning processes for the replacement of more traditional lithographic techniques that are current in the patterning industry, along with introducing inkjet machines into production lines. Oxford Lasers are also world renowned for developing state-of-the-art bespoke platforms for both the patterning and printing of PE devices, with more than 350 installed systems worldwide.

A real growth area over the next 10 years will see lasers not only used as a direct patterning technique for material removal, but also as a photonic source for the functionalisation of materials. Examples include photonic and thermal curing of conductive inks, polycrystallisation of a-Si:H and surface modification for tailoring wetting characteristics.

UK companies are collaborating and competing on an international platform with one of the highest amount of R&D and industrial work in the PE sector being conducted within Europe.

About the author

Taku Sato is responsible for R&D for chemicals with inkjets at M-Solv Ltd
## UK University Capability Matrix

<table>
<thead>
<tr>
<th>University</th>
<th>Centre or Group</th>
<th>Organic Materials</th>
<th>Inorganic Materials</th>
<th>Devices</th>
<th>Processes</th>
<th>Characterisation and Test Equipment</th>
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Universities

British universities have led the world in many aspects of plastic electronics

**Bangor University**

**Plastic Electronics Research Centre**

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Professor D M Taylor

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The activities of the Plastic Electronics Research Centre ranges from thin film deposition and evaluation through to device and circuit fabrication and testing. Three major device classes are under active investigation: thin film transistors and functional circuits; organic memory devices; and organic photovoltaics. Device fabrication methods include both conventional solution-processing and vacuum deposition. Our world-class research facilities are available to support commercial activity through fully-funded research contracts/consultancy and collaborative R&D projects such as Knowledge Transfer Partnerships.

Current projects include:

- **Thin film transistors and functional circuits (Professor D M Taylor)**
  - **Roll-to-Roll Vacuum-deposited Carbon Based Electronics (RoVaCBE)**
    RoVaCBE is an inter-university collaboration led by Oxford University and involving Bangor, Manchester and Leeds universities and funded via an Innovative electronic Manufacturing Research Centre (IeMRC) Flagship Grant. The project is focused on the fabrication of functional electronic circuits using ‘dry’ vacuum-based processes only.

- **Fabrication and Testing of State-of-the-art Organic Semiconductors**
  Small-molecule organic semiconductors embedded in a flexible host material are now routinely achieving carrier mobilities in excess of 4 cm2/Vs. This is more than sufficient for these new blends to challenge a-Si as the semiconductor of choice for display backplanes. In collaboration with SmartKem and partly funded by a Knowledge Transfer Partnership grant, we are developing protocols for fabricating and characterising thin film transistors with even better performance.

- **Organic Charge Coupled Device (OCCD)**
  Silicon-based charge coupled devices (CCD) are widely used in electronic systems as memory devices, shift registers, A-D conversion and for imaging. A similar range of applications could become possible in plastic electronics if efficient CCD action can be achieved. We have already demonstrated charge transfer in an organic version of the charge injection device, essentially a single stage CCD, and are further developing the concept.

- **Organic Memory Devices (Dr Mohammed Mabrook)**
  In this research programme, we are developing protocols for optimising the fabrication and characterisation of organic memory devices for future flexible electronic circuits. Throughout this interdisciplinary research, two research streams are run in parallel: (a) organic flash memory devices investigating the development of a low cost suite of processing techniques to produce high performance organic thin film memory devices [OTFMDs], and (b) resistive memory.
devices exploring the possibility of using Resistive Random Access Memory (RRAM) structures.

**Organic Photovoltaic Cells (Dr Jeff Kettle)**
Work on OPVs is focused on a number of key areas. Firstly, new semiconductor donor materials (small molecules and polymers) are screened using an inert fabrication facility. In a recent collaboration a co-polymer was identified which exhibited an efficiency of 5.5% when blended with a fullerene derivative. Secondly, in addition to screening materials for efficiency, we are also investigating device lifetime using a Class A solar simulator, Class B light soaking system and an outdoor testing rig. Thirdly, we use spectroscopic ellipsometry to obtain the essential data needed for modelling device performance and verifying efficiencies. Finally, by including patterned nanostructures into OPVs we can demonstrate significantly enhanced performance under oblique angle illumination.

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i.a.crisan@bham.ac.uk
W www.birmingham.ac.uk/schools/metallurgy-materials/index.aspx

Displays research at Birmingham is currently focused in three areas:

- The deposition and characterisation of transparent conductive oxide (TCO) materials for electrodes
- The characterisation of substrate materials for flexible displays. In particular the pulsed laser deposition of indium tin oxide (ITO) onto glass and flexible polymer substrates and the characterisation of the structural, physical and mechanical properties of the films are being investigated
- The development of novel methods of testing electro-mechanical reliability and characterising the mechanical properties of substrates and coatings for flexible displays.

We also work with magnetron-sputtered and sol-gel coatings produced by partner organisations. The strong interdisciplinary team has considerable expertise in coating techniques, oxides, thin films, characterisation, inorganic materials and anionic and cationic doping procedures. It has also pioneered many aspects of mechanical characterisation for flexible displays including uniaxial and biaxial electromechanical testing; bending; adhesion, pull-off force, nano-scratch and nano-indentation measurements as well as friction measurements, wear testing, fatigue, corrosion and reliability studies. It has access to a wide range of facilities to characterise the structural and microstructural properties of thin film coatings as well as their physical properties.
The Cleaner Electronics Research Group has interests and expertise in applications design for printed electronics, the development of inks and pastes for the offset lithographic printing of electronics, and the inkjet printing of low-cost biomedical sensors. Past projects have included work on printed batteries and printed displays. Facilities include ink making and characterisation equipment, screen printing and inkjet printing equipment, and an offset lithographic press.

The Wolfson Centre for Materials Processing, incorporating the Centre for Phosphors and Display Materials, carries out systematic R&D of plastics processing and inorganic materials technology for Printed Electronics (PE). We have expertise in the formulation and processing (extrusion and injection/compression molding) of polymers and polymeric composites as substrates for PE, and in the synthesis and characterisation of inorganic phosphors and dielectrics for PE with light-emitting functionality. We have excellent analytical facilities for materials optimisation and development, which include state-of-the-art electron microscopes (SEM and TEM), equipment for thermal analysis, a powder X-ray diffractometer, photoluminescence and Raman spectrometers, SIMS, and XPS. Our sub-micrometre and nanometre sized particles are specifically designed for incorporation into ink formulations, and we have rotational and capillary rheometers for the characterisation of the inks. The PE applications of R&D include 3D components and devices for electronics and displays (e.g. capacitors and ACEL displays), biodegradable consumer electronics and displays, in addition to screen printable remote phosphor screens for LED lighting and displays across a range of sectors, e.g. domestic, automotive, aviation, medical etc.
Organic Electronics Group
Professor P Kathirgamanathan
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F +44 (0) 1895 269737
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The Organic Electronics Group is currently focused on:

- OLED displays and lighting - materials (emitters and transport layers), device architecture and manufacture
- OLED lighting - using phosphorescent emitters based on Ir, Pt, Au, Ag and copper complexes
- Flexible displays based on plastic and stainless steel substrates
- Quantum dots for lighting
- Organic Solar Cells (OPV) based on small molecules. Materials (hole injectors and hosts) for OPV and fabrication of OPV
- Nanomaterials, nanoparticles and nanocatalysis
  - Electrochemical deposition of nanoparticles of metal oxides for transparent thin film transistors (TFT)
  - Electrochemical deposition metal oxides for PV
  - Nanostructured electrodes for electrochemical generation and fuel cells
  - Transparent conductors based on conducting polymers, indium tin oxide and doped zinc oxides.

The group has over 100 man years of experience in the development of organic light emitting materials, displays and lighting. Resources and facilities include:

- OLED manufacturing pilot plant (Solciet, ULVAC)- 100 mm x 100 mm substrates
- Fully equipped chemistry laboratory
- OLED measurement and characterisation equipment
- Lifetime measurement equipment
- Optical characterisation (thin film UV-visible & PL)
- Thermal characterisation (DSC & TGA/DTA)
- Surface measurement (AFM)
- Thickness measurement (Nanostep)
- Conductivity, capacitance, WF, contact angle and photovoltaic measurements.
The Organic Electronics Research Group at the Cavendish Laboratory, led by Professors Friend, Sirringhaus and Greenham, is interested in the physics of semiconducting, solution-processible conjugated polymers and molecules. We discovered in the late 1980s and 1990s that these conjugated materials behave in many respects like inorganic semiconductors and can be used in semiconducting devices such as field-effect transistors, light-emitting diodes and solar cells. These pioneering discoveries were important milestones for the field of organic electronics.

The focus of our research activity is on the scientific understanding of the electronic properties and fundamental physics of this novel class of organic semiconductors and their interfaces with other functional materials such as oxide semiconductors or inorganic nanoparticles. It is a field where new fundamental scientific discoveries are still waiting to happen. Our research programme is interdisciplinary: it spans fundamental and device physics, materials science and device engineering, and we collaborate actively with a number of synthetic organic chemistry groups.

In cooperation with the Cambridge Integrated Knowledge Centre we are interested in the development of novel solution-based printing approaches for scalable, low-cost manufacturing of organic devices with high yield and resolution. The group has spun-out three companies, Cambridge Display Technology (1992), Plastic Logic (2000) and Eight 19 (2010).
The Electronic Devices and Materials Group performs research in a range of low-temperature processing techniques for the production of electronic devices on plastic substrates, with particular reference to active matrix addressed displays (liquid crystal and organic light emitting) and biosensors.

It is investigating several novel low-temperature processes to deposit a range of thin film transistor channel materials (including amorphous silicon, nanocrystalline silicon and zinc oxide) and dielectrics (including silicon nitride and hafnium oxide) at temperatures below 125°C. In addition, the group also researches thin film transistors incorporating inkjet printed polymer-nanostructure material composites for the channel semiconductor, and has in-house facilities for producing a broad range of nanostructured materials, such as carbon nanotubes, silicon and zinc oxide nanowires and graphene.

The Inkjet Research Centre is based at the Institute for Manufacturing (IfM) - part of the Engineering Department at Cambridge University and one of Europe's largest integrated engineering departments. Its international reputation attracts students, academics, sponsors and partners from around the world. Its core strengths span all of the major engineering disciplines. The aims of the Inkjet Research Centre at Cambridge are to:

- Bring together the leading manufacturers, users, and researchers in inkjet technologies
- Define a rolling programme of research that meets the needs of the industry in the medium and long term
- Create a central nucleus to support the infrastructure of the Centre and undertake management and coordination
- Conduct a programme of dissemination to the wider industrial and academic community
- Enable companies to sponsor work to match their specific needs.
 Laboratories at Cranfield and OpTIC Technium supply leading manufacturers with large-scale structured drums, large optics and plates. Cranfield operates 1,500 sq metres of temperature-controlled ultra-precision and surface-structuring laboratories. These laboratories house unique processing systems that commercially supply:

- Large-scale micro-textured film embossing tools for passive and active film production
- Large-scale optics for lithography, telescope systems and fusion research
- Micro-channel moulds for the injection moulding of microfluidics and micro reactors.

Research programmes funded under the EPSRC Centre for Innovative Manufacturing in Ultra Precision (a collaboration with the University of Cambridge) are focusing on the development of new machine tools for the fabrication of advanced plastic based substrates for light handling and plastic electronic fabrication employing: embossing, imprinting, diamond machining, inkjet printing, laser and plasma processes.

A large-scale reel-to-reel machine system for 1.2 metre wide film (using Cranfield’s own produced ultra precision Drum rolls) is under design and due for first operation in 2014.
Multidisciplinary collaborative research focusing on organic polymer and small molecule display, solid state lighting and organic photovoltaic applications is ongoing in the Physics (Prof Monkman and Dr Dias), Chemistry (Prof Bryce and Prof Paul Low) and Engineering (Prof Petty and Dr Groves) departments. Work ranges from organic synthesis of new polymers and phosphorescent dopants, through optical characterisation of materials (especially time-resolved emission and absorption studies in the femtosecond to millisecond time regimes), to device design, fabrication and testing. The Physics group is leading the design of new optical measurements for device characterisation. We have facilities for the fabrication of both OLED, PLED and OPV in dedicated clean rooms and have also developed dedicated optical based measurements on working devices.

There is strong interaction with industry on a range of projects funded by the Technology Programme and EPSRC. Further, Professor Monkman’s group has several international collaborations in the USA and Japan working on novel aspects of OLED technology.

The University of Hull is renowned for its work on liquid crystals materials following its invention of the first commercial liquid crystal and so heralded the advent of the multi-million dollar liquid crystal display technology. It received The Queen's Award for Technological Achievement in 1979 and a Royal Society of Chemistry Chemical Landmark award in 2006 for achievements in this field.

The interdisciplinary Organophotonics group works in both physics and chemistry and continues this tradition - particularly in emerging application areas such as organic light-emitting displays, solar cells and plastic electronics. Recently we demonstrated the first pixellated full-colour display, which is both liquid crystalline and light-emitting. We have expertise in organic and inorganic synthetic chemistry, spectroscopy, organic semiconductor characterisation, photonic modelling and device processing with excellent facilities to carry out the research. Current projects include the development of liquid crystalline semiconducting and dielectric layers for flexible electronics, new strategies for multilayer photovoltaics, as well as hybrid organic-inorganic nano-cavities for efficient light-emission.
Since its formation, the Innovative Electronics Manufacturing Research Centre (IeMRC) has been the UK’s internationally recognised provider of world-class electronics manufacturing research at universities throughout UK. It focuses on sustaining and growing high-value manufacturing in the UK by delivering innovative and exploitable new technologies through its highly skilled people and by providing strategic value to the electronics industry. The IeMRC has been, and continues to be, a key supporter of fundamental research work on plastic electronics and examples of the work it supports in UK universities are as below.

Brunel – printing, via off set lithography, of interconnects, passive components, displays, battery structures and a variety of other devices. This work has developed new techniques for depositing novel materials over relatively large areas on low-cost polymeric substrates. Further details are available from Professor David Harrison david.harrison@brunel.ac.uk

Oxford – current work includes research into carbon based electronics as part of the IeMRC’s RoVacBe project, which is developing new materials and processes for the reel-to-reel, large area vacuum deposition of organic semiconductors. This work aims to deposit metals, dielectrics and semiconductor materials in a single process. Further details are available from Dr Hazel Assender hazel.assender@materials.ox.ac.uk

Bangor – research activities include a focus on organic MIS capacitors, organic thin film transistors and circuits, organic memory devices and photovoltaics, along with the fabrication of organic semiconductors, circuit design, characterisation and device modelling. Further details are available from Professor Martin Taylor d.m.taylor@bangor.ac.uk

Manchester – as part of the Organic Materials in Electronics Consortium (OMEC), current work is centred on the synthesis, characterisation, processing and evaluation of new materials for electronics. There is ongoing research into the synthesis of materials for Organic Field Effect Transistors (OFETs), Light Emitting Diodes (OLEDs) and photovoltaics. Further details are available from Dr John Morrison john.morrison@manchester.ac.uk

Leeds – within the School of Chemistry there is a focus on organic printed electronics, with research work being undertaken into the flexo-printing of dielectrics, as well as the patterning of dielectric and semiconductor layers and their characterisation. There is a specific activity on speciality polymers, organic conductive and semi-conductive materials, novel dyes and pigments, thermochromic and photochromic molecules, the formulation and delivery of functional complex fluids systems, organic printed electronics and anti-counterfeit and brand protection technologies. Further details are available from Professor Long Lin l.lin@leeds.ac.uk
Surrey – the IeMRC has supported a range of projects in the area of polymers and polymer nano-composites for optoelectronic applications. This work has focused on the investigation of the formulation, deposition and characterisation of novel transparent, flexible, conducting polymers that could be potential replacements for indium tin oxide. Related work includes research into novel techniques for processing carbon nanotube-polymer composites in order to optimise their structural, electrical and optical properties, as well as studies of the manufacture of novel plastic photovoltaic cells. Further details are available from Dr Tina Lekakou c.lekakou@surrey.ac.uk

University of Manchester
see Organic Materials Innovation Centre entry in Centres of Excellence section

METRC

METRC is a centre specialising in nanotechnology, science and engineering research and applying this to industry. We pool expertise from universities across the North of England to help to accelerate the development of new products and processes.

METRC has a critical mass of expertise in plastic electronics at the following universities:
- Durham
- Hull
- Liverpool
- Manchester
- Sheffield
- York

Please see the individual entries for each university in this guide for further details of this expertise.

METRC has funding available to help companies innovate in the area of plastic electronics by collaborating with our universities on small projects that benefit the company. Please see www.metrc.co.uk for more details.
The Thin Film and Displays Research Group at NTU is actively involved in the technology of electronic materials for plastic electronics, electroluminescent displays, thin film device fabrication, visual display characterisation, and laser processing of materials. Research is concerned with thin film and device engineering for a range of applications including transparent thin film transistors, miniature displays utilising thin film electroluminescence, and low-temperature electronic materials deposition and processing.

Recent collaborative research is concerned with the field of flexible and low-cost electronics, including the use of excimer laser processing to optimise electronic materials deposited onto plastic substrates.

Additional areas of interest include use of phosphors for bio-sensors, and the investigation of visualisation techniques using virtual environments.

Scientific Services to Industry (SS2i) is a branch of the School of Science and Technology at NTU that offers a range of thin film deposition, processing and characterisation services to industry and academia via access to facilities in the Class 100 Thin Film Display Laboratory based at the Clifton Campus.

Plastic electronics research at the Department of Materials spans the range of activity from small-scale materials synthesis, through device building and optoelectronic and microstructural investigation, to large-area roll-to-roll manufacturing processes. The technology areas currently under investigation are:

- Roll-to-roll deposited organic transistors using high web-speed vacuum evaporation
- Photovoltaic device materials and devices including:
  - Polymer/fullerene solution deposited devices
  - Polymer-based all-evaporated devices
  - Metal oxide based devices
  - Nanocrystal synthesis and devices based on PbS and CZTS
- Transparent conducting layers including:
  - Sputtered TCOs, including by R2R processing
  - Solution deposited Ag nanowires
  - Solution deposited graphene layers in large area
- Transparent Gas Barrier layers made in R2R facility with single layer coatings giving WVTR < 10⁻³ g/m²/day.

The unique R2R vacuum webcoating facility (capable of webspeeds up to 5ms⁻¹, with evaporation, sputter deposition, and polymer deposition by
flash evaporation), alongside a smaller spray rig for ambient solvent-based deposition and state-of-the-art materials characterisation, allows the development of manufacturing processes for plastic electronics. Research into the impacts of scale-up of these materials and device manufacturing processes is carried out alongside the development of new materials and architectures first tested on the smaller scale. This juxtaposition allows the development of new device systems with a realistic pull-through to large area manufacture, as members of the team are actively engaged in manufacture at the larger scale.

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Research covers:
- Magnetic field effects and spintronic applications in organic materials
- Lanthanide based materials for telecommunication applications
- Metal oxide conductors, semiconductors and dielectrics for thin film application.

The Centre for Condensed Matter and Materials Research has a wide-ranging research programmes base on organic electronics and metal oxide semiconductors. Organic electronics research is focused on materials characterisation and device fabrication with research activities on both OLED and OPV materials. The group has research interests in a range of applications including:

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Research covers:
- Carbon nanotube and graphene-based flexible electrode materials for OLED and organic PV with beyond ITO performance
- Conductive polymer/nanoparticle composite materials for electrode, active layer device applications, and actuators
- Smart fibres with multiple functionality for wearable electronics, strain sensing, and electromagnetic shielding.
The Electronic and Photonics Molecular Materials Group has a long-standing interest in many aspects of the physics and technology of organic semiconductors and organic optoelectronic-devices. Current research includes studies into the development and optimisation of organic photovoltaic devices, organic light-emitting diodes and organic field-effect transistors. We are involved with organic photonic structures and devices including organic semiconductor microcavities and photonic crystals. The group is well-equipped for experimental research and has a range of modern laboratories for both device fabrication and spectroscopy. We are also able to assess the performance and stability of photovoltaic devices when tested under ‘real-world’ conditions at the Sheffield Solar Farm.

The University of Sheffield is a member of the Polymer IRC.

The Biomaterials Science and Tissue Engineering (BSTE) Group is exploring the use of plastic electronics for implantable devices. We are exploring its use in substrate materials for building biosensors and devices that provide an interface between electronics and the nervous system for responsive prosthetics and brain-computer interfaces. We have expertise in laser-based additive manufacturing of materials and we also integrate this technology with other materials-manufacturing techniques (e.g. electrospinning) to build functional devices. We have specific expertise in the following production techniques:

1) Printing of plastic electronics and bioprinting using a versatile-laser based set-up which can print micrometer-resolution patterns in conjunction with biological sensing elements

2) A three-dimensional direct laser-based manufacturing technique which can manufacture 3D polymer structures with extremely high (100 nm) resolution.

The BSTE group has also a well-equipped tissue engineering laboratory for biological assessment of materials. We are also keen to establish further collaborations in this field.
University of St Andrews

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The Organic Semiconductor Centre at the University of St Andrews is internationally recognised for its plastic electronics research. Current research projects include the development of solar cells, lasers, and OLEDs, and developing novel applications ranging from skin cancer treatment to explosive vapour sensing. Both materials and devices are developed and studied, using sophisticated photophysical, charge transport and device measurements to understand and improve them. Soft lithographic techniques including nano-imprint lithography are used to pattern materials and control light coupling. The interdisciplinary work is supported by EPSRC, EC and industrial contracts, and the Centre has a strong track record of publications, patents and commercialisation. It provides contract measurements and consultancy to industry on issues such as:

- OLED fabrication and measurement
- Charge transport measurements
- Absolute photoluminescence quantum yield measurements
- Time-resolved luminescence
- Organic solar cell materials and devices.

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Research in the group encompasses the synthesis and characterisation of complex electroactive molecules and macromolecules for organic semiconductor devices. Key aspects focus on the design and synthesis of conjugated monomers and the conversion of these materials to polymers and monodisperse oligomers. The group has developed a strong reputation for the electrochemical and spectroelectrochemical characterisation of materials, enabling in-house analyses. Potential applications for the materials prepared in the Skabara group are widespread and the group has published or patented work relating to OLEDs, electrochromic devices, plastic batteries, sensors, field effect transistors and solar cells. Over the last few years, the developing multidisciplinary nature of this work has led to the capability of in-house device fabrication and testing for organic field effect transistors, organic solar cells, electrochromic devices and plastic batteries.
The ATI is a major cross-disciplinary research facility within the Faculty of Engineering and Physical Sciences. It houses a coherent suite of 23 laboratories including extensive fabrication and characterisation capability. These allow the ATI to address new thematic areas while supporting core activities. The ATI has expertise in all aspects of the interaction between light and matter at the nanoscale: from theoretical modelling, through fabrication of nanostructures and microstructures, to characterisation and exploitation. Most work on plastic electronics, and the closely related theme of carbon electronics, is within the nano electronics grouping.

We exploit the properties of Carbon Nanotubes (CNTs) and graphene to enhance charge separation and conduction in our devices. Low-temperature growth of novel carbon materials is a particular strength and is a core technology in a spin-out business which has recently achieved second-round venture funding.

Our work in plastic electronics is integrated with the wider ATI community. Through out-reach activities we seek to inform the range of stakeholders from businesses, who may exploit the results, to lay-members of the community. We work closely with industrial groups, through both research and development contracts, through Surrey’s highly successful Engineering Doctorate programme, and through the KTA and KTNs.

The work is supported by theoretical modelling capability and the wide range of techniques available to us, such as ultra-high-speed exciton studies and ion beam implantation and analysis.

We have tools to meet the range of fabrication scales from macroscopic to nano. For example the clean room supports photolithography, metal deposition by sputtering and evaporation, dielectric deposition by PECVD, evaporation or spin coating, reactive ion etching using both fluorine and chlorine chemistries, plasma cleaning and surface conditioning, rapid thermal processing, spin coating, dip coating, wet chemical and solvent stations, nitrogen atmosphere glove box processing including spin coating, metal evaporation and basic probe testing, and solar simulation. Other areas support traditional thick film and polymer thick film using screen print, with inkjet printing also being available. Short pulse lasers, excimer and multiplied Nd:YAG, are used for ablation to pattern films, cut materials and for ablative deposition.

We have extensive inspection and characterisation equipment: ESEM, FIB, AFM, STM, EDAX, XPS, spectroscopic measurement from UV to infrared, micro Raman, and ultra-fast.
SPECIFIC – the Sustainable Product Engineering Centre for Innovative Functional Industrial Coatings - is a 5-year Innovation and Knowledge Centre led by Swansea University and Tata Steel Europe. It was established in 2011 with funding from the EPSRC, Technology Strategy Board, Welsh Government and a wide range of academic and industry partners, including BASF and Pilkington.

The aim of the Centre is to rapidly develop and commercialise world-class functionally-coated metal, glass and plastic products used in the built environment to generate, store and release clean, renewable, energy for consumption at the point of use.

By transforming buildings into power stations, the shared vision of the partners is to revolutionise the construction sector and, by 2020, deliver significant economic and environmental benefits including:

- The creation of a new billion pound UK manufacturing sector creating business opportunities with significant export potential
- The creation of around 7,000 manufacturing and construction sector supply chain jobs
- The generation of around a third of the UK’s renewable energy target (10.8GW peak, equivalent to 5 coal fired power stations or 19TWh)
- A significant reduction in CO₂ emissions (equivalent to an annual saving of 6 million tonnes of CO₂).
Work in the area of Plastic Electronics at UCL is based in the London Centre for Nanotechnology, the Department of Physics, the Department of Electrical Engineering, and the Department of Chemistry, and involves several groups and areas of activity.

The group led by Professor Cacialli (LCN and Physics) has over 20 years experience in the area of organic LEDs, and has recently started to work also on organic solar cells and transistors. The group has also pioneered the use of scanning near-field optical microscopes for the nanostructuring of electroluminescent polymers, and more recently moved to the use of scanning thermal probes to generate nanostructures of prototypical organic semiconductors down to few tens of nm. Special attention is paid to supramolecularly-engineered semiconductors as model systems to study the scope for control of supramolecular interactions on the photophysics of conjugated semiconductors, with particular reference to conjugated rotaxanes. The group has an extensive collaboration network with groups in Oxford (HL Anderson), Cambridge (RH Friend), Strasbourg (P Samori’), Mainz (K Muellen), Nijmegen (A Rowan), Bologna (V Palermo), Singapore (PKH Ho).

Additional activity is in the group of Professor Skipper (LCN and Physics - graphene and carbon nanotubes), Professor Aeppli (LCN and Physics - organic semiconductors for quantum computing), Dr Mitrofanov (EE - optical spectroscopy), Dr Curson and Papakonstantinou (LCN and EE - solar cells) and Cyrus Hirjibehedin (LCN, Physics, Chemistry - use of scanning tunnelling microscopy to study the basic properties of magnetically doped organic molecules, e.g. phthalocyanines, on surfaces), Dr Salzmann (Chemistry - carbon nanotubes and nanographenes).
University of the West of Scotland

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The Thin Film Centre is involved in research and development work in the wide field of vacuum-deposited thin film coatings. Unique commercial-scale facilities exist for pulsed-DC reactive sputtering, plasma-assisted electron-beam deposition, RF sputtering and PECVD. Characterisation tools available include spectroscopic ellipsometry, nano-indenting, atomic force microscopy, scanning electron microscopy/energy dispersive X-ray analysis, corrosion testing, adhesion and contact angle measurement. The Centre is involved in all aspects of thin film coatings and their applications, including material and process development, and welcomes enquiries for consultancy and/or joint research projects in these areas.

In the plastic electronics area there is particular expertise in optical filter design and manufacture, ultra-barrier coatings and transparent-conducting films on polymer substrates. More recently we have become increasingly active in sensors and devices on polymers and shape-memory polymers, based on surface enhancement effects in thin films, electrochromic and piezoelectric thin films. Our facilities are also ideal for the production of novel thin film solar PV and solar thermal coatings.

University of York

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The Liquid Crystals Group has fifteen to twenty research scientists specialising in the synthesis of advanced organic materials and the evaluation of their physical properties. Materials investigated include thermotropic and lyotropic liquid crystals, low molar mass, dendritic and polymeric liquid crystals, liquid crystals for display devices and for biomedical applications.

In addition to liquid crystals, the group researches in the area of polymers for coatings, adhesives, emissive thin films, reactive mesogens and alignment agents.

It also analyses the physical properties of the materials by thermal polarised transmissive and reflective mode microscopy, differential scanning calorimetry, X-ray diffraction, differential mechanical analysis, FTIR, NMR, refractometry (to 1.5 microns), lap- and impact tests, and electrical field studies (dielectric, elastic, ferroelectric and ionic properties).

Over £1.5M of research support includes numerous collaborations with UK and overseas industry. Research contracts include EPSRC and EU Research Training Networks. The group produces approximately 15-20 papers a year and holds over 100 patents with industrial partners. It also provides consultancy advice on materials issues.
Plastic electronics centres of excellence (PECOEs)

A national resource offering open-access facilities with capabilities for accelerating product design and development

Five centres have a Memorandum of Understanding to provide a focused cluster for technology development and prototyping, aiming to translate UK strengths into the industries of the future. This combination of Centres of Excellence provides the UK with a world-class infrastructure and they have a critically-important role to play in securing the UK’s position in the coming years.

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CIKC is a centre of excellence in large-area photonics and electronics. It is an EPSRC-funded centre with a mission to facilitate the commercialisation of early-stage university technology in partnership with industry - bridging the gap between academic research and commercial exploitation.

The technology scope encompasses;

- Inkjet printing of organic transistor circuits
- Transparent microelectronics
- Organic photovoltaics
- Reflective displays on plastic
- Polymer interconnects for optical data transmission
- Liquid crystal on silicon devices for phase-only holography
- Sensing systems.

CIKC incorporates:

- A portfolio of technologies under development with commercial partners
- Infrastructure for demonstrator fabrication
- Business development support
- Research to improve the effectiveness of commercialisation of university technology
- The training of young researchers in business and entrepreneurship.

CIKC brings together technology research in Cambridge University’s Electrical Engineering Division and Cavendish Laboratory with the expertise of the Judge Business School, the Institute for Manufacturing and the Centre for Business Research to create innovative knowledge-exchange activities spanning business research, training and technology exploitation.
CIKC has a core of capital equipment to enable product development right through to pilot production, including equipment sets for

1. Liquid Crystal on Silicon (LCOS) device prototyping
2. Inkjet printing of organic electronic devices
3. Low-temperature deposition of transparent conducting oxides on plastic substrates
4. Lamination of large area liquid crystal displays on plastic.

In addition, the Electrical Engineering Division and the Cavendish are well-equipped with dark-room, wet labs, communications demonstration and test equipment, general electronic component assembly and test as well as large very high quality clean-room suites, which are utilised by CIKC projects.

CIKC has a very strong interaction with industry with 45 industrial partners involved in CIKC projects. The CIKC model is proving to be effective in generating economic value from academic science and technology and producing high-calibre young scientists and engineers ready for industry. CIKC projects have produced significant intellectual property, transferred technology to industry partners and contributed to the formation of two spin-off companies with others under consideration.
The Centre for Plastic Electronics (CPE) at Imperial College was created to integrate and coordinate the significant volume of relevant research activities in the broad field of plastic electronics, involving representatives from the departments of Chemistry, Chemical Engineering, Physics and Materials. The CPE activities are strongly supported by Imperial College, with several recent appointments and infrastructure investments. This provides an excellent platform for the CPE to exploit the research themes and flourish. Currently these activities comprise 25 academic staff and over 150 researchers and students.

The Centre’s mission is to actively stimulate new cutting-edge high-impact research and to meet Imperial’s strategic intent to harness the strengths and breadth of its research. CPE comprises the following research themes:

- Materials design, synthesis and processing
- Advanced multi-parameter structural, electrical and optical characterisation
- Nanostructure and interface control
- Multi-scale materials and device modelling
- Device fabrication and optimisation.

Embedded within the CPE is our Centre for Doctoral Training (CDT) in the Science and Applications of Plastic Electronics. The aim of the CDT is to train doctoral graduates with interdisciplinary experience and capability in the science and applications of plastic electronics with understanding of the industry and with the ability to adapt to and develop new technologies and applications. This £7.2M programme is a joint venture between Imperial College and Queen Mary University London.

The applications of plastic electronics covered include displays, energy efficient lighting, sensors, flexible electronic circuitry, sensor arrays, solar cells and applications in medical imaging, bio-electronics, memory devices and much more. The field is expanding rapidly, yet much of the basic science remains to be understood.
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CPI Printable Electronics is the National Centre for Printable Electronics in the UK. Focused on the commercialisation and scale-up of client ideas and processes in Printable Electronics, it complements the activities of the other UK Centres of Excellence. As a member of the High Value Manufacturing Catapult, CPI has strong links to the Aerospace and Automotive industries, working with its clients to develop customised applications for these markets.

With a total investment of in excess of £30M, CPI Printable Electronics is equipped with an extensive range of assets specifically chosen and developed to allow clients to understand how their products and processes perform under manufacturing conditions.

Its major activities are in the areas of:

- **Opto-Electronics**
  CPI’s OLED/OPV Prototyping Line (‘LACE’: Large Area Coating Equipment) has been designed to enable the development and production of solid state lighting and organic photovoltaic devices. With flexible form factors, low weights and high efficiencies these devices will ultimately find use in a wide range of markets including Aerospace, Automotive and the built environment. LACE is a unique, custom-built line that gives materials companies, device designers and end-users the ability to develop their technologies within an automated, controlled and scaleable environment. It can accommodate the manufacture of both small molecule and solution-based polymer OLED devices and can process up to 10 substrates (4", 6" or 8") at a time.

- **Materials and Displays**
  CPI is developing the materials technology for printable organic thin film transistor (OTFT) backplanes for displays. This technology has the potential to make very thin and ultra-flexible display backplanes, capable of driving reflective or emissive displays such as e-paper or OLED. CPI has significant OTFT development experience and capability, with facilities for prototyping display backplanes at up to 300mm substrate size. In addition, CPI has a team of experienced scientists and engineers with the ability to design, produce and characterise novel active semiconductor compounds.

- **Integrated Smart Systems**
  These are functional items produced by combining electronic components with circuits prepared by traditional printing processes. Applications include point-of-sale displays; security applications; toys and novelty goods; smart packaging and sensors, including medical diagnostics. The print element will be delivered using conventional printing techniques which can readily be adopted by the established print industry. CPI offers a complete solution for Integrated Smart System design, processing and pilot manufacture. Its roll-to-roll
printing line has the capability to support flexo, offset litho, rotary screen and gravure printing up to 420mm web. Industry standard pick-and-place technology is used to position electronic components on the printed substrate. Cut/crease operations allow different substrate shapes to be produced. Our on-site experts can assist companies of any size to exploit and ultimately profit from this high growth market.

**Vacuum Coating**

With its extensive range of Vacuum Coating equipment operated by experienced staff, CPI offers its clients access to a wide variety of thin-film deposition systems; in particular giving them access to:

- Expertise in the development and characterisation of polymeric barrier materials for sustaining the lifetime of organic electronic devices
- Expertise in a wide range of vacuum processing and deposition technologies delivering optical, electrical and semi-conducting functionality
- An understanding in sputter coating, evaporation and Atomic Layer Deposition (ALD) processes, including the impact of combining these with more conventional coating technologies.

The equipment employed is housed in high quality clean room environments handling a variety of both rigid and flexible substrates up to 420mm web. It includes:

- Pilot scale roll-to-roll sputtering
- In-line and batch sputtering from 100mm to Gen 2 substrates
- Novel linear HiTUS sputter coating
- ALD for high integrity conformal coatings.

CPI will always strive to ensure that the structure of a project meets its clients’ needs in terms of confidentiality, protection of IP etc. Clients can engage with CPI Printable Electronics in a way that suits them, from simply hiring equipment to engaging in full joint development programmes.
The Chemistry Department at the University of Manchester has significant activity in the synthesis, processing and application of conjugated organic materials, quantum dots and nano-dimensional materials. Applications being targeted through collaboration with industry and other academic institutions (Professor Turner coordinates the EPSRC Organic Materials for Electronic Consortium) include displays, OFETs, photovoltaics and sensors.

The department has key expertise and skills in the areas of:
- The synthesis of new organic materials (polymers and conjugated liquid crystals) for electronics and on using novel synthetic methodology (e.g., microwave assisted)
- New routes to the high-volume synthesis of quantum dots and nano-dimensional materials
- The inkjet printing of functional materials including conductive metals and electroactive materials
- The development of novel sensor technology based on organic thin film transistors
- Capabilities in fabrication and testing of OFET devices
- The application of high-throughput methodologies to materials synthesis.

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The Welsh Centre for Printing and Coating (WCPC) is a leading research and development centre for advanced manufacture by printing. It has comprehensive printing facilities with ink and coating development capacity which are unique in Europe. The open access facilities and expertise of WCPC are already addressing the UK’s ability to exploit its indigenous research, providing support for innovative businesses moving from being primarily R&D focused to launching pilot manufacturing lines.

WCPC has a unique expertise that includes the fundamental understanding of the physics of the full range of volume printing processes, printing of functional materials, manufacturing process development and production optimisation. Research on fundamental aspects has been recognised by prestigious EPSRC Platform and Portfolio awards and a record of technology transfer into industry through winning the 2009 EU Regiostars competition. Printing is also a core technology in the development of advanced point-of-care sensing and devices for medical applications, such as scaffolding for supporting cell growth. WCPC has research laboratories dedicated to developing health applications of printing as part of the Swansea University Centre for Nano Health.

WCPC supports companies across Wales and Europe, thus contributing to the European manufacturing economy.

Case Studies

Flexographic printing is one of the volume processes that has the potential for the reel-to-reel large-area manufacture of polymer electronics. It is already extensively used for the printing of flexible films for packaging, operating on run web widths of up to 1.6m at speeds of up to 200m/min.

In flexographic printing ink is transferred from an enclosed chamber to an anilox roll, which consists of finely engraved cells. The role of the anilox is to provide a metered amount of ink to the features on the printing plate. Rolls of varying engraved volumes are used to achieve this, depending on the printing application. The ink is transferred via the cells to the plate, where it is received on the raised regions, but remains in the anilox cells where the non-image regions of the plate have been washed away during plate production. Finally, the ink in the image regions is transferred to the substrate. In order to achieve ink transfer, it is necessary to apply a small positive engagement between the printing plate and the substrate. The deformation of the raised
features on the plate as they are subjected to the engagement will affect the size of the printed feature.

As part of the FP7 project ‘Fast2Light’, WCPC has been improving the printing of fine line grids by flexography. The objective of printing a grid of fine lines was to reduce the resistance of the transparent conductor used as the top layer of the OLED light. Silver grids were printed using the latest Kodak NX Kodak plate technology. The performance enabled 30µm ± 1µm grids to be printed at high speed on a 500mm web on our Timson Tflex 508.

A recently-completed TSB project, ‘ACCUFLEX’, has focused on improving the accuracy and consistency. This included the development of improved registration and a novel concept in image carrier construction. This system enabled the plate to be run with only a 25 – 50 µm engagement compared with the over 100µm engagement normally required.

These projects have highlighted the potential of flexography for the manufacture of wide-area flexible electronics. Flexography also has the potential application to printed sensors, with recent trials including the printing of antibodies as a bio sensing element.
## UK Company Capability Matrix

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<tr>
<th>Company</th>
<th>organic materials</th>
<th>inorganic materials</th>
<th>substrates and films</th>
<th>devices and device design</th>
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Applied Laser Engineering Ltd
Molesey Business Centre,
Central Avenue, West Molesey,
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Alex Askari
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F +44 (0)20 8783 1348
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Applied Laser Engineering is a leading manufacturer of high definition laser engraving systems available in a range of sizes and formats. We specialise in machines which produce engravings into a typically cylindrical form where high resolution and high accuracy are required. Engravings can be of a graphical nature, a simple texture or really almost any pattern that you can think of. Flat sheet engravings can also be produced either wrapped onto a drum or in the flat using our new X/Y systems. Systems can utilise a drum scanning technique, galvo scanning or acousto-optic scanning or a combination thereof. A wide range of substrate materials can also be engraved including polymers, metals, and ceramics to date.

Our systems support the printed electronics arena, either directly or modified via an R&D collaboration for a specific end purpose.

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Cambridge Display Technology (CDT), a member of the Sumitomo Chemical Group of Companies, is a global pioneer in the research, development and commercialisation of technologies based on polymer light emitting diodes (P-OLEDs).

OLEDs are a fast-growing, new generation of display technology which is anticipated to replace liquid crystal displays (LCDs) and cathode ray tubes (CRTs) in many existing applications as well as opening up exciting possibilities for new product forms such as flexible or wearable displays. P-OLEDs are already in commercial use, and are expected to pervade mobile applications, televisions and lighting. CDT owns key intellectual property around P-OLED materials, devices and processes such as inkjet printing which are used in the manufacture of P-OLED displays.

CDT is based in Cambridge with a Technology Development Centre in Godmanchester.
Carbonlite Converting Equipment Limited
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F +44 (0)1706 377444
E peter@ccequipment.co.uk
W www.carbonlite.co.uk

Carbonlite designs, builds and supplies reel-to-reel, coating, laminating, printing and micro structuring machines. Machines are available for processing webs either in air or in vacuum, web widths from 150 to 600mm.

Our machines are designed in modular form so that they can be easily customised to suit process requirements and easily reconfigured or extended to cope with future process requirements.

Coating and printing heads are built in cartridge form; any of the known techniques can be supplied. Multiple coating and printing heads can be fitted for multi layer coatings. A UV casting module is available for manufacturing micro structured films.

The web transport system is all servo so the machines can be equipped with a re-registration system.

We have both vacuum and in air coaters available for trials and process development, capable of replicating most of the manufacturing processes used in flexible electronics. Specifically, we are developing a reel-to-reel manufacturing process for organic solar cells.

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Cintelliq is an independent limited company which provides information services and technology consultancy to the organic semiconductor industry. Cintelliq provides a range of services including a newsletter on organic semiconductors, Organic Semiconductor Analyst Direct; a series of reports, including the respected Organic Semiconductor Patent Analyst which provides comprehensive analysis of relevant patent applications in Europe, Japan and the US; consulting services, including technology intelligence, competitor review and patent analysis; and a conference series.
Conductive Inkjet Technology

Conductive Inkjet Technology has developed a unique and revolutionary family of catalytic materials and associated equipment to address the needs of the rapidly-emerging printed electronics market. CIT’s catalytic inks can be used with inkjet and flexographic printers. A variation of that ink can be photo-imaged to support the higher resolution requirements of touch screens and displays. CIT has developed a full suite of equipment to support these exciting new technologies.

Inkjetflex.com is the manufacturing arm of Conductive Inkjet Technology. Using CIT’s revolutionary Digital Print and Plate technology we produce copper on polyester flexible circuits in any quantity – from as little as one square foot. The unique characteristics of this process are:

- 300 mm wide web with no restriction on image length
- Solid copper with a sheet resistance as low as 20 mΩ/☐
- Fully additive technology with minimal waste generation
- A two-step process of patterning and metallisation
- Fully digital roll to roll printing process.

CPI Printable Electronics

see CPI Printable Electronics entry in Centres of Excellence section

De La Rue International plc

De La Rue is the world’s largest commercial security printer and papermaker, involved in the production of over 150 national currencies and a wide range of security documents such as travellers’ cheques and vouchers. Employing over 4,000 people across 31 countries, the company is also a leading provider of cash-handling equipment and software solutions to banks and retailers worldwide, helping them to reduce the cost of handling cash.

The company is working on innovative techniques to provide power into paper or polymer based substrates to power printed electronic systems. In particular we have developed a mobile phone powered Ultra high RF diode array which harnesses radio energy. We are seeking partners and end user collaborators to further develop printed systems for the security print industry. Of particular interest will be low power printed display, logic circuit and inter-connects manufacturers.
DuPont Teijin Films (UK) Ltd

DuPont Teijin Films is the world’s leading supplier of Mylar® PET polyethylene terephthalate, Melinex® PET polyethylene terephthalate and Teonex® PEN polyethylene naphthalate films. The company specialises in film products and related services for the specialty, industrial, packaging, advanced magnetic media, photo systems, electrical and electronic markets. DuPont Teijin Films supplies a wide range of films for use in a broad range of plastic electronics and lighting applications. These films have the highest levels of clarity and surface quality for these critical applications and a range of pretreatments giving functionality ranging from improved adhesion to sophisticated planarisation effects.

DuPont Teijin Films’ Research and Technology Group is currently developing plastic substrate alternatives to glass that can be processed cost effectively in high volumes using roll-to-roll techniques. In particular, Teonex® PEN polyester film offers a unique combination of excellent dimensional stability, low moisture pick up, good solvent resistance, high clarity and very good surface quality, making a promising substrate for subsequent vacuum or other coating processes.

Eight19 Ltd

Unit 9a, Cambridge Science Park, Milton Road, Cambridge, CB4 0FE
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E info@eight19.com
W www.eight19.com

Eight19 takes its name from the time it takes sunlight to reach the earth - 8 minutes and 19 seconds. Its mission is to develop the technologies and manufacturing processes that will bring off-grid solar power to a new generation of users, transforming lives and accelerating economic development.

Today, there are 1.6Bn people in the world without electricity. The majority of these live in the world’s most economically-deprived communities, where the up-front cost of solar power is unaffordable.

Eight19’s printed plastic solar technology is designed to deliver flexible, lightweight, robust and lower cost solar cells for a variety of solar-powered applications. Solar modules are created using low temperature, solution processable inks in high-speed, low energy, roll-to-roll manufacturing processes.

Today, using IndiGo technology and a mobile phone, Eight19 delivers solar electricity to communities in Africa and India as an affordable pay-as-you-go service. It’s cheaper than kerosene, the most common source of power at present, and much cleaner and safer.
Epigem is a creator and supplier of printable electronics technology with a 25 year history of partnering with both large and small companies and universities, from proof of concept idea realisation to commercial microengineered component and film manufacture. Our composite boards, films and coatings provide miniaturised optical, electrical and fluidic functions, and can be integrated on any substrate: glass, PMMA, leather, film (PET, PEN etc). Our best in class EPIMESH transparent conducting film - 1 Ω/☐ surface resistance, 95% optical transmission (85% on 125 micron PET) is produced in sheets or reel-to-reel (305 mm web width) supporting applications including photovoltaic solar cells, display touch screens and lighting. Epigem provides R&D services via the FLUENCE MNT Centre (more than 100 companies and universities were supported from 2006 to 2011 - an £11 million public and private investment).

We manufacture replicated optics and microfluidic devices for industrial and medical measurement instrumentation process control boards and disposables; meeting the need to process low fluid volumes, to recreate natural micro environments (e.g. blood vasculature) and for precise diagnostic process and sensor integration (optical, electronic, acoustic). Our collaborative research achievements include a system for measuring the aerodynamics of surfaces using microfluidic tapes applied to any platform: aircraft, cars, sails, turbines has been developed with CSEM in Switzerland.
G24 Innovations Ltd
Wentloog Environmental Centre,
Wentloog, Cardiff CF3 2GH
Leigh Turner
Business Assistant
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F +44 (0) 2930 837341
E info@g24i.com
W www.g24i.com

Production of G24i’s Dye Sensitised Thin Film began in 2007 using a high-speed, environmentally friendly, roll-to-roll manufacturing process similar to inkjet printing. The highly automated process transforms lightweight metal foil into half-a-mile of Dye Sensitised Thin Film in less than 3 hours. The film produced is a thin (<1mm thick), extremely flexible and versatile nano-enabled photovoltaic material that converts light energy into electrical energy, even under low-light, indoor conditions.

G24i is the global leader in energy harvesting - the recycling of light to electricity through the manufacturing of next generation Dye-Sensitised Cells (DSC). This disruptive technology has the potential to make disposable batteries obsolete. G24i’s DSC modules are ideal for powering a broad range of electronic devices in all lighting conditions including indoor, ambient light such as window blinds and shades, computer accessories, remote controls, sensors, personal healthcare products and much more.

The 23 acre site is the first production facility to produce renewable energy products using only renewable energy from a 120 metre tall, 2.3 MW wind turbine built in 2011.

Flexink Ltd
Unit 1 Freemantle Business Centre, 152 Millbrook Road East,
Southampton SO15 1JR
Professor Iain McCulloch
E sales@flexink.co.uk
W www.flexink.co.uk

Flexink is a specialty chemicals SME with a portfolio of ready-to-use semiconducting inks and matching dielectrics optimised for common printing process employed in the fabrication of organic transistors and solar cells. We have the capacity to provide commercial scale printing inks based on solutions of organic small molecule, oligomer and polymer semiconductors. Our research group is focused on the design and synthesis of a range of semiconducting fused heterocyclic aromatic molecules and polymers. We currently supply these materials to many of the world’s leading organic electronic device manufacturers worldwide. The performance of our formulations is world-leading, including high-charge carrier mobility charge transport materials for transistors, and high-efficiency light-absorbing polymers for solar cells.

The Flexink management and technical team comprises four experienced PhD industrial scientists with a background in specialty chemicals manufacture of organic semiconductors. We have broad expertise in organic chemistry, polymer chemistry, materials science, colloid and formulation science and semiconductor physics. We understand the application requirements for organic semiconductors and have a track record in bringing new materials into the marketplace. The co-founders and management at Flexink are Professor Iain McCulloch and Dr Martin Heeney, who are both also academic staff in the Chemistry Department at Imperial College, London, with previous industrial experience at Merck Chemicals Organic Electronics Research.
Gwent Electronic Materials Ltd
Monmouth House, Mamhilad Industrial Estate, Pontypool
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Les Embury
Managing Director
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F +44 (0) 1495 752121
E les@gwent.org
W www.gwent.org

GEM manufactures inks and pastes formulated for deposition by additive processes such as inkjet, flexography, offset lithography and screen printing on all forms of substrates. They produce conductive materials that may contain precious or non-precious metal, dielectrics, material sets for electroluminescent displays, synthetic metallo-organic materials, polymer-based inks and pastes and enzyme inks. These are used in a variety of electronic devices, displays and sensors.

Core staff members at GEM have between them 100 years of experience working in paste production for the electronics and sensor industries. This extensive knowledge enables them to provide materials to exact customer specifications through joint collaboration and sampling and to offer contract research to build new products to specific requirements or to suit individual processes.

Facilities include GEM-designed, computer-controlled dispersion equipment for agglomeration-free, repeatable materials and an extensive range of test and analysis equipment. To ensure high standards and repeatability, all products, including research contracts, are carried out to EN29000 ISO/TS 16949 standards.

Hewlett Packard Laboratories
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HP Laboratories in Bristol carries out corporate research for the Hewlett-Packard company, including into the area of plastic electronics, such as displays, sensors and actuators. Expertise includes optics, electrooptics, novel plastic manufacturing approaches.
High Force Research Ltd is a contract chemical R&D company with a proven track record over two decades. We specialise in the synthesis of high-purity, novel organic and inorganic compounds for use in printed electronic, biological and pharmaceutical compounds.

HFR undertakes custom synthesis, process development and optimisation of chemical processes for manufacture from grams to kilograms and then to large, industrial scale.

HFR have been involved in printed electronic compounds for the last five years and have developed a number of small molecule semiconductor compounds and polymeric semiconductor and OLED materials to high-purity and performance standards.

Facilities include ISO class 8 clean rooms / laboratories and a range of analytical instrumentation including HPLC, GC, NMR, FTIR, UV, DSC and GPC polymer analysis.

HFR welcomes enquiries from companies and academic groups that require high purity chemical synthesis and process development particularly for printed electronic and advanced materials.

IDTechEx gives strictly independent marketing, technical and business advice and services in three forms - consulting, research and events, covering:

- Printed, organic and flexible electronics
- RFID and wireless sensors
- Electric vehicles
- Energy harvesting and storage
- Photovoltaics
- Smart packaging

Our work includes technology and market benchmarking, analysis of companies, due diligence, in-company masterclasses and global research.
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R&D Centre, West Road, Wigton, Cumbria CA7 9XX
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Product Manager – BOPP
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E Stephen.Langstaff@innoviafilms.com
W www.innoviafilms.com

Innovia Films produces speciality Biaxially Oriented Polypropylene (BOPP) and Regenerated Cellulose films for packaging, industrial and security applications. It develops innovative substrates using expertise in coating and polymer science, linking this to some unique manufacturing capabilities.

Products include:

- **NatureFlex™** - a family of compostable films manufactured from renewable raw materials (wood pulp). Key product characteristics are excellent printability with a wide range of processes and superior anti-static performance.
- **Cellophane™ POO** – an ion-permeable membrane film designed to extend the life of batteries.
- **Propafilm™** - high clarity BOPP development films that can be printed by roll-to-roll processes with a variety of electronically conductive materials.
- **Clarity®C** - a high performance base BOPP film, which forms the foundation of Guardian® polymer banknote substrate produced by Securency International which incorporates a variety of security features.

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Intrinsiq Materials is an advanced materials company with facilities in the UK and US, providing nanoparticle based copper ink formulations for printed electronics applications. Our copper inkjet ink, 'Intrinsiq CI', and copper screen print paste, 'Intrinsiq CP', are innovative ink formulations designed for photonic curing at room temperature in air, by laser or broadband flash techniques. Conductivities are comparable to commercial silver inks on a range of substrates, including paper. The company has additional inks under development, including nanoparticle based nickel and silicon.
Keeling & Walker Ltd
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Staffordshire ST4 4JA
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Managing Director
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W www.tinoxide.com

Keeling & Walker Limited is a leader in the manufacture of tin oxide based materials. The product range encompasses grades for ceramic, electrical, electronic and display applications. Keeling & Walker supplies antimony doped tin oxide (ATO) materials, either as powders or nanoparticulate dispersions and inks in aqueous or organic media. These materials can be used to produce optically transparent electrically conductive and infrared reflective coatings on plastic and glass substrates via a range of coating and printing techniques. Good transparency, electrical conductivity, surface flatness and adhesion to a variety of substrates make these materials suitable for many applications which require a transparent electrical conductor, such as displays or photo-voltaic devices.

Loughborough Surface Analysis Ltd
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W www.LSALtd.co.uk

LSA provides a responsive, confidential contract surface-analysis service to the plastic electronics industry and university researchers. As a small, independent company, we are flexible and responsive, offering rapid turn-around analysis as standard. Customer involvement in the analysis is actively encouraged. Each project is individually managed by an experienced analyst responsible for ensuring continuity.

The company’s staff are experienced at assisting with a wide range of issues, such as:

- Research and development
- Materials characterisation
- Contamination identification
- Staining
- Dewetting
- Delamination
- Failure analysis
- Quality control
- Reverse engineering.

Specialising in SIMS, XPS, Auger, 3D profiling, nanohardness and nano scratch testing, we can provide other surface analysis techniques through a network of companion laboratories.
MacDermid Autotype Ltd
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MacDermid Autotype is a global industrial manufacturer of high-quality precision-coated films for use in the printing, automotive and electronics industries. For many years it has been producing high quality optical hardcoated films for membrane touch, touchscreen and display applications. The Autotex® and Autoflex® product range includes ‘velvet’, ‘fine’, ‘antiglare’ and ‘gloss’ finishes that provide precise optical control. The antiglare and gloss products are used in the demanding touchscreen sector where optical, physical and mechanical properties must all be fit for the application.

Our well established manufacturing processes, in clean room environments, enable the introduction of nano- and micro-patterns into hardcoat layers to add a range of additional functionality. Modification of hardcoat chemistry can be used to control the surface energy of coatings, thereby introducing hydrophobic or oleophobic behaviour. New developments are in progress to introduce anti-reflection, electroactivity and other functionality of crucial importance in the display sector, including products for nomadic and automotive applications.

MacDermid Autotype, in partnership with other organisations, has developed other bespoke optical films for particular applications, including specialist diffusers, micro prisms and diffractive structures.

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Merck are currently striving to enable the commercialisation of organic electronic applications through the supply of ready-to-use semiconducting inks and the ancillary materials and technology required to fabricate organic field effect transistor (OFET) devices, as well as photovoltaic cells.

Our range of high-performing semiconducting materials is optimised to deliver excellent electrical performance and ambient stability, through understanding and control of the semiconductor microstructure and morphology and the use of intelligent formulation design. In addition, we offer optimised dielectric and surface modification materials to compliment our semiconducting materials.

We have recently expanded our state of the art facilities at our Chilworth Technical Centre, near Southampton in the UK, to include new laboratories dedicated towards the development of novel material systems for Organic Photovoltaics and Flexible Displays. The Centre now encompasses synthetic chemistry labs, formulation and printing development and high-specification application labs including device fabrication with electronic measurement and analysis. An integrated technical team has been established with specific expertise in synthetic chemistry design, material scale-up, materials science, formulation, printing, semiconductor physics and devices.
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MFLEX UK Ltd. is the European research and development centre for MFLEX Inc., performing advanced development work in printed displays, printed electronics, materials, and processes for application into high-volume consumer goods.

MFLEX Inc. (NASDAQ:MFLX) is a provider of advanced, flexible printed circuits and value-added component assembly solutions to the electronics industry.

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E n.walker@microsharp.co.uk
W www.microsharp.com

Microsharp Corporation Limited (MCL) develops optical film light manipulation solutions. Its micronanostructured polymer films enable redirection of light for improved viewing and novel optical designs. Products include diffusers, lenticulars, microlens arrays, Fresnel lenses and prismatic films. MCL has extensive in-house facilities including roll-to-roll film production, cleanrooms, Zemax and Eldim advanced measuring equipment for research, product design, product evaluation and process engineering. Microsharp has long established links with universities, expert advisors, suppliers and manufacturing subcontractors, which enables MCL to provide a wide range of products and services.

Microsharp works with its clients to develop tailored innovative light management solutions that enable and enhance the ability to provide cost effective display solutions. We combine an understanding of end user applications in the low energy lights (LEDS and OLEDs), displays, media, security and daylighting industries with our capabilities in optical design and testing, UV curable and self-organising lacquers (resins), microprecision replication and optical film products.
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Molecular Vision is an R&D stage in vitro diagnostic company that has developed a technology platform that could radically change how diagnostic tests are administered to patients. Its low-cost, disposable point-of-care (PoC) device is able to measure previously incompatible parameters on a single test from a single sample, providing both quantitative and qualitative information.

A spin-out of Imperial College London (founded in 2001 by Professor Donal Bradley and brothers Professor Andrew and Dr John de Mello) and now part of the Abingdon Health Group, the company leverages its expertise in optical detection to measure the light signal change associated with one or several optical parameters in biological assays on its BioLED™ technology platform. To date, Molecular Vision has validated the flexibility of the platform by multiplexing an albumin and creatinine panel in a urine sample as well as a triple test for myoglobin, CK-MB and troponin in a serum sample; each on an integrated microfluidic device.

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M-Solv Ltd performs application specific process R&D and makes advanced production tools for micron scale machining, functional printing and patterning. It is active in the rapidly-emerging thin film and flexible electronics market with an emphasis on new manufacturing techniques that can be incorporated for economic and environmental reasons.

Recent developments have been in the deployment of inkjet production tools for touch panel applications for the mobile and handheld market, development of a hybrid one step interconnect process for thin film PV applications and the development of an HDI/IC substrate manufacturing platform currently coming on to market. All applications look to replace or disrupt incumbent costly lithographic based processes with direct, dry laser etch processes and/or digital printing for the fabrication of novel functional components.

M-Solv Ltd is leading the way with the development of its processes on to a reel-to-reel platform utilising flexible glass as the new substrate of choice for future electronic applications. It has particular interests and core competencies in thin film PV, capacitive touch panel, AMOLED display and HDI sectors.
The National Physical Laboratory (NPL) is the UK’s National Measurement Institute and is a centre of excellence in developing and applying the most accurate measurement standards, science and technology.

The Organic Electronics team at NPL carries out world-leading metrology research for organic, plastic and printed electronics. Collaborative programmes are ongoing with large industrials, SMEs, universities and R&D centres to support materials and product development on three main themes:

- Performance: Nano- to micro-metre scale characterisation including bulk and surface properties of thin-films and devices
- Durability: Long term and accelerated testing, degradation mechanism elucidation, failure analysis, seals and barrier layer characterisation
- Large area characterisation: Off-line inspection, in-line testing, large area metrology.

NPL offers a broad complementary suite of measurement techniques, combined with a scientific team with significant industrial and academic experience in organic electronics.

Major recent metrology advances and capabilities include water vapour transmission rate through barrier layers, optical performance of electronic displays, charge mobility, solar cell efficiency, large area photocurrent mapping, photoconductive atomic force microscopy, scanning kelvin probe microscopy, photoelectron spectroscopy, secondary ion mass spectrometry, micrometre scale surface energy mapping and micro- and nano-Raman spectroscopy.
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The NSG view of printed electronics remains resolutely different to most of the wider plastic electronics community. We have created a technology platform based upon integrating low-cost silicon micro-controllers with traditional print. The print processes are long-established and widely-used within the print & packaging industry. We introduce two-way interactivity into printed media - such as paper, plastic or card - that inseparably links the physical and digital worlds.

Novalia’s experienced team come from a diverse range of backgrounds. We bring together all of this knowledge and creativity to write ‘apps’ for print. From initial concept design through to full manufacture the team is able to deliver working, production-ready solutions. Our approach is to partner with significant clients who have the desire to add value to their products or brands by creating a 21st century user experience. Some sectors in which we are currently active include packaging, books, aerospace, automotive, posters, security, cosmetics, music, advertising, industrial goods, brand protection and point of purchase.

NSG Group

NSG Group is a global supplier of float glass and glass products, which operates under the Pilkington brand name in the building products and automotive industries.

Coating technologies on glass, including atmospheric chemical vapour deposition (A-CVD), vacuum sputtering and sol-gel coating are core competencies and generate a wide range of products. These include NSG TECTM glass, which is based on fluorine doped tin oxide coating and combines high optical transmission with low emissivity and conductivity similar to ITO (sheet resistance of 7 to 70 Ohm/square). Sputtered coatings based on silver with anti-reflective oxide layers offer even lower emissivity and lower sheet resistance <1.0 Ohm/square while maintaining high transparency.

Another core competency is in the production of ultra-thin float glass, down to 0.3mm for current commercial production and even thinner products in advanced stages of development. This thin glass can be chemically strengthened and coated with conventional ITO for use as an electronic substrate. A major advantage of glass over plastic substrates in these applications is the phenomenally low water and oxygen vapour transmission rates for glass. So low that NSG also makes SpaciaTM evacuated double glazing with a hermetic seal for durable, high performance insulating windows with low thickness profile.
OpTek Systems is a leader in the provision of advanced laser processing and inspection solutions. The company supplies solutions in the form of in-line modules, fully integrated machine tools and sub-contract services. OpTek processes are applied to a wide range of materials, creating micron scale features, to exacting tolerances. This material can be presented in a range of formats from small metallic components to large area polymer webs. Tools are supplied for cutting, drilling and shaping, as well as welding, de-metallisation, surface modification and even molecular realignment. Examples of typical installations include, tools for cutting and shaping optical fibre, high speed drilling of injection moulded components, de-metalizing a range of substrates, cutting and drilling biological diagnostic sensors, drilling of precision spray and injection nozzles.

At OpTek Systems we merge our experience in laser processing, precision engineering and materials interaction, with core skills in automation, control, visualisation and system integration, to provide robust, reliable production equipment for a variety of manufacturing environments.

Founded in 1996 to commercialise Quantum Tunnelling Composite (QTC) technology, Peratech is a privately-held company with 20 employees. QTC is a unique, patented electronic material which can be used to make completely new forms of switches and sensors with a working resistance range of more than one trillion ohms and capable of carrying large currents. QTC composites are largely non-linear and are sensitive to various stimuli - including pressure, voltage and volatile organic compounds.

The required resistance range and sensitivity of the QTC can be chosen during the manufacturing process. Usually, Terra-ohm ranges would be used to produce switching devices and Kilo-ohm ranges used for sensors. QTC can be manufactured as a solid, powder, coating or ink and can be applied to many surfaces including films and textiles. Recently, QTC Clear ink has been produced to facilitate new types of touch screens with inherent pressure sensitivity.

QTC is at the heart of a rapidly-growing number of commercial products and has received many national and international awards, the most recent being the Queen’s Award for Innovation 2012.
Plastic Logic Limited

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Plastic Logic is at the forefront of research and investment into next-generation plastic electronics. Founded in 2000 by researchers from the Cavendish Laboratory at Cambridge University, Plastic Logic was the first business to develop and manufacture plastic electronics solutions on a commercial scale. In 2008, the company opened the world’s first commercial plastic electronics manufacturing facility, based on its unique OTFT process, in Germany.

The technology has wide applicability, but the first area of exploitation is active matrix backplanes which enable truly flexible and rugged displays that can be integrated into revolutionary form factors products. Independent consultants confirmed that Plastic Logic flexible display manufacturing process has reached yields competitive with the much more mature LCD industry, making us the most advanced flexible display OEM in the world. Plastic Logic’s Technology Centre in Cambridge continues to develop the TFT technology and is open to partnerships for new applications.

Plasma Quest Ltd

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Research and systems development company Plasma Quest Limited (PQL) specialises in thin film coatings. Its proprietary remote plasma thin film sputter deposition process is an enabling technology that delivers high-quality, low-stress films at high deposition rates, without heating. The technology is ideally suited for deposition onto flexible (organic) substrates, where the PQL ambient temperature process often gives properties that conventionally require a high deposition temperature process or a post deposition anneal. Specifically, PQL is able to deposit ITO, AZO, ultra-thin gold and silver with excellent electro-optical properties, high mobility FETs, photoluminescent and electroluminescent devices and most dielectric materials, all onto flexible plastic substrates.

Further enhancements of the technology will enable large-area, high-throughput production systems to be developed, suitable for use in batch or roll-to-roll processes. These production systems will have all the advantages of PQL’s advanced thin film deposition technology.

The benefits of the PQL thin film deposition process include:
- High target utilisation (>90%)
- High deposition rate reactive sputtering of dielectrics
- Sputtering from thick ferromagnetic targets
- Preservation of thin film stoichiometry when using a conditioned compound target.
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Polar OLED produces novel liquid crystalline organic semiconductor materials for use in OLED applications. Building on the historic work of the University of Hull in the field of liquid crystals and optoelectronics, Polar OLED was spun out in 2008 to commercialise materials that have been developed by the University. Polar OLED has expanded this range of materials and owns an IP Portfolio of novel material sets.

Based on these IP-protected materials Polar OLED is developing systems that can improve the production speed, device efficiency and technical performance of OLED devices.

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PolyPhotonix is a UK company specialising in OLED manufacturing process development, OLED device manufacturing and research and the development of OLED applications.

Organic Light Emitting Diodes – OLEDs - are a highly-efficient light source that can be used in many applications from automotive, to medical and general lighting applications.
Progress in printing electronic logic (transistor-based circuits) has been hampered by the need to reliably pattern very small features, and the difficulty of accurately registering successive process steps.

PragmatIC has developed novel solutions to these challenges. PragmatIC employs an imprint process able to achieve nano-scale features, already proven in high volume commercial printing (e.g. holography). In addition, PragmatIC has a broad suite of intellectual property covering novel device architectures, including entirely planar devices that require only a single patterning step.

PragmatIC’s unique technology has spurred a range of customer-led prototyping projects. Announced customers include: Tigerprint (part of the Hallmark Group); DeLaRue (the world’s largest commercial security printer); and Innova Films (a leading global manufacturer of labels & packaging films).

PragmatIC’s primary business model is technology licensing, however it has also announced its own pilot line. The PragmatIC Pilot Production Program (P4) builds on prototyping activities to involve the entire value chain (including end users) for commercial deployment of integrated product solutions into low-volume early-market applications.
Printed Electronics Ltd was established in 2006 as probably the first company to wholly focus on the development of printed/plastic electronics. Inkjet printing of complex functional inks on virtually any substrate has been successfully demonstrated. More recently high precision multilayer screen printing, digital graphics and laser machining has been added to produce professional preproduction and small batch products.

Specific skill sets include:
- A dedicated and experienced technical team with a wide range of electronics knowledge
- The development of complex functional fluids and their functionalisation for electronic applications
- Understanding the complex interactions between inks and substrates and the development of processes to aid successful printing
- Customer product and process development
- Project management skills for grant aided funding
- The integration of printed and conventional electronics to produce hybrid circuits on a wide range of unconventional materials including paper and card, posters, biodegradable materials, clothing, ceramics, non-conformal surfaces, flexible substrates etc
- Practical courses on printed electronics where participants can use equipment to produce circuits
- Specialised courses for companies who want to concentrate on specific aspects of printed electronics.
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Qudos Technology is a UK research and development company specialising in micro and nano-scale technologies. The company is based at Rutherford Appleton Laboratory near Oxford and offers services to both commercial customers and academic institutions and operates from a class 1-100 cleanroom facility. The company’s strength lies in its ability to work with customers in developing their device concepts, produce prototypes and to set up production if required. Our process engineers are highly skilled and experienced; we can perform a wide range of processes including the more simple processes such as deposition and dicing right through to more advanced techniques such as greyscale masks, nanoimprinting and etching.

Processes and services offered include:
- Process and device development
- Single and multi-step processing such as thin-film deposition, etching and lithography
- Ebeam direct write and mask making including greyscale
- CAD
- Displays, photonics, sensors and micro electromechanical systems fabrication
- Inspection: Metrology and SEM
- Flexible Substrate Processing
- Nanoimprinting
- Dicing
- CAD to device delivery
- Project management.

Materials range from silicon, ITO films on glass, quartz, novel crystals and flexible substrates. Experience in plastic electronics comprises R&D processing and the testing of flexible substrates for display projects.

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RK Print’s Rotary Koater offers reel-to reel coating, printing and drying techniques with either one or two stations inline for development or basic production.

Utilising state-of-the-art servo control the custom built VCM offers multiple inline stations achieving registration accuracies of less than 50 microns.

The application of conductive polymers has traditionally been by spin coating but this is inappropriate for large-scale production on flexible substrates. Whether an all-over film or pattern is required the methods used must achieve the correct film thickness and surface quality as well as being viable for current production technologies. RK offer a range of devices for evaluating the majority of coating and printing techniques from laboratory to production.

The RK Flexiproof 100 is essentially a miniature flexo press and is being used world wide to prepare printable electronic, OFETs, OLEDs etc.
Silvaco Europe is a leading supplier of Technology Computer Aided Design (TCAD) software, and a major supplier of Electronic Design Automation (EDA) software for circuit simulation and design of analogue, mixed-signal and RF integrated circuits.

Silvaco offers 2D and 3D design solutions for complex semiconductor devices in organic and inorganic material technologies using ATLAS. This includes an extensive model offer to designers involved in large-area electronic applications using organic- and oxide-based materials.

Silvaco also offers flexible design solutions to circuit designers in the area of plastic electronics. We have an international first with our ‘Universal Organic Thin Film Transistor’ UOTFT compact model released in 2009. This is now available as a standard library and has been integrated with our parameter extraction software UTMOST IV and circuit simulator SmartSpice.

Designers can also deploy mixed-mode simulations to which allows them to capture the full device physics within a complex SPICE netlist to tackle complex circuit design applications.

SmartKem delivers world class ‘organic’ semiconductor materials for the manufacture of ultra-thin, lightweight and flexible electronics that can be used in applications such as TVs, PCs, tablets and mobile phones.

SmartKem’s organic semiconductors have world leading electronic performance, can be processed at room temperature and can be easily formulated into electronic ‘inks’ for the printing of organic transistors used in displays, sensors and logic circuits.

SmartKem’s target customers are electronics manufacturers who are in the process of evolving from traditional silicon technology to printed / organic electronics.

The market entry point for SmartKem is electronic displays with many eReader, LCD and OLED manufacturers all responding to the demand for lightweight, low cost and flexible displays. The company aims to sell organic semiconductor molecules and inks to organisations in this value chain or alternatively license its IP and proprietary know-how. A future pipeline of second and third generation improved materials has been conceived and the company expects to create a strong leadership position through a combination of world-class innovation and a flexible business model.
Solar Press is an early-stage company whose vision is to be the world’s leading provider of Organic Photovoltaic (OPV) process technology to enable the low-cost reliable manufacture of solar panels in high volume in all regions of the world. The company was founded in 2009 by The Carbon Trust and C Change, a partnership of leading academics from institutions including Imperial College London, and ETH Zurich.

By using materials that can be printed onto plastic film using conventional high-speed printing techniques, Solar Press is opening the way for radical reductions in manufacturing and transportation costs compared to other solar technologies.

Solar Press works in partnership with coating equipment manufacturers and materials suppliers to deliver a unique turn-key manufacturing solution for OPV solar cell production. Its customers are companies in all regions of the world wishing to manufacture OPV solar panels to address local market needs. The company is initially targeting production of low-cost photovoltaic modules for developing markets, for solar lighting and charging applications.

Thorn Lighting is driving polymer organic led lighting technologies suitable for luminaire integration and electronic control systems, based on a purely UK supply chain. It is actively involved in collaborative programs with Cambridge Display Technology (CDT), Pilkington, Tridonic UK, the University of Durham’s Physics Department and designers OCTO. Understanding how each subcomponent interacts with each other is of paramount importance in creating an optimised luminaire system. Thorn Lighting, through Project TOPLESS and TOPDRAWER, has supported the drive from basic research through applied research and onwards towards manufacturing and ultimately exploitation in conjunction with its partners and government financial support.

The core competences necessary to be successful in creating a polymer oled luminaire are organic material R&D, scale-up capability, and device architecture design through modelling (CDT), substrate development, including metallisation of an appropriate anode and integrated internal and external optical outcoupling (Pilkington, in-conjunction with CDT and Durham), electronic driver modules and addressable control systems (Tridonic), luminaire designs (Octo), understanding the market, its’ dynamics, standardisation development and metrology (Thorn). These are all pre-requisite for a successful luminaire creation, and not one single company, nor organisation can substitute for this. The supply chain development is unique too; the technology is still far too immature to replicate tradition volume manufacturing supply chain models, managing and maintaining requires multi-business strategies aligned to a common output.
Timsons Limited has a long and successful history in the design and manufacture of reel-fed printing presses. Its performance has been recognised by Queens Awards for International Trade and Innovation. Currently a leader in the manufacture of bespoke presses for the production of books, the company is developing new roll-to-roll solutions for functional material applications. These will handle a range of flexible substrates incorporating alternative printing, deposition and drying solutions. With robust precision build, the platforms are designed to address future requirements for the manufacture of high-volume low-cost printed electronics.

TWI Ltd is a leading research and technology organisation with over 700 staff around the world providing technical support to industrial clients. For more than 45 years, it has advised on all aspects of electronic, photonic, sensor, MEMs and medical packaging. Its expertise covers: flexible electronic, display, lighting and photovoltaic technologies, including, interconnect, barrier coatings, replacements for ITO, packaging, thermal management and modelling for flexible, rigid and harsh environment systems.

The microtechnology activity at TWI comprises a packaging clean-room, a coating deposition, assessment and characterisation facility and a wide range of other technologies required to maintain and extend its leadership in fields associated with interconnection, packaging and protection within displays and electro-photonic systems. Development programmes are also carried out that lead to cost-reduction, miniaturisation and ‘ruggedisation’ of components and assemblies. TWI’s work spans a vast array of processes and includes the development of laser and e-beam technologies.

TWI provides an impartial, confidential service to small and large businesses to help them develop ideas, solve problems and produce cost-effective products.
VG Scienta Limited is an established company with 50 years experience in supplying high-quality vacuum-based systems to scientists undertaking pioneering research in numerous fields.

This close association has given VG Scienta an unrivalled position and insight into the needs of the scientific community.

Since 2003, VG Scienta have been working closely with the research community in supplying and developing organic and metals deposition systems, of which the OFT Edge Series are the latest highly-flexible tools for research, offering SMD, PVD, CVD, ALD plus analytical modules for research and pre-production.

Developed in consultation with leading OLED experts at Technical University of Braunschweig, the OFT Edge Series incorporates highly configurable systems for depositing and analysing organic and inorganic layers on both flexible and solid substrates for device fabrication.

Feature benefits include:
- Application driven product family
- 'Plug and play' configurability
- Precise control of multi-source deposition including co-deposition
- Mask handling and alignment
- Configurable doping
- Cluster tool architecture
- Computerised process controls.

VG Scienta remains at the cutting edge of science supplying high-quality solutions to meet the exacting standards of advanced UHV technology.
General contacts

Supporting businesses and the science base, a network of departments are on hand to help

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The Department for Business, Innovation and Skills has responsibility for enterprise, business relations, regional development and fair markets, along with responsibility for science and innovation, further and higher education, and skills.

UK Trade & Investment (UKTI)
UK Trade & Investment Enquiry Service, BIS Enquiry Unit,
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UKTI works with UK-based businesses to ensure their success in international markets, and encourage the best overseas companies to look to the UK as their global partner of choice.

UKTI has a customer commitment to helping its UK and international customers by providing a range of services. It also has a co-ordination role across government to establish a more systematic approach to relationships with companies which are the most economically significant investors and exporters.

The service is provided by the Department for Business, Innovation and Skills under a shared-service agreement.

Engineering and Physical Sciences Research Council (EPSRC)
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The Engineering and Physical Sciences Research Council is a corporate body with executive responsibilities established under the Science and Technology Act 1965 and by Royal Charter. It is a non-departmental public body principally funded through the Science Budget by the Department for Business, Innovation and Skills.

EPSRC supports excellent, long-term research and high-quality postgraduate training in order to contribute to the economic competitiveness of the UK and the quality of life of its people. At any one time, it is supporting a portfolio of research and training between £2-3billion.
The Technology Strategy Board is all about driving innovation. Its role is to stimulate technology-enabled innovation in the areas which offer the greatest scope for boosting UK growth and productivity. It promotes, supports and invests in technology research, development and commercialisation; spread knowledge by bringing people together to solve problems or make new advances; advises Government on how to remove barriers to innovation and accelerate the exploitation of new technologies; and works in areas where there is a clear potential business benefit, helping today’s emerging technologies become the growth sectors of tomorrow.

The Technology Strategy Board is an executive non-departmental public body, established by the Government in 2007 and sponsored by the Department for Business, Innovation and Skills (BIS). The activities of the Board are jointly supported and funded by BIS and other government departments, the devolved administrations, regional development agencies and research councils.

The PELG is a volunteer group representing the UK plastic electronics community. Its mission is to promote the development of a successful Plastic Electronics sector in the UK.

ESP KTN is the UK’s fastest growing network spanning the fields of electronics, photonics, sensors and much more - click www.espkttn.org to find out more.