Foreword

The world of electronics has seen many changes over its comparatively brief history. The thermionic valve gave way to the transistor, analogue gave way to digital, and functionality became ever more concentrated in the ubiquitous chip.

We now have the development of Plastic Electronics, which is a move away from silicon-based products and into organic materials with unique properties.

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 science and engineering base. I am sure you will find the information here interesting, and I hope it will lead to new manufacturing joint ventures as well as to strengthening existing collaborative research and development activities.

The UK is the number one destination for foreign direct investment into the European Union, with a growing proportion coming in high tech sectors. We want to facilitate new investment in Plastic Electronics technologies, particularly in the creation of research and development 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.

Shriti Vadera
Parliamentary Under Secretary of State for Business and Competitiveness
About this guide

The aim of this guide is to highlight the UK’s capabilities in the Plastic Electronics sector. 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. The Government is keen to promote collaboration between UK companies and universities as well as with inward investors. UK Trade & Investment, for example, operates a comprehensive service for those looking to establish facilities in the UK.

We hope that the guide will be a useful source of reference for all people working in the sector, both within the UK and overseas, 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 www.berr.gov.uk

Further printed copies can be obtained from the contacts below, please quote reference URN 08/668:

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Plastic Electronics (PE) is the general term used to describe electronics based on semiconducting organic materials as opposed to silicon semiconductors.

It is a technology that could overturn silicon-based electronics, or simply create new products and facilitate new markets that are not possible with existing technology. The reality will almost certainly be a combination of the two. It is inevitable that the use of plastic materials in conjunction with high-volume, low-cost production techniques will offer electronic circuits with radically different price, performance and functionality than that seen today.

The worldwide market for Plastic Electronics products has been estimated to be worth up to £15 billion by 2015 and, for new markets, the figure could be up to £125 billion by 2025\(^1\) – larger than the silicon electronics industry today. It is suggested that the development of PE is happening at ten times the speed seen with silicon technology.

PE goods have the potential to be slimmer, lighter, more efficient, more robust, easier to manufacture and cheaper than conventional electronic devices. They should also be more environmentally-friendly than current devices, in production, use and – potentially – end-of-life disposal.

Potential applications include point-of-care medical diagnostic devices, novel drug delivery devices, smart packaging, real-time newspapers, intelligent signage, ‘smart’ clothing and accessories, printed electronics for consumer products, flexible solar cells and solid state lighting. The applications are likely to be split between high-resolution/small area and low-resolution/large area devices. The former will be developed for electronics and sensors, the latter for displays and photovoltaic panels.

As significant as the potential of the PE devices themselves is the realisation that they will be made using low-temperature, simple fabrication techniques. Modified versions of conventional coating and patterning processes, supplemented with additive printing processes such as ink-jet or gravure, can be used to deposit a sequence of metal, dielectric and semi-conducting layers of organic and inorganic materials. This sequential processing can create simple functional circuits or complex laterally-patterned arrays of transistors, photovoltaic cells, batteries, sensors and displays, all deposited on a common substrate.

The UK is at the forefront of this technology revolution with world-leading research, development and production in all parts of the supply chain from basic organic and inorganic chemicals, paper, plastic and foil substrate manufacturers, printing press and inkjet

\(^1\)Forecast from IDTechEx, http://www.idtechex.com
printing equipment manufacturers, to the device designers and manufacturers who will produce flexible displays and functional electronic systems.

UK companies are already delivering devices and systems that have broken the constraints of conventional electronics: they show the UK’s strength in innovative design and our breadth of support infrastructure.

In the pages following the materials of PE are summarised, the manufacturing processes outlined, and some of the applications of Plastic Electronics identified.

**Plastic Electronics materials**

Underpinning the Plastic Electronics revolution is the development of materials that are able to be processed using novel manufacturing methods.

**Conductive materials**

Every electronic circuit needs highly-conductive connections between devices to increase the speed of circuit operation and reduce power consumption and heat. For PE circuits, conductors need to be easy to pattern and inherently low in cost. They can be broadly classed into five groups: micro-particles, nano-particle dispersions, metal oxides, seeding materials and organic conductors.

**Micro particles**

Micro particle inks are composed of metallic particles (typically 0.5 to 30µm) dispersed within a resin system binding the particles together and binding them to the substrate. The resin is usually dissolved in a solvent to create an ink that can be printed using a variety of printing processes. The most commonly used metal is silver due to its high conductivity/low resistivity and chemical stability, although other materials including nickel, gold and carbon graphite are also used. The formulation process is complex, accommodating physical, chemical and electrical characteristics and requirements. Material resistivity of the deposited and cured ink is generally greater than the bulk resistance of the base material. Additional high temperature processing can improve these properties, though the material’s resistivity may still be three to five times its bulk resistance.

**Nanoparticle dispersions**

In nanoparticle dispersions, nanoparticles (typically 5 to 300µm) are suspended chemically within a dispersing liquid. Their small size allows low viscosity inks to be manufactured for use in processes such as inkjet printing. Post-deposition sintering at below 150°C can increase the conductivity of the deposited ink by several orders of magnitude. Other nanomaterials such as carbon nanotubes are under investigation to improve conductivity, cost and ease of processing.
CASE STUDY

Conductive Inkjet Technology

Conductive Inkjet Technology (CIT) has developed a unique technology for laying down conductive tracks as narrow as 2.5 microns onto non-porous substrates. It had recognised the problems inherent in inkjetting nano-particle ink – with multiple passes needed to achieve sufficient solid content, and high-temperature sintering unsuitable for some plastics. So it came up with a radical new solution.

The key to the approach is a UV-cured catalyst ink that has been designed for reliable inkjet printing, with only a single pass needed to lay down a pattern. The ink is not conductive and so there are no concerns about particles blocking inkjet nozzles. UV curing then creates the adhesions to the base substrate, and standard electroless plating chemistry allows highly-conductive metal to be grown on the pre-printed pattern.

Mike Johnson, Business Development Director, reports, ‘The metal we normally lay down is copper, as it is low cost and has good conductivity but it is equally possible to lay down nickel, silver and also top coat with gold. The process uses standard piezo driven inkjet printheads produced by a range of manufacturers. And the technology works excellently on a range of substrates including PET, polycarbonate, glass and silicon.

‘With inkjet alone, line widths are limited to no less than 50 microns, especially in a volume manufacturing environment. However as the CIT ink is UV cured, it is possible to print thin lines and then cure just the centre using a laser. Washing off the excess ink in the plating process enables line widths of below 20 microns. Alternatively, using existing photomask equipment, the ink can be spin-coated and exposed using a mask to produce fine metal conductors. Line widths of 2.5 microns have been demonstrated on glass which are invisible to the naked eye.’
Metal oxides
For displays and lighting, metal oxides are generally used as conductors because of their transparency. The most widely used is indium tin oxide (ITO) although the increasing cost of indium, its brittleness on flexible substrates and its requirement for vacuum processing have stimulated research into cheaper, more versatile alternatives.

Seeding materials
Seeding materials are not inherently conductive but can be used to ‘grow’ metals by electroplating with the seeding layer that has usually been patterned by a printing process. This gives the prospect of resistivity close to the bulk resistivity, and allows thick layers of pure metal to be patterned with higher conductivity than when using conductive inks.

Organic conductors
A small number of organic compounds can conduct electricity. The most common are aromatic compounds containing thiophene, aniline, pyrole and their derivatives. One of the commonly used commercially is PEDOT:PSS, a film-forming liquid with variants capable of being patterned by various printing processes. The PEDOT material is almost transparent and so can be used in the manufacture of displays, lighting and photovoltaic cells. The field of organic conductor formulations is rapidly changing with improvements in conductivity and ease of processing.

Organic semiconductor materials
Organic semiconductor materials allow the manufacture of functional devices such as light emitting diodes, photovoltaic cells, plastic transistors, printed memory and sensors.

Organic Light Emitting Diodes
Organic light emitting diodes make up the largest portion of organic semiconductor patents and – at present – are the PE materials produced in the greatest volumes. They offer bright, low-power displays and lighting on rigid and flexible substrates. OLEDs come in two variants – small molecule and Polymer OLED (also called large molecule). In the former, layers are assembled in vacuum using vapour deposition. P-OLED layers are air processable so can be spin coated, inkjet printed or used with other printing techniques.

Organic Field Effect Transistors
A fundamental building block of Plastic Electronics, the organic field effect transistor (OFET) needs to be capable of operating reliably at a low charge and ON/OFF ratio. A major challenge is to manufacture solution-based formulations of organic semiconductors and matched dielectrics that have the required ink properties as well as possessing excellent electrical performance.

The greater the functionality of the device, the faster the transistors’
switching speed needs to be. Transistor speed increases with the semiconductor material mobility, and a reduction in the source-drain gap. The main organic semiconductors available are pentacene and poly thiophenes. Organic semiconductor mobility has been increasing steadily over the years, with the present limit at about 3cm²V⁻¹s⁻¹. This is the same order as amorphous silicon. Reducing the source-drain gap length requires the accurate deposition of organic liquids and other process treatments to enable a performance approaching that of polysilicon. Other factors also influence the optimised operation of the OFET. Nevertheless, functioning printed OFETs are being produced and advances in deposition methods will improve transistor performance and yield.

**Substrates**
The unique characteristic of PE is that it can be based on flexible plastic substrates. This enables reel-to-reel manufacturing for increased productivity and economic benefits.

Manufacturing electronics on flexible plastic substrates is, however, technically challenging. Plastic substrates cannot be processed at high temperatures – they have poorer barrier properties to moisture and gases than traditional rigid substrates, and poorer dimensional stability.

Substrate flexibility and surface properties make the adhesion of organic and inorganic coatings difficult. For display and lighting applications, the optical properties of most plastics are not as good as glass. Research is active to improve barrier coatings, stability, surface finish and material processing requirements.

The most common plastic substrates used in displays and lighting are PET™ and PEN™. These offer good optical properties and can be processed at moderate temperatures (100°C for PET and 150°C for PEN). Materials such as PVC, polyimide and polycarbonate are used in other Plastic Electronics applications.

In some cases paper can be used as a substrate. This opens up a variety of applications such as smart sensors and tags on packaging, and e-tickets. Paper in its most basic form is rough, porous, has poor barrier properties, is dimensionally unstable and has high natural variability. However, many coating and calendaring methods are available which make paper more amenable to PE use.
pixels connected together electrically in a stoically driven (each segment has its own interconnect line) or in a multiplexed manner whereby multiple picture elements (or pixels for short) can be electrically addressed at the same time (pixels are the crossing points of data columns and scan rows in dot matrix displays). This allows for reduction in the number of driver chips and connecting wires, while giving reasonable performance for small displays. A big advantage of these passive matrix (PM) displays is their low cost of manufacture, facilitating a broad range of consumer and commodity applications. Most segment, alphanumeric and small graphic displays are using this multiplexing scheme. However, as the amount of data to be shown on a display screen increases, there is a need for increasing numbers of row lines to be multiplexed and the contrast of the displays decreases.

Active Matrix Driving Scheme

When a large number of display lines are multiplexed together, the liquid crystal material is not driven for a sufficiently long time to maintain high image quality. The driven pixel starts to create a good optical contrast but immediately upon removal of the driving voltage, the fluid begins to relax back to its natural state. Furthermore, passive driven displays have a rather long response time (>100ms) resulting in a smearing effect when images.

CASE STUDY

DuPont Teijin Films (UK) Ltd

DuPont Teijin Films (DTF) is the world’s leading supplier of Mylar® PET polyethylene terephthalate, Melinex® PET polyethylene terephthalate and Teonex® PEN polyethylene naphthalate films. To stay at the leading edge, DTF must continually refresh its product offerings - especially in higher-added-value markets.

During the early 2000s DTF became aware of growing interest in the general area of Plastic Electronics based on conjugated polymers, which opened up new opportunities for combining the advantages of a flexible substrate with roll-to-roll processing. From initial dialogue with the leading technology developers, it became apparent that film substrates tailored to meet the demanding requirement of dimensional stability at elevated temperatures - coupled with exceptionally smooth surfaces - would require the development of a new family of films. To enter into this new technology area successfully, DTF embarked on collaborative programmes with these leading developers to identify the property set required of the film, and then to develop films to meet it. Key to this was an effective feedback loop to understand how film improvements affected device performance.

Government funding through its Technology Programmes helped in bringing the parties together and speeding up collaboration: work with the University of the West of Scotland was particularly valuable. DTF has since made a major investment in terms of both personnel and hardware to develop a family of films, and has recently commercially launched products based on Melinex® and Teonex® PEN polyester film that offer a unique combination of excellent dimensional stability, low moisture pick up, good solvent resistance, high clarity and very good surface quality tailored for subsequent vacuum or other coating processes.
Manufacturing technologies
A key advantage of Plastic Electronics is its ability to produce products using additive printing techniques requiring fewer resources and with lower economic batch sizes than for silicon semiconductor technology. The entry cost to establish a globally-competitive manufacturing plant based on conventional fabrication methods for glass-substrate-based LCD TFTs is more than £2 billion. Furthermore, the world of conventional silicon-based electronics has been forced by the economies of scale to create a small number of very expensive manufacturing plants for many of the electronic devices that are manufactured. This focussing of resource has resulted in a reduction of the number of products that can be economically manufactured. This limits innovation, and stifles the opportunity for companies to trial bespoke products in a standardised world.

The entry cost for PE manufacturing is at least an order of magnitude lower than its silicon counterparts and, as the process matures, it is likely that the manufacturing cost will reduce. What is also likely to happen is for simple PE devices to be created with modifications to existing printing equipment. This will allow SME companies with no involvement in electronics to adopt the technology platform and add value to their existing product base by creating devices with additional functionality, such as intelligent food packaging that can ‘sniff’ electronically whether the contents are still fit for sale, or adding cartoon-like animation to the outside of a carton.

Most conventional printing techniques for graphics can be adapted for the deposition of functional materials. Each printing process has its own characteristics, however, and its suitability needs to be matched to the materials being printed and dimensions required. Where necessary, other thin-film deposition techniques may be used.

Printing
Offset lithographic printing
Offset lithography is the most popular printing process in the graphics printing industry and is typically used to print books, newspapers and packaging. The process produces detailed patterns by virtue of the water repellent (hydrophobic) and water loving (hydrophilic) area on the plate. The system transfers ink using a series of rollers. Film thicknesses are typically 0.5 to 2µm and resolution can be down to 10µm.

Screen printing
Screen printing is particularly suited to the deposition of thick films up to 30µm, and of materials which contain large particles. It is a relatively low speed for
Screen printing is used commercially on flexible substrates for PCB manufacture, blood glucose sensors, electro luminescent displays and membrane switches. Rotary screen printing allows higher speeds and continuous patterning printing.

Rotogravure printing
The rotogravure process is a high-volume printing process used to produce high-quality packaging and publication prints. It is inherently a simple process with the image being formed either electromechanically or by laser on a cylinder by a series of cells (or recesses), which carry the ink. The gravure image carrier cylinder rotates in a bath of ink which is passed to the substrate from small cells (recesses) in the gravure cylinder. Rotogravure can achieve 10µm features with wet thickness of the order of 2-5µm, with packaging printing being capable of speeds up to 700m/min.

Inkjet printing
An inkjet printer operates by electronically controlling the production of a jet of ink from a nozzle to form droplets on a substrate. By moving the head over the image, a pattern can be created over a large area. Inkjet heads usually contain an array of nozzles to increase production rate. Inkjet printed OFETs have been used in a number of applications.
CASE STUDY

Welsh Centre for Printing and Coating (WCPC)

Part of Swansea University’s School of Engineering, the WCPC was created in 1996 to support what was then an embryonic Plastic Electronics sector. Its aims were – and are - to undertake fundamental research, to provide education and training at all levels, and to supply technical services to academic and industry partners. The expectation was that this would be of growing interest: the reality has exceeded that – hugely.

WCPC’s director Dr Tim Claypole, explains, ‘We have seen a rapid increase of interest in our activities – we moved to new custom-built laboratories and offices in 2006 to keep pace with them.

‘Our experience is that industry is looking for the support of people who have a deep understanding of electronics and materials, but coupled with our extensive experience in printing. Our partners range from SMEs to global multinationals, and they come to us because we deliver.

‘Our facilities are excellent. Class 7 cleanrooms cover printing technologies including flexography (sheet-fed and roll-to-roll), gravure, screen, pad, inkjet and offset lithography. We also have facilities for functional ink making, analytical equipment and measurement equipment for both the physical characterisation of the functional ink profile on the substrate and the quantification of device performance.

‘Current areas of development include roll-to-roll OLED manufacture, high resolution and register flexography, fundamental ink transfer mechanisms, EL manufacture, mass produced OFETs and printable transparent conductors.

‘It has been an exciting 12 years - but that only reflects the dynamism of the Plastic Electronics movement itself. With growth predicted to be rapid, we’ll have our work and challenges cut out for many years to come.’
Thin-film deposition

Thin-film deposition covers several means of depositing a thin film of material onto a substrate or onto previously deposited layers. Essentially, the material to be deposited is vaporised, the vaporised atoms then travel to the substrate where they are deposited, either directly or – in some techniques – following a chemical reaction. Most approaches allow layer thicknesses to be controlled within a few tens of nanometers.

There are two main types of methodologies used – Physical Vapour Deposition (PVD) and Chemical Vapour Deposition (CVD).

Physical Vapour Deposition

The material to be deposited is vaporised by heating, impact from a beam of electrons or ions, or contact with a plasma so that particles of material escape its surface. Facing it is a cooler surface which draws energy from the particles as they arrive, causing them to form a solid layer.

Thermal evaporation vaporises the coating material, predominantly metals, in a vacuum and the subsequent vapour is used to coat all the surfaces in the line of sight between the source and the substrate. The evaporation can be carried out using resistance heating or by pulsed ion beam (PIBPVD) or electron beam (EBPVD) systems. It is often used to produce thin, 200-500nm decorative coatings on plastic parts and for high throughput packaging applications. The thermal evaporation process can also coat 1mm layers.

Sputter coating involves metallic and non-metallic materials being directly vaporised in a vacuum using high-temperature plasma and deposited on a surface to form a highly pure, uniform coating layer typically 10 to 250nm thick. In magnetron sputtering, the plasma density is constrained by a magnetic field that intensifies the vaporisation rate and deposition onto the substrate. Vaporisation carried out in an inert atmosphere, typically argon, yields a deposited material the same as the target. Using this method, thin metallic films can be laid down for use as display back-planes or photovoltaic connector layers. It is possible to introduce gases such as oxygen and nitrogen that will react with the vaporised material and deposit on the substrate as oxides and nitrides for dielectrics and permeation barrier materials.

While sputter coating is a relatively expensive process, it provides coatings with high levels of control, purity and uniformity. The industry was originally based primarily on batch operations but now is moving towards continuous roll-to-roll machines that enable significant quantities of polymeric films to be coated for use in flexible electronic applications.
CASE STUDY

Plasma Quest

Traditional magnetron-based sputtering is a far-from-perfect process. Magnets are needed behind the target to give sufficient ion density, but they lead to a ‘race track’ on the target surface with problems including low target utilisation, the need to use thin targets for ferromagnetic materials, and a lack of process stability. But research and systems development company Plasma Quest Limited (PQL) has come up with a better way.

PQL’s Professor Mike Thwaites explains, ‘In our HiTUS (High Target Utilisation Sputtering) based systems, the plasma is generated remotely in a quartz tube adjacent to the main deposition chamber. With suitable magnetic coupling, a high density of low energy Ar ions (not energetic enough to sputter directly) is delivered to the target surface. Biasing the target negatively, as in conventional magnetron sputtering, accelerates the Ar ions across the sheath where they collide with and sputter the target. Because the plasma is generated remotely, there is no need for local magnets behind the target, so there is no racetrack and the problems that that entails.’

There are other gains too – ten times faster deposition, the possibility of sputtering from thick targets, and more. See the company entry later in this guide. And PQL has also developed the process in a linear system. ‘Here the plasma is generated remotely as before,’ Professor Thwaites reports, ‘but - instead of being steered through 90° towards a circular target - it is directed along the long axis of a cylindrical target and the entire target can be sputtered. Currently, we are able to sputter from a target 50 cms long by 7.5 cms in diameter, with the same advantages as before.’

100nm gold deposited directly onto PET
Chemical Vapour Deposition
In CVD, chemical compounds are formed in situ by reaction between the material to be deposited (typically introduced as a vapour) and the substrate so as to lay down layers of organic or inorganic materials. It is capable of producing thick and flexible coatings onto metals and polymeric substrates and will coat all the accessible surfaces of the substrate, not just line of sight. The process has been modified and extended over many years and now encompasses many variants.

Conventional CVD uses a metal compound that will evaporate at a fairly low temperature and deposit as metal when it contacts the substrate at a higher temperature. It is used in semiconductors and related devices including integrated circuits, sensors and optoelectronic devices.

Plasma-Assisted CVD (PACVD) can be performed at lower temperatures and is used to apply diamond coatings or silicon carbide barrier coatings onto plastic films and semiconductors, including 250nm thick semiconductors.

Atomic Layer Deposition (ALD) is similar to CVD. It employs pulses of chemical vapour that react with the substrate surface to form a monomolecular layer (10 to 100nm thick), giving extremely uniform coatings controllable down to 1nm.

Applications
Some early applications of Plastic Electronics are summarised here, although the entries given by universities and companies elsewhere in this guide will give a more comprehensive view of where the technology will be applied in future.

Displays and lighting
Display and lighting applications are at the forefront of the Plastic Electronics revolution, ranging from simple displays through to high-resolution colour devices.

Electroluminescent devices
Recent improvements in electroluminescent (EL) material performance have led to its increased use as a display and light source, and it is commonly used as a backlight for small LCDs. The UK is a world-leader in the manufacture of EL components and assemblies for signage, advertising and hand-held products.
CASE STUDY

Plastic Logic

Plastic Logic is working to transform the way we read the written word. It offers a backplane technology that enables a display to become flexible, thin, and light - yet robust like a sheet of paper. A spin-out from Cambridge University’s Cavendish Laboratory, Plastic Logic’s new manufacturing processes combine the power of electronics with the pervasiveness of printing.

Founded in 2000, the company is building on over ten years of fundamental research - developing and exploiting a portfolio of intellectual property based on printing active electronic circuits using advanced plastic materials.

It has developed the first process for printing electronic circuits on plastic substrates to be ramped-up to an industrial scale. Not only is it capable of making incredibly thin, light and robust displays, it can do so more simply than conventional processes.

In an active-matrix display, each dot is controlled by an active switching element, usually a thin film transistor (TFT), and by the signals on an array of intersecting row and column electrodes. Up to now, TFTs have been fabricated with amorphous silicon deposited at high temperature on a rigid glass substrate. This active-matrix backplane can then be combined with many frontplane technologies such as LCD, OLED or electrophoretic ‘electronic paper’ to make a display.

Even though electronic paper is typically thin and flexible, a rigid display results when it is combined with a glass-based backplane. What is needed is a flexible backplane – Plastic Logic’s. And if the display is flexible, thin, light and robust, then so is the reader device itself. It feels much more like a sheet of paper. QED.
Organic Light Emitting Diodes
OLEDs directly convert electricity to light, and are generally more efficient than LCDs. Displays using OLED technology have a very wide viewing angle – approaching 180° – and a typical pixel response time around 0.01ms. Most OLEDs today are manufactured on glass substrates, but printing them onto flexible substrates will open the door to new applications such as roll-up and conformable displays, and components that can be integrated into clothing.

OLED technology also has the potential to revolutionise lighting design. It has already been demonstrated on glass and significant progress is being made into manufacturing OLED lighting on plastic substrates. ‘Electronic wallpaper’ will revolutionise the lighting industry, but to achieve this goal there must be improvement of the barrier properties of plastic substrates to reduce ingress of oxygen and moisture, and the development of the handling technologies necessary for roll-to-roll manufacturing to deliver high quality devices at commercially attractive prices.

Power supplies
Plastic Electronics offers an unprecedented opportunity to generate and store electrical power through the combination of flexible photovoltaic cells and printed batteries. This opens up possibilities for disposable, self-powered consumer electronic devices (such as ‘smart’ cards and ‘smart’ tickets) and robust equipment that can operate off-grid, such as solar powered mobile phones and computers.

Solar cells (photovoltaic (PV) cells) based on silicon technology can operate with efficiencies of greater than 12%. To compete commercially, PV cells on plastic substrates should be comparable in efficiency and be robust, lightweight and simple to manufacture. Two primary technologies are used: dye-sensitised cells and organic semiconductor cells (OPV).

Dye-sensitised PV cells have a slightly lower efficiency (currently at a maximum of around 11%) than silicon cells, and OPV cells current efficiency is currently around 5%.

The potential commercial benefit of reduced materials and manufacturing costs, coupled with the unique ability to print PVs and batteries onto a common substrate with other printed circuitry, is unmatched in conventional electronic design.

Radio Frequency Identification
Radio Frequency Identification technology (RFID) involves products with an antenna, power source and application circuitry to be accessed remotely using an external transmitter and receiver. Unlike bar coding, no direct line of sight is required, multiple readings can be taken at the same time and the amount of information stored
can be significantly larger. Market researchers predict that the RFID market will be worth £100 million by 2010.

At present, RFID tags are generally placed on high value products due to the cost of the tags. The development of high-volume, low-cost production techniques such as printing the antenna using conductive inks is becoming common practice and ‘proof of principle’ demonstrators of printed circuits that can perform basic functions as an RFID tag are available.

**Sensors**

Low-cost disposable sensors for physical characteristics such as strain, load and acceleration are possible using Plastic Electronics. In medicine, patient health management in the home can be improved by the automatic objective measurement of blood glucose in diabetic patients, for example, or products for monitoring hormone levels. The PE sensors should be inexpensive and robust, improving care and reducing the need for hospital and surgery visits.

**Smart packaging**

Smart packaging covers a variety of sensors and actuators that give ‘intelligence’ to the packaging of food and beverages, pharmaceuticals and tobacco products. Sensors are being developed to monitor gas composition within packaging, allowing an accurate measurement of product condition that can offer real time sell-by date information, rather than a calculated date used at the point of packaging.

In pharmaceuticals, the authentication of the drug source and patient dosage can be crucial to maintaining patient health and wellbeing. Drugs placed in ‘intelligent blister packs’ could monitor dosage and alert the patient if they have missed a dose. Organic integrated circuit tagging of the packaging would allow medicines to be traced and validated through the supply chain to prevent substitution of illegal substandard drugs.
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Abertay has extensive experience in the metrology and usability issues of all kinds of displays, optical systems and materials. There is an extensive suite of state-of-the-art equipment including Westar FPM510 goniometer and Eldim EZ160R conoscopic systems. In addition there are general-purpose optics laboratories with a wide range of instrumentation and a set of usability laboratories incorporating the latest psychophysical equipment and techniques.

Abertay is active in a wide range of application areas including the sunlight readability of displays and the usability of head-mounted displays. It is currently specialising in the development of usability metrics for the displays industry.

The University has been involved in collaborative projects with a wide range of partners including NCR, Raymarine, GDS, MCE, BAE Systems and NPL.

Metrology and usability services are offered on a commercial basis and collaborative projects sought with other universities and commercial partners.

The Institute for Bioelectronic and Molecular Microsystems (IBMM) offers a range of design, microfabrication, prototyping, research, characterisation and Micro- and nano-technology (MNT) training services to the worldwide polymer electronics, MNT, micro electromechanical systems (MEMS) and bio-tech communities. An accredited Centre of Excellence for Technology and Industrial Collaboration, combining academic and technical expertise, IBMM is specifically geared to meet individual customer needs.

Using a wide variety of techniques and materials, developed in support of research into polymer electronics, micro-electrokinetic devices, biomolecular sensors and lab-on-a-chip devices at the university, IBMM provides solutions from design to prototype production. Photomasks, thin film coatings and biochip devices comprising integrated micro-fluidic and plastic electronic systems can all
be produced, together with off-the-shelf or bespoke training packages and industrial problem-solving, complemented and supported by in-depth research, characterisation and analytical capability.

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Displays research at Birmingham is currently focused in three areas:

- The deposition and characterisation of transparent conductive coating materials for electrodes
- The synthesis and modification of alternative candidate coating compounds
- The characterisation of substrate materials for flexible displays.

Of particular interest is the pulsed laser deposition of indium tin oxide (ITO) on to glass and flexible polymer substrates: the structural, physical and mechanical properties of the films are being investigated. The university also works 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; adhesion, pull-off force, nano-scratch and nano-indentation measurements; and friction measurements, wear testing 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.

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www.brunel.ac.uk/about/acad/wolfson

The Wolfson Centre for Materials Processing – incorporating the Centre for Phosphors and Display Materials – has been continuously involved in systematic research and the development of plastics processing and inorganic materials technology, often in collaboration with industry, for many years. Its expertise is in synthesis, characterisation and optimisation, and the processing of plastics, composites
and inorganic materials such as phosphors and dielectrics. There are excellent analytical facilities to aid the optimisation and development of novel synthetic and processing routes.

The applications in printed display technologies include AC electroluminescent displays (phosphors, dielectrics and architecture), DC electroluminescent displays and field emission display displays, as well as phosphors for LEDs and fluorescent lighting. The centre has worked in most areas of phosphor R&D and also developed extrusion technologies now widely used in industry. Novel synthetic procedures are developed to synthesise materials that are compatible with today’s requirements, such as toxicity and particle size. The centre’s sub-micrometre and nanometre-sized particles are specifically designed for incorporation into ink formulations, where there is a great deal of commercial interest for novel electronic devices.
and infrastructure to enable those with exploitable concepts to achieve commercial success. Combining world-class research with a strong partnership with business, CIKC will engage with industrial partners to secure intellectual property and create credible business propositions.

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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.

The group is investigating several novel low-temperature deposition 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 ink-jet 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 and silicon nanowires.

**University of Cambridge**  
**Inkjet Research Centre**  
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www.ifm.eng.cam.ac.uk/pp/inkjet/default.html

The Inkjet Research Centre is based at the Institute for Manufacturing (IfM), part of the Engineering Department at Cambridge. Involved in research and teaching, it 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 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.

**Coventry University**
The Sonochemistry Centre at Coventry University, Faculty of Health and Life Sciences, Priory Street, Coventry CV1 5FB

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Designated as a Centre of Excellence, the Sonochemistry Centre at Coventry University has provided expertise and research on the applications of power ultrasound to academic institutions, companies and government organisations for over 30 years.

![High Tg laminate as received](image1)

![Sonochemical surface modification in water](image2)

Much of this research has received UK and EU funding together with industrial sponsorships, and has led to safer and more cost-effective chemical processes in industry. Ultrasound is a ‘clean and green’, energy efficient technology and current projects include:
• Sonochemical surface modification/adhesion promotion/cleaning of polymers/plastics/ceramics prior to depositing conductive material e.g. ink (for printed/plastic electronics) or metal (copper, silver etc). Using optimised ultrasonic techniques, it has been demonstrated that some of these materials can be surface modified in water (see below).

• Production of conductive nanoparticles using novel sono-electrochemical techniques. Enhanced electroplating and electroless plating rates/efficiency/throwing power from both aqueous and ionic liquid electrolytes gives improved dispersion and mixing of particles into viscous liquids. Applications might include the production of conductive inks/pastes/polymers.

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Within the Physics, Chemistry and Engineering Departments, collaborative research programmes are underway focusing on organic polymer-based display and solid state lighting applications. 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. There are facilities for fabrication of both OLED and PLED in dedicated clean rooms, and Durham has also developed dedicated optical based measurements on working devices. The group interacts with industry on a range of projects funded by the Technology Programme, EPSRC and the Regional Development Agency and works closely with the Plastic Electronics Technology Centre facility based close-by.
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UEA is at the forefront of the design and synthesis of advanced organic and organometallic functional materials and – in particular – the development of novel phthalocyanine, porphyrin and triphenylene derivatives.

As well as exploiting expertise in synthetic chemistry, research programmes also focus on the investigation of thin-film formulations of organic materials – especially hybrid organic/inorganic structures for semiconductor, photoconductor and sensing device applications, the development of novel liquid crystals, the use of polymer imprinting for the development of heterogeneous catalysed reactions, and the development of applications of photophysical properties of purpose-designed derivatives of phthalocyanines, porphyrins and multichromophore arrays. Research into liquid crystals has particular focus on the development of chiral dopant materials, the generation of stable room temperature helical mesophases, and the exploitation of self-annealing properties of columnar phases for organic electronics. In the area of photophysics, programmes investigate the development of applications of infrared-absorbing materials, new materials for non-linear absorption, and photosensitisers for the generation of singlet oxygen for medical and environmental applications.

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The university is researching Plastic Electronics technologies that could be used in appropriate combinations to manufacture lighting and display devices in the future. Research groups are developing:

• Lithographic nanostructuring (nano imprinting/embossing) of active polymers for enhancing their optical properties
• The inclusion of quantum dot nanoparticles in active polymeric media in order to modify their electrical conduction or light-emitting properties
• The development of polymer
magneto-optoelectronic films for novel applications in displays and optical data storage applications
- Large-area patterning covering functional glazing, electronic louvring, decorative features, display technologies, and micro- and nano-scale patterns on hard and flexible substrates
- The functional miniaturisation of optical and electronic devices, optical components and devices including fresnel lenses, spatial light modulation, holograms and membrane sensing
- Biodegradable electronics
- Sensors – chemical and physical.

The university’s resources include both expert researchers and world-class fabrication facilities. Researchers are keen to work collaboratively to find solutions to industrial problems.

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www.organophotonics.co.uk

The University of Hull is well-known for its work on liquid crystal materials, following its invention of the first commercial liquid crystal which heralded the advent of the multi-million dollar liquid crystal display technology. It was awarded 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.

Red and green electroluminescence from nematic liquid crystal semiconductors

The interdisciplinary Organophotonics Group has expertise in both physics and chemistry and continues earlier work, particularly in emerging application areas such as organic light-emitting displays, solar cells and Plastic Electronics. Recently it has demonstrated the first pixellated full-colour display, which is both liquid crystalline and light-emitting. The resulting patents have been licensed by the University. It has also invented a completely new solar cell configuration using liquid crystal gels.
The group is studying semiconducting nematic liquid crystals as organic semiconductors. Hybrid inorganic/organic devices containing nanocrystals of II-VI semiconductors dispersed in polymers are being investigated as an alternative source of narrow-band efficient electroluminescence. There are excellent facilities for the synthesis and characterisation of liquid crystals and organic semiconductors as well as device fabrication laboratories.

**Imperial College London**

Molecular Electronic Materials and Devices Research Collaboration, Departments of Physics and Chemistry, South Kensington Site, London SW7 2BZ

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The Molecular Electronic Materials and Devices Programme at Imperial College is a cross-disciplinary, cross-departmental activity involving the Departments of Physics and Chemistry. Twelve staff are involved together with their extensive research teams. With a clear focus on the fundamental science underpinning the application of the optical and electronic properties of molecular materials, the programme spans a wide range of experimental and theoretical expertise, ranging from molecular modelling, organic synthesis and detailed materials characterisation, through structure fabrication, to device physics and application.

**ITO-free polymer LED pixels fabricated on a flexible plastic substrate with highly conductive vapour phase polymerised poly(ethylenedioxythiophene) (VPP-PEDOT) anodes**

Photos by Meilin Sancho (Imperial College London)
The programme has proficiency in the molecular design of conjugated aromatic polymers optimised to self-assemble in well-organised morphologies. The impact of microstructure on the fundamental photophysics of thin films is evaluated, along with electrical characterisation and device fabrication. Strong expertise and extensive facilities reside within the programme in the complementary areas of organic light emitting diodes, organic field effect transistors, organic photovoltaics and organic photonic structures. Hybrid inorganic/organic devices are also of strong interest.

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www.engineering.leeds.ac.uk/ietsi/

The thin films coating activity, part of the ETSI Institute, is researching the related areas of coating and printing liquids onto substrates. The group focuses on developing fundamental understanding in these areas with a view to improved productivity, and uses both computational tools and experimental methods to study the processes. The group also has a successful track-record in knowledge-transfer activities, either through producing predictive software for industry or through delivering short courses. Typical research projects include:

• Filling of cavities and tracks with conducting inks  
• Spreading and drying of liquid drops on surfaces  
• Coating and planarisation of uneven topographies  
• Computer simulations of printing and coating processes.

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www.omic.org.uk

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 co-ordinates 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 high volume synthesis of quantum dots and nano-dimensional materials
- Inkjet printing with a large research programme of functional materials including conductive metals and electroactive materials
- Capabilities in fabrication and testing of OFET devices
- The application of high-throughput methodologies to materials synthesis.

Nottingham Trent University
Displays Research Group, School of Science and Technology, Clifton Campus, Clifton Lane, Nottingham NG11 8NS

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The Displays Research Group is a founding partner of DisplayMasters and is actively involved in the technology of electronic materials for displays, thin film device fabrication, visual display characterisation, and the laser processing of materials. Research has been focused on device engineering for high luminance miniature displays utilising thin film electroluminescence. The resultant laterally-emitting thin film electroluminescent display technology can provide fixed legend displays with luminences greater than 3000cd/m² suitable for symbology injection, direct view, or near-to-eye applications.

Recent collaborative research is concerned with the emerging 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 the use of phosphors for bio-sensors, and the investigation of visualisation techniques using virtual environments.

Thin Film Services (TFS) is a branch of the Displays Research Group. TFS 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.
**Polymer IRC**

Universities of Bradford, Durham, Leeds and Sheffield

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h.e.clancy@leeds.ac.uk  
www.polymerirc.org

The Polymer IRC is a focal point for multidisciplinary polymer science and soft nanotechnology. It links over 400 scientists and technologists across the four universities, and incorporates a vibrant industrial club. Major research efforts are directed towards the development of organic materials for applications in electronic devices for consumer goods.

**University of Durham**

A minimal model for reaction-induced phased separation (RIPS), a self-assembly process for applications including photovoltaics.

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**University of Leeds**

Novel extrusion/lamination process for rechargeable lithium batteries by continuous extrusion of polymer gel electrolyte.

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a.m.voice@leeds.ac.uk  
www.leedslithiumpower.com

**University of Sheffield Polymer Centre**

A new class of wide band gap carbazole based conjugated polymers with high fluorescence quantum yields for low-cost, flexible, bright coloured flat screen displays with low power consumption.

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Novel, high dielectric constant gate insulators for organic transistors. Control and modulation of light emission with unconventional resonators and photonic crystals for organic photonics.

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See also individual university entries.
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Professor Ray’s group is involved in a collaborative research programme to fabricate thin film organic devices with a view to system integration on large-area, flexible plastic chips for displays. The aim is to develop a low-cost enabling technology for fabricating custom designed phthalocyanine (Pc) based devices (TFTs, switches, photodiodes, memory etc) through solution and self-assembly processes. These multifunctional Pc molecules will be UV resistant and thermally stable up to 400°C, and the proposed research will represent a quantum leap in emerging organic electronics.

The group is also investigating the fundamental properties of phthalocyanines with long alkyl substituents with a view to fabricating optical biosensor arrays. The work involves the preparation of nanotubes, the nanoscale investigation of structural, compositional and morphological properties, and the investigation of biosensing properties of the self-assembled tubes.

Dr Heeney’s research group is concerned with the design, synthesis and properties of a range of conjugated organic materials and polymers for use as both active and passive components in a variety of organic electronic applications. It has particular interest in the development of p- and n-type organic semiconductors for use in organic field effect transistors, in the preparation of low band gap donor materials for organic solar cells, and in the design of novel cross-linkable dielectric materials for transistor applications.

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The Organic Semiconductor Centre pursues a wide range of research relating to Plastic Electronics, including displays, solar cells, transistors and lasers. Both materials and devices are developed and studied, and quantitative measurements of charge transport are
made by time-of-flight mobility measurements. Other facilities include time-resolved spectroscopy for studying aggregation in organic semiconductors and exciton diffusion. This is complemented by scanning near-field optical microscopy to investigate the homogeneity of films. Soft lithographic techniques have been developed giving simple patterning of organic semiconductors with 400 nm feature sizes.

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The Electronic and Photonic 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 organic light emitting diodes, organic photovoltaic devices and organic field-effect transistors. The group also has a detailed interest in organic photonic structures and devices including organic semiconductor microcavities and photonic crystals. It is well-equipped for experimental research and has a range of modern laboratories, including a dedicated scanning near-field optical microscope used to characterise the nanoscale optical properties of device-applicable thin films. There is a range of facilities for device fabrication and evaluation in a large clean-room facility in the Sheffield University North-Campus Nanotechnology Facility.

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

A wearable light source developed at the Organic Semiconductor Centre for the treatment of skin cancer

The Electronic and Photonic 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 organic light emitting diodes, organic photovoltaic devices and organic field-effect transistors. The group also has a detailed interest in organic photonic structures and devices including organic semiconductor microcavities and photonic crystals. It is well-equipped for experimental research and has a range of modern laboratories, including a dedicated scanning near-field optical microscope used to characterise the nanoscale optical properties of device-applicable thin films. There is a range of facilities for device fabrication and evaluation in a large clean-room facility in the Sheffield University North-Campus Nanotechnology Facility.

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

A wearable light source developed at the Organic Semiconductor Centre for the treatment of skin cancer
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 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 electrochromic devices and plastic batteries.

The Advanced Technology Institute is an interdisciplinary research centre dedicated to advancing next-generation electronic and photonic device technologies. ATI brings together electronic engineers, physicists, chemists and biologists within one integrated working environment, supported by state-of-the art laboratory and clean room facilities.

The Institute houses expertise on:
- OLEDs
- Transparent electronics
- Organic photovoltaics including polymeric, small molecule, carbon nanotubes and hybrid approaches such as ‘Inorganics in Organics’
- High performance organic FETs
- Hybrid organic/inorganic systems for large area electronics
- Organic devices encapsulation technologies
- In-house carbon nanotube growth and functionalisation.
Advances in organic electronic devices are accelerated by extensive nano-fabrication facilities, surface analysis and characterisation capabilities underpinned by dedicated theoretical support.

**Swansea University**  
Welsh Centre for Printing and Coating, School of Engineering, Singleton Park, Swansea SA2 8PP

Contact: Tim Claypole  
T: +44 (0) 1792 295214  
t.c.claypole@swansea.ac.uk  
www.swansea.ac.uk/printing

The Welsh Centre for Printing and Coating specialises in the application of materials by all forms of printing processes. It has particular expertise in screen, flexographic, offset, gravure and pad printing, and has expertise in the modelling of the print process using techniques including finite element, finite difference and statistical and neural networks.

Towards renewable energy: transmission electron microscope image of the interior of a plastic solar cell containing carbon nanotubes in a conducting polymer matrix

**Roll-to-roll facility**

It has comprehensive analytical facilities in its own laboratories and has access to facilities within the university (such as scanning electron and atomic force microscopy and infra-red spectroscopy). The laboratories are fully equipped for sample material manufacture (up to 5 Kg),
analysis and the characterisation of material properties relevant to the print process. An Integrated Manufacture by Printing laboratory, constructed with Wales Assembly Government KEF support, includes facilities for screen, flexo, offset, inkjet, pad and gravure printing at production scale for product development. These are available for contract research and development projects. Additionally, the centre undertakes research and development on industry print production facilities.

**University College London**  
Department of Electronic and Electrical Engineering, Torrington Place, London WC1E 7JE

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d.selviah@ee.ucl.ac.uk  
www.ee.ucl.ac.uk/~odevices/

The Optical Devices and Systems Research Group in the Department of Electronic and Electrical Engineering designs, models and characterises polymer multimode waveguides. High bit rate, 10 Gb/s, signals suffer from high loss, crosstalk and distortion when passing along copper tracks in conventional PCBs, so research adds a layer of polymer optical waveguides to multiple copper layer PCBs to permit high-speed data transport. The key to the introduction of this technology is the development of a commercial optical connector. In the StorLite project with Xyratex (‘03-‘06), the group developed, patented and licensed a low-cost, self-alignment technique and demonstrated 10 Gb/s error free transmission through two connectors and a 10 cm waveguide. In the following £1.3 million IeMRC Flagship OPCB project, UCL assembled a supply chain of three universities and nine companies (PCB layout and modelling software suppliers, polymer suppliers, waveguide fabricators, PCB manufacturers and several end users) to compare a range of polymer waveguide fabrication techniques and to introduce the technology into a commercial production line.

**University of the West of Scotland, Paisley**  
Thin Film Centre, School of Engineering and Science, High Street, Paisley PA1 2BE

Contact: Professor Frank Placido  
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F: +44 (0)141 848 3627  
frank.placido@paisley.ac.uk  
www.thinfilmcentre.co.uk

The Thin Film Centre supports research and development work in the wide field of vacuum-deposited thin film coatings. 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 plus 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 displays area, there is particular expertise in optical filter design and manufacture, ultra-barrier coatings and transparent-conducting films. Paisley is also interested in glancing-angle deposition of alignment layers for LCDs.

**University of York**
The Liquid Crystal Group, Chemistry Department, Hesslington, York YO10 5DD

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jwg500@york.ac.uk  
www.york.ac.uk/depts/chem/staff/jwg.html

The Group has approximately 15 to 20 research scientists specialising in the synthesis of advanced organic materials and the evaluation of their physical properties. The materials investigated include thermotropic and lyotropic liquid crystals, low molar mass, dendritic and polymeric liquid crystals, liquid crystals for display devices and for bio-medical applications. In addition to liquid crystals, the group also researches polymers for coatings, adhesives, emissive thin films, reactive mesogens and alignment agents.

The group analyses the physical properties of the materials by thermal polarised transmissive and reflective mode microscopy, differential scanning calorimetry, X-ray diffraction, differential mechanical analysis, fourier transform intra-red spectroscopy, nuclear magnetic resonance, refractometry (to 1.5 µm), lap and impact tests, and electrical field studies (dielectric, elastic, ferroelectric and ionic properties).

The group currently has over £1.5 million of research support involving numerous collaborations with UK and overseas industry, and produces approximately 15-20 papers a year. It holds over 100 patents with industrial partners. In addition the group also provides consultancy advice on materials issues.
## Company profiles

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<th>Metrology and Modelling</th>
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3T Technologies Ltd
7 Chapel Drive, Little Waltham, Chelmsford, Essex CM3 3LW

Contact: Dr Stuart Speakman
Chief Technology Officer
T: +44 (0)1245 362253
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info@3ttechnologies.com
www.3ttechnologies.com

3T Technologies Limited (3T) is a research and development company developing manufacturing solutions for next-generation flat panel display and flexible electronic applications, including emerging transparent thin film transistor (TTFT) device technology. 3T’s all-dry laser-based processing technology provides innovative solutions for the high-precision micro-patterning of high-value organic and inorganic thin film coatings such as transparent oxide (e.g. ITO and zinc oxide) and display (e.g. OLED and EL) materials, using a range of coating deposition methods.

Leveraging the benefits of existing industrially-proven techniques, 3T’s thin film processing toolkit, which includes a range of novel device and circuit designs, is engineered to enable lower-cost electronics manufacture on large-area glass substrates while simultaneously providing a migration path to high-volume product manufacture on roll-to-roll plastic media. 3T is working to establish collaborations with industrial partners with expertise across the flat panel display and flexible electronics supply chains in order to accelerate time-to-market delivery of commercial-scale leading-edge thin film manufacturing solutions.

Applied Laser Engineering Ltd
Molesey Business Centre, Central Avenue, West Molesey, Surrey KT8 2QZ

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Engineering Director
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www.appliedlaser.co.uk

Applied Laser Engineering designs and manufactures a range of laser engraving systems. These use a variety of different lasers to engrave the surface of cylindrical forms for the production of a wide range of printing or texturing applications, including flexography, gravure, screen printing, intaglio security and currency printing, fat panel display coating processes, anilox ink transfer rolls, paper and plastic embossing etc. Although all current machines engrave onto a cylindrical surface, some of the products are used in the flat. A variety of materials can be engraved including various plastics, elastomeric, ceramics and metals. The speciality of the systems is the very high registration accuracy over small and very large formats. There are
machines in the field up to a 7m face-width by 3.5m circumference. Engraving pixel sizes typically range from 3µm upwards with a system resolution of 1µm on all axes.

**Applied Multilayers Ltd**
Garden Court, Gee Road, Coalville
LE67 4NB

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Director
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M: +44 (0)7711 985621
www.applied-multilayers.com

Indium tin oxide (ITO) is a crucial material in the manufacture of displays, being both transparent and electrically conductive. Applied Multilayers has recently developed a high rate ITO process that produces high transparency, high conductivity ITO with a coating smoothness on the sub-nanometre scale. The company uses its patented reactive ‘closed field’ magnetron (CFM) sputtering process that combines high density reactive plasma with low energy deposition – ideal conditions for defect free, thin film growth. Another advantage of the process is that the coatings are deposited at room temperature. These conditions are ideal for glass and even delicate polymer substrates.

The CFM process can also be used to produce metal-oxide layers and precision multi-layer optical coatings such as matched anti-reflection coatings to further enhance display transmission.

Applied Multilayers offers a range of optical coating equipment from small batch research systems to large-scale production machines. The equipment is usually supplied with a turnkey process capability. The company also offers a powerful process development capability as well as specialised coating services.

**Armstrong Optical Ltd**
31 Caxton House, Northampton Science Park, Kings Park Rd, Northampton
NN3 6LG

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Director
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www.armstrongoptical.co.uk

Armstrong Optical is a supplier of optical metrology systems and sensors, optical components and assemblies, and thermal imaging cameras and sensors. It aims to supply cost-effective, off-the-shelf or custom solutions to measurement requirements that surpass end-user specification.

The metrology systems include visible and infrared interferometers for form and optical performance assessment; non-contact 3D surface profiling.
systems to measure dimensions, roughness and shape; distance and vibration measuring systems with nanometre resolution; instruments to objectively measure minimum detectable and minimum resolvable contrast and temperature difference; high performance microlens arrays, micro-optics and classical optics; instruments to measure film and coating thickness down to tens of nanometres; and high performance translation, rotation, swivel and lift stages including vacuum and non-magnetic compatibility.

**Cambridge Display Technology Ltd**

Building 2020, Cambourne Business Park, Cambridge CB23 6DW

Contact: Alexandra Gay
Marketing Services Co-ordinator
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F: +44 (0)1954 713620
enquiries@cdtltd.co.uk
www.cdtltd.co.uk

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 and cathode ray tubes in many existing applications. They also offer 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 including inkjet printing) which are used in the manufacture of P-OLED displays.

CDT is based in Cambridge, UK, with a Technology Development Centre in Godmanchester, near Huntingdon, and offices in Japan and the USA.

**Centre for Process Innovation**

Wilton Centre, Wilton, Redcar, Cleveland TS10 4RF

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www.uk-cpi.com

The Centre for Process Innovation (CPI) is a UK national resource to stimulate
and promote innovation within the chemical and process industry sectors. It aims to decrease the risk inherent in industrial research through the provision of expertise and access to funding bodies, and thus to speed up the route from innovation to marketable products.

The flexible electronics substrate facility contains a pilot scale roll-to-roll sputter coater with associated test and treatment equipment, situated within a Class 1000 clean-room facility. It can handle up to 4km rolls of thin film polymers (12-250 µm) with a web width of up to 390mm, and can continuously apply ultra-thin layers of metals, oxides and barrier coatings from its current library of over twenty targets, including precious metals. CPI currently works in close liaison with DuPont Teijin Films and the facility is an open-access centre of excellence for the UK electronics, displays and coated film industries.

See also the Plastic Electronics Technology Centre (PETeC) entry on page 75

Conductive Inkjet Technology
Brookmount Court, Kirkwood Road, Cambridge CB4 2QH

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mjohnson@conductiveinkjet.com
www.conductiveinkjet.com

Conductive Inkjet Technology (CIT) offers UV curable inks and technology for the direct writing of conductive metals onto non-porous substrates. It provides the lowest cost enabling technology solution for many printed electronics products, including RFID tags, smart packaging and a variety of display applications.

CIT supplies patented UV curable catalyst inks directly to its customers under a licence agreement, and can also supply a range of inkjet equipment which spans laboratory test equipment right up to a high-speed reel-to-reel full production presses.

The achievable inkjet line widths and spacings are a function of the droplet size and the wetting properties of the ink on the substrate. Today, 50µm is the state-of-the-art for inkjet printed features. However, using UV lasers, CIT has demonstrated the ability to create sub-5 µm conductive features. These metal features are practically invisible on a transparent plastic or glass substrate.
CIT also work on feasibility programmes to integrate this technology into customers’ processes. By using a range of equipment manufacturers, optimum solutions are provided to customers.

CPFilms
13 Acorn Business Centre, North Harbour Road, Cosham, Portsmouth PO6 3TH

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Marketing Manager
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david.newbitt@cpfilms.co.uk
www.cpfilmsusprod.com

CPFilms is a leading worldwide manufacturer of precision-coated films and film products with ISO 9001:2000 facilities. It is located in Runcorn, UK and Virginia, California, serving a wide range of industries including the displays sector.

CP Films provides full-service performance film enhancement – including vacuum metallising and sputter coating, deep dyeing, coating and laminating, and optically clear release films. It is at the forefront of transparent conductive coating technology, supplying the highest quality ITO, anti-reflective and shielding films. These technologies are available singly or in combination to meet precise customer needs.

DEK Printing Machines Ltd
11 Albany Road, Granby Industrial Estate, Weymouth, Dorset DT4 9TH

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Global Marcom Director
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F: +44 (0)1305 760123
kmoore-watts@dek.com
www.dek.com

DEK is a leader in precision material deposition for advanced electronics
assembly, having pioneered many of the equipment and processes currently driving the high-accuracy mass imaging of electronic materials. Founded in 1969, DEK is based in Weymouth with additional manufacturing operations located throughout Europe, Asia and the Americas.

By combining the strengths of an extensive product portfolio encompassing machines, stencils, screens, consumables, and process support products, DEK delivers comprehensive support for a range of deposition processes. Meeting all the technical, commercial and environmental targets that define success in the modern electronic manufacturing arena, DEK’s screen printing technologies are ideal for printing low-viscosity materials on thin, flexible substrates.

**De La Rue International plc**
Overton Technical Centre, Overton, Hampshire RG25 3JG

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Technology Manager
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F: +44 (0) 1794 389501
Philip.G.Cooper@uk.delarue.com
www.delarue.com

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 6,000 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 pioneering new technologies, from tailored solutions to protect the world’s brands through to government identity solutions in secure passports, identity cards and drivers’ licences.

**Design LED Products Ltd**
Alba Innovation Centre, Alba Campus, Livingston, EH54 7GA

Contact: Dr James Gourlay
Technical Director
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F: +44 (0)141 585 6301
james.gourlay@designledproducts.com
www.designledproducts.com

Design LED Products Ltd designs and manufactures products based on its LED/Light-guide technology. The technology is a patented, printed
light-guide process, used in conjunction with conventional light emitting diodes, and enabling thin (less than 1mm thick) mechanically-flexible backlights and low resolution segmented displays. The low cost, high reliability and range of functionality exceeds other display technologies, including electroluminescent films or discrete LEDs used with injection-moulded light-guides.

The company is active in a range of market sectors including consumer electronics and appliances, automotive, point of sale, industrial interface and medical, where its products provide either brand/product enhancement or enhanced human machine interfacing. It has developed thin flexible segmented or non-segmented backlights in sizes from below 1cm to over 1m, with a wide range of colours and brightnesses, some supplied as curved products. Several switching technologies have been embedded within this light-guide technology, such as capacitive switches, to enable colour changing illuminated indication to switch status, in addition to icon indication and branding.

DuPont Teijin Films (UK) Ltd
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TS90 8JF

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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, with 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 it a promising substrate for subsequent vacuum or other coating processes with potential for use as a flexible substrate for electronic and other device manufacture.

**Elumin8**  
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Elumin8 manufactures complete electroluminescent systems based on electroluminescent (EL) lamps – paper-thin, flexible, cool burning and energy efficient light sources. The technology uses silk-screen printing techniques to print a phosphor-based ink on to a conductive substrate. A small electrical charge is passed through the phosphor layer, illuminating it as a result. By controlling the sequencing and amount of luminosity, Elumin8 can create moving dynamic images and forms, transforming previously static designs and advertising campaigns into flashing, eye-catching animations.

The EL system comprises the thick film EL lamp with digital driving electronics. The company designs and produces power and control systems capable of driving complex EL systems up to 100 m². The client base is very broad and includes architects, interior designers and engineers. Outdoor posters are produced for international clients measuring 40m².

Elumin8 places great value on excellence in design and manufacturing. All the manufacturing of inks, EL lamps and electronics is based at Poole, Dorset.

**Epigem Ltd**  
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Epigem is a polymer microfabrication specialist offering micro and nanotechnology platforms (for manufacture and product development services) to the optoelectronics, chemical processing and life science industries. It provides systems for embossing, imprinting, the photochemical processing of microstructures plus pilot coating, printing, plating on flexible or rigid substrates and within microstructures – batchwise or reel to reel under clean
room conditions to facilitate the production, for example, of customised microlens arrays, diffractive optical elements, waveguide circuitry, fine line printed circuitry and microfluidic components suitable for a range of display, lighting, polymer electronics and biophotonic applications.

The Fluence Microfluidics Centre is operated by Epigem within the UK’s Micro and Nanotechnology (MNT) Network and includes access to printing and coating equipment for polymer electronics product development. The centre specialises in multifunction integration and 3D interconnection of multiple microstructured layers containing a range of embedded materials and components. Epigem is part of the EU supported Integramplus consortium (www.integramplus.com) specialising in integrating/packaging silicon electronics and micro electromechanical systems with polymer backplanes and platforms. The MNT Network and Integramplus services also provide strong links to design, modelling, simulation, measurement and training expertise.

ElectroScience Laboratories (ESL) has manufactured thick film pastes for over 45 years. Its earliest screen-printable pastes were for deposition onto alumina substrates, and were oxide-based and fired at temperatures up to 1000°C. It was soon realised that low-temperature-cured products were required for a variety of substrates, and polymer conductors, resistors and dielectrics have been made from the 1970s.

One of the latest products, ESL 1901-S, is a silver-filled, flexible resin material designed for use as a conductor on low-temperature substrates. This silver conductor may be used in the manufacture of four and five wire analogue resistive touch panels, for printed antennas in RFID applications and as conductors in flexible solar cells. After screen-printing and curing, the silver film remains reasonably flexible and the resistance of the conductor remains constant over time. This versatile polymer has also been successfully used on other substrates such as fabric.

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Exopack Advanced Coatings are leaders in the development and manufacture of precision coated films, papers and speciality substrates for imaging, electronics, medical and optical film technologies. Serving a wide variety of market sectors, the range of gloss and anti-glare hardcoats and optically clear adhesives are ideal for applications where durability, superior clarity and zero defects are critical. The combination of process and formulating expertise with impressive ISO certified, cleanroom facilities provides customers and partners alike with reliable and competitive coating, laminating and converting services. In flat panel displays, the roll-to-roll coating capabilities and expertise in handling thin, flexible substrates support existing and emerging, rigid and flexible display technologies.

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G24i utilises materials science and nanotechnology to create a new class of advanced solar cells which it claims are the closest mankind has come to replicating nature’s photosynthesis.

The 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 a half-mile of dye sensitised thin film in less than three hours. The film produced is a thin (< 1mm), extremely flexible and versatile nano-enabled photovoltaic material that converts light energy into electrical energy, even under low-light, indoor conditions. These advanced cells are silicon- and cadmium-free and can be incorporated in a wide array of energy-saving products.

The 18,000 square metre fabrication plant will be the first facility ever to produce solar cells relying exclusively
on renewable energy including solar, wind, geothermal and other green sources.

**GE Aviation Systems – Newmarket**

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GE Aviation Systems – Newmarket is a leading supplier of high-reliability custom electronics covering application-specific integrated circuits, hybrid circuits and multi-chip modules. As a result of a product diversification programme, a dedicated area for the manufacture, repair and test of ruggedised displays has been set up. The class 10,000 clean room capability includes lamination of displays to withstand harsh environmental specifications and tape automated bonding of anisotropic conductive adhesive films for interconnections to displays and driver boards. A facility for the assembly of optical filters and backlights has also been established. Investment has also been made in automated optical test equipment to characterise the display, and environmental test equipment to assess vibration and temperature cycling/thermal shock performance.

**Gwent Electronic Materials Ltd**

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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. It produces conductive materials that may contain precious or non-precious metal, dielectrics and 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.

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Interest in displays covers novel display technologies that would enable new application areas, or radically transform existing ones, and prototyping of new information devices and services that utilise displays.

HP Laboratories currently sponsors PhD students at Bristol, Exeter and Imperial College in areas related to display technologies, and is active in a Technology Strategy Board funded collaborative programme to demonstrate potentially scalable manufacturing processes for bistable, colour, plastic displays.

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IMPT has developed a new cost-effective technique for depositing layers in the manufacture of flat panel displays without the need for a vacuum, e-beam or plasma. IMPT’s Layatec™ and Layajet™ processes are capable of depositing ITO and conducting oxide layers for the production of flat panel displays ranging in size from small hand-held devices to large – greater than 50inch – displays.
With no need for vacuum processing, Layatec™ and Layajet™ allow for continuous reel-to-reel or large area deposition, which significantly improves productivity without huge capital costs. The processes can be simply scaled up to any size and can be used to deposit thick or thin films from ultra-fine dense films to thick porous coatings. The running costs of Layatec™ and Layajet™ are also significantly less than existing technology.

Inca Digital Printers Ltd
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Inca Digital Printers Ltd works in partnership with print-head manufacturers, ink suppliers and equipment makers to design and make a variety of flat bed and sheet fed inkjet printers. About 30% of Inca’s staff works in research and development, and the facilities can be used to develop printing solutions for novel materials to be deposited on a variety of different substrates.

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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, and linking this to some unique manufacturing capabilities.

Products include:
• Natureflex™ – a 100% biodegradable family of films manufactured from sustainable raw materials (wood pulp). Its manufacturing has recently become carbon zero. Key product characteristics are excellent printability with a wide range of processes, and superior antistatic 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
• Guardian™ – a highly opacified BOPP incorporating a variety of security features used in the manufacture of polymeric bank notes.

Intertek MSG
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Intertek MSG provides measurement-based solutions to materials- and processing-related problems in a wide range of industries, including the flat panel display industry.

Of particular relevance to the development and manufacture of such components and devices are:

• The characterisation of all aspects of the materials and processes used in the deposition of coatings onto films and substrates, including plastics and glass
• Contamination analysis and the use of analytical techniques in root-cause analysis of production and quality problems
• The analysis and understanding of adhesion and adhesive failure in coatings and laminates, combining sophisticated surface analysis techniques with a comprehensive capability in mechanical property testing and morphological studies.

The group’s analytical capability also includes a comprehensive chemical
analysis and chemical deformation team, an ability to quantify trace levels of inorganic and organic components in complex mixtures, techniques such as microscopy and X-ray diffraction to study material structure and strengths in the measurement of physical properties of materials – including optical and mechanical properties.

**iTi – imaging Technology international**
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iTi is a Lab2FabSM precision systems manufacturer, approved by Dimatix, HP, Trident and Xaar, and acknowledged for its technical expertise in industrial inkjet technology. iTi’s high-precision development tools and production deposition systems enable the incorporation of additive digital inkjet fabrication into manufacturing processes. The company’s in-depth understanding of the capabilities of inkjet technologies, combined with expertise in design engineering and inkjet integration, assist partners in a wide variety of deposition applications ranging from the direct writing of UV curable resist on PCBs to the application of multiple materials for the fabrication of complex functional devices. iTi has extensive experience of jetting conductives, dielectrics, UV resist and other functional fluids.

iTi offers a family of printhead-independent, precision analysis and process development tools ideal for companies who wish to incorporate the advantages of inkjet technology into their manufacturing workflow. iTi’s systems enable customers to transition from Lab2FabSM – from R&D through pilot line manufacturing to full scale production. Products include the Drop Watcher, Inkjet Web Press, XY Materials Deposition Systems, Digital Web Press and Versatile Jet. These systems are used by a wide range of companies including inkjet printhead and fluid manufacturers, universities and many companies new to inkjet, such as those involved in printed electronics, photovoltaics and displays.
Keeling & Walker Limited is the world leader in the manufacture of tin oxide based materials, providing grades for ceramic, electrical, electronic and display applications. The company supplies antimony-doped tin oxide 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 infra-red reflective coatings on plastic and glass substrates via a range of coating and printing techniques. Good transmittance in the visual range, 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.

Kodak is the inventor and a continuing pioneer of small molecule organic light emitting diode (OLED) technology, supplying materials and know-how to its many licensees world-wide. Supporting this activity, Kodak is developing low-cost high-performance backplane technologies based on its recently-announced atmospheric pressure CVD process for zinc oxide TFTs.

Kodak European Research (KER) in Cambridge has been working for several years on materials and process technologies for flexible reflective displays and flexible photovoltaics. Drawing on its strengths in ink formulation, media design, colloidal materials and surface science and building on Kodak’s broad range of digital printing technologies, the KER team is developing low-cost roll-to-roll approaches to high-resolution additive patterning of optoelectronic materials for a range of applications.
KER is also actively seeking emerging technologies in materials, processes and device architectures for Plastic Electronics from European companies and academia.

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Laser Micromachining Limited (LML) helps industry exploit novel uses of lasers – including the development, prototyping and manufacture of complex plastic electronic devices. LML provides flexible, responsive and cost-effective services and allows customers to access the latest laser micromachining processes to gain a competitive advantage in emerging micro and nanotechnology sectors. LML staff are experts in all areas of microfabrication and provide a complete solution from design through to manufacture.

**MacDermid Autotype Ltd**  
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MacDermid Autotype is a leading company producing precision nano – and micro-structures onto film substrates, typically polyester, polycarbonate, polymethyl methacrylate and triacetyl cullulose.

For many years, it has been producing high-quality optical hard-coated films. The Autotex and Autoflex range include ‘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 vary with different applications.

Product ranges include the Motheye and MARAG™ films. They show excellent Anti-Reflection (AR) properties.
with less than 1% reflectivity over the entire visible spectrum, combined with low dependency on angle of view. As the human eye is also very sensitive to specular reflection, Antiglare (AG) is also a requirement and a combined AR/AG (or MARAG™) film has been developed with the Fraunhofer Institute for applications where high-performance and low reflection/high transmission features are needed.

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

**Merck Chemicals Ltd**
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Merck is 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. Its range of high-performing semiconducting materials are optimised to deliver excellent electrical performance and ambient stability through the understanding and control of the semiconductor microstructure and the molecular energy levels responsible for electrochemical oxidative processes. In addition, it offers matched dielectric and interfacial treatment formulations to complement its semiconducting materials.

The company has invested in new, dedicated laboratories at Chilworth, encompassing synthetic chemistry laboratories and device fabrication facilities with electrical measurement in a controlled, clean room environment. 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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Nano Print Ltd (NPL), previously Plastic ePrint Ltd, is a spin-out company formed in June 2006 following pioneering research at the University of Manchester. NPL owns a suite of intellectual property related to a planar nanoelectronics platform.

As a technology development company, NPL is committed to forming partnerships, strategic alliances and collaborations across the printed electronics (and related industries) value chain. NPL provides intellectual property licences in addition to research, development and supply chain support to partners and customers.

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NPL is renowned for excellence in measurement with a mission to provide tangible benefits to industry and society. It is involved in a number of projects in the field of Plastic Electronics.

NPL has extensive capabilities in thin film and surface analysis including X-ray photoelectron spectroscopy, time-of-flight secondary ion mass spectrometry, atomic force microscopy, scanning tunnelling microscopy, spectroscopic ellipsometry and contact angle goniometry. A recent addition (2007) is a combined XPS / UPS / SEM
system with imaging capability. Other microscopy techniques include polarised optical microscopy and TEM. 2008 will see the addition of a grazing incidence X-ray diffraction facility for crystal structure determination.

Current projects include the depth profiling of organic materials using cluster ion beams, the microscopic measurement of surface energy, and the prediction of drop shapes for printing organic electronic components. NPL is researching the measurement of carrier mobility in semiconducting organic layers at sub-100 nm thickness, using dark injection transient spectroscopy, admittance spectroscopy and transient electroluminescence. Electric fields are measured using electro-absorption, with numerical models for charge transport.

Novel optoelectronic aspects of the metallophthalocyanine material system are being investigated by studying the effects of electric fields on charge transfer, charge separation, and recombination processes; the role of interfacial states on charge transport; and the dependence of charge transport on supramolecular organisation, molecular ordering and thermal annealing.

At the system level, the optical properties of organic displays are being measured, including angular emission profiles.

**OLED-T Ltd**
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OLED-T invents, patents, develops, manufactures and licenses high performance small molecule organic materials for use in the manufacture of Organic Light Emitting Diode (OLED) displays. The materials are suitable for both active matrix and passive matrix OLED displays, and can also be used for lighting and flexible displays.

OLED-T has developed materials and the associated processing and device technology for each of the layers in an
OLED display, and has placed particular attention to improving the injection and transport layers. OLED-T’s world-class injection and transport materials enhance the performance of all OLED displays based on either fluorescent or phosphorescent emitters, offering the following advantages:

- Increased lifetime for all colours
- High stability in a manufacturing environment
- Lower voltage and higher efficiency
- High purity – in excess of 99.9%
- Lower toxicity compared with existing aluminium-based materials
- Excellent price/performance.

A number of exciting new materials and technologies are planned over the next two to three years based on OLED-T’s existing core intellectual property covering material development, material synthesis, device applications and device structures.

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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 molecular realignment. Examples of typical installations include tools for cutting and shaping optical fibre, high-speed drilling of injection-moulded components, de-metalising a range of substrates for electronic circuits, sensors and displays, cutting and drilling biological diagnostic sensors, and the drilling of precision spray and injection nozzles.

The company combines experience in laser processing, precision engineering
and materials interaction with core skills in automation, control, visualization and systems integration. It provides robust, reliable production equipment for a variety of manufacturing environments.

**Oxford Instruments plc**
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Oxford Instruments has a broad range of capabilities that provide the tools, processes and solutions needed to advance fundamental nanoscience research and its transfer into commercial nanotechnology applications.

With a unique set of technologies to enable the manipulation and observation of matter at the smallest scales, Oxford Instruments offers solutions for the fabrication and characterisation of nanoscale materials, structures and devices, and environments in which to perform fundamental nanoscience. This involves the combination of core technologies in areas such as low temperature and high magnetic field environments, X-ray, electron and optical-based metrology, nuclear magnetic resonance and advanced growth, deposition and etching.

The first technology business to be spun out from Oxford University over 40 years ago, Oxford Instruments today employs over 1,200 people worldwide.

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Pelikon is a leader in the design and manufacture of flexible printed segmented electroluminescent (pSEL™) intuitive touch displays, backlights, animated backlights, and pSEL hybrid and driver electronics for the home appliance, consumer and industrial displays markets. It has offices worldwide.

Pelikon has developed a new flexible display product that combines electroluminescent material with the reflective properties of the LCD. The polymer dispersed liquid crystal (PDLC) used in the pSEL hybrid product was developed at the Pelikon facility in Cambridge. At 0.25mm thick, the product can be mounted behind capacitance touch sensors and is flexible enough to be mounted over metal domes for keypads. With emissive and reflective modes, it operates in all
conditions from darkness to direct sunlight and is low power and low cost. The ‘dead front look’ and ‘reconfigurable keyboard’ features make products visually appealing.

Pelikon’s manufacturing plant in Cardiff uses automated reel-to-reel manufacturing, cutting and optical test equipment. The displays are printed on ultra-thin PET substrates making them thin, flexible and extremely robust. Pelikon is an ISO 9002 credited supplier and is RoHS compliant.

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Philips Research Laboratories UK has researched active matrix displays for over 20 years. Amongst other topics, it pioneered processes for making inorganic TFT arrays on polymer substrates.

An early focus was on low-temperature polysilicon TFTs on plastic, to allow the integration of flexible drivers. More recently, however, it has achieved two breakthroughs that offer a rapid and low CAPEX route to manufacturing electronics on plastic. The first is the patented EPLaR process, which enables existing glass-based a-Si TFT manufacturing plants to be re-used with minimal investment to make arrays on flexible substrates. The second is the development of designs for display row driver integration in a-Si. Together, these approaches offer robust flexible displays which can be brought rapidly to market, based on known materials and high-yield processes in existing factories, whilst benefiting from attractively small borders.

The company recently licensed its EPLaR technology to Prime View International of Taiwan and would be pleased to work with potential customers who wish to use this flexible electronics technology in their products.

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Research and systems development company Plasma Quest Limited (PQL) specialises in thin film coatings. Its thin film sputter deposition system is an enabling technology that delivers high-
quality, low-stress films deposited at high rates. The technology is ideal for deposition onto flexible (organic) substrates where the ambient temperature process often gives properties that conventionally require heat treatment.

The resistivity of unheated ITO is better than $4 \times 10^{-5}$ ohm-cm, with 95% optical transmission in the visible range. Un-annealed copper resistivity is $1.98 \times 10^{-6}$ ohm-cm. PQL’s high density plasma ($10^{12}$-$10^{13}$ ions/cm$^3$) generation system, which is generated remotely from the sputter target, facilitates the sputtering advantages: it is also well suited to PECVD.

800nm Permalloy on 25µm Kapton® sheet

Additionally the low energy plasma bombardment (~30eV) of the substrate beneficially enhances the film density and mechanical integrity, with control over internal film stresses. It enables gold deposition onto PET® without a seed layer. It is capable of low temperature deposition of a-Si:H with properties comparable to PECVD.

Other benefits include:
- High target utilisation (>90%)
- High-rate reactive sputtering of dielectrics
- It sputters thick ferromagnetics
- It maintains conditioned compound-target stoichiometry.

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Plastic Logic is a leader in flexible, solution-processed, organic TFTs. This technology has wide applicability, but the first area of exploitation is that of flexible active matrix backplanes. These lightweight, robust backplanes can be integrated with a broad range of display media. Plastic Logic is now focused on bringing the technology to the market through a product range of flexible e-reader products that will transform the way we read the written word. Early products will use electrophoretic media (e.g. EInk) but will move to other technologies including LCD and OLED.

Plastic Logic has been developing its technology for five years and now has 75 employees in Cambridge, with a
close relationship with the Cavendish Laboratories of the University of Cambridge. It is moving the technology from the laboratory into volume production in a 10,000m² manufacturing facility located in Dresden, Germany. This facility will be in production with an initial annual volume of 1.1 million units by end 2009, and 2.2 million units by end 2010.

**Polymer Vision Ltd**
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Polymer Vision Ltd is an independent spin-out from Philips. In 2004, and as then still an internal Philips R&D activity, it announced the world’s first roll-able display – a flexible display as thin as paper and, for the first time, the screen of a mobile device could actually be made larger than the device itself.

Polymer Vision presented the READIUS®, a fully functional prototype of a mobile device with a roll-able display in 2005. The READIUS® successfully established the capability and integration possibilities of roll-able displays for the mobile market.

The Southampton facility combines state-of-the-art technology capabilities with a world-class team of scientists, able to apply advanced silicon technology concepts to polymer electronics and organic semiconductor devices. It is home to the world’s first roll-able thin film transistor (TFT) polymer electronics pilot production facility and is rapidly establishing itself as a world leader and innovator in the commercial evolution of polymer/organic electronics.

**PRP Optoelectronics Ltd**
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PRP Optoelectronics Ltd has more than thirteen years’ experience in the design and manufacture of LED displays, and continues to serve major customers in military, aerospace and industrial markets.

It designs and manufactures custom hybrid LED displays and monolithic LED arrays. Hybrid LED displays range from seven segment to complex multi-colour displays, with integrated drive and interface electronics. Applications include military and civil aircraft flight decks and include night vision.
compatibility where this is required. Monolithic LED displays, with up to 512 emitters on a single chip, are fabricated in standard GaAsP and high-brightness AlInGaP using PRPs on-site processing facilities. Typical applications are in printing, film marking and miniature displays for thermal imaging applications.

The product range has now been extended to include light sources and the associated electronic control systems for medical applications such as photodynamic therapy.

**QinetiQ Ltd**
Micro Nanotechnology Laboratories, Building K Room 2030, Malvern Technology Centre, St Andrews Road, Malvern WR14 3PS

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QinetiQ Ltd is one of Europe’s largest commercially-focused science and engineering companies with capabilities in the development of novel materials and devices for sensing and manipulating the electromagnetic spectrum for both military and commercial applications.

QinetiQ is active in the development of electronic devices, circuits and systems using additive processing and printing technologies. One emphasis is on the purely additive, low-temperature and non-vacuum processing of electronics. The aim is to develop methods that allow electronic circuits to be written at low cost onto arbitrary substrates – including surfaces which may be flexible or curved. The company has used soft lithographic printing methods extensively to achieve high-resolution patterning of the critical features of electronic devices to dimensions of a few microns. Combining soft lithography with digital printing, it has demonstrated a route to high performance but completely reconfigurable circuitry, applicable to fast prototyping and small run production. Application areas include the use of printing methods in display backplane fabrication and the writing of sensor arrays for medical monitoring applications.

**Qudos Technology Ltd**
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Qudos Technology Ltd is a leading research and development company for micro and nano-scale technologies. It manages the National Prototype Facility at Rutherford
Appleton Laboratory near Oxford and offers services to customers from commercial and academic institutions. Worldwide clients benefit from one of the most comprehensive tool sets and expertise available in the UK. Operating from a class 1-1000 clean-room, Qudos’ processes and services meet the latest market requirements, and include:

- Single and multi-step processing such as thin film deposition, etching and lithography
- Ebeam direct write and mask production
- Displays, photonics, sensors and micro electromechanical systems fabrication
- Process and device development
- CAD to device delivery.

Materials range from silicon, ITO films on glass, quartz, novel crystals and flexible substrates. Sizes of substrates range from single chips to 150mm. Experience in Plastic Electronics comprises R&D processing and the testing of flexible substrates for display projects.

The Qudos National Prototype Facility enables high-tech organisations to realise and bring world-leading next-generation technology to market.

**Tecan Ltd**
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Using precision photolithography and advanced electroforming techniques in a class 1000 cleanroom environment, Tecan manufactures metal, epoxy and hybrid multi-level components and apertures – with sub-micron feature sizes and tolerances possible. Micro-
parts, filters, masks and embossing tools are all manufactured to extreme levels of accuracy using this innovative technique.

Deposition masks are used in a wide range of vacuum-chamber evaporation and sputtering processes to fabricate both simple and complex micro-engineered electronic components and products. They are used for selective deposition onto substrates during the manufacture of flat panel displays.

Single masks, multi-mask sets and frame systems are all available dependent on the application. Multi-level masks can be produced with ‘stepped’ recesses, limiting the need for spacer sheets in multiple-sheet sets. Finished masks, produced in stainless steel and nickel with optional gold-plating, typically withstand post-deposition cleaning for up to 10 times longer than non-coated masks.

Burr-free aperture edges and controllable draft angles enable improved deposition performance.

**Teclyn Ltd**  
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**Measuring electronic device performance**

Teclyn provides the step between prototype and manufacturing in the fast-moving printed electronics industry. It exploits knowledge of manufacturing principles to transform ideas into printed product. This allows demonstrators to become saleable mass-produced products, leading to custom batch manufacturing of printed electronics on sheet or reel-to-reel by:
• Inkjet
• Flexography
• Gravure
• Offset Lithography
• Screen
• Pad.

Teclyn operates within the state-of-the-art laboratories and manufacturing facilities at the Welsh Centre for Printing and Coating, Swansea University. The partnership with the university allows for full device development from concept, design and prototype to batch manufacturing. Teclyn’s founders can call on over 50 years’ total experience in printing as a manufacturing process, and offer a gateway to a network of material suppliers, leading industry companies and end users.

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Teer Coatings Limited (TCL) specialises in magnetron sputtering based thin film deposition, providing a coating service, coating equipment and contract R&D services. The company’s proprietary Closed Field UnBalanced Magnetron Sputter Ion Plating (CFUBMSIP) technology provides thin film coatings with exceptional adhesion, structure and integrity.

In addition to metals (including precious metals such as gold, platinum, etc) and alloys (deposited either directly from alloy sputtering targets or from multiple different coating sources), films can be deposited reactively from alloy or elemental metallic sputtering targets to form oxides, carbides, nitrides etc or mixtures thereof. The quality of such coatings is evidenced by the recent adoption of this technology to produce complex multilayer filter stacks for optical applications. Transparent conductive oxides can also be readily deposited. The process is suitable for deposition on a wide range of substrates, including thermally sensitive materials, such as plastics.

UDP 650 Coating System
More recently TCL has developed a plasma-enhanced chemical vapour deposition (PECVD) capability, ideally suited to the production of coatings for surface energy control, i.e. for selective hydrophilic or hydrophobic behaviour.

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TTP creates, develops and commercialises new products and businesses based on advances in technology. Since its foundation 20 years ago, TTP has worked with some of the best-known and most successful companies in the world.

With a strong focus on emerging technology and product development, TTP has extensive laboratory and pre-production manufacturing facilities and employs top class engineers, scientists and business development specialists to realise breakthrough innovations. TTP’s approach blends in-depth scientific understanding with fast-track product and process engineering to realise new business opportunities in the ever-decreasing timescales demanded by the market.

TTP’s offerings in the display sector include novel technologies for displays and backlights, applications of novel LED and laser sources, liquid crystal devices and micro/nano structured components and surfaces. It has next-generation digital printing technologies which enable a wide range of passive, active and structural materials to be printed onto almost any substrate. Product engineering skills cover full development from initial specification through detailed design and transfer to manufacturing.

TTP works with multinational and new venture businesses alike, either as a technology provider or as a development and commercialisation partner.
Timsons Ltd has a long and successful history in the design and manufacture of reel-fed printing presses. Its performance has been recognised by the granting of three Queen’s Awards – two for International Trade and one for Innovation. Currently a world leader with its range of bespoke reel-fed presses for the production of books, the company has developed a new reel-to-reel press to produce high-quality print on unsupported flexible plastic films.

In conjunction with the Welsh Centre for Printing and Coating and other industrial partners, it is planned to extend the capabilities of this new press to create a complete, purpose-built system for the production of high-volume, low-cost, printed electronics. In addition, the press will also have applications in the production of biomedical sensors together with smart and security packaging.

TWI Ltd is a leading research and technology organisation with over 500 staff around the world providing technical support to industrial clients. For more than 40 years, TWI has advised on all aspects of electronic, opto, fibre, sensor, MEMs and medical packaging. Its expertise includes lighting and display technologies, including thermal management and modelling.

The TWI Cambridge Microtechnology Centre comprises clean-rooms and other facilities required to maintain and extend its leadership in technologies associated with packaging and interconnection within electro-photonic systems, including low-cost replacements for ITO. TWI also conducts development programmes that lead to cost-reduction, ruggedisation and miniaturisation of components and assemblies. TWI’s work spans a vast array of processes and includes the development of laser and e-beam technologies.
The organisation also assists with the refinement of business processes associated with product development, commercialisation and manufacture, and advises customers on all aspects of environmental law.

All work is conducted within an ISO 9001 system and TWI offers a single, impartial source of advice.

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Xennia was founded in 1996 as an independent inkjet research and development company. Unlike other inkjet integrators, who are primarily engineering focussed, Xennia understands that chemistry is the key to unlocking the potential for inkjet as a reliable printing or dispensing tool for a wide range of industrial applications. With one of the most experienced inter-disciplinary teams of inkjet chemists and engineers in the business, it delivers chemistry-driven solutions designed to meet customers’ unique requirements.

Xennia offers a growing range of XenJet print engines, peripherals and inkjet development tools. It also offers a one-stop contract development service for new inkjet applications from initial proof of concept through functional prototypes to the manufacture and supply of full production systems and inks.
General contacts

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BERR’s role is to ensure business success in an increasingly competitive world. Within BERR, the unit that represents the interests of the Electronics, Photonics and IT sectors is the Electronics and IT Services Unit (EITSU).

EITSU helps promote competitiveness in the Electronics, Photonics and Software & IT Services sectors. To achieve this, the unit maintains close links with some of the main business players in these sectors as well as working through key stakeholder groups such as the Information Age Partnership, the Photonics Leadership Group, and the Electronics Leadership Council.

The Unit works with these stakeholders to:
• Identify future strategies, areas of growth potential, drivers and challenges facing the sectors
• Influence domestic and European regulatory policy that may impact on the sectors’ competitiveness
• Promote innovation
• Promote ITEC skills.

UK Trade & Investment
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UK Trade & Investment is the Government organisation that supports businesses moving to the UK, and supports UK businesses in overseas markets.

For inward investors, it can help with setting up in the UK by access to practical information, market research services and key business contacts; it can help expand existing UK operations with insights to help optimise the UK operation, find suitable expansion locations, and support access to new markets; and it can access a multitude of networking and R&D partnership opportunities. In addition, the Global Partnerships Programme enables overseas organisations of any size to find the right partner in the UK.

For exporters, UK Trade & Investment has extensive contacts in every industry in every country. Through a range of unique services - including participation at selected trade fairs, outward missions and providing bespoke market intelligence - it can help access to foreign markets and overcome overseas rules and regulations.
The Technology Strategy Board (TSB) is a business-focused organisation dedicated to promoting technology-enabled innovation across the UK. It invests in research and development; builds partnerships between business, research and Government to address major societal challenges; and runs a wide range of knowledge exchange programmes to help innovation flourish.

The Plastic Electronics Technology Centre (PETeC) is a national prototyping institute for the development and commercialisation of printed electronics. Customers will be able to test design concepts and novel materials for a wide variety of products including thin film transistors for flexible displays including e-paper, organic photovoltaic cells, sensors and solid state lighting applications.

The development of plastic and printable electronics requires a multidisciplinary approach to solving the challenges of processing materials that are quite different to conventional silicon semiconductors. The services that PETeC offers reflect this need, and include scientists with extensive experience of organic materials, process technology, and manufacturing in the key product application areas. PETeC has core competencies in the areas of flexible substrate preparation, metallization, barrier layer processing,
and the patterning processes for flexible and printable electronics together with device modelling.

PETeC aims is to de-risk industrial research and development, by providing access to expertise and state of the art equipment, and to speed up the route from an innovative idea to a marketable product. It is therefore an ideal facility for start-ups and larger manufacturing companies to get prototype production up and running. The Centre’s in-house staff and access to state-of-the-art printers and coating machines will be able to improve first generation products more efficiently for the Centre’s customers.

The PETeC project is being delivered with funds from regional, national and European sources by CPI, which has been formed from the merger of the Centre for Process Innovation (CPI) on Teesside and the Centre for Nanotechnology, Microtechnology and Photonics (Cenamps) in Newcastle upon Tyne.

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Knowledge Transfer Networks (KTNs) funded by TSB (see above), stimulate innovation in the UK’s key technology sectors by promoting collaboration, best practice and knowledge-sharing between industry and academia. By encouraging partnerships and teamwork, KTNs aim to position the UK as the innovation engine for Europe. There are 22 KTNs of which UK Display and Lighting (UKDL-KTN) is one.

UKDL-KTN cover displays, lighting and backlighting in all aspects from fundamental materials development through to applications for specific end users. It caters for technology from the point of its invention to the time when it must be refurbished, recycled or safely disposed of.
This publication has been compiled by the UK Display and Lighting Knowledge Transfer Network.

The cover photograph is by courtesy of the Centre for Process Innovation.

The information included in this guide has been provided by individual universities and companies. The Department for Business, Enterprise and Regulatory Reform does not accept any legal responsibility for any errors, omissions or misleading statements.