

**The 3rd International Colloquium on
Integrated Manufacture by Printing (IMP).
14th & 15th April 2008,
Gregynog, Newtown, Powys.**

This colloquium was aimed at those working in the field of printing for device manufacture. It aimed to provide an opportunity to network, informally present recent and in-progress work together with discussions on topics where more understanding and research is required. In these respects I believed it fulfilled these aims.

1 DAY 1

1.1 Introduction to IMP & UKDL

The introduction was given by Eifion Jewell. Eifion is based at Swansea University but works for UKDL.

This was the 3rd in a series of IMP colloquia, initiated by an EPSRC grant in 2003 and the aim is to cover the science base of “printed functionality”. It was run by the Welsh Centre for Printing and Coating at Swansea University in partnership with the Printing and Graphics Science Group of the Institute of Physics and the UKDL.

UKDL is the Knowledge Transfer Network for the Displays, Lighting and Plastic Electronics industries with a membership of around 750. It has 4 sub-groups, one of which is FLEXYNET, established to provide a forum for members of the flexible displays community to meet and discuss the sector's threats and opportunities. FLEXYNET is now a major sub-group and is managed by a committee drawn from OEM and SME companies active within the sector, supported by relevant academics.

1.2 IOP Printing and Graphics Science Group - Dilwyn Jones, Emral Ltd

Dilwyn is the chair of this Institute of Physics Group, of which I am secretary. Novel printing applications such as the fabrication of visual displays, flexible electronics, smart packaging, lighting and photovoltaics based on organic and polymer electro-optic materials fall within its remit.

Dilwyn outlined the purpose and objectives of the Group and the conferences we run. The Group was formerly the Printing, Packaging and Papermaking Group but was relaunched and renamed in 2007 to reflect a change in the technical and commercial environment.

Dilwyn returned later to present on web handling issues.

1.3 Printed Electronics Arena – the Swedish cluster approach - Ragnar Fridman, Norrköping Science Park, Sweden

Ragnar outlined a Swedish initiative aiming to take printed electronics to market – the Printed Electronics Arena (PEA). PEA is another example of a tripartite partnership between regional government, industry and research organisations.

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The location in Norrköping aims to build on local industrial clusters in packaging, building elements and large displays. PEA appear to have strong local links with paper and board mills and converters.

The envisaged production route is through an “incubator” in Norrköping to use conventional printing methods to produce electronics. Their aim is that this incubator will look after the entire product development and production process, leaving the partner to do what they know best, presumably the product concept and subsequent marketing and sales.

Radnor presented an interesting overview of the technology components and applications of Printed Electronics. In terms of technology, antennae (being simply high conductivity lines) are undoubtedly the easiest to realise. Display systems (and in particular backplanes) are currently being printed as are the first semiconductor systems. PEA are looking at the usual printing modalities of inkjet and screen with a possible mention of offset. The applications areas reflect this technology roll-out but may also give some indication as to where PEA are heading.

Radnor made one particularly pertinent comment on smart packaging. It is often said at these meetings that security artefacts on pharmaceutical packaging is the “killer application” driving this. His view is that this is unlikely to be the case as this application would require close to 0% failure rate, unlikely to occur particularly in the early days. Finally on packaging, Radnor was particularly envious of the UK Faraday Packaging Partnership.¹

1.4 Printed electronics on paper – the potential, issues and ways forward - Alan Hodgson, Alan Hodgson Consulting Ltd.

My paper aimed to show where paper fits in as the substrate for future Printed Electronic devices. It started from the premise that paper is the substrate for much of the output of home and commercial printing. Printing methods that were developed for and matured in commercial printing are now being applied for manufacture in applications such as printed electronics, printed displays and photovoltaic devices. It went on to examine the potential use of paper substrates in printed device manufacture and the technical issues involved. The stated aim of this work is to develop a road map for the tasks needed to make this feasible for widespread application.

The 3 elements of the road map as set out were as follows.

1. The need for new “fluids” and modified presses to be developed to be able to produce the device technologies.
2. Surface modification of paper substrates. I spent the majority of time on this area.
3. Barrier layer materials. I spent little time on this as this will be the subject of a future PGS conference.

1.5 Identifying the relationship between anilox properties and printed film thickness for flexographic printing - John Cherry, Swansea University

This work is a good example of knowledge gained from conventional printing technologies being leveraged into printed electronics.

In traditional flexographic colour printing the specifications for the cells on the anilox rolls are based on years of experience. However, when moving to the fluids needed for printed electronics, which can be highly expensive and need very specific layer thicknesses, this experience is not enough.

There is also the problem of measurement. In conventional printing we simply measure optical density. In some cases the printed electronic layers may be amenable to optical measurement but in some cases measurement of the release of material from the anilox using optical or SEM techniques may be better. Another good option seems to be white light interferometry.

Unfortunately the printed film thickness is a complex function of anilox cell geometry, print speed, anilox engagement and material properties. This work, previewed before at a previous IoP conference, is still in an early stage. The aim is to generate enough information from various materials to enable to better calculation of printed layer thicknesses.

Although flexographic printing has the edge on speed of application it is the potential for precision deposition that may give inkjet printing the edge for some printed electronics applications. It is also likely to be much more frugal on materials for smaller applied volumes. It was noted in a subsequent presentation (Section 1.7) that around 1 litre of fluid is necessary to prime a flexography printing system!

1.6 Winding issues in reel-to-reel manufacture - Dilwyn Jones, Emral Ltd

Dilwyn, who presented earlier as Chair of the IoP PGS group (section 1.2) returned to one area of his own consultancy business, web handling. The presentation looked at strains that can be produced in coated layers during web handling such as tensile failure, wrinkling and edge delamination. It moved on to look at roll pressure effects, winding and pattern alignment issues. All of these are areas where knowledge gained in conventional manufacture is directly transferable to printed electronics.

One issue that I believe is notably absent here for printed electronics applications is the issue of static electricity. Web handling of non-conductive plastics in particular is prone to static electric discharge. In addition to presenting a health and safety hazard, such discharges could destroy sensitive electronic components and may limit the production speed (and hence the economic advantages) of some device production. This is once again an area where paper substrates may confer an advantage.

1.7 Flexographic printing of fine features- David Bould, Swansea University

This was the 3rd offering from Swansea and the second looking at issues around flexographic printing. The presentation began by listing the pros and cons of flexographic printing for printed electronics. On the plus side, it is capable of high speed and definition where the resolution and ink weight can be independently controlled, within limits. As a result, some commercial applications are now starting to appear. However, this printing technique uses a flexible image carrier, so deformation and swell of this carrier produce registration and definition issues. It can also put a rather low practical limit on the amount of material that can be applied.

This study aimed to investigate the definition obtainable on this flexible image carrier and the resultant definition on the print to create a workable envelope for track and gap feature sizes in printed electronics. Both digital and conventional flexographic plates were considered and significant differences observed. The features on the printing plate were investigated with white light interferometry and the final print by image capture and analysis.

It was the conclusion of this work that although flexography has many attributes for the manufacture of printed electronics there are still plenty of issues to be addressed. Although the key variable seems to be the flexo plate differences between conventional plates and digital seem to almost disappear on printing. There is evidently a number of competing variables here.

1.8 From subtractive to additive processing of micro/nanoelectronic materials - Bill Taylor, MIMIV Limited

MIMIV are the owners of patents for printable field emitting display technology which they claim will lower the manufacturing cost for large flat panel TV's. They also hope that their intellectual property can be used elsewhere in the wider printed electronics field. They use an additive screen printing process, and were seeking venture capital support.

1.9 The UKDL – Chris Williams

Chris Williams is the Director of UKDL (UK Displays & Lighting), a Knowledge Transfer Network. It has been in existence effectively since 2004 in various guises. Although Eifion had already described the organisation in some detail earlier (section 1.1) Chris concentrated rather more on the subgroups and special interest groups being planned.

Of the 4 subgroups FLEXYNET (Plastic Electronics) is of particular interest to us. It was once again emphasised that we should not take "plastic" too literally and that this should encompass paper too. This industrial committee that runs this has a mix of component suppliers, equipment manufacturers and plastic electronics producers.

The UKDL plan some special interest groups for later in the year. He made mention of Printing for Printed Electronics, and Materials.

The day finished with a dinner and drinks – a valuable networking event.

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2 DAY 2

2.1 Modelling ink transfer in rotogravure printing- Davide Deganello, Swansea University

Davide covered the physics of ink release in gravure printing. The key geometric variable here is the depth to opening ratio of the gravure cell. The model Davide presented assumes no air entrapment in the cell, likely to be more correct in low speed printing.

The model assumes that the printed media is moved vertically away from the cell so that symmetrical release can be assumed. He believes that this makes little practical difference to the real situation.

2.2 Manufacturing electronic devices using soft lithographic processes - Richard Young, Brunel University

Richard presented some work on a soft lithographic printing process – effectively printing with an elastomeric stamp. By way of background, he showed some circuitry produced by the Cleaner Electronics Group at Brunel. This group have been using offset litho presses to produce passive components (batteries, connections etc) for printed electronics and have produced a handbook of conductive lithographic films.² As a result, this work can be seen as an extension of their work on lithography for printed electronics.

The aim of Richard's work is to produce a low voltage high electric field generator for electroluminescent displays using this micro contact printing technique. They print a thiol etch resist onto a gold substrate and wet process the print using an I₂/KI aqueous solution. They get anomalous effects on dilution which I attribute to chemical edge effect, common in photographic processing.

The electroluminescent application is of particular interest as the Swansea group have already demonstrated this display technology on a paper base.

2.3 Protein printing for the manufacture of biosensors – Chris Cook, University of Manchester.

Chris works with Brian Derby at Manchester and this work was conducted in collaboration with a number of organisations including Xaar, so it is using inkjet. The aim is to develop a manufacturing technology that will allow the accurate deposition of biomolecules for tissue engineering applications.

The work appears to show that proteins can be jetted without significant damage to their structure or configuration. However, there may be some loss of enzyme activity and change in their hydrodynamic radius.

The opportunity for printed sensors is large but is probably some time off in bulk applications.

2.4 Screen printing gelatine for bio applications - Tatyana Korochkina, Swansea University

Continuing the biological applications theme of this section of the day another paper from Swansea looked at biological applications of screen printed gelatine. The 3rd International Colloquium on Integrated Manufacture by Printing DPJ Edit.doc

The paper focussed on viscosity behaviour, and was delivered by Davide in Tatyana's absence.

2.5 Drop-on-demand inkjet printing of organic and inorganic fluorescent nano-particles - Min Wu, University of Strathclyde

This paper reported the use of inkjet to place nano-size fluorescent macromolecules onto substrates for photonic and optoelectronic applications.

This group at Strathclyde are evidently doing some interesting work. It would be interesting to have them along to present at the next IoP PGS Student Conference.

2.6 Inkjet printing and direct-write electronics – Bojun Xu, University of Manchester

Although the title appears to imply a comparison of inkjet and direct write technologies for electronics fabrication, the presentation was predominantly about how to optimise the fabrication parameters for inkjet printed silver conductors. Unfortunately there is little or no information about the comparison with direct write technologies.

This group use silver neodecanoate-containing fluid as a light and thermal sensitive source of metallic silver. They print multiple layers to get significant bulk conductivity and to reduce the "coffee ring" effect. The residual organics are removed through a laser curing process.

2.7 Silver inks for flexo and gravure print – Eifion Jewell, Swansea University

Continuing the theme of silver inks Eifion presented some work on silver ink technologies for flexo and gravure printers. The presentation began with a review of the technologies involved in conductive inks, characterising them by particle size as follows.

1. Large particle inks, predominantly based on silver and carbon, are derived from the thick film screen printing inks. Inks of this type are currently used for RFID antennae and usually consist of conductive particles in a liquid resin.

These inks are available from a number of suppliers but have limited conductivity. A number of these have poor physical properties such as rub resistance and have a tendency to dry within anilox rollers!

2. Nanoparticulate inks as dispersions or solutions used in inkjet. These nano particles can be sintered to form a conductor at a temperature that decreases with particle size.

These inks have rather fewer actual suppliers and need sintering to get significant conductivity.

In summary, there is still development work needed to provide adequate conductive inks for flexo and gravure printed electronics.

3 **SUMMARY**

Overall, an interesting meeting and worth a visit when the 4th IMP meeting comes along next spring. It is useful in that this meeting gives adequate coverage to both impact and non impact printing issues.

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¹ See <http://www.faradaypackaging.com>

² Brunel University, "Handbook of Conductive Lithographic Films",
http://dea.brunel.ac.uk/cleaner/Electronics_Projects/Handbook_1.htm