# UV&EB Opportunities in Printed Electronics—Summary Report

**By Graham Battersby**

RadTech International NA commissioned this study on opportunities in printed electronics (PE). The RadTech Electronics Focus Group wanted to know what was happening in all of the PE markets and gain answers to the following questions:

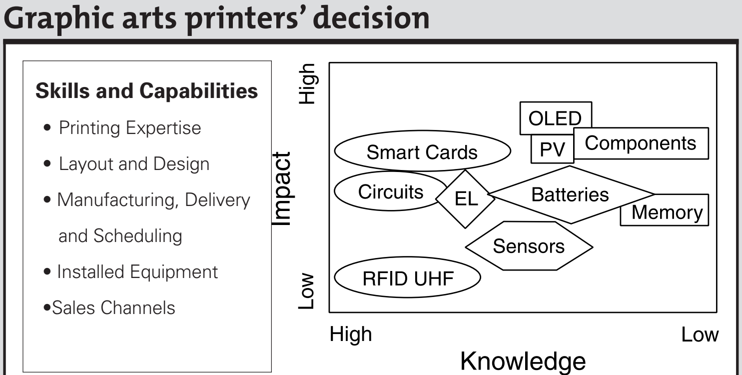
- Where are UV&EB materials and processes being used today?
- Where can existing materials and equipment offer benefits?
- What new materials, equipment or processes need to be developed?

## Graphic Arts Assessment

Figure 1 shows what skills a typical graphic arts (GA) printer may have and where these are of benefit to the PE market. The horizontal axis shows where the printer has high to low knowledge while the vertical axis is an estimate of the relative financial impact of the different market segments to the printer.

**Figure 1**

**Graphic arts printers' decision**

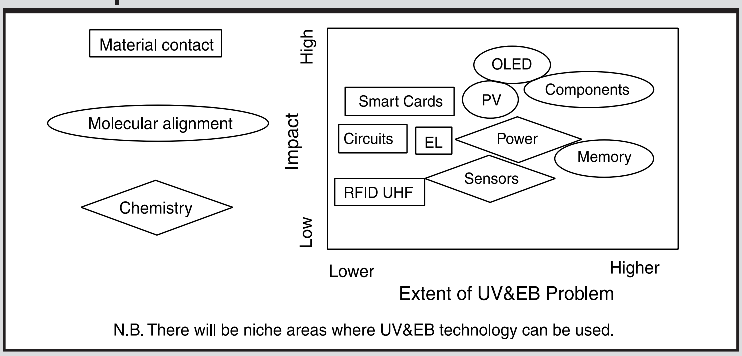



The rectangles are organic light emitting diode (OLED) displays, photovoltaics (PV), components (e.g., transistors, etc.), and memory (electronic data storage). These are linked as a group because they usually need a clean room—not very common in a traditional print shop. The resolution needed for these end uses is also very high. A typical resolution for PE is about 100 times finer than that needed in GA. This is a problem since the processes developed in GA have been focused around the resolution of the human eye at a typical reading distance of one foot, about 100 microns. One micron is a significant distance in PE, so there is a disconnect between what a press was designed to do and what is required for PE. There is significant work still needed to understand the resolution capabilities of all the different printing processes both in the machine direction, transverse direction and in terms of registration when multi-layers of materials are needed. Inkjet printing has a resolution of about 20-30 microns and is one of the highest resolution printing methods used today. Adding a laser to "clean-up" the resultant print is also quite common.

The rectangles are a problem for the GA printer because they need a clean room and fine resolution. But what about the diamond areas—batteries and electroluminescent displays? The problem—a thick layer is usually needed and a screen process is normally used. This is not that uncommon, but if you

## Figure 2

### UV&EB problem




want to print a zinc carbon battery or an electroluminescent display, you will probably have to do this by screenprinting rather than litho, flexo or gravure.

Sensors are a hexagon since they are very dependent on the chemistry involved. Since the volumes are not too large and the cost of materials is high, inkjet (which can be primed with a small amount of material compared to a typical printing press) is the most popular printing process being used today.

The oval areas are where we see some overlap between the GA printer's skills and the market needs. Printing ultra high frequency (UHF) radio frequency identification device (RFID) tags for packaging customers, and games and novelties for fast food chains such as McDonalds, and integrating 13.56 MHz RFID technology into graphics for entry tickets, purchase cards and transportation tickets are growing markets that the GA printer should look at closely.

When looking at the advantages of inkjet one can see why this is a very common method of printing electronics, which in turn makes it easy for a company to do the "printing" themselves. This also raises the problem of the term "printed electronics" since it causes many misunderstandings. Maybe if it was called low-cost electronics or organic electronics, there would not be the confusion and hype that is associated with the printed electronics name. Printing is not usually a key part of the PE production process unlike the printing of a magazine or packaging carton. One does not have to be a skilled printer to use an inkjet machine, so it is easy for a printed electronics company to do the printing part of their PE business themselves.

One other point that is often overlooked is that electronic companies are quite different than normal graphic arts customers. Sales channels are quite different. While some printers may see this as an opportunity, others will find that a completely different sales and marketing plan (and staff) is required.

When looking at skills and capabilities of a GA printer, compare them to the needs of the PE market. There is very little, if any, overlap.

### The Fundamental Problem with UV&EB in PE

Most electronic materials require particle/polymer contact or alignment. Any material that prevents this contact or disrupts alignment reduces performance. Many organic electronic ink formulations are based on volatile materials so good contact or alignment occurs as the ink dries.

*This is the opposite of what UV&EB currently has to offer.* This is the biggest problem facing the use of UV&EB technology in PE. The functional materials used in PE have to touch or align themselves. Anything that remains in the film can disrupt this contact or alignment and detracts from the performance of the electronic material. This interference problem occurs with:

- Conductive inks. All types whether conventionally dried or annealed.
- OLEDs. Polymeric and small molecule.
- Electroluminescent materials.
- Conductive polymers.
- Nanomaterials such as nanotubes and nanowires.

*This fundamental problem makes it difficult to see how UV&EB could play a major role in PE today.*

Figure 2 explains the problem another way. The rectangles rely on silver or material contact, the ovals on alignment and the diamonds on chemistry. Even materials that stop chemical reactions from occurring, as with a sensor or a battery, will be a problem.

That is not to say UV&EB will have no applications in PE, but it will prevent it from being used with most of the major material groups.

One final explanation for this problem—in GA, industrial coatings or automotive coatings, UV&EB materials are playing an important role—adhesion, resistance properties, optical properties, etc. In PE, they are not bringing anything to the table; on the contrary, they are preventing electronic materials from contacting each other.

There will be niche areas such as those listed below:

- Ozone cleaning of substrates.
- EB vapor deposition.
- Etch resists and shadow masks.
- Conductive adhesives.
- Insulating layers.
- Barrier coatings and sealants.

Margins may be quite good. The point to make here is that PE is quite different from the opportunities UV&EB has in graphic arts, industrial coatings or automotive coatings.

## Business Opportunities

When looking at PE versus other printing markets, it is in a very early stage of development. Risk of failure is high. It will take some time before most PE businesses are cash flow positive.

Technology change is rapid, and it is important to constantly assess your business plans and research and development (R&D) strategy. It may not lend itself to some of the more rigorous R&D management tools like StageGate, since the technology and business opportunities are changing so rapidly. StageGate works fine when you are in a growth or maturing phase, but not so well when you are in an embryonic phase and you are focused on Gates 1 (ideas) or even Gate 0 (fuzzy front end).

The ability to assess technology and business potential is critical and an error of judgment can be very costly. It is also interesting that with all of the hype associated with PE many of the answers to your investigative business questions may be self serving. Who wants to admit their technology is wrong or the rate of market adoption is a lot longer than predicted? Reliable data is hard to find in the PE market and it could all change in a few months, if someone finds a solution to the basic problems of UV&EB interfering with material performance.

PE business start-up costs are quite low, capital equipment costs are not too high, some infrastructure costs with clean rooms, etc., but nothing too expensive. Entry cost is likely to remain low or be lower in the future, so being a fast follower is not a bad strategy. Let other people make the mistakes then join in with proven technology and a market that is more developed. The problem may be barriers caused by intellectual property. It should be noted that the velocity of patenting is high—another big difference between PE and GA.

A safer approach some companies are taking is through venture capital (VC) funding. For example, BASF and Dow Chemical are taking this approach, which gives them insight into the more promising technologies. The costs are not too high (low VC funding levels) compared to trying to do all of the work in their own R&D labs. If the business looks good, there is an option to acquire. Although the results of this study do not look too promising for UV&EB processes and materials in PE, there are many very promising new business opportunities in PE that are worthy of more detailed investigation, but are outside the scope of this report.

It is easy to get caught up in the market data on PE which is at best a good guess. Look at the data more generally and really focus on "Does it work?" and "What role can I play?" The market data is all for finished products and a lot depends on where you operate in the value chain. It is recommended that some wide error bars be placed around the market data that is available today.

To help put the PE market data into context, it is useful to compare it to some GA data. Sales of ink are about 2% of a finished printed product cost and market figures for finished printed products in GA are very large. For example, the North American printing market today is about double what the world PE market is predicted to be in 2020.

Even though the ratios of ink to finished product sales are small in the GA market, the overall GA market is so large it can make for a very viable material supply business. It may not be true for PE as you can see in the calculation below, which shows a material selling at $1,000/kg that would only be 0.45% of the cost of OLED display sales:

- OLED display sales were about $800 million in 2006 (IDTechEx).
- About 60 million units were sold.
- Assume each display measures 10cmx10cm (actual size is less than this).
- Assume 6 g/sq m of material is used = 3,600 kg.
- At $1,000/kg material sales would be $3.6 million.

## UV&EB Development Needs

If UV&EB materials are to gain any significant share of the PE market then the first thing that needs to be developed is a UV&EB-curable conductive ink that is at least as conductive as the conventionally dried inks being sold today. Currently, UV-cured inks are about 50% less conductive than a conventionally dried conductive ink of the non-annealed type.

For annealed conductive inks, either organo metallics or nanosilvers that rely on no binder or organic material remaining in the film after heating, technology is not available today to do this in the presence of a UV&EB-curable monomer or oligomer. The detailed printed electronics report that is available to RadTech members and discussed earlier in this paper has some ideas on how this may be overcome.

Related to the silver contact problem is the interference with the alignment of OLEDs and polymers such as poly 3,4-ethylenedioxythiophene (PEDOT), etc. If it were possible to have a UV&EB material present that did not interfere with alignment, then this would be a significant step forward.

Since most electrical materials work through touch or alignment, having UV&EB materials surrounding them in a film detracts from their performance. UV&EB technology has been designed to be non-volatile, yet most of the printed electronics carrier systems in use today are designed to be volatile. *There is a major disconnect between how our UV&EB technology works and what the needs of printed organic electronics are.*

Today, UV&EB can participate in the following markets:

- Conductive adhesives. It has been difficult to find any market data (at most $100-200 million), but as PE develops different components will need to be attached to printed areas, so the conductive adhesives market will grow (e.g., connecting batteries, speakers or LEDS to circuits.)
- Etch resists. Margins are very tight for etch resists used in circuit board manufacture today but there has been a rapid increase in sales of etch resists in Europe for manufacture of RFID antennas.
- Insulating layers or dielectrics. This market is turning a disadvantage into an advantage as UV&EB materials have good insulating properties. Formulations that have good lay and no pinholes are important to guarantee good insulating properties.
- Ozone produced from UV lamps is used to clean substrates such as glass and indium tin oxide (ITO) coated glass.
- EB units are used in the vapor deposition of ITO and other similar materials.

There is scope to improve UV&EB materials, but new technology will have to be developed. A detailed business and technical justification is recommended, since it will be important to estimate how much of the market will move over to the technology if it is developed, how much will it cost to develop and what are the chances of success. These projects should be balanced against all the other projects that could be worked on outside of PE.

Inkjet has many advantages in PE over higher volume analogue printing processes, so any materials that are developed should have inkjet printing as one of their specifications.

With volume being relatively small (little need for web speeds) and with the problems identified with UV&EB materials, any changes will probably be more easily introduced via UV rather than EB.

## Specific Markets

### *Conductive Inks*

It is estimated that the conductive ink market today is about $115 million although the electromagnetic interference (EMI) shielding market is estimated to be about $1.5 billion (IDTechEx). Conductive inks sales for RFID were at best $2 million in 2006.

The EMI shielding market may be worth looking at in more detail for UV&EB technology, since conductivity requirements may not be too high. In addition, antistatic coatings may also be worth consideration [e.g., Agfa Gevaert Group (AGFA) uses PEDOT as an antistatic coating on their photographic paper.]

Comments made in an open forum from three major ink suppliers of RFID and electronic article surveillance (EAS) tags confirmed the low price of antennas (about 2 cents per antenna) and the difficulty of competing with stamped aluminum antennas with silver-based inks.

### *RFID*

UHF continues to develop slowly and does not look to be a good business area for material suppliers. Silver-based inks and printing has no clear economic benefit over metal antennas. UV-cured conductive inks are not widely used because of poor conductivity, but there is a need for UV-cured conductive inks for narrow web label printers who want to integrate RFID production into their labels. Smart cards and entry tickets (13.56 MHz) are showing significant growth and integrating the printed antenna into the production of tickets (graphics and lamination) offers economic advantages. It is not clear where UV&EB would play a role in the printed RFID chip. RFID is still predicted to be a major percentage of the printed electronics market, so keep a close eye on how the market develops. Market data on RFID has not been included, since the data reported so far has been very unreliable.

### *Displays*

It is not clear where or why UV&EB technology would play a significant role in the application of any electrically activated or stimulated display material; they rely on alignment or contact. OLEDs are decomposed easily by UV. UV&EB could play a role in photoresists, sealants, insulating layers, and conductive adhesives.

Printing LCD color filters is gaining momentum and may have some UV opportunities. Integrating graphics into electroluminescent displays may have synergy with UV screenprinting. Hard coats or anti-reflective coatings may also be an opportunity. Plextronics estimates the market for displays to be about $7 billion by 2011.

### *Lighting*

Printed lighting is not yet cost effective, but some designer applications may be seen in two years. UV&EB process does not lend itself to application of OLEDs—alignment and decomposition. There may be some opportunities in some supporting products such as sealants, photoresists or filters. It is very hard to predict the rate adoption for OLED lighting hence the market size. Low hundreds of millions of dollars by 2012 would be realistic.

***Batteries***

Screenprinting of thin batteries is being done today. Some of the market data is a little uncertain since a battery is just one component of an end product. For example, the data for 2005 ranges from $20-200 million. By 2010, sales in the low hundreds of millions of thin film batteries would be reasonable. No use or need for UV&EB materials is apparent.

***Photovoltaics***

There may be some opportunities for conductive inks, reflective coatings, electrical and thermal insulating layers, and conducting adhesives, but not a significant need for UV&EB technology. It is thought that a market size in the low hundreds of millions would be reasonable by 2010. With the recent increases in oil prices, this type of alternative energy sourcing could prove to be very attractive, provided the efficiencies of conversion continue to improve.

***Circuits and Interconnects (e.g., games and novelties)***

This area is one of the more attractive for suppliers of materials and equipment for printed electronics. Volume could be significant and could be roll-to-roll.

It requires the ability to incorporate electronics into traditional printing processes and we could sell the advantages of UV&EB. It would still require a good UV&EB-curable conductive ink to be developed. Maybe this would extend traditional GA customers business. It is important to check the IP position. It is recommended to look at this area in more detail since it looks to be the most attractive to RadTech members.

***Memory***

This market is very early in its development and compared to the other areas discussed, this would probably be a lower priority for more detailed investigation. However, it is worth watching.

***Sensors***

Few products in this market are being sold, but there are many examples of "sensor chemistry" that have already been developed. No one has taken them to the next level of commercialization. Some conducting polymers are sensitive to different chemical environments and changes in their physical properties can be translated into an estimate of the chemical environment that is causing this change. As you might expect, the military has a great deal of interest in this area. Inkjet printing of small amounts of expensive sensor material looks to be an attractive application method. Market size will probably be larger than batteries and photovoltaics by 2010 (high hundreds of millions).

***Clothing and Textiles***

Conducting products or sensor chemistry that is not diminished through use of UV&EB materials is still needed. The wash-and-wear needs are significantly different compared to anything else—how will they get "electronics" onto clothing without a binder? Maybe UV&EB offers advantages over a plastisols if heat is a problem. Is there concern over UV materials on clothing? Market size is unknown, but thought to be quite small except for military use.

***Patents***

The whole issue of IP is quite different from GA. Patenting velocity is very high and there may be patents already issued on UV-curable conductive inks, UV-curable barrier coatings for printed electronics, and even the printing of nano materials for use in electronic applications. IP needs to be looked at carefully.

## Conclusion

It will be difficult for a graphic arts printer to make a good business plan in the printed electronics market. It was questioned whether the skills a graphic arts printers has would be of the same value in the printed electronics market. This paper explained how most electronic materials work through contact, alignment or chemical reaction and that any material preventing these processes from happening (such as a UV&EB oligomer or monomer) detracts from that electronic materials performance.

The printed electronics market is significant in that it will have a noticeable impact on our lives and the technology is very exciting. Our technical enthusiasm will need to be tempered with a more realistic assessment of the adoption rates of these new products, and the value and skills needed at each of the different manufacturing steps.

RadTech members can get the full detailed report at *www.radtech.org.*

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