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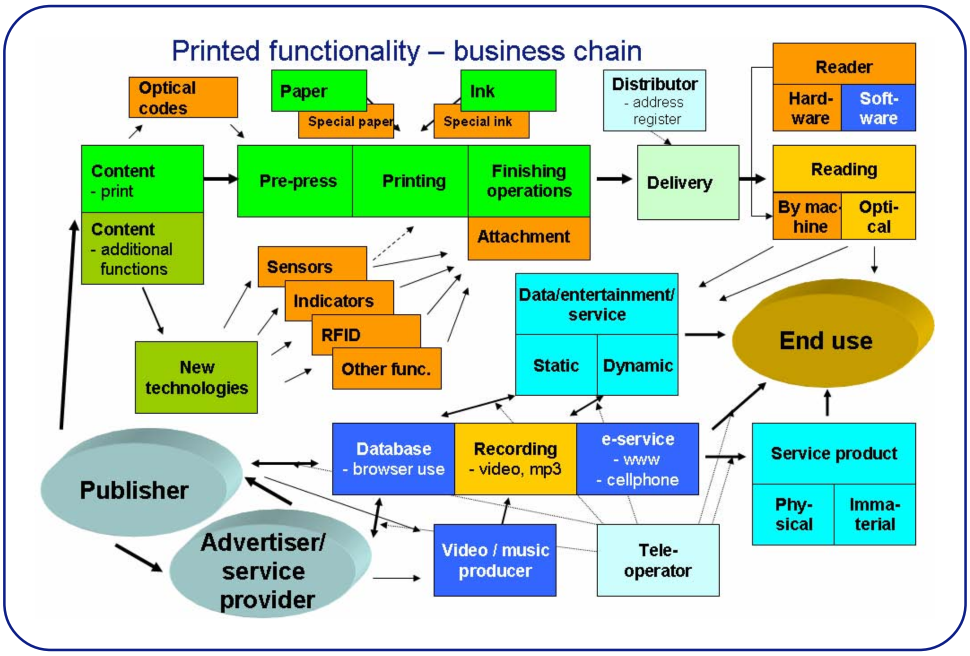

Ulf Lindqvist, Kim Eiroma, Liisa Hakola,
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Technical innovations and business from printed functionality

VTT TIEDOTTEITA – RESEARCH NOTES 2436

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Keywords printed functionality, business models, Value chain, 2D codes

Abstract

Printed functionality means adding new functionalities into flexible substrates like paper or plastic by using printing methods. It has been the scope of this study to define innovative new applications of printed functionality, to study the required technology and to create business models for these applications. Special attention has been paid to the new role of conventional printing plants in the value chain of printed functionality.

Roadmaps were created for the different technologies for printed functionality. Business models for the additional services available through printed functionality are complex because of the variety of earning logics and the number of players in the value chain. Each player has the opportunity to overtake new roles and functions.

The global market of printed electronics is expected to grow up to 40 billion euros until 2017. In the same time the global market for printed functionality suitable for conventional printers is expected to grow to 17 billions.

New applications of printed functionality were innovated in brainstorming seminars. Some of them were tested in pilot scale, business models were created for them, and they were also analysed regarding environmental aspects and usability.

In summary, printed functionality is an opportunity for the printing industry to create an additional value and service for their products, but requires demanding development work, clear business models and intensive cooperation with other players in the value chain like materials suppliers, machine manufacturers and service providers.

Preface

The research project "Technical Innovations and Business from Printed Functionality – FUNKTIOBISNES" has been carried out by four knowledge centres at VTT Technical Research Centre of Finland during the years 2006–2008. In a preliminary study in 2005 roadmaps were created for printed functionality, and huge technical potentials and global market opportunities were predicted. At the same time it became obvious that the business potentials and the future role of the printing industry in printed functionality needed to be outlined.

The project was initiated as a Key Technology Action with a strong support from the Centre of Printed Intelligence (CPI) of VTT. The project has been supported by Tekes – Finnish Funding Agency for Technology and Innovation, the Graphic Industry Research Foundation of Finland (GTTS) and by the following companies: Hansaprint Oy, Ikistoori Oy, Joutsenpaino Oy, Lomakevaihtoehto Oy, M-real Oyj, Sanomapaino Oy.

The project was governed by a Steering Committee with the following members: *Jukka Saariluoma*, Hansaprint Oy (chairman), *Henry Espo*, Joutsenpaino Oy, *Lasse Gädda* and *Markku Leskelä*, M-real Oyj, *Inkeri Huttu*, Tekes, *Tapani Korpihete*, Lomakevaihtoehto Oy, *Hannu Saarnilehto*, Sanomapaino Oy, *Atte Tuominen*, Ikistoori Oy, *Jaana Villikka* and *Helene Juhola*, VKL.

Project Manager has been *Ulf Lindqvist*, the technology surveys and roadmaps have been written by *Liisa Hakola*, expert for printed electronics and flexo printing has been *Salme Jussila*. *Pertti Moilanen* has been responsible for the value chains and the pilot scale printing tests, *Timo Siivonen* for the business models, *Timo Kaljunen* and *Kim Eiroma* for the inkjet printing tests, *Elina Rusko* for the environmental analysis and *Pasi Välkkynen* for the usability evaluations.

Espoo, on 29 February, 2008

Ulf Lindqvist, Kim Eiroma, Liisa Hakola, Salme Jussila, Timo Kaljunen, Pertti Moilanen, Elina Rusko, Timo Siivonen, Pasi Välkkynen

Contents

List of symbols and abbreviations

EB	Electron Beam
ERY	McKinley-Diffey Erythema action spectrum
HCD	Human-Centred Design
OCR	Optical Character Recognition
OLED	Organic Light Emitting Diode
PV	Photovoltaics
RFID	Radio Frequency Identification
SED	Standard Erythema Dose
UV	Ultra Violet
UVI	UV Index
1D bar code	One-dimensional bar code = linear bar code
2D code	Two-dimensional bar code
3D code	Three-dimensional code
Ω	Ohm, unit for resistance, inverse value for conductivity
µm	micro meter (10^{-6} m)
pl	pico liter (10^{-9} l)

1. Introduction

1.1 Background of the project

In the last years the printing industry has faced declining shipment and profitability worldwide. At the same time new applications for printing technology has been found in printed electronics and printed functionality. Printing technology is predicted to be the most efficient way to produce less demanding electronic circuits and components in the future.

Roadmaps for printed functionality were developed in a preliminary study at VTT in the year 2005. It became obvious, that the business potential and the future role of the printing industry in printed functionality needed to be outlined in a separate research project.

The project was initiated as a Key Technology Action with a strong support from the Centre of Printed Intelligence (CPI) of VTT.

1.2 Definitions

Printed functionality means adding new functionalities into flexible substrate, typically paper and plastic, in addition to regular graphical properties by using printing methods. Functionality can be on the surface of the substrate or within it, or both. Printed functionality can be codes containing links to additional information. Such codes include one- and two-dimensional bar codes as well as hidden/embedded, reactive and electronic codes. Furthermore, printed functionality can be visual effects and images, multi-layer structures, electronics, optics and displays as well as sensors and indicators.

Hybrid media is closely related to printed functionality. Figure 1.1 shows how printed media, digital media, printed functionality and hybrid media connect to each other. In the figure printed means that every part of the certain component is made by using printing methods. Printed/attached means that some parts of the component can be done by other means besides printing methods. One example is printed RFID tag where the antenna is printed and the chip attached to the printed antenna by other means.

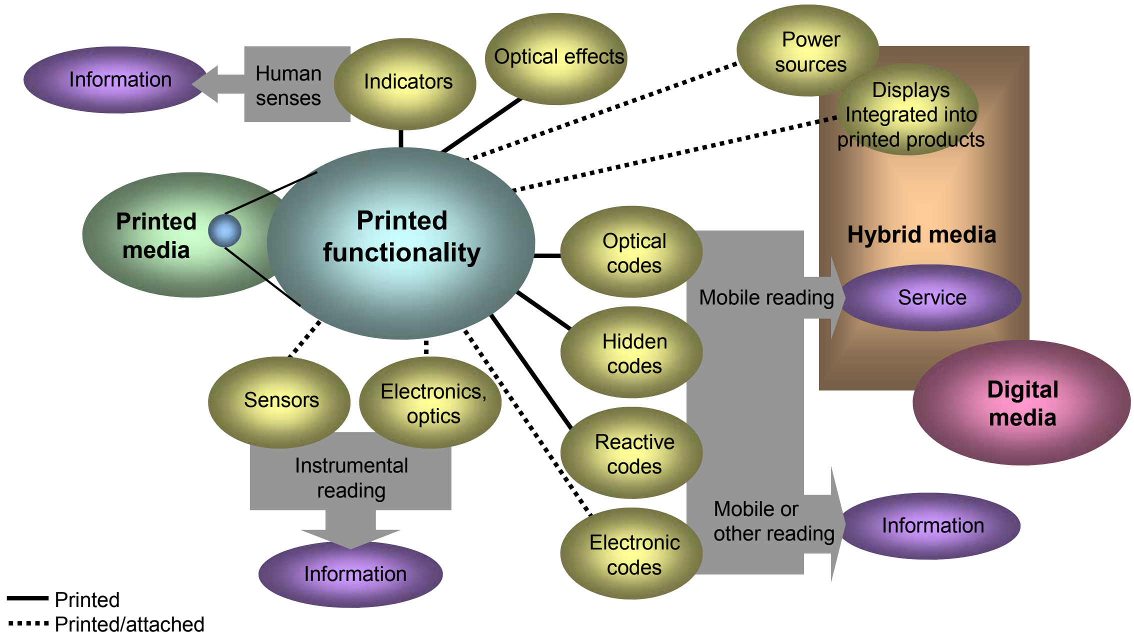

Figure 1.1. Definition of printed functionality and its link to printed media, digital media and hybrid media.

Hybrid media is defined as the integration of different media, contents and functionalities – especially convergence between fiber-based products and digital media. Electronic paper or e-paper (in Figure 1.1 displays integrated into printed products) belongs to the same context, even if the substrate here is plastics rather than fibre-based materials. One example of hybrid media applications is using printed two-dimensional bar codes as a link to digital media. A code printed on a publication or a package can be imaged with a camera phone that has software for decoding the information in the code. The decoded information can contain a link to a website which the user can access with the network connection in his mobile phone.

1.3 Technologies of printed functionality

Technologies that can be used for innovating new printed functionality applications and services, can be divided into electronics, optics, displays, optic codes, hidden codes, electronic codes, other codes, sensors, indicators and others. Tables 1.1–5 list technologies and their main properties in following categories: electronics and optics, displays, codes, sensors and indicators as well as others, respectively. In Table 1.1 only those technologies that are applicable for printed products are listed. Other technologies not listed include masks, via holes, interconnections and micro lenses.

Table 1.1. Printed functionality technologies in electronics and optics.

	Functionality	Special inks needed	Suitable printing methods	Reading technologies needed	Applicability for printed products	Other notes
Electronics						
Conductor	Conductive structure	Conductive ink	Flexo, gravure, screen, inkjet	Measurement of resistance	Packages, publications, documents, books, non-conventional substrates	Can be used in electronic codes
Capacitor	Passive component	Conductive and dielectric ink	Flexo, gravure, screen, inkjet	Measurement of capacitance		Can be used in sensors
Resistor	Passive component	Conductive and dielectric ink	Flexo, gravure, screen, inkjet	Measurement of resistance		
Inductor	Passive component	Conductive and ferrite ink	Flexo, gravure, screen, inkjet	Measurement of inductance		
Optics						
Light guide	Transferring light from one place to another, illuminating structures	Optical monomers and pre-polymers	Flexo, gravure, screen, inkjet	Human eyes	Packages	Requires a light source
Hologram	3D image	Aluminum particles	Flexo, gravure, screen, inkjet	Human eyes	Packages, security printing, publications	
Kinegram	Variable image depending on viewing angle	Metal particles	Flexo, gravure, screen, inkjet	Human eyes		
Optical effects	Shadows, highlights, special inks	Special inks or regular inks	Offset, flexo, gravure, screen, inkjet, electrophotography	Human eyes	All kinds	Might require a special light souce

Table 1.2. Printed functionality technologies in displays.

	Functionality	Special inks needed	Suitable printing methods	Reading technologies needed	Applicability for printed products	Other notes
Transistor	Semi-conductive component for displays	Conductive, semi-conductive and dielectric ink	Flexo, gravure, screen, inkjet	Current/voltage curves, On/off ratio	Packages, magazines, newspapers	Requires a power source
OLED display	Thin, flexible display with small power consumption	Transistors, transparent conductive ink, 1–3 light-emitting polymers	Flexo, gravure, screen, inkjet	Human eyes		
Thermochromic display	Display based on thermochromic phenomena	Thermochromic, conductive and dielectric ink	Flexo, gravure, screen, inkjet	Human eyes		
LCD display	Thin and cheap display	Optical binder, PDLC, binder, transparent conductor	Flexo, gravure, screen, inkjet	Human eyes		

Table 1.3. Printed functionality technologies in codes.

	Functionality	Special inks needed	Suitable printing methods	Reading technologies needed	Applicability for printed products	Other notes
Optical codes						
Linear / 1D bar codes	Identification of product groups	No	All	Bar code reader	Packages	EAN, UPC, JAN
2D bar codes	Identification of products	No	All, digital for personalization	Bar code scanner, mobile device with camera	All kinds, hybrid media	QR Code, Data Matrix, PDF417, Maxicode etc.
3D codes	Identification of products, colour etc. as 3rd dimension	No	All, digital for personalization	Bar code reader or scanner	All kinds, hybrid media	
OCR (Optical Character Recognition)	Identification based on text	No	All, digital for personalization		All kinds	The most challenges in reading technology
Hidden codes						
Micro text	Packing and hiding text	No	All	Magnifying device	All, especially security products	
Digital watermarks	Hiding information	No	All	Digital watermark reader software in camera device	All, especially security products, hybrid media	
Reactive codes	Hiding information, providing effects	Reactive ink (invisible, thermochromic, erasable etc.)	All	Code reader or scanner	All, especially security products	May require a special light source
Electronic codes						
RFID (antenna)	Information in machine readable form	Conductive ink	Flexo, gravure, screen, inkjet	RFID reader, remote reading	Packages, hybrid media	Chip also needed for RFID tag
Conductive bar codes	Code made of conductive material	Conductive ink	Flexo, gravure, screen, inkjet	Code reader, contact reading	Packages, hybrid media	
Other codes						
Magnetic codes	Information in machine readable form	Magnetic ink	Flexo, gravure, screen, inkjet	Magnetic reader	Packages, security printing, hybrid media	

Table 1.4. Printed functionality technologies in sensors and indicators.

	Functionality	Special inks needed	Suitable printing methods	Reading technologies needed	Applicability for printed products	Other notes
Sensors						
Temperature sensor	Senses changes in temperature, instrumental reading	Conductive inks	Flexo, gravure, screen, inkjet	Resistance measurement at different temperatures	Packages	User needs a reading device
Humidity sensor	Senses changes in moisture, instrumental reading	Conductive inks, humidity-sensitive material	Flexo, gravure, screen, inkjet	Resistance measurement at different humidity	Packages	User needs a reading device
Indicators						
Freshness indicator	Indicates changes in chemical environment	Material sensitive to freshness	Flexo, gravure, screen, inkjet	Human eyes	Packages	
Humidity indicator	Indicates changes humidity	Material sensitive to humidity	Flexo, gravure, screen, inkjet	Human eyes	Packages	
Temperature indicator	Indicates changes in temperature	Material sensitive to temperature	Flexo, gravure, screen, inkjet	Human eyes	Packages, printed media	

Table 1.5. Other printed functionality technologies.

	Functionality	Special inks needed	Suitable printing methods	Reading technologies needed	Applicability for printed products	Other notes
Power sources	Battery or similar	Oxide materials, conductive and dielectric inks	Flexo, gravure, screen, inkjet	Not needed	All kinds where power needed	
Solar cell	Transforms light into electricity	Transparent conductive ink, active material, conductive and semi-conductive inks	Flexo, gravure, screen, inkjet	Not needed	All kinds where power needed and used in sunlight	
Bioactive applications	Analyzes and improves conditions and environment	Bio-active material, conductive inks	Offset, flexo, gravure, screen, inkjet	Human eyes or instrumental reading	All kinds	
Decoration	Decoration to non-conventional substrates	No	All	Human eyes	All kinds if based on other than fibre-based	

1.4 Markets of printed functionality

In a preliminary study in 2005 business roadmaps for printed functionality were made for both Finland and the global market. Table 1.6 shows the results obtained in this study.

Table 1.6. Business roadmap on hybrid media.

	2005	2008	2010	2015
GLOBAL				
TURNOVER	230 M€	500 M€	1.500 M€	10.000 M€
PERSONNEL	750 my *	1.200 my	5.000 my	23.000 my
MARKET SHARE	100 %	100 %	100 %	100 %
COMPANIES	< 30	< 100	< 300	< 500
FINLAND				
TURNOVER	5 M€ **	25 M€	65 M€ ***	500 M€
PERSONNEL	~ 20 my	80 my	200 my	1.200 my
MARKET SHARE/EU	10 %	20 %	15 %	15 %
COMPANIES	~ 3	~ 5	~ 20	~ 50

* my = man years (the number of persons involved in the activities are 2–3 times higher)

** the turnover of Finnish mass media 2003 was 3,7 B€

*** the break-through of e-papers is expected to come 2010–2012

The business roadmap showed a significant growth in hybrid media and e-paper activities during ten years, for example turnover in Finland was expected to become hundred times bigger and also the global turnover would become over forty times bigger. It was expected that Finland will have a large market share of 10–20 % in Europe since Finland is strong in mobile technology. Finland also already has research activities on hybrid media for several years and several hybrid media pilots have been done in Finland especially during last two years.

Besides hybrid media and electronic paper also the other sectors of printed functionality showed considerable growth potential. Figure 1.2 summarizes all business roadmaps made in the study. The total global turnover was estimated to be about 2500 M€ 2005 and was expected to grow 28 times to 70 000 M€ in 10 years. The OLED displays were the most important sector, whereas materials and manufacturing of other components (including low-quality OLED displays) were expected to be number two. The other sectors were still of small volume. Printable sensors were expected to grow rapidly in the next years to come, but a slight saturation was expected after 2010. Hybrid media should have an exponential growth accelerated by the deployment of electronic paper around 2012. Visual indicators on packages have a similar growth curve as hybrid media, but the volume is about the half.

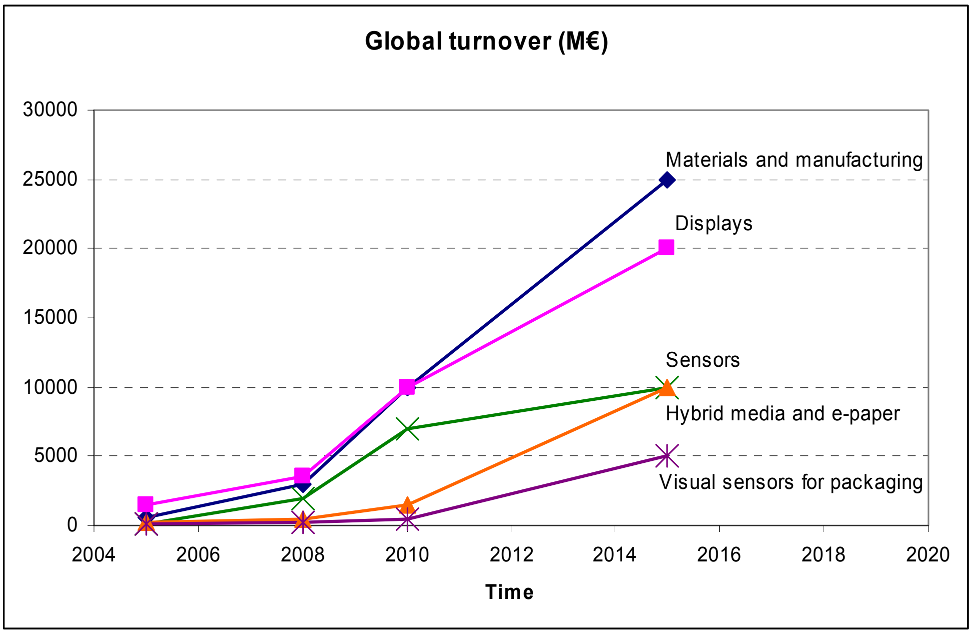

Figure 1.2. Expected growth of printed functionality in different sectors.

For Finland, the corresponding trends are given in Figure 1.3. From a marginal volume today, especially OLED displays as well as hybrid media and e-paper were expected to grow very rapidly. Altogether, the sectors would generate 1500 M€ turnover year 2015 and employ about 5000 man years. In hybrid-media and e-paper, Finland could gain 5 % of the global market, in other sectors significantly less.

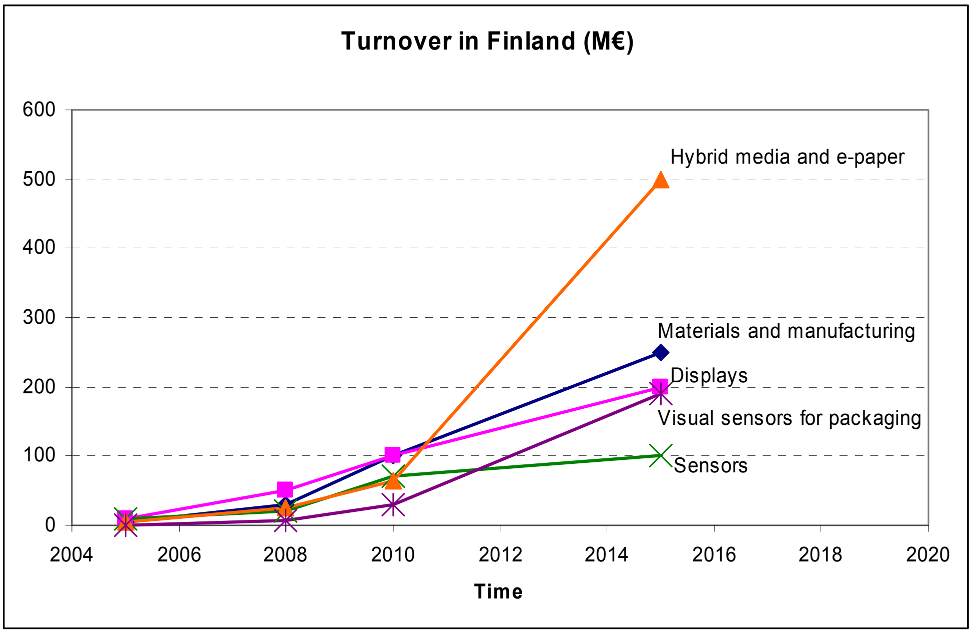

Figure 1.3. Expected growth of printed functionality turnover for Finland.

1.5 Scope of the project

It has been the scope of this study to define some innovative applications of printed functionality, and to create business models for these applications. In the first step the printed functionality production has been classified and typical innovations have been defined within each cathegory. After this, the production processes for the new applications were analysed and the sufficiency of traditional printing plants to meet the technical requirements was estimated. Finally, general business models were developed for the most important types of applications.

The final aim has been to define the new role of the printing plants in the value chain of printed functionality. Special attention was paid to the performance of traditional printing plants, which types of new services are within their ability and what kind of material and immaterial investments are needed. This should involve an evaluation of existing know-how and technology compared to new requirements and investment needed in human resources and equipment.

2. Technical demands on printed functionality

2.1 Hybrid media

Hybrid media is defined as the integration of different media, contents and functionalities – especially convergence between fiber-based products and digital media.

2.1.1 Types of hybrid media codes

The most common hybrid media codes are nowadays two-dimensional bar codes (2D codes). Another upward hybrid media technology is digital watermarks. 2D codes are optical and digital watermarks hidden/embedded. However, both of the codes can be decoded with camera phones if suitable software is available. Also there are several PC software available for creating such codes.

2D codes consist of lines of bars or cells i.e. usually small polygons and the lines are organized in a square or a rectangle i.e. a matrix. The organization of the elements depends on the bar code type and the information encoded into the symbol. Examples of 2D codes are presented in Figure 2.1. 2D codes have large information capacity and the information is durable. Linear bar codes can be used to identify an object and the identification number serves as a link to a database. The data density of 2D codes is greater, and in addition to containing an identification number, they can contain data such as a direct web link that does not need to be first queried from a database. This enables the information to be read anywhere if a suitable decoding device is available. Also the physical size of 2D codes is scalable without affecting the amount of information.

Figure 2.1. Two-dimensional bar codes: from left Code 49, QR Code and Data Matrix.

Several companies including Upcode, ShotCode, Intelcom and Nokia offer suitable 2D code decoding software that can be installed into different camera phone models. 2D code type QR Code is popular in Asia whereas Data Matrix in Europe and USA.

Digital watermarking means hiding digital information into images, music, videos or printed documents. In the case of images pixel content is modified – usually by locally diminishing the amount of blue pixels i.e. digital watermark appears as yellow pixels embedded into the image. Figure 2.2 presents the principle of digital watermarking. Usually digital watermark can't be seen with naked eyes, but in hybrid media applications it has to be visible to some extent in order that camera phone can find it. Digimarc from USA is the leading digital watermark developer and they offer camera phone software for decoding digital watermarks.

Figure 2.2. The principle of digital watermark. From left: original image, image with digital watermark and digital watermark i.e. modified pixels. (Image source: Digimarc, www.digimarc.com)

RFID readers are becoming available for mobile phones (for example Nokia 6131 NFC model) and personal digital assistants (PDAs). They allow similar hybrid media applications as bar codes and 2D codes. The difference between RFID and optically readable codes in this scenario is that RFID codes can contain more information, for example several URLs, phone numbers etc, but they are more expensive and printing them is more challenging, typically demanding attaching the chip after printing.

2.1.2 Demands on processes

Hybrid media codes can be printed along with other graphic content. If codes have to be personalized, they have to be printed with digital printing methods to allow online (inkjet) or offline (electrophotography) personalization. The biggest challenges in hybrid media are with coding and reading technology. The things to consider include:

- what code type to use
- where to get a suitable reading software
- is there a licence fee for using reading software
- how to distribute reading software to end-users
- is reading software free to end-users.

However, as long as the code type can be chosen code creation is straight-forward since there are several – even free – PC software available for code creation. These software create the code with desired content as an image file that can be included in the print lay-out.

2.1.3 Demands on materials

The most common hybrid media codes can be printed with regular graphic inks. However, if physically very small codes have to be made, the printing substrate has to be high-quality to prevent ink spreading. Codes can easily become unsuitable for decoding due to too excessive ink spreading. If hybrid media codes are reactive, conductive or magnetic, special inks have to be used for printing.

2.2 Indicators and sensors

The difference between indicators and sensors is that indicators can be detected with human senses (usually visible colour change), but sensors require instrumental reading. In instrumental reading usually some standard property such as conductivity is measured and the reading device transforms the measurement result into response that the end-user can easily understand. Sensors can also collect information over a period of time and present the whole history when read.

2.2.1 Demands on processes

Sensors and indicators require special inks for printing which results in a need for extra printing units for these materials. If the sensors and indicators are pre-printed in other location and added as a label to the final product an attachment unit is needed. In the case of packages it has to be considered in which production phase the sensor or indicator will be added. Options include during package printing, during packing or after packing. In the two latter cases inkjet printing is the most suitable printing method, but in the first case also conventional printing methods can be used. Some sensors and indicators might also need activation after printing so it has to be considered how, when and where activation should be done. Furthermore, reading device for sensors has to be developed.

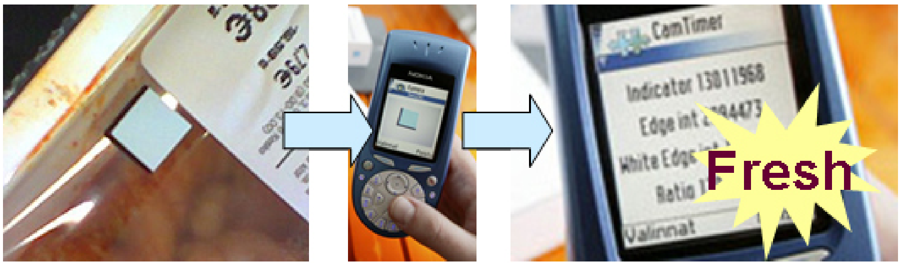

Figure 2.3. Also printed indicators can be interpreted instrumentally.

With indicators some solution for telling the end-users about the colour change has to be considered. So far there are no standards that define what colour change to use (from red to blue or from green to yellow etc.) so the end-user might be confused if different producers use different colour change. One way to achieve this is by using camera phone software for telling the end-user about the correct colour change reaction and for confirming that the end-user has interpreted the colour change correctly /Hak05/. Figure 2.3 presents an example of such a case.

2.2.2 Demands on materials

Special inks are needed for printing indicators and sensors. The compatibility of the inks and substrates used in each case has to be optimized since compatibility has an effect on performance. Also different products and applications set different demands for sensitivity and performance of the indicators and sensors which also requires precise optimization from the material point-of-view.

2.3 Printed electronics

Printed electronics means electronic devices or components fabricated from conductive, semi-conductive and/or dielectric materials by the means of printing technology. The electronic device or component can serve as an independent unit or as a part of a larger system. Printed electronics enables inexpensive single-use electronics, but can not replace silicon in high-performance applications. Printed optics and opto-electronics are often included in the general term of printed electronics. /Lin06/

2.3.1 Demands on processes

Printed electronics requires from one to several printing units for making a certain component. These printing units have to be online or if the component is attached as a separate label an attachment unit is needed. Also many electronics inks require special curing for activation such as heat for several minutes or UV-curing resulting in a need to integrate also new curing units.

Printed electronics usually requires better accuracy and smaller details than are used for graphic applications. Special attention should be paid to the design of printed electronics printing units and processes, because existing graphic processes might not be suitable for printing electronics. For example, many electronics applications require accuracy of 1–10 µm whereas presses designed for graphic applications can only meet the level of 20–50 µm (Figure 2.4).

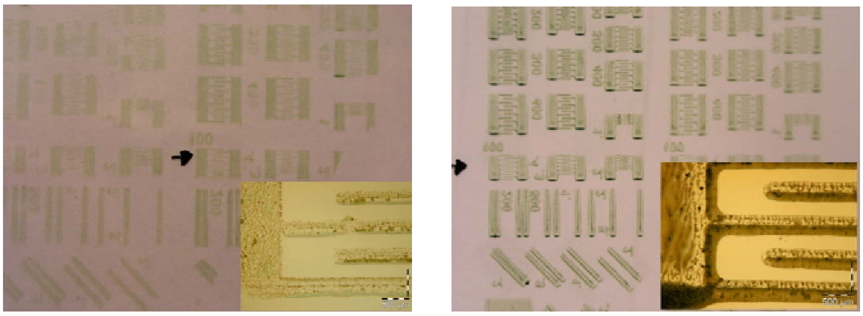

Figure 2.4. Flexo printed Drain-Source electrode structures for organic transistors. On the left toluene based Pani-T solution and on the right N-metyl pyrrolidone based Pani-M solution (both from Panipol Ltd.) has been used.

With printed electronics it should be kept in mind that moving from laboratory-scale to industrial-scale will always result in significant loss in performance. The losses are due to production variations, compromises for process tolerance, operator variations and reliability concerns among other things. /Kah07/

2.3.2 Demands on materials

Special inks are needed for printed electronics. The compatibility of the inks and substrates used in each component has to be optimized since compatibility has a direct effect on the final performance. Since many components consist of several different ink layers also compatibility between different inks has to be adjusted.

Many inks for printed electronics are considerably expensive. One litre of metal nano-particle ink can cost nearly 10 000 €. High price hinders the use of electronics inks in industrial-scale – especially with conventional printing methods where material consumption is higher than in inkjet printing. Ink manufacturers should pay more attention to lowering ink prices. For example special inks (thermochromic, UV fluorescent etc.) for UV flexo cost about 50–500 €/kg.

2.4 Technology roadmap

Tables 2.1 and 2.2 present roadmap on different printed functionality technologies for Finland and globally, respectively. Figures 2.5 and 2.6 summarize the roadmap, respectively. The different levels in the roadmap include technology available, the first commercial pilot and established use. The different technologies are divided into 8 categories including hybrid media: optical codes, hybrid media: hidden/embedded codes, printed indicators and sensors, special effects (reactive inks) in other uses besides security printing, electronic codes/RFID, printed electronics and optics, displays integrated into printed products (based on E-Ink technology) and printed power sources. In this context RFID means all RFID technologies. Printed RFID technology would fall into the same category as printed electronics.

Table 2.1. Printed functionality technology roadmap for Finland.

Technology	Available	First commercial pilot	First established use case	Commercial solutions in wide use
Hybrid media: optical codes	2005 (1)	2005 (1)	2009	2010
Hybrid media: hidden/embedded codes	2007 (2)	2007 (2)	2009	2010
Indicators and sensors	2002 (3)	2003 (4)	2010	2012
Special effects	1980's-1990's	Early 2000's (5)	2008	2010
Electronic codes/RFID	Codes: 1990's RFID: 1960's	Codes: 2007 RFID: 1970's	Codes: 2009 RFID: 1990's	2012 RFID: 1990's
Printed electronics and optics	Early 2000's	2008	2010	2015
Displays integrated into printed products	Early 2000's	2005 (6)	2007 (7)	2010
Power sources	2006 (8)	2008	2012	2013

(1) The first Upcode trial in Sopranos's publications
(2) Upcode: Koli opas will include hidden codes in late 2007
(3) VTT files a patent on printed freshness indicators /Hei06/
(4) Findus tests Bioett indicator for transportation of meat balls to IKEA in Finland /Hak06/
(5) e.g. a label in the cider bottle
(6) CityMarket Malmi uses E-Ink technology for shelf labels
(7) Ella Store Labels (UPM-Kymmene) /Nik07/
(8) Enfucell developed screen printed power source /Mik07/

Table 2.2. Printed functionality technology roadmap globally.

Technology	Available	First commercial pilot	First established use	Commercial solutions in wide use
Hybrid media: optical codes	Japan 2003 (1) Others 2006 (2)	2003 (1)	Japan 2005 (3) Others 2009	2010
Hybrid media: hidden/embedded codes	2004 (4)	2005 (5)	2007	2010
Indicators and sensors	2003 (6)	2003 (7)	2003 (8)	2011
Special effects	1980's-1990's	Late 1990's	Early 2000's	2005
Electronic codes/RFID	Codes: 1990's RFID: 1959 (9)	Codes: Early 2000's RFID: 1970's (9)	Codes: 2008 RFID: 1990's (9)	Codes: 2010 RFID: 1990's
Printed electronics and optics	Early 2000's	2006 (10)	2008	2012
Displays integrated into printed products	Early 2000's	2004	2005	2008
Power sources	2001 (11)	2007 (12)	2010	2012

(1) Teleoperators NTT DoCoMo and Vodafone pre-install decoding software into camera phones
(2) February 2005: 64 % have used hybrid media codes at least once, 89,1 % have seen codes in publications/packages /Ntt05/
(3) Nokia pre-installs decoding software to N9X Series camera phones
(4) Mobot in USA
(5) ELLEgirl magazine tests Mobot technology /Hak06/
(6) Swedish BioEtt: printed time-temperature indicator /Hak06/
(7) Findus tests Bioett indicator for transportation of meat balls to IKEA in Finland /Hak06/
(8) Swedish Skånemejeriet has used BioEtt since 2003 /Hak06/
(9) RFID tags invented 1959, RFID tags for theft prevention introduced 1970's and become popular 1990's /Rie06/
(10) The first simple games and electronic books including printed electronic come to market /Org06/
(11) Power Paper introduced the first printed power source
(12) Japan: Toppan Printing installed information displays into sub-way stations with printed power source

In Figures 2.5 and 2.6 when the curves cross with different roadmap levels (established use etc.) it means that the technology has reached that level during the corresponding year presented in x-axis.

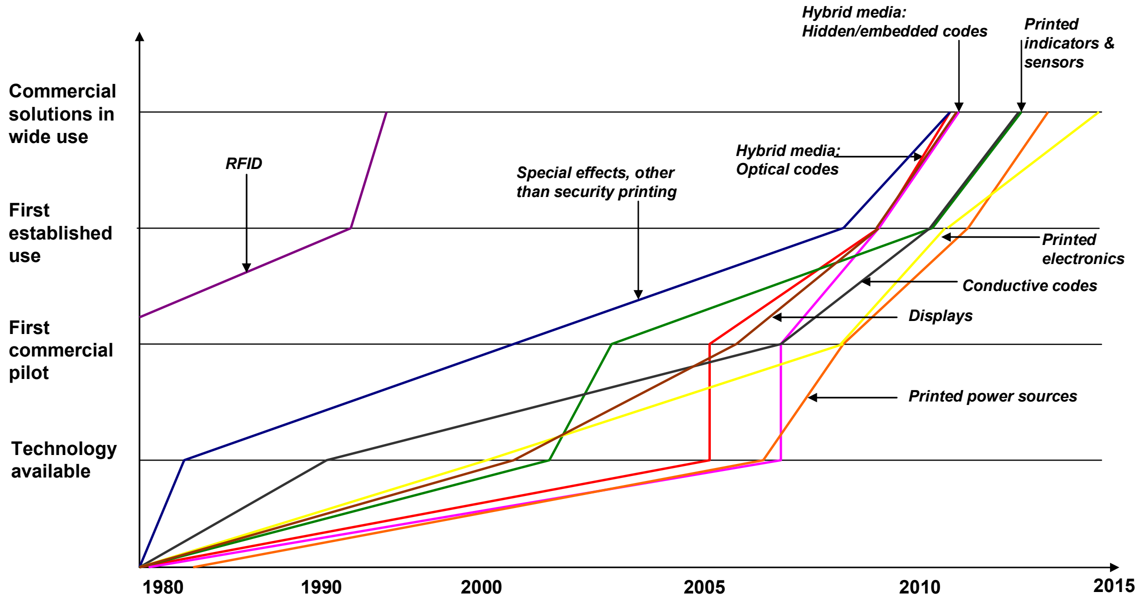

Figure 2.5. Printed functionality technology roadmap for Finland.

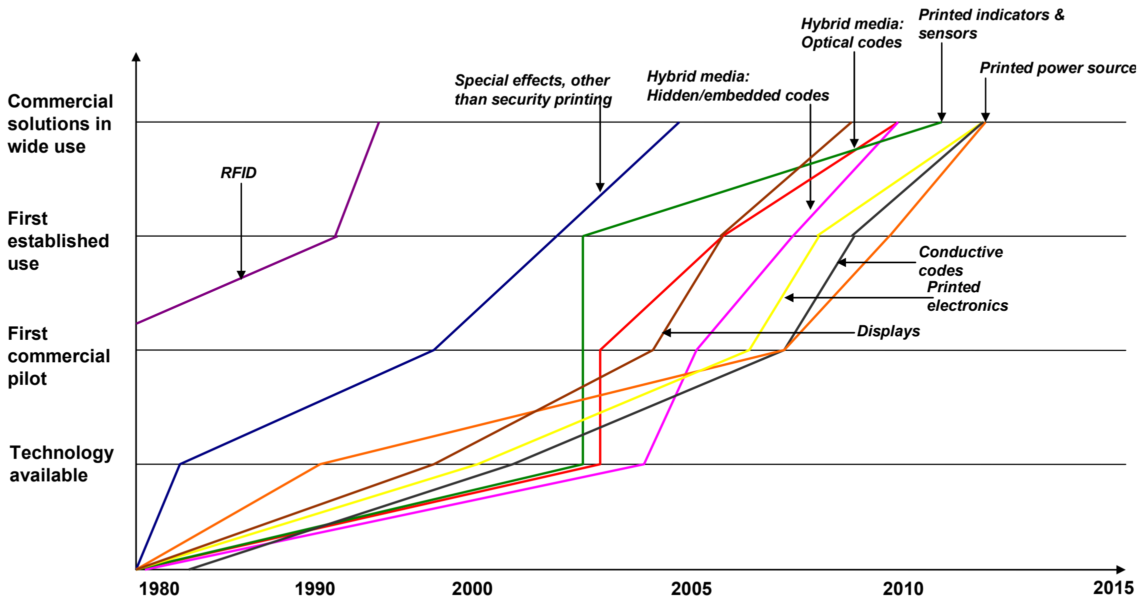

Figure 2.6. Printed functionality technology roadmap globally.

From the roadmaps it can be seen that many printed functionality technologies have been available for several years or will become available in the next few years. Especially inks for special effects, hybrid media technologies, displays based on E-Ink technology and printed indicators have been available already sometime, but their established use is just kicking-off – at least in Finland. Also in the near future it is expected that many technologies will have their commercial breakthrough. The trend seems to be that the more different functional materials are needed for making a certain component and the more intelligent the material itself is, the later the technology will become common. For example, hybrid media is based on graphic inks and it will become common sooner than active printed electronics that is based on conductive and other functional inks.

It can be seen that in piloting and commercial use Finland is a bit behind from the global schedule. However, it should be remembered that in some cases global established use might not mean that all other countries besides Finland use certain technology. For example, with hybrid media Japan is ahead of Finland, but the rest of the world is behind.

Printed power sources are a necessity for many applications based on e.g. displays or printed electronics. However, printed power sources are expected to become common later than the technologies that rely on them. This probably means that at first printed electronics applications will be based on external, not-printed, power source or are passive components that don't require a power source.

One observation is that printed electronics will become common earlier than electronic codes. Although electronic codes are usually considered simpler than printed electronics they always require a special reading device. The developmental status of these reading devices hinders the use of electronic codes although the technology itself has been available for some time. On the contrary, printed electronics can be used in many applications outside consumer applications where instrumental reading is easier to implement. For example, printed electronics can be simple conductors and there are several existing measuring technologies for them.

3. Business models for printed functionality

3.1 The logics of earning in printed functionality

The earning logics of printed functionality is much wider than in traditional printing or media production. It can be based on at least

- direct sell, e.g. ordering a product or a service via a barcode in the ad
- AD sales, e.g. banners on sites with access via hybrid media
- access and subscription, e.g. access to pay sites over hybrid media
- royalties and licences, e.g. entertainment available over hybrid media
- selling of brands, e.g. connecting to brand sites over hybrid media
- freemium models, e.g. giving restricted access for free
- management of logistics, e.g. identification of registered mail via barcodes or RFID tags
- e-Business, e.g. any form via links to printed media.

In most cases the printed functionality offers an additional (interactive) value or service to an existing product to a low additional cost. To find the earning logics is often the main part of the innovation.

The players have the possibility to extend their roles in printed functionality and one of them may control the whole value chain. This is illustrated more in detail in Chapter 3.4.

The publisher has the strongest position and can easily expand his role and become a data base provider and also manage content creation. He can also manage the additional services of the media. Also the printer can expand his role by managing the new technologies. He can principally also become a data base and content provider.

3.2 The markets of printed functionality

In a Delphi study performed by eleven experts the development of the Finnish market of publication, printing and printed functionality were estimated to grow like in Figure 3.1 until the year 2017. The graph shows the meridian of the experts. The expected growth is very modest in this evaluation in average, but the variations between the experts were significant. The optimists expected a growth in turnover up to 2 billion euros until 2017. The export was estimated to be 35 per cent of the turnover of printed functionality in 2017, and the share of producers related to the traditional printing industry was estimated to be the same.

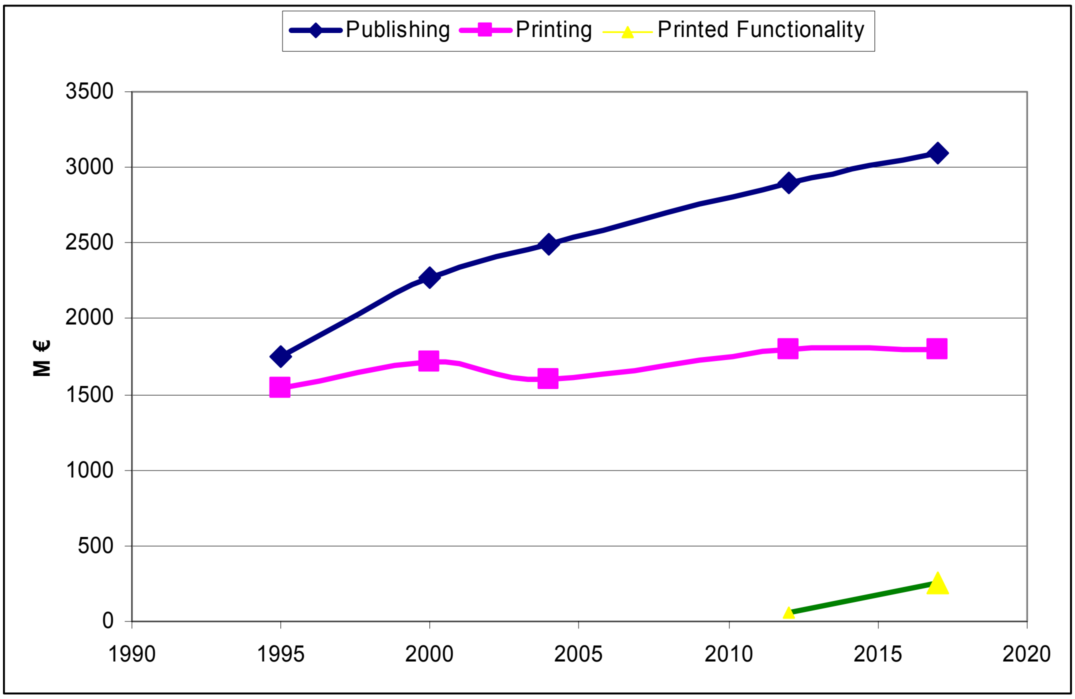

Figure 3.1. The estimated growth in Finnish publication, printing and printed functionality according to an expert panel of eleven persons.

The expert on printed electronics B. Kahn (2007) emphasizes the need for the printing industry to find a new standleg because of the globally declining industry shipments and profitability in combination with increasing costs for printing equipment (Figure 3.2).

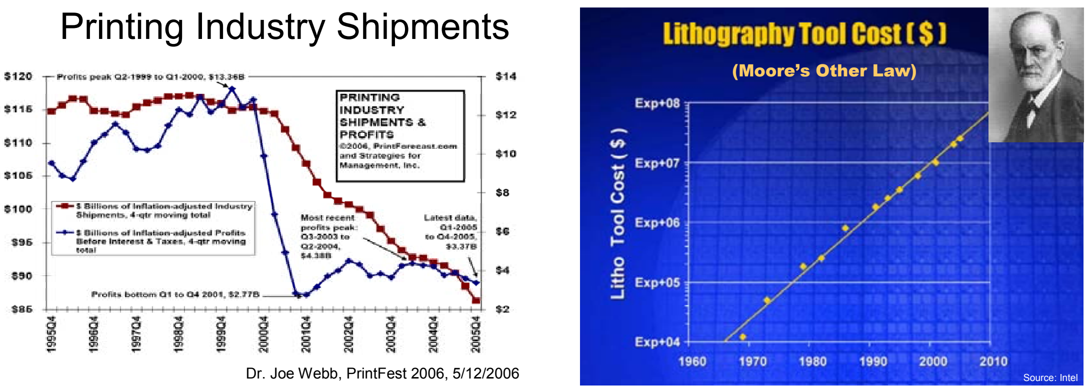

Figure 3.2. The global market of the printing industry suffers from declining profitability and increasing equipment costs.

Table 3.1 gives an updated version of the expected markets for printed functionality in Finland and globally. The estimation is based on the expertise available at VTT.

Table 3.1. An estimation of the markets of printed functionality.

	2005	2008	2010	2015	2018
GLOBAL					
TURNOVER	150 M€	240 M€	1.100 M€	7.500 M€	17.000 M€
PERSONNEL	1.000 my	1.400 my	5.500 my	31.000 my	65.000 my
MARKET SHARE	100 %	100 %	100 %	100 %	100 %
COMPANIES	~ 150	~ 200	~ 500	~ 2.000	~ 3.000
FINLAND					
TURNOVER	3 M€	12 M€	40 M€	175 M€	250 M€
PERSONNEL	~ 20 my	~ 70 my	~ 200 my	~ 750 my	~ 1000 my
MARKET SHARE/EU	10 %	20 %	15 %	12 %	10 %
COMPANIES	~ 3	~ 10	~ 20	~ 50	~ 50

3.3 General models for printed functionality

The value chain of printed functionality contains a number of new players compared to the conventional chain of the printing process. New players are at least the providers of service, technology, on-line content, tele-operators and the suppliers of new materials.

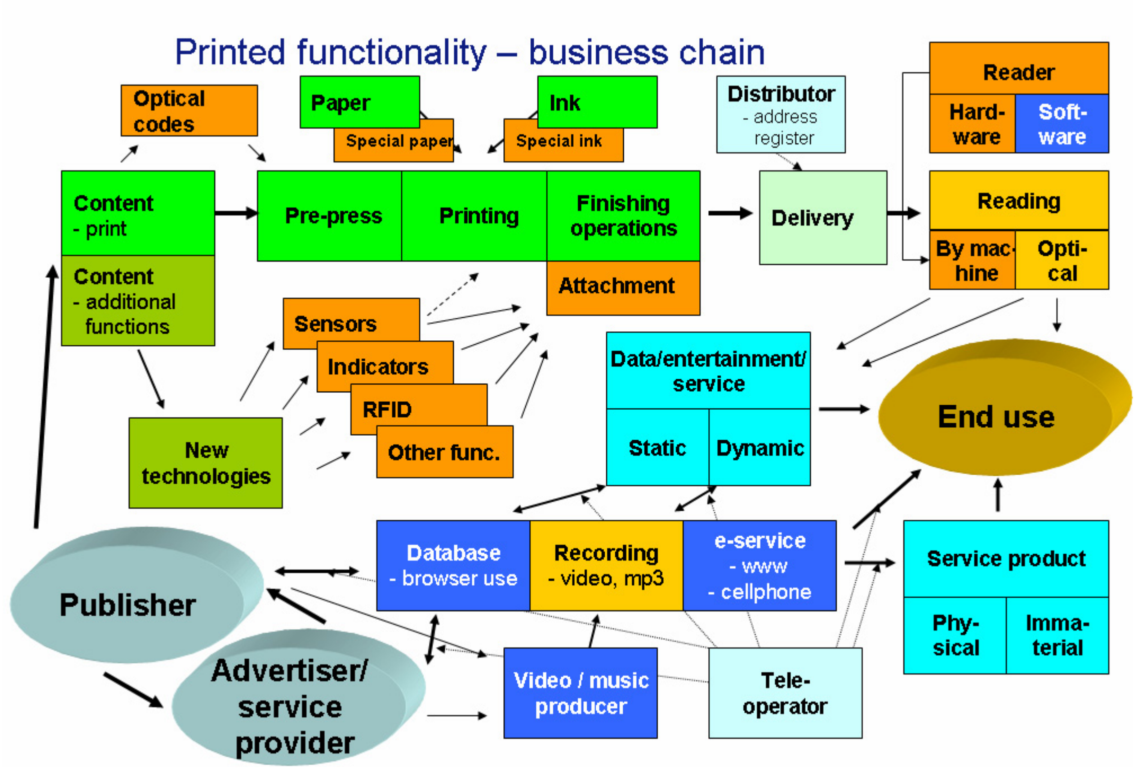

Figure 3.3. The business chain of printed functionality and its main players.

3.3.1 Hybrid media

Regarding the visual 2D-codes, all information is read from the code or the code offers a link to hybrid media. In both cases the printing of the code is not a technical problem. The main product or the application could be nearly whatever. Of course for rough surfaces the resolution of the print may limit the minimum size of the code or the data size.

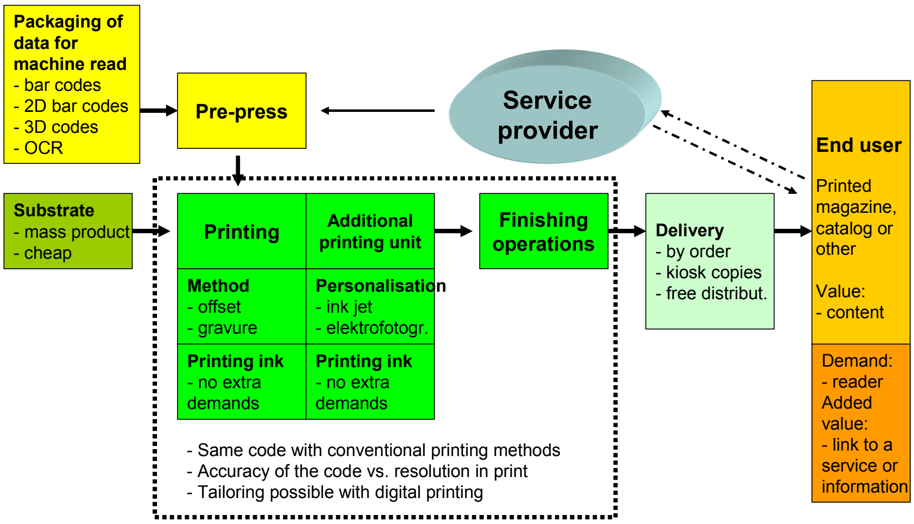

Figure 3.4. The manufacturing chain of optical codes.

From business point of view the hidden optical code is a far more complex solution. The realized user group of hidden codes is significantly smaller than the user group of visual codes. This means that the business potential is only just starting to grow. On the other hand the information – exact place, required reader – about the hidden code should be told to the customer via another channel.

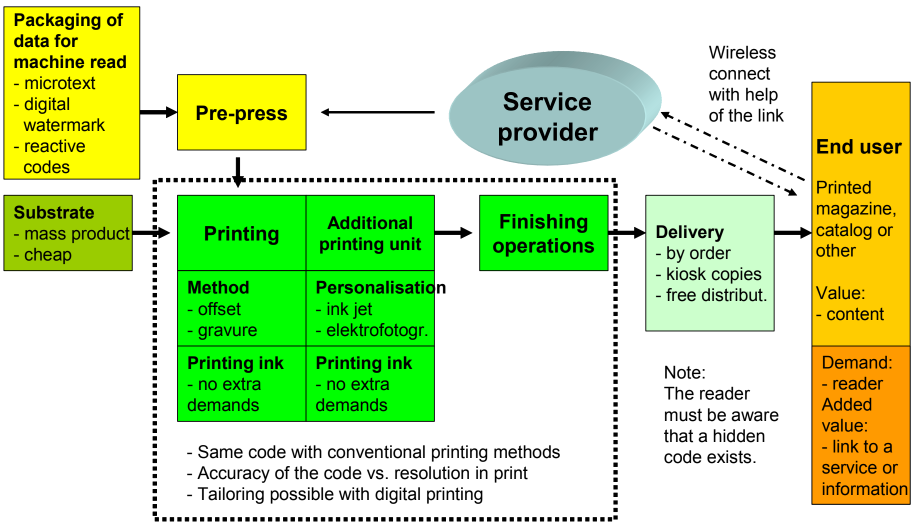

Figure 3.5. The manufacturing chain of invisible codes.

3.3.2 Indicators and sensors

The easiness of printing indicators and sensors with special ink is strongly related to matching the ink properties with the specified printing method. When printing as a part of the main run of the volume product, the ink properties must be tailored to fulfil the needs of a given printing unit type in a proper speed range. As a matter of fact the printing speed of the volume product may not be decreased under a certain level because the printing process is optimized to work in a certain speed range. Of course the typical tight production schedule also prevents running with low speed. Therefore it is obvious that a common process will be to print indicators and sensors beforehand and attach them to the volume product.

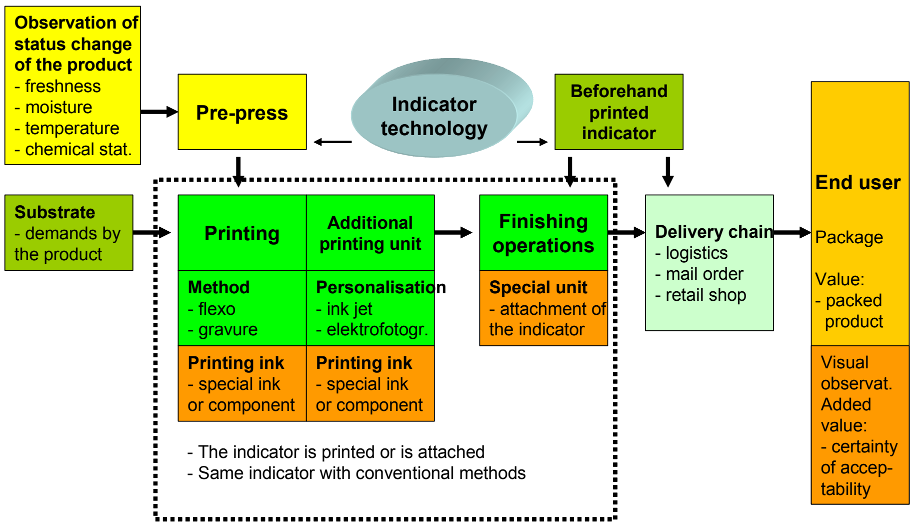

Figure 3.6. The manufacturing chain of indicators.

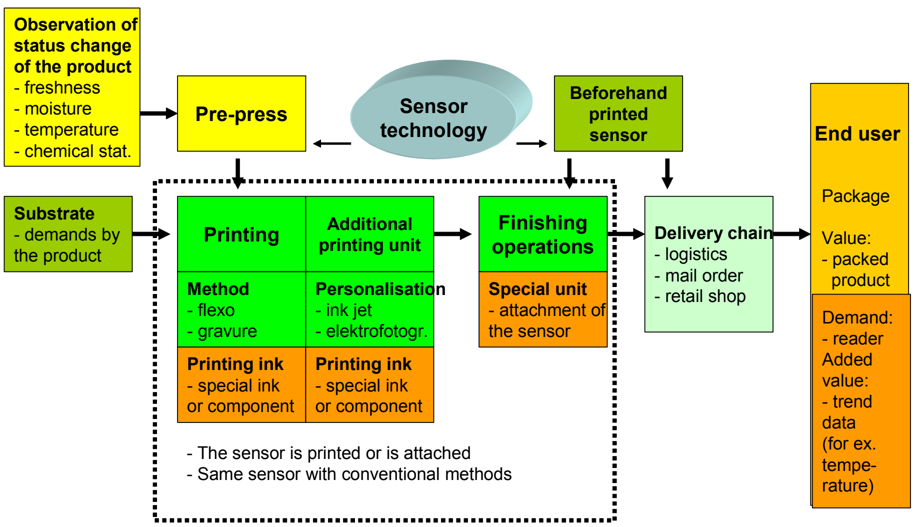

Figure 3.7. The manufacturing chain of sensors.

3.3.3 Printed electronics

Fabrication of electrical circuits and other functional systems on flexible substrates can take place as a roll-to-roll printing process. This can significantly lower the production costs due to a higher throughput and the reduction of process steps. However, there are two important fields of research that will have a lot of influence on the realization of printable organic electronics: a) the functional materials e.g. semiconducting polymers must be tailored to the printable form and b) the printers must be modified to work with these new functional inks /Söd05/.

In Figures 3.8 and 3.9 the production of electronics is integrated as part of the conventional process (of a printed product). It should be noted that this has been done only in order to compare the chain with the previous cases as in Figures 3.4–3.7. In practice the production chain of printed electronics is more complicated and is mainly based on special equipment.

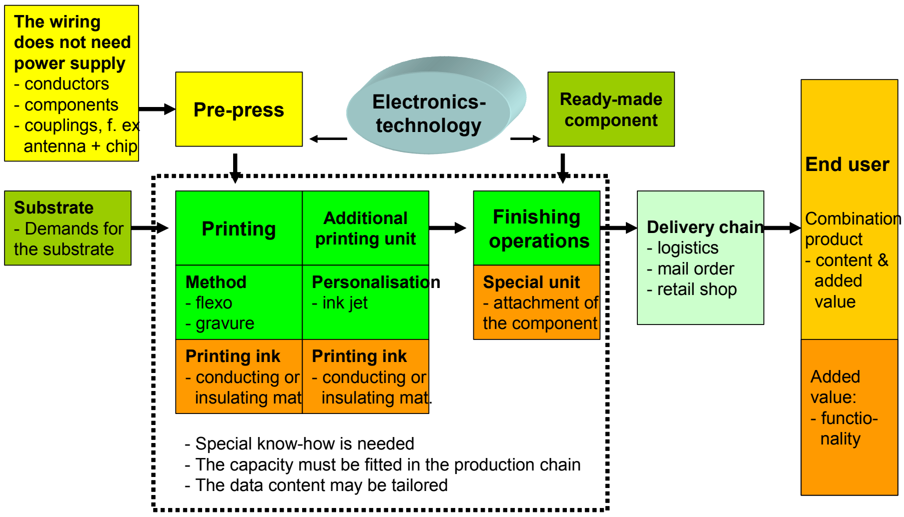

Figure 3.8. The manufacturing chain of passive electronics.

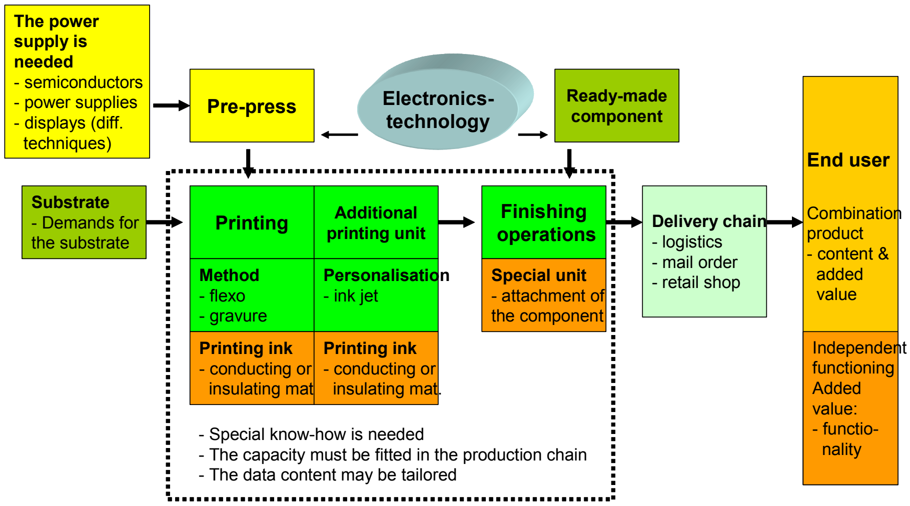

Figure 3.9. The manufacturing chain of active electronics.

The presentations in "Printed Electronics USA" conference this year give some sort of perspectives to these problems and their solutions. For example Walt Bonneau of Cubic Corporation expressed his view that printed electronics offers a host of opportunities for the transit industry, providing cost effective replacements of conventional ticketing, and Thomas Jensen of Paksense said that they believe that there are tremendous opportunities to apply printed electronics technologies in smart packaging and labelling /Pri07/. At least there are many participants involved in the research of printed electronics just to mention 200 organizations now developing printed transistors.

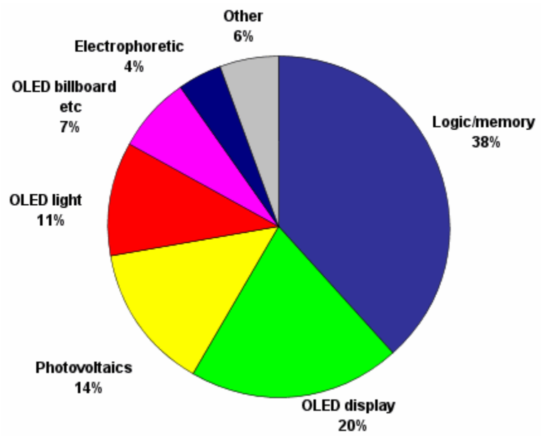

Figure 3.10. Market forecast to 2027 – a $330 billion market. The chart shows the value by component in 2027 (Source: IDTechEx) /Idt07/.

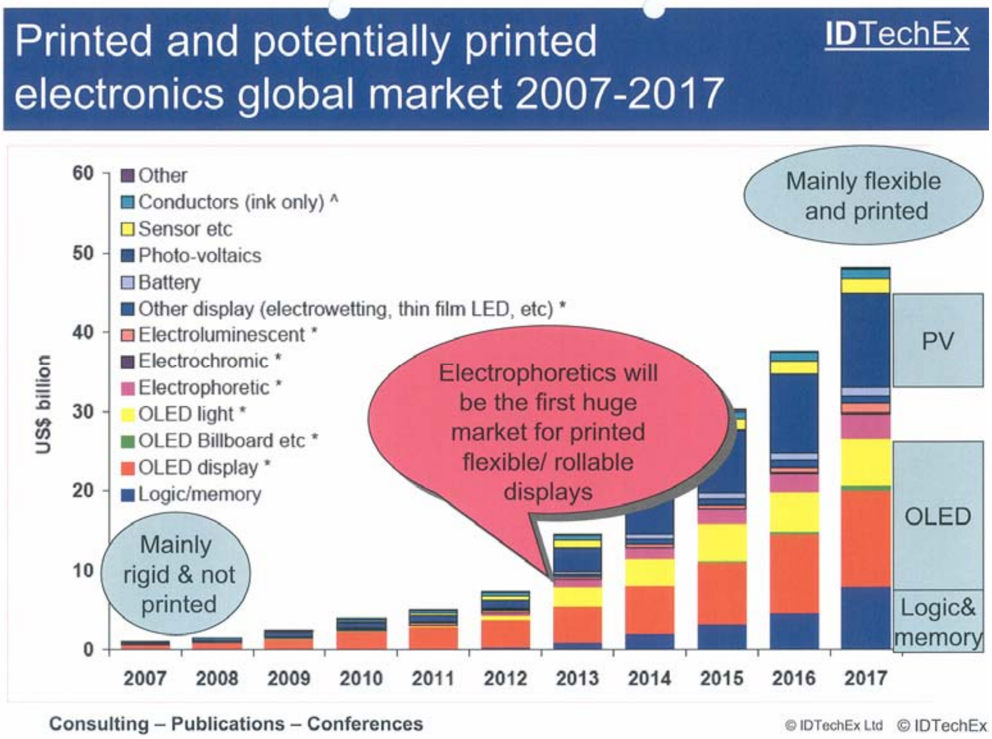

Figure 3.11. Market forecast for printed and potentially printed electronics during 2007–2017 (Source: IDTechEx) /Har07/.

According to the new IDTechEx report 'Organic & Printed Electronics Forecasts, Players & Opportunities 2007–2027' /Das07/ the market for organic and printed electronics will rise from $1.18 billion in 2007 to over $300 billion in 2027 (Figure 3.10). The whole range of printed organic and inorganic electronics including logic, displays, memory, power and sensors have been analyzed globally in this report and it is suggested that key elements of device production are the manufacturing technique, substrate and material deposited. It was also mentioned that close collaboration has been generated between material, chemical, printing, plastics, paper and electronics companies who are developing certain areas together. Figure 3.11 gives a market forecast for a shorter time range 2007–2017.

3.4 Applications of printed functionality

In Table 3.2 the products are analysed from the user aspects. The table describes the applications, its producer, its end user and the probability of realisation within the next five years.

Table 3.2. The applications, the producers and the users of a given technology.

TECHNOLOGY	APPLICATION	BY WHOM	FOR WHOM	P (within 5 years)
Hybrid media:	Additional info	Newspapers	Publishers	100 %
Optical codes	Additional info	Tickets	Customers	100 %
	Additional info	Packages	Manufacturers	90 %
	Effects	Advertisements	Many companies	70 %
Hybrid media:	Brand logo etc.	Packages, labels	Brand owners	40 %
Invisible codes,	Brand logo etc.	Newspapers	Publishers	40 %
Embedded codes	Brand logo etc.	Advertisement	Brand producers	50 %
Printed indicators	UV sensors	Labels	Tan oil mfrs	70 %
and sensors	Thermometer	Packages	Food industry	70 %
	Freshness indicator	Packages	Food industry	60 %
	Humidity indicator	Packages	Food industry	30 %
	Alcometer	Newspaper	Publisher	30 %
	Alcometer	Packages	Consumers	20 %
	Time indicator	Fast food bar	Fast food chains	30 %
Special effects	Thermometer	Packages, drinks	Beverage mfrs	100 %
reactive inks	Flashing label	Discos	Beverage mfrs	100 %
	Lottery score indica	Lottery	Lottery company	50 %
Conductive codes	RFID for shops	Logistics	Product mfrs	80 %
RFID	RFID on products	Labels	Product mfrs	70 %
	RFID on prints	Books etc.	Publishers	40 %
	RFID in mailing	Logistics	Logistic companies	50 %
	RFID baggages	Airports	Aircompanies	70 %
	RFID in mfr	In plant	Industry companies	70 %
Optics & electronics	Components	Consortia	Consumers	30 %
Printed displays	Many applications	Consortia	Consumers	30 %
Energy sources	Many applications	Consortia	Consumers	50 %

3.5 The players in the business chain and their role

The typical players and the actions in their roles in the value chain are shown in Table 3.3. The main question is who is willing and capable to add value to a printed product. In other words who will be the "king" of the chain.

Table 3.3. The roles of the players in the manufacturing chain.

	Primary role	Function	Benefit	Additional roles	Managing the chain
Publisher	Sells newspapers and ads	Packaging (prepress), additional services	Additional services for end user; Media position stronger	Data base provider, Content creation	XXX
Advertiser	Promoting sale	Offering additional services	Increased sale	Data base provider, Content creation	XX
Technology provider	Business from new technology	Produce, sells or licens	Incomes from sales or IPR		0
Printer	**Prints and attaches**	**Printing and attaching technology**	**Additional incomes, Networking**	**New technologies, Data base provider, Content creation**	**X**
Materials supplier	Sells materials	Supplying of materials	Additional profit from materials, Networking	New technologies	X
Data base provider	Offering service	Data base building and updating, Interactivity	Part of the network	Content creation	X
Content provider	Content creation	Allocated visualisation	Part of the network	Data base provider	0
Distributor	Offers distribution services	Delivery of printed products, Updating of address register	Part of the network, Additional services	Data base provider, Personalization, Inserting	X
End user	Read the newspaper and see the ads	Interest and ability to use the additional services	New services and additional value		

In principle everyone who can manage the whole network could be the leader. In practice the publisher has a very strong position because he controls the input to the printed product. The publisher could also get the most benefit by selling more products and/or linking additional services to the main product.

Examples of players, who have taken a new role in the value chain are:

- Publishers: Kauppalehti with links to stock rates over UP Codes
- Advertiser: NIKE's & Apple's iPOD as a personal trainer
- Technology provider: Litrex Corporation (CA) delivers sheet-fed presses to be integrated in production lines for displays and other jettable fluid applications
- Printer: UpCode Ltd offers code technology and consulting worldwide
- Materials supplier: E-Ink offers ink particles for electronic displays in a variety of applications
- Data base provider: Google offers ad referral program and blog ad service

- Content provider: Mobot's (MA) visual search technology connects consumer to brands in media
- Distributor: The Finnish mail company Itella Oy delivers newspapers and keep the mailing lists up to date
- End user: Viral marketing and peer-to-peer information.

3.6 The role of the printing plants

To build up a working 2D-code solution requires both willingness and connections from the partners involved. It should be noted that in same cases the copyright owners may prevent the implementation of a new 2D-code application.

For certain products the printing of various effects with special ink has been a stable technique for quite some time. In these cases the added value of the printed product always requires a customer willing to pay for such effects. On the contrary special inks are not available for all kind of production processes.

From the printing point of view the production of conductive codes is regarded as a similar task than printing with other special inks. Again the ink properties are supposed to act as a key factor. Even if the production of the code could be easily solved, a large-scale use would require a great amount of specified readers. Therefore a probable use could be within a narrow sector, in which all users would be equipped with the readers. An apparent application area is product identifying. When comparing the costs, a simple printed conductive code results as cheaper than RFID.

RFID chips are not made by printing in normal volume printing presses. Ready-made chips may be attached to printed sheet, label or package blank in a special printing and converting process line. Then the printed sheet (with RFID) is processed as a part of the finished printing product in the bindery machine.

It should be noted that if the antenna for the RFID is printed in the same printing line as the main product, the printing of silver ink requires a closed chamber in the printing unit. To modify an existing printing unit to work as a closed chamber system could be complex. An example of an integrated flexographic press for producing RFID labels is shown in Figure 3.12. One printing unit is a closed chamber type for printing the antenna.

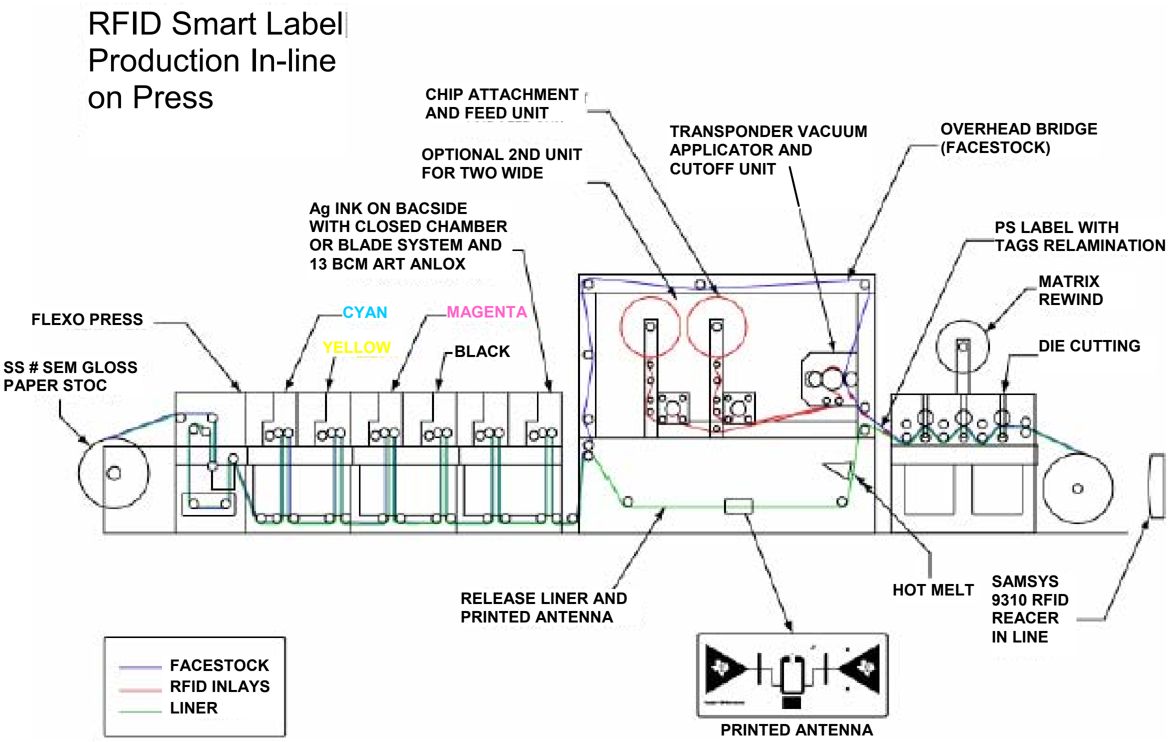

Figure 3.12. An integrated flexo press line for producing RFID labels /Nei05/.

4. Innovation of new applications of printed functionality

4.1 Outcome of the innovation process

Two innovation seminars were organized during the project. In the first seminar the participants were divided into three groups: 1. Optical and conductive codes; 2. Sensors and indicators; 3. Printed electronics. The first task of the groups was to generate new ideas falling into the specified area. The second task was to give value for each idea in regard to following aspects: Innovativeness, significance, feasibility now and feasibility later.

The second seminar was held one year after the first seminar. Between the seminars a project trip was arranged to USA. The target of the second seminar was to summarize all the new information from the project trip and based on this new data generate fresh new ideas.

4.1.1 Hybrid media

For hybrid media applications a lot of new ideas were generated. Some examples of the ideas were as follows:

- Paying by cellphone: a 2D-code is printed to the bill.
- Simple conducting codes instead of RFID-tags.
- Utilization of 2D-codes when downloading different services from internet.
- Security elements in simple ID cards.
- On-line bus information by reading 2D-code from the bus stop.

4.1.2 Sensors and indicators

Different kind of packaging solutions were the main application area for the innovations of sensors and indicators. Examples of the ideas include:

- Anti-counterfeiting sensor in the retail package.
- Weather indicator printed in newspaper (together with weather forecast).
- A sensor which is capable to monitor the state of the reader and the environment. With help of the data the output could be adapted to better fit the state.
- Freshness indicators in different kind of food products.
- A simple indicator for UV radiation.

4.1.3 Printed electronics

There were several new innovations connected to the concept of printed electronics, and they reflected the wide field of organic electronics applications. The presented ideas could be classified to the following groups:

- simple displays in packages
- anti-counterfeiting
- logistics
- power sources
- smart packages
- OLED displays
- digital codes.

None of the new ideas was practicable at once but all of them were estimated to be realistic after some years when the required manufacturing technology has developed.

4.1.4 Innovations chosen for further analysis

Seven of the innovations were chosen to further development:

- Weather sensor in newspaper
- Conductive identifier for individualization
- UV indicators in newspaper or sun lotion bottle
- Inexpensive conductive codes to replace RFID
- Security elements in event passes
- Anti-counterfeiting by RFID
- Combination of RFID and sensors for controlling the whole chain.

One outcome of the innovation process was also the classification of the ideas to the categories technology, application and function. This was done to new ideas generated in the second seminar. The result is shown in Figure 4.1. It could be noticed from the figure that the customer should have benefit from the innovation and customer's pleasure and safety could be the key functions. It is also visible that adapting printed electronics technology to the innovations of this seminar did not gather any new ideas.

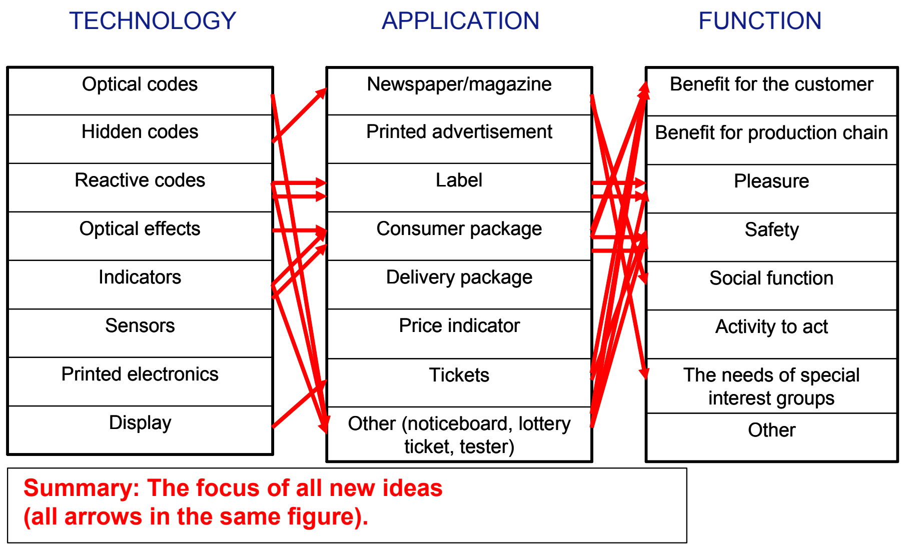

Figure 4.1. Technology, application and function of the ideas of the second innovation seminar.

4.2 Piloting in laboratory scale

From the innovations chosen for further analysis four were chosen for piloting in laboratory scale: weather sensor in newspaper, UV-fluorescent security elements, UV-indicator and conductive codes.

4.2.1 Weather sensors in newspaper

Weather sensor was divided into temperature, moisture and air pressure sensor. Temperature sensor was implemented with flexography printing, but for moisture and air pressure sensor only a short literature survey was carried out.

Two types of thermochromic flexography inks were purchased for the temperature sensor: one thermochromic ink having a colour change temperature at 15 °C from Xsys Print Solutions and another thermochromic ink having a colour change temperature at 0 ºC from Thermographic Measurements Co. Ltd. These inks are invisible above the critical temperature and turn to pink/light blue as the temperature decreases below the critical temperature (Figure 4.2). In addition we used thermochromic ink which turns from invisible to dark blue as the temperature decreases below 8 °C.

All samples were printed on copy paper with Flexiproof-100 printer manufactured by RK Print-Coat Instruments Ltd (Figure 4.3). It was noted that the colour change from the invisible state to the coloured state and also the colour change in reverse order happened in a few seconds.

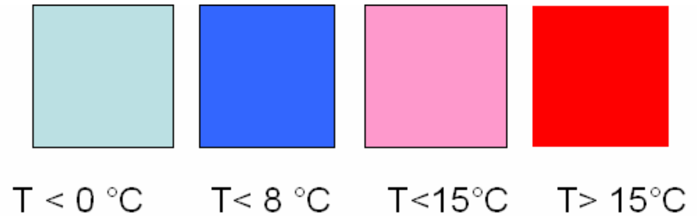

Figure 4.2. Temperature sensor implemented with three thermochromic inks and one normal graphic ink for temperature T > 15°C.

Figure 4.3. Flexiproof-100 printer (RK Print-Coat Instruments Ltd) that was used in printing the thermochromic samples.

4.2.2 UV-fluorescent security elements

A UV-fluorescent security element means a low-level security element such as authenticating name tags in seminars or temporary works passes. Since such applications require personalized information, inkjet printing was chosen as the most potential method to test in laboratory scale. UV-curable UV-fluorescent inkjet ink (HexiJet 9-080) that is colourless/invisible in normal light and red under UV light was supplied by Hexion Specialty Chemicals. Figure 4.4 presents inkjet printed samples in normal and UV light. Also standard black UV-curable inkjet ink (HexiJet 9-012) and colourless UV-curable inkjet printable clear coat (Spectrashield 453-154-2) from the same ink manufacturer were used.

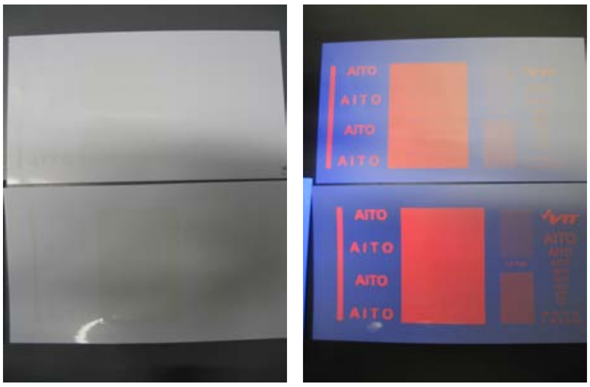

Figure 4.4. Inkjet printed UV-fluorescent ink on paper substrate under normal light (left) and under UV light (right).

The first goal was to test ink-substrate compatibility between cardboard and plastic substrates. The cardboard substrates were Avanta Prima (215 g/m^2), Avanta Ultra (215 g/m^2), Carta Integra (235 g/m^2) and Carta Solida (225 g/m^2) from M-Real. The substrates were Avanta Prima (fully coated folding boxboard, GC2), Avanta Ultra (same as Avanta Prima, but with coated back), Carta Integra (fully coated bleached paperboard with coated back) and Carta Ultra (fully coated bleached paperboard. The plastic substrates were Kemafoil (surface treated PET), PVC 300 B/F (surface treated PVC), Sicoffset 1880 (PVC) and Sicoffset 6060 (PVC) that are commonly used in plastic card applications supplied by Tavani Oy.

VTT's state-of-the-art inkjet research environment was used for the printing trials. The printing system (XY-MDS from iTi & Apollo II from FUJIFILM Dimatix Spectra) is based on industrial-type piezoelectric printheads from FUJIFILM Dimatix Spectra which makes it possible to up-scale research results to industrial environments (Figure 4.5). Printheads with 80 pl drop size were used and resolution was 363 dpi.

Figure 4.5. Inkjet research environment at VTT. From left: XY-table for moving the substrate (right, XY-MDS) and control unit for the printheads (Apollo II), online UV-curing and industrial printheads for 4-colour printing (two printheads shown).

Simple line elements were printed on the different substrates with the UV-curable black ink and the UV-curable and UV-fluorescent transparent ink. The line width, which gives an indication on the spreading tendency of the ink on the particular substrate, was analyzed. For the cardboard substrates, line width for the black ink was slightly lower for the Carta -substrates, whereas for the UV-fluorescent ink, the line width on the Avanta -substrates was lower. For the plastic substrates, the differences were greater: the PVC 300 B/F and Sicoffset 1880 -substrates were by far more compatible with both inks. Establishing ideal compatibility between the inks and substrates would have required further studies and optimization of both inks and substrates and was beyond the scope of this work. The main finding for the compatibility tests was that the UV-fluorescent ink was still clearly visible under normal lighting conditions.

After the compatibility tests the best substrates were chosen for further analysis. These were chosen on the basis of lowest ink spreading tendency. The Avanta cardboards and PVC 300 and Sicoffset 1880 plastic substrates were chosen for further studies. The goal was to test how to make UV-fluorescent printing more invisible in normal light. At first the optimum printing settings were found and smaller drop size tested. Finally the effect of printing a transparent layer on top of the visible and UV-fluorescent print was tested. A UV-curable clear coat was used for this purpose. Printheads with an 80 pl and 30 pl drop size were used to vary the amount of deposited ink and hence the coverage of the clear coat. A printing resolution of 300 dpi was used.

In printing different combinations layer upon layer of the three different UV-curable inks, it was found that the ink would behave differently on different UV-cured ink surfaces. The clear coat ink wouldn't wet the cured UV-fluorescent layer, resulting in a discontinuous film of droplets. The clear coat ink and black ink, however, did wet the substrates well, and gave good edge definition. The UV-fluorescent ink spread on all substrates, resulting in ragged edges and low contrast. Although the substrates were chosen for their low spreading tendency, the results show that wetting behaviour is very sensitive to changes and the uniformity of the surface energy/tension of the substrate and ink. A more systematic approach must be taken in order to understand these phenomenons.

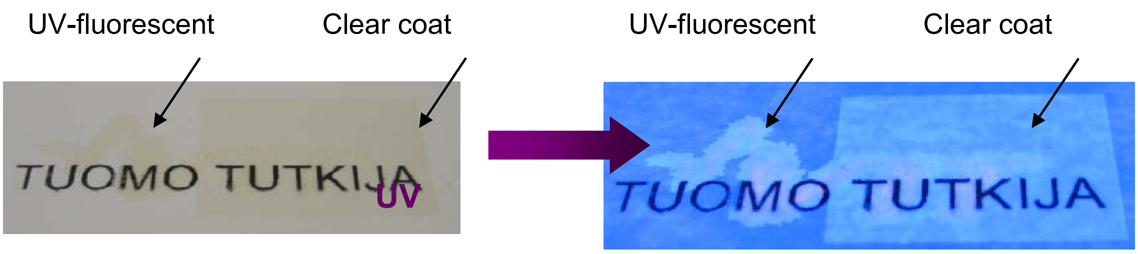

Figure 4.6. Printed UV-fluorescent, black and clear coat layers under normal light (left) and UV-light (right).

The clear coat did however perform its task of hiding the underlying UV-fluorescent (under normal lighting) transparent layer quite satisfactorily (Figure 4.6). The main challenge is to formulate these inks in a way that each controllably wet the surface (substrate or cured ink layer) they are printed on. In addition, surface treatment such as plasma or corona treatment of the substrate could be considered as a means to modify the surface energy of the substrate. Another challenge is to find a UV-fluorescent formulation that gives a strong enough fluorescence and subsequent high contrast when exposed to UV light. Further optimization of the whole process is needed if a similar product is to be taken into production scale.

4.2.3 UV-indicators

UV-indicator is a printed element that changes its colour based on the amount and power of the UV light that it is exposed to. Based on literature photochromic ink was found to have potential as an UV-indicator (Figure 4.7). Photochromic inks are used for example in eye glasses whose lenses become darker outdoors. Usually photochromic inks react to sun light and are either reversible or irreversible. Commercial inks are available for flexography, letterpress, screen printing, waterless offset and inkjet.

Figure 4.7. T-shirt printed with photochromic ink indoors (left) and outdoors (right). (Image source: Chromatic Technologies International, www.ctiinks.com)

The goal of this laboratory pilot was to investigate if the colour of the printed photochromic area is dependent on the power of the UV light that it is exposed to. The principle is that based on different colour value it can be interpreted how harmful the UV exposure is. The colour of the photochromic area would be compared to a reference colour strip to help interpretation.

UV index

The UV index (UVI) is an international standard measurement of how strong the ultraviolet (UV) radiation from the sun is at a particular place on a particular day. It is a scale primarily used in daily forecasts aimed at the general public. The calculations are weighted in favour of the UV wavelengths that human skin is most sensitive to according to the McKinlayDiffey Erythema action spectrum. /Epa07/

One UVI is 25 mW/m^2. The radiation of 3 UVI cause moderate risk of harm from unprotected sun exposure and the radiation of 8 UVI cause very high risk of harm from unprotected sun exposure – unprotected skin can burn quickly. There are some areas on the earth, where the UV radiation can achieve 12 UVI. /Fmi07/

The radiation dose can be expressed in standard erythema doses (SEDs), where 1 SED = 100 J/m^2 normalized to 298 nm according to the International Commission on Illumination erythema action spectrum. A dose of 10 SEDs can cause erythema on skin. /Thi04/ It can be achieved in two hours with radiation of 6 UVI.

Methods and materials

Two photochromic flexography inks (DynaColor UV Flexographic Blue and Red) from Chromatic Technologies International were printed with VTT's FlexiProof 100 laboratory press (anilox 13/18 cm^2/m^2). Six substrates were used: newspaper 1 (52 g/m^2), newspaper 2 (48,8 g/m^2), newspaper 3 (42,5 g/m^2), copy paper (80 g/m^2), Avanta Ultra cardboard (215 g/m^2) and Carta Integra cardboard (235 g/m^2). Newspaper substrates were supplied by Sanomapaino and cardboards by M-Real.

Black light lamp, Philips moneycheck TTG690 18W, was used for simulation of UV-A radiation. Osram Ultra-Vitalux Sun Lamp 300W was used to simulate the radiation of the sun. The certain amount of radiation was controlled by placing the sample in appropriate position under the lamp and measuring the radiation in that position with Erythema weighted sensor. Example: 3 UVI = 75 mW/m^2 → distance 100 cm to the lamp and 45 cm to the centre line of the lamp.

Figure 4.8. Measurement system.

The amount of radiation was controlled with DeltaOhm HD 2102.2 photo-radiometer. Tree radiometric probes were used: LP471ERY, LP471UVA ja LP471UVB, ERY= McKinley-Diffey Erythema action spectrum.

A pair of Osram 15W/12 Lumilux de Luxe Daylight lamps was used to get normal light for photographing. Canon PowerShot G6 camera was used to photograph irradiated samples. Colour measurements were made with Personal IAS device.

Visual observations

With Sun Lamp the UVI values of 2 and 9 were used (UVI 9 corresponds 1500 mW/m^2 UVA value). With Black light lamp the UVA value of 4500 mW/m^2 was used. The change in lighting had an effect on photographing as well as on visual observation. Regarding further studies the amount of light should be standardized and the camera controls should be optimized.

The printed substrates did not differ a lot from each other when they were visually evaluated. When the UVI values of the Sun Lamp were under 12 there was not very much change in the observed colour. However, between UVI values from 2 to 9 the change was noticeable (limit for protection is 3), but thinking of a production level solution this was judged as too low difference. The Black light lamp gave greater colour change than the Sun Lamp, because its UVA value is three (3) times the UVA value of the Sun Lamp. The change time from lightning of the UV lamp to observation in colour took 15–30 seconds, returning back to normal state took about 1 minute with blue inks, but with red inks the returning time was over 10 minutes.

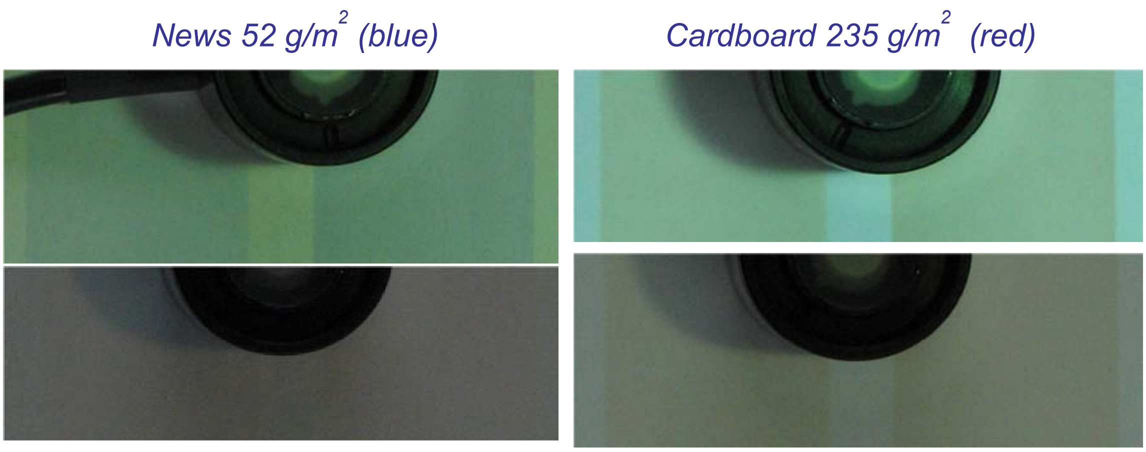

Figure 4.9. Photographing with sun lamp radiation. Upper samples were irradiated with UVI value 9 and lower samples were irradiated with UVI value 2.

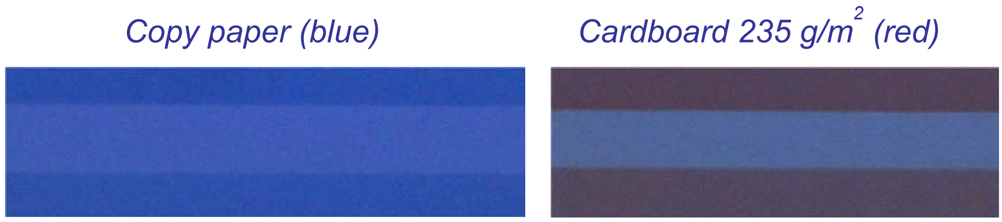

Figure 4.10. Photographing with black light lamp radiation. The UVA value was 4500 mW/m^2. It can be seen in the middle of the pictures that Black Light Lamp has blued the substrates.

Colour Measurements

The UVI values of the Sun Lamp were 3 (U3) and 9 (U9). The UVA value of the Black light lamp was 1500 mW/m^2 (V1), which was same than UVA value of Sun Lamp with UVI 9 radiation. The measurement from unirradiated sample was used as a reference (U0). The colour difference ΔE was calculated from the measured colour values.

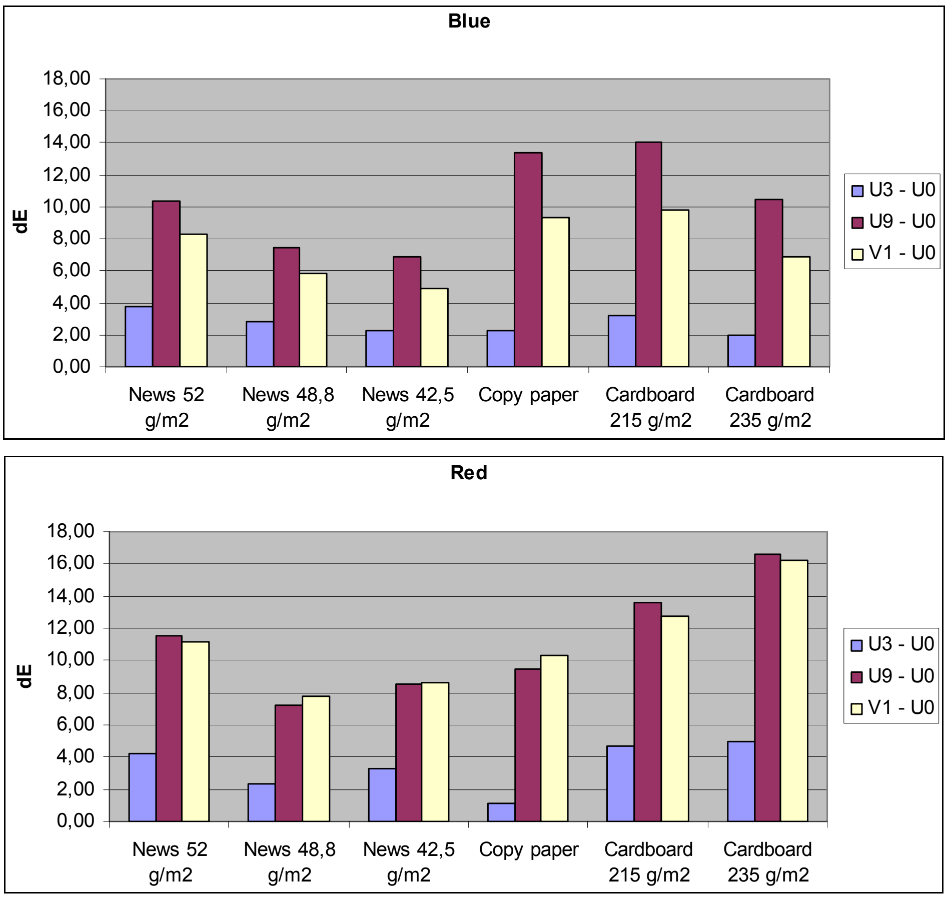

Figure 4.11. Colour measurements. The colour difference dE was calculated from measured colour values. U0 is unirradiated sample. U3 and U9 are Sun Lamp samples, which were irradiated with UVI values 3 and 9. V1 is Black Light Lamp sample, which was irradiated with UVA value 1500 mW/m^2.

The best response from the newsprint samples was noticed with News 52 g/m^2. The copy paper sample had a better response with blue ink. The 235 g/m^2 cardboard worked better with red ink. The Black Light Lamp gave a better response with red ink.

As a conclusion, it was found that photochromic inks have potential to act as UV indicators based on optical colour change. However, when considering an industrial solution further development of inks, material compatibility and optimization of colour change is needed. It should be also remembered that current photochromic inks react mainly to artificial UV light and sun light, but not to UV light coming from the sun.

4.2.4 Conductive codes

Conductive code is a code that can store information without the help of a chip. Potential of both flexography and inkjet printing for producing conductive codes was investigated. The test structure consisted of lines of different width that were analyzed with a reading device developed at VTT. The principle of the reading device is to see if it can detect differences between printed and unprinted areas.

In inkjet printing silver nano-particle ink (Inkjet Silver Conductor Ag-ij-g100-s1 from Cabot Corporation) was used. The samples were printed with VTT's state-of-the-art inkjet research environment with 80 pl drop size and 540 dpi resolution. Cardboard and photographic paper were used. Resistance was analyzed from the samples and the samples were also analyzed with the reading device. On cardboard the resistance was over 2 GΩ thus indicating very little conductivity probably due to surface roughness and fiber network on the cardboard. On photographic paper the resistance was 30–120 Ω with one ink layer and 12–45 Ω with two ink layers. Figure 4.12 presents data from the reading device. Also cardboard substrates were readable with the reading device despite the low conductivity.

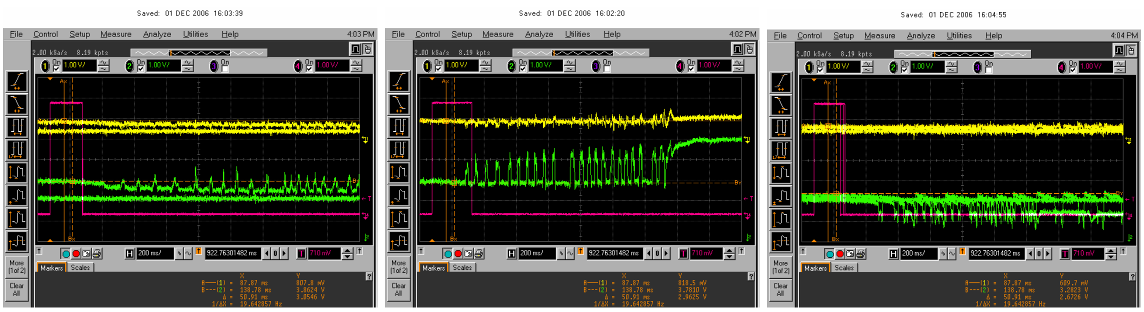

Figure 4.12. Data from the reading device for conductive codes. From left one ink layer on cardboard, two ink layers on cardboard and one ink layer on photographic paper.

Data from the reading device shows that it can distinguish printed and unprinted areas (green line at the bottom) thus indicating that inkjet printed conductive codes can be made. Figure 4.13 shows examples of inkjet printed conductive elements.

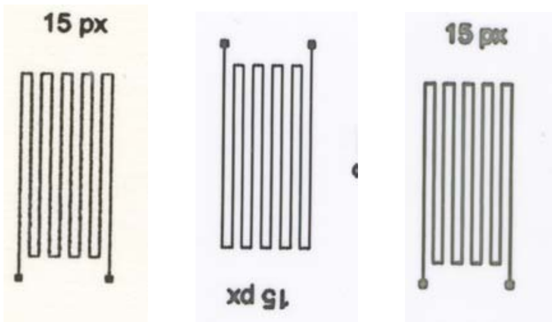

Figure 4.13. Inkjet printed conductive structures. From left cardboard (one ink layer), photographic paper with one ink layer and photographic paper with two ink layers.

We also tested the suitability of flexo printed conducting polymer lines for conductive codes. Both toluene based Pani-T solution from Panipol Ltd (solid content 6 w-%) and water based Pani-W solution (solid content < 10 w-%) from Panipol Ltd were printed with the Flexiproof-100 flexo printer on copy paper, photographic paper and cardboard substrate (Figure 4.14). The print quality on photographic paper was not good due to spreading and so it was not analyzed further. Before measurement with the reading device the square resistance value of the conducting polymer lines printed on copy paper and cardboard was measured (see Table 4.1).

Table 4.1. Square resistance values of flexo printed conducting polymer lines on cardboard and copy paper.

Substrate	**Polymer solution**	**Square resistance**
Cardboard	Pani-W	16 MOhm/sq
	Pani-T	6.5–10.3 kOhm/sq
Copy paper	Pani-W	> 120 MOhm/sq
	Pani-T	> 480 kOhm

From the reading device measurements it could be concluded that the Pani-T/ cardboard combination worked best, but even then the signal of the reading device was unclear and noisy. The conducting polymer line should probably be thicker and more homogeneous to get a better signal.

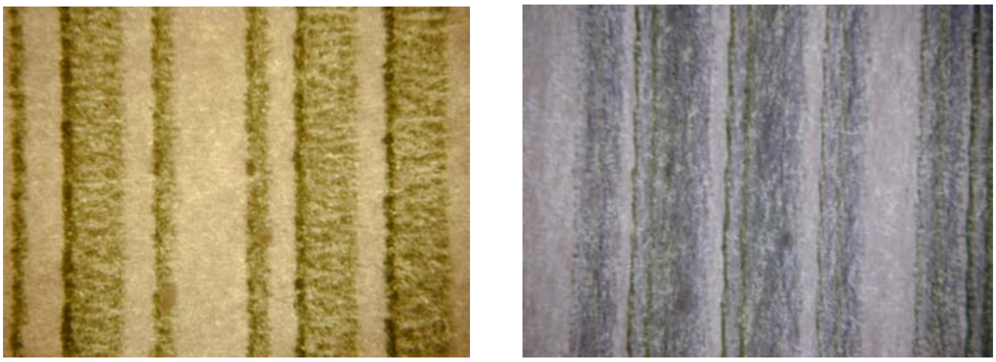

Figure 4.14. Conducting line structures flexo printed with Pani-T solution (6 w-%) on copy paper (on the left) and cardboard.

4.3 Demands and restrictions for full scale trials

In this section the evaluation was made in order to clarify what would be possible for the printers when utilizing their existing printing presses and what would be the limiting factors.

4.3.1 Sheetfed contract printing

For sheetfed printing the number of printing units is not a problem: a re-run is made with special ink (if register demand is not critical).

During the project one partner tested UV-visible inks in a sheetfed offset press. An example of a simple security element was printing of carton cards with UV-fluorescent ink. Also a 2D-code was included in the lay-out.

4.3.2 Web-fed contract printing

The most promising production possibilities were noticed with special web-fed printing and converting lines. Generally flexo offers more possibilities for the use of special ink than offset (even if both are equipped with UV-curing). Functional property is made by printing or converting to printed sheet, label or carton blank for packages. The machinery has a large variety of possibilities, including on-line finishing and lamination.

4.3.3 Web-fed volume printing

Newspapers are produced with large offset press lines typically together with proper inserting capacity. During weekdays the capacity may not be fully used, which means that free printing units could be modified to use special inks. In this case one limiting factor is the limited availability of special inks for fast-running newspaper offset press. In addition, one target is also to decrease the needed minimum ink amount, because of the high price of the special ink. Inserts for the main product may be printed with other printing methods offering more possibilities for functionality.

Regarding magazines and directories printed with heatset press the printing units are fully used for printing of the main product. But the finishing process is versatile giving freedom to add functionality. One solution is to bind a printed sheet containing functional property to be an integral part of a magazine or a directory in the stitching or adhesive binding line. Another way is to insert a pre-printed insert containing functional property to the main product in the process.

4.4 Business models for the innovations

4.4.1 Weather sensor in newspaper

Special colour, which indicates weather temperature, is printed on tabloid afternoon newspaper. The business model is based on advertisement. Advertiser buys every day one third of tabloid newspaper page, where the sensor is printed. The sensor is a small piece (5 m^2) of special colour and thus the material cost is marginal. The circulation of newspaper is 200 000 copies and is published 6 days a week. This makes annually 300 advertisements. In the year 2015 ten large newspapers publishers print this sensor, sponsored by advertisements.

Table 4.2. Business potential of weather sensors in newspapers in Finland.

Finland	2010	2015
Costs (special ink)	<< 0,1 M€	< 0,5 M€
Companies (newspaper publishers)	1	10
Market share (of daily newspapers total circulation)	10 %	50 %
Business volume (additional advertising incomes)	about 1 M€	about 5 M€
Consumer benefit/mistrust	Fun	Additional information

4.4.2 Conductive identifier for individualization

Finland produces 25 millions of books a year, which could be equipped with a printed recognizer at a cost of 0,25 €/book. If the price of the book could be increased by 0,8 €, it would give an additional turnover of 20 M€. The costs for the identification and readers must be added. The bookstore and the logistic chain will profit from simplified processes, which covers the additional costs.

Table 4.3. Business potential of conductive identifiers in books in Finland.

Finland	2010	2015
Costs (printed conductive identifier)	> 5 M€	> 5 M€
Companies (book publishers)	7	> 7
Market share (of printed books)	95 %	100 %
Business volume (additional incomes for book printers)	about 20 M€	> 20 M€
Consumer benefit/mistrust	Easy to find	Easy to find

4.4.3 UV indicators in sun lotion bottle

More than 2 millions suntan cream packages are sold in Finland each year. Printing an indicator on the label would cost 0,5 € and the bottles or tubes could be sold for an additional price of 2 € each. Half of the packages could be equipped with a label in 2010 and all the items in 2015. The consumer is obviously ready to pay extra for the label and his safety, so the costs could easily be transferred to the end product.

Table 4.4. Business potential of sun lotion bottles in Finland.

Finland	2010	2015
Costs (special UV indicator ink)	about 0,5 M€	> 1 M€
Companies (label printers)	1	> 1 ?
Market share (of sold lotion bottles)	50 %	100 %
Business volume (additional incomes for label printer)	about 2 M€	about 4 M€
Consumer benefit/mistrust	Knows when more protection is needed	Knows when more protection is needed

4.4.4 Inexpensive conductive codes to replace RFID

A shoebox could be equipped with a sticker containing an inexpensive conductive code. In the year 2010 stickers could be applied to 2 millions of shoeboxes to a price of 0,25 € each. With additional costs for input of identifying data and profit, the required additional price needs to be approximately 1 €. The shops also need to be equipped with readers. This would give an additional turnover of 2 M€ in 2010 and 4 M€ in 2015. In this case the end consumer is not prepared to pay the additional price, but the shops and the logistic chain will profit from better processes and easiness to find the shoes wanted.

Table 4.5. Business potential of inexpensive conductive codes in Finland.

Finland	2010	2015
Costs (printed special conductive sticker)	about 0,5 M€	> 1 M€
Companies (printers)	1	> 1 ?
Market share (of sold shoe packages)	20 %	50 %
Business volume (additional incomes for sticker printer)	about 2 ME	about 5 M€
Consumer benefit/mistrust	None	Find the shoe needed easily

4.4.5 Security elements in event passes

The entrance ticket or club card can be equipped with an identifying code to a price of 0,1 € each. The ticket price may be increased by 0,25 € each. Moreover, printing equipments are needed for the tickets and readers at the entrance. In 2010, one big event with 60.000 tickets could be involved, and in 2015 three events with 200.000 tickets in total. In addition to the calculated profit, the arrangers will profit from more flexible control, as the ticket gives the access paid for.

Table 4.6. Business potential of security elements in event passes in Finland.

Finland	2010	2015
Costs (special ink)	about 5 000 €	> 20 000 €
Companies (printers of the event passes)	1	1
Market share (participants of all big events)	5 %	25 %
Business volume (additional incomes from securing elements)	> 10 000 €	> 60 000 €
Consumer benefit/mistrust	Mistrust	Economic benefit

4.4.6 Anti-counterfeiting by RFID

A producer of mobile phones could equip his 1,5 millions phones for the Finnish market with RFID stickers to a price of 1 € each. The retailer can prove the genuineness of the product, which enables an extra price of 5 €.

Table 4.7. Business potential of anti-counterfeiting by RFID in Finland.

Finland	2010	2015
Costs (special colour)	about 1,5 M€	about 1,5 M€
Companies	1	1
Market share (of sold mobile phones)	80–90 %	80–90 %
Business volume (incomes of printed RFID tags)	> 7 M€	> 7 M€
Consumer benefit/mistrust	Warrantee	Warrantee

4.4.7 Combination of RFID and sensors for controlling the whole chain

Registered mail could be equipped with an RFID sticker to manage logistics to an additional price of 1 € each. The national post office could sell the insurance for 2 €. The end user is ready to pay for safe delivery. Approximately 5 per cent of the annual 22 millions of post deliveries use the sticker in 2010 and 20 per cent in 2015.

Table 4.8. Business potential of controlling production chains in Finland.

Finland	2010	2015
Costs (printed RFID sticker)	about 1 M€	about 5 M€
Companies (RFID printers)	1	1
Market share (of valuable postal packages)	5 %	20 %
Business volume (incomes for the RFID sticker printer)	about 2 M€	about 10 M€
Consumer benefit/mistrust	None	Cost savings

4.4.8 Innovations roadmap

Roadmap was made for the innovations that were chosen for further analysis. Since some of the chosen innovations resemble each other from the production point-of-view, the innovations were divided into five categories: weather sensor, UV fluorescent security element, UV-indicator, electronic identifier (not RFID) and printed RFID. Each innovation was analyzed based on when it can be realized in laboratory, when it can be realized in production and what are the requirements for the realization in production. Table 4.9 presents the two first properties for each innovation.

Table 4.9. Roadmap for the chosen innovations.

Innovation	Realized in laboratory	Realized in production
Weather sensor 1) temperature 2) humidity	Now Now	1) Now 2) 2009
UV fluorescent security element	Now	Now
UV-indicator (photochromic ink)	Now	2008
Electronic identifier (not RFID)	Now	Now
Printed RFID	Partially now (antenna)	Partially now (antenna)

For weather sensor the requirements for realization in production are:

1) Temperature sensor
    - thermochromic inks that react in different temperatures → multiple printing units needed
    - ink-substrate interactions optimized for maintaining reactivity in desired level
    - method for quickly checking the functionality of the sensor (online).
2) Humidity
    - commercial hydrochromic ink
    - possibly hydrochromic inks that react in different humidity
    - ink-substrate interactions optimized for maintaining reactivity in desired level
    - method for quickly checking the functionality of the sensor (online).

For UV fluorescent security element the requirements for realization in production are:

- ink-substrate interactions optimized for maintaining reactivity in desired level
- UV fluorescent ink invisible under normal light
- method for quickly checking the functionality of the sensor (online)
- extra printing unit for UV fluorescent ink – digital if personalisation needed.

For UV-indicator based on photochromic ink the requirements for realization in production are:

- ink-substrate interactions optimized for maintaining reactivity in desired level
- photochromic ink reacts to different levels of UV radiation with different colours
- method for quickly checking the functionality of the sensor (online)
- extra printing unit for photochromic ink.

For electronic identifier (not RFID) the requirements for realization in production are:

- ink-substrate interactions optimized for maintaining conductivity in desired level
- uniform print quality: not large variations in profile or size of the details, no missing dots or fields
- method for quickly checking the functionality of the identifier (online)
- inexpensive commercial conductive ink that available in large volumes
- lay-out designer with knowledge in electronics
- suitable reading device for the end-user
- extra printing unit for conductive ink – inkjet if personalisation needed
- extra curing unit for sintering the conductive ink (depending on ink type used).

For printed RFID the requirements for realization in production are:

- ink-substrate interactions optimized for maintaining conductivity in desired level
- uniform print quality: no large variations in profile or size of the details, no missing dots or fields
- method for quickly checking the functionality of the RFID tag/antenna (online)
- inexpensive commercial conductive ink that available in large volumes
- lay-out designer with knowledge in RFID technology
- suitable reading device for end-user
- extra printing unit for conductive ink
- extra curing unit for sintering the conductive ink (depending on ink type used)
- attaching unit for attaching the chip and its connections to the antenna or for attaching the whole tag → accuracy important.

Realisation of the first three innovations based on reactive inks is relatively easy compared to the last two that are based on conductive inks. However, even with reactive inks optimisation to a certain substrate, production process and end-use are required.

4.4.9 Recyclability of the innovations

According to one principle, any type of printed paper and board can be recycled but the range of products in which it can be used is restricted. Different types of used paper and board are recovered and recycled for different purposes. Amounts of recycled fibers and criteria for their quality depends on the grade of paper being produced. Some papers, such as corrugated materials, can be made from 100 % recycled paper. For certain uses, like the production of graphic and hygienic papers, the fibers have to be de-inked.

The evaluation of the recyclability of printed paper and board products has decisive importance for improving recovered paper use. But the evaluation of recyclabity and de-inkability of a printed product is very case specific. The recyclability and de-inkability of a printed product are depended on a variety of issues – paper and board type and printing method among other things. With new type of printed products no specific answer is available previously. In case the innovations will become bulk products, their suitability for recycling will be more significant than if they are in small series production. General considerations taken into account are shortly introduced here.

Recycling

Good recyclability refers to the ease of processing of recovered paper into a new product. Materials added such as printing ink or adhesives should be benign during recovered paper processing and not affect water loops, paper production, and paper converting. The process residues (rejects and sludges) enriched with nonfiber components should not be harmful to the environment and offer possibilities for suitable use in other industrial processes, energy recovery, or final disposal by landfilling. /Put00/

In general, paper and board packaging materials are very suitable for recycling. Nonfiber materials, like fillers, coating materials, pigments and inks create an area where improvements could be done. Nonfiber materials affect the recycling process but problems are different with different paper and board grades. Inks and pigments can create problems for de-inked grades but not for packaging where de-inking normally does not take place. /Hyv01/

Guidelines and test methods for evaluating the recyclability of printed products are needed in development of recycling friendly paper and board products. This is the only way new products can satisfy the requirements for a more complete closed paper cycle. No international standards exist for testing the recyclability of single paper and board products, and no common definitions exist for minimum requirements on recyclability. Institutes and paper mills throughout Europe have developed their own assessment methods. With the help of these methods it can be estimated whether printed products meet the criteria of recyclability. Test methods to evaluate the recyclability of printed products are provided e.g. by Papiertechnische Stiftung (PTS) and the International Association of the Deinking Industry (INGEDE). /Put00, Ing02/

Materials which are unusable in new production consist of nonpaper components and paper and board detrimental to production. Tolerance regarding unusable materials differs widely from country to country. Nonpaper components are the main factors hindering the recyclability of paper and board products. Contaminants reduce the efficiency of the papermaking machine, increase energy consumption, and lower paper quality. The various contaminants are considered differently depending on the type of paper produced. Regardless of the type of paper to be produced from recycled paper, the quality and strength of the paper is improved the more impurities and contaminants that can be removed from the collected paper. /Cep02, Rec00/

The contaminants increases with complex compounded papers, printed products, packaging, chemical additives, fillers, new paints, colouring agents, plastics, laminates, and adhesives. Substances can be classified as objectionable or prohibited materials. Objectionable materials can exist in the collected paper to certain extent, depending on which type of paper is produced. These materials are often part of the different types of waste paper intended for recycling. Prohibited materials are those which can cause serious damage in the production of paper, and preferably should not be present in the most types of paper production. /Rec00/

Types of paper and board which are detrimental to production have been treated in such way that they are unsuitable as raw material for the manufacture of paper and board. In other case, they are actually damaging, or their presence makes the whole consignment of waste paper unusable. A growing number of mills have, however, adapted treatment plants to handle such grades, and the range of papers and boards capable of being recycled is increasing all the time as technology develops. The criteria for defining the percentage of “unusable materials” for these grades will be subject to individual mills’ specifications. /Cep02/

Bonding the substrate material to other materials, which are difficult to remove and/or harmful to production, can diminish recyclability. A nonpaper component is suitable for recycling if it can be separated from the recovered paper by recognized technical processes and recycled or disposed without damage to the environment.

De-inking

In de-inking printing ink and impurities are removed from the recovered paper. De-inkability refers to the extent to which ink is removed. De-inking primarily uses recovered graphic paper products such as old newspapers and old magazines as wood-containing products. It also uses wood-free paper from offices. /Ren00/ Commonly, used and collected packaging materials are recycled for manufacturing corrugated board materials or coreboard. For production of these materials, fibers are not de-inked.

Recovered paper de-inkability can be determined by INGEDE test methods. The efficiency of ink separation depends on the ink properties and printing method. Also the used de-inking procedures differ depending on used printing method and inks. This needs to be taken into consideration if the created new printed products are recycled for such uses that require de-inking.

Offset printing can cause problems in the ink removal process. These problems appear after the paper ages and alkyd binder of the offset ink cures. Rotogravure printed paper is easier to de-ink than offset printed paper. Flotation de-inking does not efficiently remove water-based flexographic printing ink, but washing can remove this water-based ink. /Rec00/ According to certain sources de-inking of digitally printed products, such as office papers, is considered problematic. This is because during disintegration recovered nonimpact printed paper produces particles which are too large for removal by conventional de-inking processes such as flotation or washing. Due to adaption of new de-inking process steps and chemistry, the situation might become better. /Ren00/

In addition, the efficiency of ink separation depends highly on the ink properties and depending on the printing ink composition, the de-inkability of different printed products can vary considerably. De-inking also depends on other factors than ink properties. De-inking of coated paper for example is generally more successful than de-inking of uncoated paper. De-inkability of a printed product is depended on different factors, main influential factors are: ink type, ink properties, printing technique and printing conditions, aging of the print, paper surface. /Ren00/

Ink disposal according to material safety data sheets

Usually conductive inks are harmful to environment in liquid form. Inks that contain metal particles should not be drained or to allow material to contaminate ground water system. The proper disposal is land-filling or incineration. Inks containing conductive polymers are a hazard to water environment. The proper disposal occurs in toxic waste disposal plant. Reactive inks that require UV- or EB-curing generally don’t present environmental disposal hazards when fully cured. /Bay99, Cab05, Hex06/

4.4.10 Usability aspects of the innovations

Usability is a non-functional quality of a product, dealing with for example ease of use, learnability and accessibility. Usability of a product may also contain some functional issues, if the function is important for some usability quality of the product. For example, an 'undo' feature is clearly a function, but it is intended to make the use of the application more pleasant and the user errors less severe, thus affecting the usability of the software. Usability deals primarily with the user interface between the user and the product, and with the interaction, that is, how the product reacts to the actions of the user and how it displays its state. From the human point of view, usability is based on the senses and cognition – the data processing capabilities of the user. Although the technology develops rapidly, human capabilities remain much the same. /Dix04/

Human-Centred Design (HCD) is a design method in which the user and the needs of the user are the basis for the design process. HCD contains individual methods to evaluate the user requirements and the usability of the product, but the most important feature of HCD is that it is an **iterative** process. Experience has shown that all user needs are not known in advance and therefore the designers have to be ready to adapt their designs when new information about the user needs is gathered. Central to HCD is taking the usability methods into the design as early as possible, to avoid designing and building a product and then finding it unusable and requiring extensive changes. The idea is to get the design to the right track as early as possible, by adhering to usability guidelines, by building early prototypes and evaluating them. Usability is thus not a quality that can be glued on top of a complete product, but it has to be designed into the product from the very beginning.

HCD has been developed to be a part of software development process. Because printed functionality deals mostly with non-software technologies, the HCD process needs some adaptation to fit into the design of printed products. Printed functionality products may be either 1) entire 'applications' from the user's point of view, or 2) hardware components of some more complicated systems. An example of the first is a printed indicator that changes colour according to some environmental event. The indicator is an independent application and its usability depends on its context – how it is embedded into the printed product – and does not very much affect anything outside its immediate surroundings. An example the second kind, printed functionality product as a hardware component, is an RFID tag that contains a link to some web service. The tag requires other hardware components (for example a mobile phone) and software (tag reading software, web browser) to offer a meaningful service to the user. In this case, the usability qualities of the tag affect the usability of the whole service, and the user requirements for the tag are affected by the user requirements of the whole service.

Much success has already been achieved in researching the usability aspects of **hybrid media**. Tag-based interactions are studied much with the recent advent of mobile phone cameras and RFID readers. Because hybrid media can be seen as extending the world wide web to the physical world, many analogies from the web user interfaces, such as tags as physical hyperlinks, are useful with hybrid media. For more information, see for example /Väl07/. **Sensors and printed electronics** are similar to hybrid media in that they act as a part of other systems to provide a service to the user. The user requirements and usability aspects of the sensors depend thus from the application they are used to build.

VTT has developed methods for human-centred design for hardware components and architectures that tie the components together to meaningful services and applications. The **publications and deliverables from the MIMOSA and MINAmI** projects deal with this approach /Kaa06/. The components of those projects include mobile phones, RFID tags and sensors, making many of the results applicable to printed functionality as well. The basic method includes 1) scenario development, 2) scenario evaluation with users and application field experts, 3) analysis of scenarios with available technologies, 4) identification of functional and user requirements for the applications, 5) analysis of which components are affected by which requirement, and 6) prototyping and user experiments with prototypes to find out requirements that cannot be gathered with analytical methods.

Indicators and optical effects can act as individual applications, but they offer very little interaction with the user. Typically the user of an indicator can only read the indicator and not affect the indicator in any way except by taking it to a desired location. The usability aspects of an indicator thus deal with effectively communicating the value of the indicator, usually in conjunction with what is printed around the indicator. Techniques to improve the usability include thus colour choices, icons around the indicator to show what it is indicating, and other techniques familiar to graphic designers. The key questions in visualising the indicator include 1) the existence and location of an indicator, 2) the intended environment (for example an UV indicator in a newspaper is of little use indoors), 3) what physical phenomenon is being measured, 4) visualising the change for example with appropriate colours, 5) the meaning of the change (binary, for example over or under 25 degrees, vs. continuous, for example the higher amount of red means higher temperature).

5. Conclusions and recommendations

This study has been limited to printing of 2D codes and simple sensors and indicators on fibre based materials with regular or commercially available inks with conventional printing methods or inkjet. These are assumed to be the most interesting applications of printed functionality for commercial printing plants. The technical conclusions presented here, refer to these applications only. Printing of electronics has been beyond the scope.

5.1 Printed functionality and the printing industry

- The term printed functionality includes codes, sensors, indicators and printed electronics.
- The printing industry faces declining shipment and profitability worldwide. Printed functionality is seen as one solution to the problem.
- The advantages of printing technology are: big printing areas, high quality production, reasonable costs, variety in plates, already existing equipment, a broad spectrum of materials, use of additives, operation in low temperature and atmospheric conditions, integration and scaling of processes. Production speeds of 10–100 m^2/s and resolutions of 10–100 µm are common in traditional printing.
- However, these speeds can hardly be reached in demanding production of printed electronics or when using special inks that need several and long treatments, like curing, heating, evaporating etc. In these cases the production speed will obviously be 1–2 decades lower, which is still strongly above the performance of traditional manufacturing methods for electronics.
- There is an increasing demand for low end semiconductors and electronics suitable for mass production by printing.

5.2 The future markets of the application suitable for printers

- Printable materials are weak in conductivity, resolution, registering and transistor properties compared to silicon, but may be suitable for low end products.
- The choice of printing method depends on material properties (viscosity, surface energy), physical properties (resolution, register, thickness, roughness), economy (productivity, plate making, waste, material costs) and other factors (edge smoothness, morphology, typology).

- The IDTechEx estimated the global market for printed electronics to grow to 35 b€ until 2017 and to 250 b€ in 2027. The market for hybrid media suitable for conventional printing is far more modest. We estimated it to increase worldwide.
- The ability for the printing industry lays in new innovative service forms based on printed elements (hybrid media) which enables unlimited possibilities for innovations, whereas printed electronics is more demanding.
- Successful innovative companies (like Litrex and Dimatix in U.S.A.) have collected expertise in printing, electronics, chemistry and mechanics to develop equipment based on flexo and inkjet for electronic printing. Litrex has sold worldwide one hundred sheet-fed (inkjet) printing systems for production systems for displays and other jettable fluid applications. When manufacturing displays for electronic devices the most of the printing equipment operate as an integrated part of the production lines.
- Big efforts are invested in fast roll-to-roll electronic printing but so far on pilot scale only.

5.3 Technical demands on the printers of printed functionality

- Limiting material factors for printing electronics are particle morphology, mobility and scaling performance. Also solubility may be a problem. This makes it difficult to make an ink with the wanted conductivity properties suitable for regular printing processes.
- Limiting factors in processing are registration and the metrologic profile of the surfaces. On paper 1,3 % of the printed areas are often left without ink, whereas 33 % of the ink goes outside the register limit.
- Printing (even simple) electronics can hardly ever be made in an existing heatset or coldest production line as a fill-out activity to the magazine printing. The process will require special equipment and materials that can only be developed in an intensive co-operation with experts in ink and electronics.
- Optical codes, UV-codes, electric codes and invisible codes can easily be printed in inkjet or small sheet-fed presses in offset or flexo. For these methods special inks are already commercially available.
- Special inks for printed functionality in heatset, offset newspaper or gravure printing are usually not available commercially and must be developed in co-operation with ink experts and applied to individual printing presses.
- Successful pilots were developed for printing UV-radiation detectors, temperature indicators, invisible codes and detectors and electronic codes. Other pilots studied

on laboratory scale were temperature sensors, inexpensive conductive codes, security elements, combination of RFID and sensors for controlling the logistic chain and anti-counterfeiting indicators.

5.4 Investments needed and their repay

- In the case of optical codes no additional investments are usually needed. The code can be printed with one of the existing inks in one of the existing units on the press. The only critical factors are the resolution and the contrast which ought to be checked. However reading requires a device, at least a mobile phone with camera and downloaded reading software.
- Printing optical codes is usually not a technical problem per se, but every application should include an additional service with its own business model and earning logics. Developing such innovative services may offer the printer and his customer new business opportunities, but they require imagination, innovations and creativity.
- When other functionalities are needed, such as special codes, indicators and sensors, special inks are needed. This may require an extra unit in the press, if none of the ordinary printing units is applicable.
- Special inks are today commercially available for many applications for inkjet printing, sheet-fed flexo and offset in minor scale. However, functional inks for heatset and offset newspaper printing are seldom available, and must be developed in co-operation with an ink manufacturer and applied to the individual press line. The problem can be partly overcome by using pre-printed inserts with functionality.
- The costs of the inks for printed functionality are expensive compared to regular inks, and the cost range is wide. In general, the prices for the special inks are 5–50 times higher than regular printing inks, but conductive inks with metal nano-particles may be even 1000 times more expensive. However, the total material costs may still remain marginal thanks to the small size of the elements used. On the other hand, special inks often require additional investment in printing units and drying facilities.
- The additional value of a functional printed product varies strongly, but in the simple cases calculated here for applications of optical codes or indicators, they seemed to be most suitable for small and medium sized companies with a flexible and often sheet-fed production. In this case only small investments are needed. But the jump in technology from traditional printing to printed electronics is long and challenging. To be successful in this area a printing plant must find good co-operation partners – i.e. ink manufacturers, electronic experts, material suppliers – develop the production together with them, and finally find their role in the new value chain.

5.5 General recommendations

- Printed functionality is an opportunity for the printing industry to create an additional value and service connected to their products. Printing barcodes is technically simple, but economic success requires innovative new services and business models.
- Indicators and sensors require special inks, conductive or reactive to physical changes, which are usually commercially available for digital printing or small-scale sheet-fed printing only. Development of special inks for web-printing with suitable runnability is complex.
- Printing electronics requires development of the printing process, investment in special equipment and co-operation with ink manufacturers, electronic experts and material suppliers.
- The value chain of printed functionality is complex compared to that of conventional printing and contains many new players, and a company should choose its strategy carefully and specify its new role in this chain.
- Last not least a successful developing project usually requires a demanding customer.

6. Executive summary

Printed functionality means adding new functionalities into flexible substrate like paper or plastic by using printing methods. Printed functionality can be codes with links to additional information, visual effects, multi-layer structures, electronics, optics, displays, sensors and indicators. The codes, in turn, can be 1- or 2-D optical barcodes, hidden, embedded, reactive or electronic codes.

It has been the scope of this study to define innovative new applications of printed functionality, to study the required technologies and to create business models for these applications. Special attention was paid to the new role of the conventional printing plants in the value chain of printed functionality, their performance and ability to develop new service forms and the need for investment in new equipment and materials.

Codes can usually be printed along with other graphic content with regular inks. Personalisation of the codes requires digital printing, and for physically small codes high-quality substrates are needed to prevent spreading. Codes always require a reading technology, as do sensors whereas indicators can be detected with human senses. Sensors and indicators require special inks and extra printing units. In this case the on-press performance of the ink and its compatibility to the substrate must be checked in addition to the required special properties. If the sensors or indicators are printed on a label, a special attachment unit is needed.

Printed electronics, finally, are fabricated from conductive, semi-conductive or dielectric materials using printing technology. They require separate printing units for the special inks and often also curing by heat or UV beam. Printed electronics require much higher accuracy than traditional graphic applications, and moving from laboratory scale to industrial scale always results in loss of performance. The inks for printed electronics are considerably expensive, and since many components consist of several different ink layers also the compatibility between the different inks must be exactly adjusted.

Roadmaps were created for the different technologies for printed functionality. Special materials for indicators and displays based on the E-Ink technology have been available for some time, but their established use is just ahead. Many new technologies are also expected to have their breakthrough. In commercial use of printed functionality Finland is a bit behind the forerunners like Japan. Printed power sources are needed for many displays and printed electronics, but are still expected to become common later than the technologies relying on them. Printed electronics will also become common earlier than electronic codes because of the developmental status of the reading devices.

The business models for the additional service available through printed functionality are complex because of the variety of earning logics and the wide value chain. The earning logic can be based on direct sell, AD sales, access and subscription, royalties and licences, selling of brands, management of logistics or e-Business. The business chain also contains many players: publishers, advertisers, technology providers, printers, materials suppliers, data base providers, content providers and the end users. Of these, the publisher seems to have the best prerequisit to manage the value chain but each player, including the printer, has the opportunity to overtake new roles and functions.

The global market of printed electronics is expected to grow up to 40 billion euros until 2017. In the same time we expect the global market for printed functionality suitable for conventional printers to grow from 200 millions to 17 billions. The corresponding figures for Finland are 3 and 250 millions respectively.

New applications of printed functionality were innovated in two brainstorming seminars. More than sixty innovation embryos were created, of which the following have been piloted on a laboratory scale: Temperature sensors, UV-fluorescent security elements, UV-indicators and Conductive codes. All these application were rather easily realised and functioned well on the laboratory scale. Printed UV-indicators and UV fluorescent security elements were also successfully made in full scale printing in two different sheet-fed printing houses. However, full scale printing of sensors in newspapers was not carried out since the inks requiered were not available commercially for offset newspaper printing.

Business models were calculated for the following hypotetical applications of printed functionality for the Finnish market: Weather sensors in newspapers, Conductive identifier for individualisation, UV-indicators in newspapers or on sun lotion bottles, Inexpensive conductive codes to replace RFID, Security elements in event passes, Anti-counterfeiting by RFID, Combination of RFID and sensors to control the value chain. For all the cases profitable applications were found, though the market potential varied a lot and was most promising for identifiers in books and for anti-counterfeiting. Material costs are marginal, but the production costs may vary strongly depending on which existing equipment can be used.

It seems that the time to market for web-fed sensors and indicators is still 2–5 years and for printed electronics 5–10 years. Equipment for sheet-fed printing of electronic components already exist, and e.g. Litrex has already sold one hundred installations worldwide, mostly to be integrated in hybrid production lines. Also digital and flexo printing of indicators and sensors appeared to proceed rather smooth in the participating printing companies.

Also the recyclability and usability aspects of printed functionality were analysed. The evaluation of recyclability and de-inkability of a printed product is very case specific and with new type of printed products no specific answer is available previously. Generally bonding the substrate material to other materials, which are difficult to remove and/or harmful to production, can diminish recyclability. A nonpaper component is suitable for recycling if it can be separated from the recovered paper by recognized technical processes and recycled or disposed without damage to the environment.

Usability is a non-functional quality of a product describing ease of use, learnability, accessability and the interface between product and user. Hybrid media, tags and barcodes extend the world wide web to the physical world. Usability refers mostly to the interactions with mobile phone cameras and RFID readers. The usability aspects of a sensor or an indicator refer to effective reading and interpreting of the indicator, since the user can only read it, not affect it. The key questions in visualising the indicator are location, environment, physical phenomenon measured, visualising the change and the meaning of the change.

In summary printed functionality is an opportunity for the printing industry to create an additional value and service for their products. The value chain of printed functionality offers many new roles and opportunities for the printer. Barcodes indicators and sensors can rather easily be innovated and realised without big investments in technology. For more complex products, such as printed electronics however, an exact application of material compatibility and process application is needed in co-operation with other stakeholders. These applications are beyond the scope of this study.

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Appendix 1: UV Detector materials and patents

General information [1]

The UV spectrum is divided into UV-C (100–280 nm), UV-B (280–320 nm) and UV-A (320–400 nm) radiation. The UV-C radiation and radiation at shorter wavelengths is absorbed in the upper and middle atmosphere. The UV-B radiation (about 0.5 % of the solar radiation) is responsible for most of the effects of sunlight on the body. The erythemal action spectrum (Fig. 1/1) has been defined by the International Lighting Commission (commission internationale de l'eclairage, CIE) as a result of various experiments on the human skin and it confirms that the carcinogenesis effectiveness of the UV-B is much higher than that of UV-A.

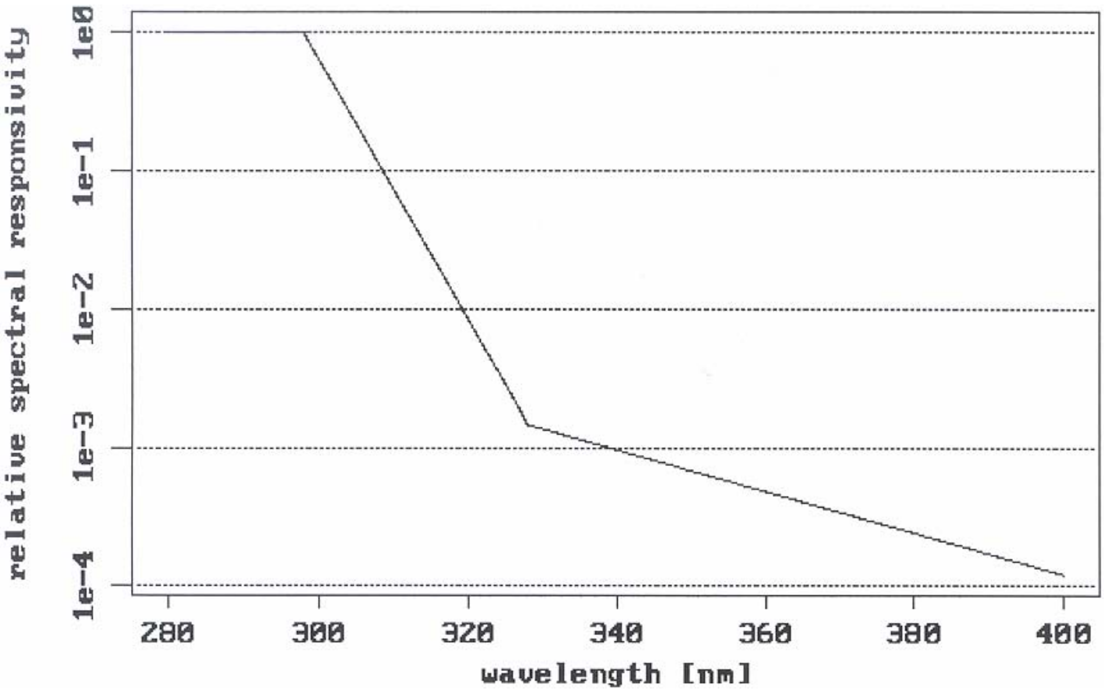

Fig. 1/1. The erythemal action spectrum as a function of the wavelength [1].

US Patent No. 4,134,853: Photochromic composition

Inventors: R. Ehrlich and M. Ehrlich

Date: 16.1.1979

A photochromic composition consisting essentially of titanium dioxide, ferric oxide and lead nitrate. This photochromic composition can be combined with moldable materials such as a plastisol and formed into toys such as dolls.

In one specific example, 1000 grams of titanium dioxide was added to distilled water to make a slurry. To the slurry was added 100 grams of ferric oxide and 10 grams of lead nitrate. The excess water was evaporated in a flash dryer and the resulting mixture calcined for fifteen minutes at 1000 ºC.

Titanium dioxide should be in anatase crystalline form since rutile crystalline form will not produce the desired photochromic composition.

Typically, the composition will darken after exposure to sunlight for approximately 15–30 seconds and will return to its normal colour within about 15 minutes after removal from sunlight.

The photochromic composition is particularly useful when incorporated into a plastic material (in the range of about 1–50 %) which is then used to form dolls which will appear to tan when exposed to sunlight.

US Patent No. 3,329,648: Compositions of matter composed of vinyl polymers and inorganic photochromic oxides

Inventor: John A. Chopoorian

Date: 4.7.1967

This invention relates to novel compositions of matter comprising polymers of various esters of acrylic and methacrylic acids, styrenes or vinyl halides having uniformly dispersed throughout the body thereof, a photochromic material comprising various admixtures of inorganic metal oxides.

There are 3 groups of photochromic materials that may be used in the present invention:

a) Admixtures consisting of a primary or host inorganic metal oxide doped with a lesser amount of another guest inorganic metal oxide (e.g. TiO_2 doped with Fe_2O_3, FeO, Cr_2O_3, CuO, NiO, MnO_2 or Mn_2O_3; Nb_2O_5 doped with Fe_2O_3, FeO, Cr_2O_3, CuO, V_2O_5, MnO_2 or Mn_2O_3; Al_2O_3 doped with Cr_2O_3 or V_2O_5; ZnO doped with CuO or V_2O_5; SnO_2 doped with CuO; or ZrO_2 doped with CuO or NiO). The rutile form of TiO_2 is sufficient; however the anatase form containing at least 5 % of the rutile material is preferred.
b) Admixtures of TiO_2 with a combination of 2 doping (guest) metal oxides. For example TiO_2 doped with Fe_2O_3 or FeO and NiO; or TiO_2 doped with Fe_2O_3 or FeO and CuO result in a more intense color change than TiO_2 doped with Fe_2O_3, FeO, NiO or CuO alone. Again, the rutile form of the host compound is satisfactory, but the anatase form containing at least 5 % of the rutile material is preferred. The slurry

is evaporated and ground, then calcined at a temperature between 400–1100ºC to give the active admixture.

c) TiO_2 in admixture with MoO_3 or WO_3. These admixtures are produced in mole ratios of about 1–15 mole percent of TiO_2 to about 25–1 mole percent of MoO_3 or WO_3.

UK Patent Application GB2,067,060: Ultraviolet radiation dosimeter

Inventors: Anthony Davis and Thomas John Tate

Date of filing: 10.12.1980

A photochemical UV dosimeter has a photosensitive element which has an action spectrum (response vs. wavelength) very close to that of human skin in the erythemal (skin reddening) range of the ultra-violet (ie. wavelengths below about 320 nm). The preferred photosensitive element in the dosimeter comprises a photosensitive material, especially a polysulphone, particularly dimethyl polysulphone, having an effective thickness of below about 10 microns, preferably below about 1 micron.

The photosensitive element may be dispersed in an inert matrix or, preferably, mounted on a non-photoactive support. In either case the preferred material is polyvinyl alcohol or regenerated cellulose strip (cellophane-Trade Mark).

The photochemical response, as read at 302 nm is independent of dose rate, at least from 0.5 to 2.5 J/cm^2, and of temperature, from -4° to 50ºC, giving A302 of 0.2 for 1 J/cm^2 of radiation at 280 ± 0.5 nm. The action spectrum is independent of dose and closely approximates to that of human skin.

According to reference [2] the polysulphone undergoes UV induced photodegradation when exposed to UV wavelengths shorter than about 340 nm. This photodegradation is quantified by measuring the pre- and post-exposure optical absorbance at 330 nm in a spectrophotometer in order to determine the change in optical absorbance (ΔA_{330}).

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A solution of iodouracil (0.2 mg/mL) and KI (0.1 m) in 0.23 M borate buffer (pH 7) forms triiodide upon exposure to UVB. In the presence of thyodene, the blue starch-iodine complex is formed, the intensity of which is proportional to the amount of UVB exposure.

US Patent 6,132,681: Disposable dosimeter for sun radiation

Inventors: Ori Faran, Ezra Natan and Dmitry Lastochkin

Date of patent: 17 October 2000

Assignee: Skyrad Ltd.

A disposable dosimeter for sun radiation comprising a matrix with at least one active chemical compound distributed therein, capable of changing its original color to a new color due to a chemical reaction induced by exposure to UV radiation, said matrix made of a material having transparency sufficient for visual detection the change of the original color to a new color, said matrix containing at least one absorbing compound capable of absorbing the UV radiation, said active chemical compound being capable of changing its color after exposure to UV radiation with an efficacy corresponding to at least 1 MED, said UV radiation being accumulated during at least 15 minutes of exposure and said active chemical compound having a resistance to change the new color neither during exposure to temperatures up to 50 °C nor during exposure to visible light.

The present dosimeter advises the user to terminate exposure to the sun's radiation after the whole dosimeter's surface has changed its initial color to the color that appears at the border of the surface. This coloration signifies that the user has already been exposed to 1 MED (minimum erythemal dose).

Examples of active photochromic or photosensitive compounds listed in the patent are:

aromatic o-nitro derivatives,
2,3,4,4-tetrachloro-1-oxo-1,4-dihydronaphthalene designated as TKN
azasuccinic anhydrides derivatives [3],
spiropyran derivatives [4],
bisimidazoles derivatives [5].

Examples of materials suitable for use as absorbers include:

2,4-bis(2,4-dimethylphenyl)-6-(2-hydroxy-4-n-octyl-oxyphenyl)-1,3,5-triazine,
2-hydroxy-4-(N-octoxy)benzophenone,
2-(2H-benzotriazol-2-YL)-4,6-tritertpentylphenol or
2,2'-dihydroxy-4-methoxybenzophenone.

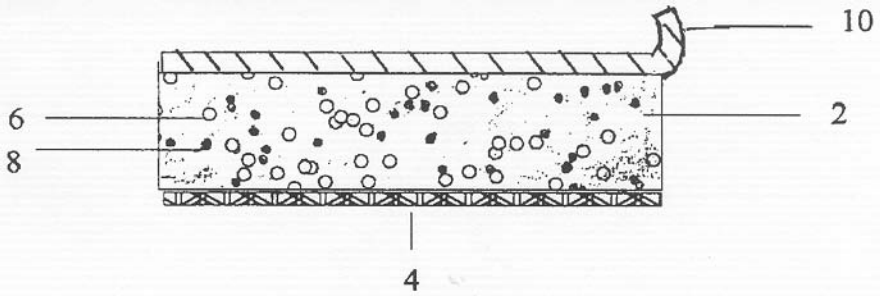


fig. 5a

2 = polymeric matrix
4 = a layer of sticky material
6 = active photochromic or photosensitive compound
8 = UV absorbing material
10 = a thin layer of an opaque foil.

US Patent 6,734,440: Sunlight dosage indicator

Inventors: John Questel and Christian Sololowski

Date of patent: 11.5.2004

Assignee: Questel Adhesives (Akron, OH, USA)

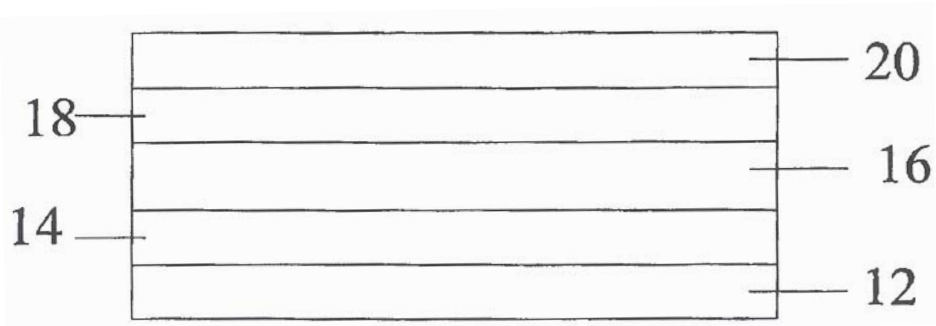
A multilayer sunlight dosage indicator comprising (a) an indicator layer comprising a sunlight-sensitive ink, wherein the ink undergoes a color change upon exposure to a known amount of sunlight; and (b) an overlayer comprising an amount of at least one UV absorber. A method for indicating the amount of exposure to sunlight using an indicator layer of sunlight-sensitive ink which undergoes a color change upon exposure to a known amount of sunlight and an overlayer comprising an amount of at least one UV absorber. It is possible to adjust the sensitivity of the indicator by controlling the UV absorbing materials in the overlayer.

– Fair-skinned people require only about 15–60 minutes of midday summer sunshine to induce an erythemal reaction. Thus, a sunlight dosage indicator that changes color after about 15–60 minutes is needed for use by fair-skinned people. On the other hand, people with normal skin may require 1–2 hours of exposure before an erythemal reaction is observed so that a sunlight dosage indicator with a response time of 1–2 hours is needed for them.

– The indicator layer comprises a sunlight-sensitive ink. For purposes of this specification, a sunlight-sensitive ink is a material which reliably changes color upon exposure to the ultraviolet radiation present in sunlight. Materials that change color upon exposure to UV radiation in this ink formulation include, but are not limited to ethyl orange, Congo red, methyl red, indigo carmine and specirazine ethyl violet. The indicator layer may further comprise binders, surfactants, viscosity control agents and color change enhanchers.

– Overlayer (b) of the present invention comprises a colorless lacquer mixture formed from ingredients comprising a binder, a thickener, a polyester resin, and one or more solvents. The mixture further comprises processing aids such as waxes, surfactants and the like, Suitable binders include, but are not limited to, polyamide resins. Ethyl cellulose is a preferred thickener.

The overlayer functions to adjust the response time of the sunlight dosage indicator. A colorless lacquer can absorb UV radiation, thereby decreasing the amount of radiation reaching the sunlight-sensitive ink in the indicator layer. For example, ethyl cellulose is a UV absorber. An overlayer 2 mils thick, comprising ethyl cellulose, transmits only about 40 % of light having a wavelength of 260 nm.



12 = a removable layer
14 = an adhesive layer
16 = a substrate
18 = an indicator layer
20 = a clear overlayer

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Title
Technical innovations and business from printed functionality

Abstract
Printed functionality means adding new functionalities into flexible substrates like paper or plastic by using printing methods. It has been the scope of this study to define innovative new applications of printed functionality, to study the required technology and to create business models for these applications. Special attention has been paid to the new role of conventional printing plants in the value chain of printed functionality.

Roadmaps were created for the different technologies for printed functionality. Business models for the additional services available through printed functionality are complex because of the variety of earning logics and the number of players in the value chain. Each player has the opportunity to overtake new roles and functions.

The global market of printed electronics is expected to grow up to 40 billion euros until 2017. In the same time the global market for printed functionality suitable for conventional printers is expected to grow to 17 billions.

New applications of printed functionality were innovated in brainstorming seminars. Some of them were tested in pilot scale, business models were created for them, and they were also analysed regarding environmental aspects and usability.

In summary, printed functionality is an opportunity for the printing industry to create an additional value and service for their products, but requires demanding development work, clear business models and intensive cooperation with other players in the value chain like materials suppliers, machine manufacturers and service providers.

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