Smart Inks – Status Quo and Future

L. Lin,

Digital Printing Centre of Industrial Collaboration and Department of Colour & Polymer Chemistry, The University of Leeds, Leeds LS2 9JT, UK

Abstract

Anti-counterfeit, product safety monitoring, brand protection are just few of the buzz words/phrases attracting much of the recent attention in the world of industry and commerce. Interestingly, successful development of relevant productions heavily relies on the technical advancements in smart, functional speciality inks. In many cases, the heart of the technology is functional speciality colorants, whilst in practice, formulation of workable, smart inks containing such colorants is no less challenging. This paper gives a review of the existing smart "ink" systems and an overview of the directions for future development.

Keywords: Smart inks, anti-counterfeit, functional inks, speciality inks, brand protection

Introduction

Recent years have seen a significant increase in the interest for smart, functional printing inks, driven mainly by legislation demands, together with rapid progress in electronics manufacturing industries. Naturally, both academic and industrial research and development rose to the challenge. Smart/functional ink formulations contain functional/speciality materials that are capable of physical chemical changes induced by environmental changes, often detectable either instrumentally or visually. Typical examples of smart inks include heat-sensitive inks, light-sensitive inks, moisture sensitive inks, pressure sensitive inks, magnetic inks, bio-reactive and electricity sensitive inks. The current paper intended to review various technologies, based on smart inks, and to propose future directions of research and development in this particular area.

Whilst fully appreciating the fact that the essence of most smart inks is the smart materials, the current paper structures discussions according to the fields of application of smart inks, thus covering the following topics.

- Anti-counterfeit/brand protection applications;
- Product-safety-monitoring applications;
- Applications in medical diagnostic sensor devices; and
- Applications in manufacturing of electronic devices

Applications of smart inks in anti-counterfeit / brand protection

Prevention of banknote counterfeit

Fuelled by the recent rapid advancement in digital image reproduction technology, counterfeit is rising! More widely counterfeited articles include banknotes, bond certificates, passports, driving licences, and branded products, with banknotes being the most counterfeited. Security alerts on circulation of counterfeit banknotes can be seen in the news at an alarmingly high frequency. (www.4ni.co.uk, 2005; Carlsen and Riishøj, 2005; Parliamentary Office of Science and Technology, 1996)

The number of counterfeit banknotes taken out of circulation is relatively small, compared to the total number of banknotes issued. During calendar year 2004, the number of counterfeit Bank of England banknotes taken out of circulation was around 325,000, with £20 being the most counterfeited, at 0.0273% against the total number of genuine banknotes in circulation. (Table I) (Bank of England, 2005)

Table I Profile of genuine and counterfeit Bank of England banknotes in 2004

Denomination	Counterfeit banknotes taken out of circulation	Genuine banknotes in circulation	Percentage of counterfeit against genuine banknotes
£5	19,000	209,000,000	0.0091%
£10	15,000	585,000,000	0.0026%
£20	285,000	1,045,000,000	<u>0.0273%</u>
£50	6,000	118,000,000	0.0051%

However, the number of counterfeit banknotes in circulation is much greater. In Britain, against the £89.9 billion (face-value) banknotes issued between 1996 and 1999, an estimated £90 million counterfeit banknotes were in circulation. Over the years, statistics indicate a general trend of increase of the value of counterfeited banknotes worldwide, as can be seen from Figures 1 – 3.

It is thus not surprising that of all anti-counterfeit/brand protection technologies, those employed in the banknotes are of the most sophisticated. A typical banknote would carry several or all of the following anti-counterfeit features:

- Water mark
- Hologram
- Metal strip
- Latent image
- Metameric image

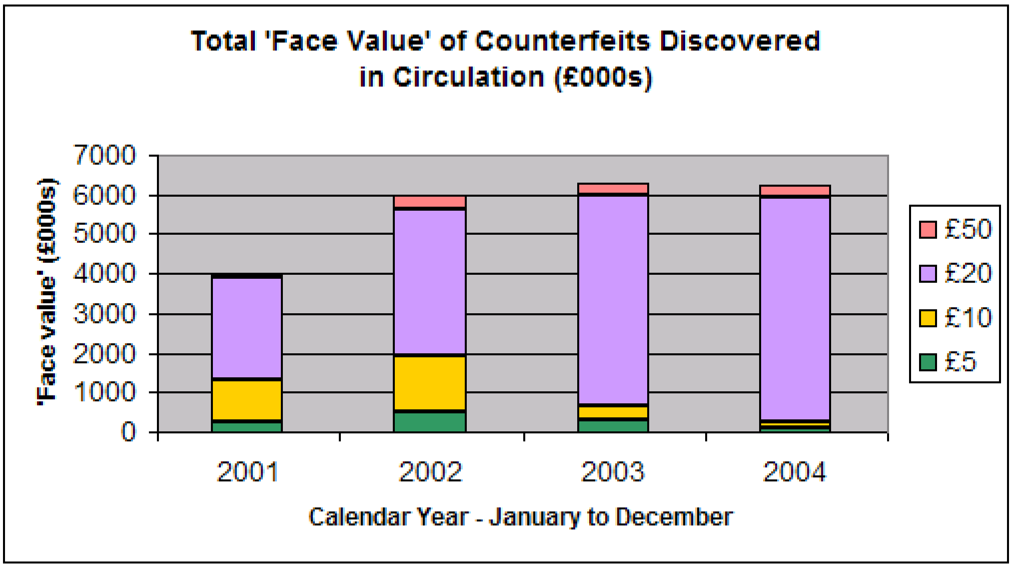


Figure 1 Total “face value” of discovered counterfeit Bank of England banknotes between 2001 and 2004 (Bank of England, 2005)

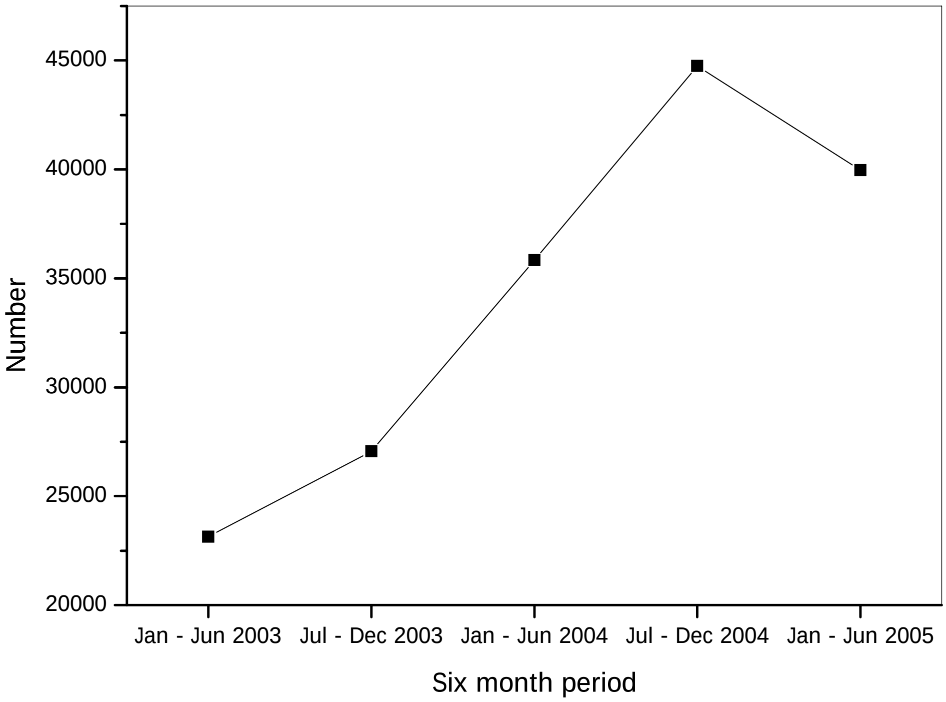


Figure 2 Number of confiscated counterfeit Deutsch Marks in six month periods (Deutsche Bundesbank, 2003, 2004a, 2004b, 2005a, 2005b)

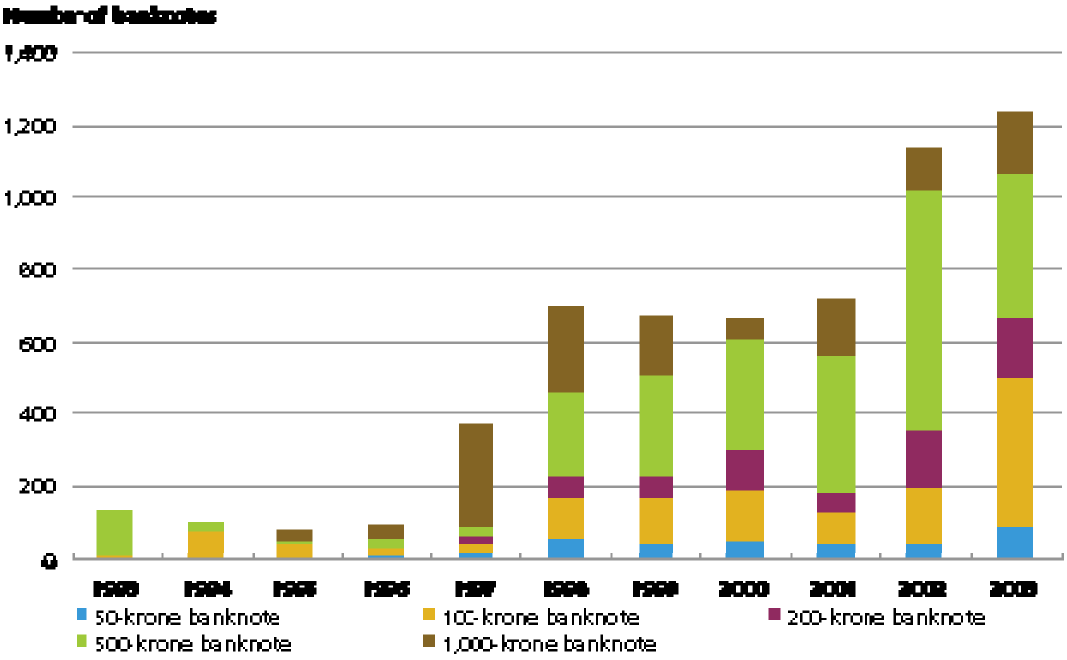


Figure 3 Number of counterfeited Danmark krones between 1993 and 2003 (Carlsen and Riishøj, 2005)

- Raised image (Intaglio print)
- Micro-dot
- Security thread
- Optical-brightener-free paper
- Fluorescent image
- Anti-copying/anti-scanning patterns

Of these features, fluorescent images are created using smart inks, while others are either applied through paper-making process or created using speciality printing technology. A typical fluorescent ink contains fluorescent dyes and medium.

Anti-counterfeit technologies based on thermochromism

Anti-counterfeit technology based on thermochromic colorants has been reported. Singer (1997) reported a method for the production of temperature sensitive security document using thermochromic inks. Thus, the security document included a substrate having top and bottom surfaces where at least one of the surfaces was adapted to carry printed images. A coloured background was printed on at least a portion of one of the surfaces, such as the surface which was adapted to carry printed copy, using a heat sensitive ink. The key ingredient in such a security document was the thermochromic dye which changed from colourless to coloured when heated. Based on this patent, Verify First Technologies developed TouchSafe® "Heat Reactive Verification Seal" and ThermoHide™ "Heat Sensitive Camouflaged Message" hidden message technologies which combine thermochromic and conventional inks. TouchSafe® “Heat Reactive Verification Seal” is a fingerprint seal that requires the user’s interaction and must be breathed on, rubbed or touched to verify authenticity. ThermoHide™ is a covert hidden message that both verifies authenticity and protects the document from copying or alteration attempts.

Touch or breathe on the fingerprint seal, a message such as “valid” will appear to verify authenticity. Typical examples of security document carrying TouchSafe® “Heat Reactive Verification Seal” are shown in Figure 4.

Figure 4 TouchSafe® “Heat Reactive Verification Seal” security documents (Verify First Technologies, 2005a)

With the ThermoHide™ “Heat Sensitive Camouflaged Message” hidden message technology, brisk and rapid rubbing of the indicia areas on the security document would reveal a hidden valid or alert message thus verifying authenticity. Additionally, the heat from a colour copier can activate the hidden alert message, resulting in a permanent warning message being produced on the colour photocopy rendering it void. The activated message on the security document would revert back to its original camouflaged state upon cooling. Examples of security document carrying the ThermoHide™ “Heat Sensitive Camouflaged Message” hidden messages are given in Figure 5.

A further technology, based on Singer’s (1997) invention, developed by Verify First Technologies is the NoDupIt® “Heat Reactive Verification Signature or Logo” technology. With such a technology, logo phantom and/or signature obscure when digitally scanned or photocopied, a feature particularly useful for security documents where a signature or logo must be pre-printed but digital reproduction forbidden. Examples of security document carrying NoDupIt® “Heat Reactive Verification Signature or Logo” are shown in Figure 6.

Figure 5 Security documents carrying ThermoHide™ “Heat Sensitive Camouflaged Message” hidden message (Verify First Technologies, 2005b)

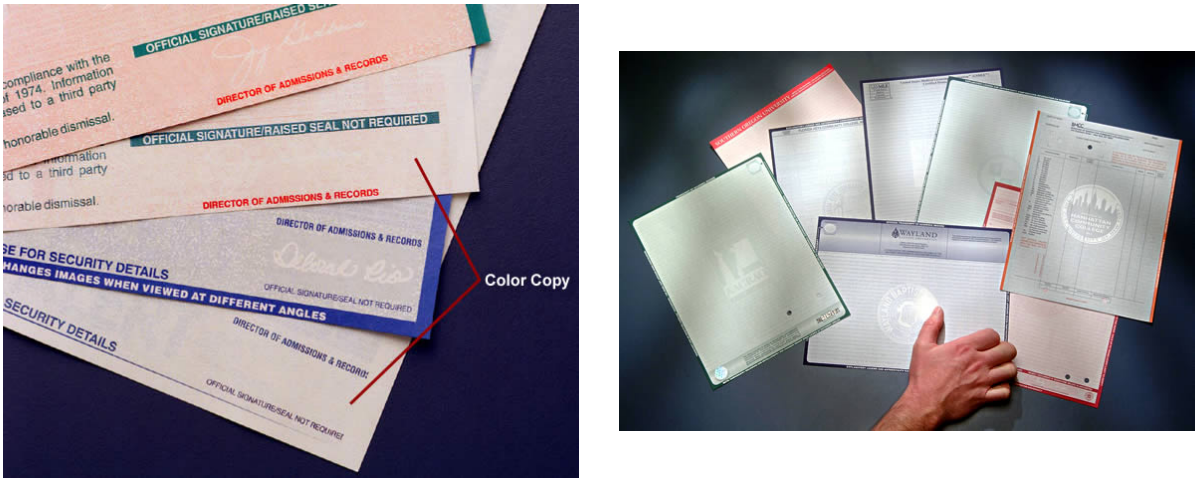


Figure 6 Security documents carrying NoDupIt® “Heat Reactive Verification Signature or Logo” (Verify First Technologies, 2005c)

Philips (1999) developed a mechanism for document protection based on thermochromic pantograph and a validation mark. Thus, the thermochromic pantographs, which carry a latent image, are printed onto a substrate. The latent image is rendered visible when sufficient heat is applied to the document, activating the reactive properties of the thermochromic ink. The latent image could form a warning message such as “STOP” or “ALERT” which could alert the recipients that a counterfeit copy has potentially been created. Verify First Technologies (2005d) developed anti-counterfeit products known as ThermoSafe™ “Density Change Copy-Void Pantograph”, which reveal a warning message when a colour photocopy is made. Utilising a temperature sensitive camouflage pattern to conceal the extreme NaNOcopy™ background, ThermoSafe™ creates a robust warning message when copied. The temperature sensitive "thermochromic" camouflage also acts as a verifier which disappears or changes colour when touched, rubbed or breathed on. Examples of security document carrying ThermoSafe™ "Density Change Copy-Void Pantograph" are shown in Figure 7.

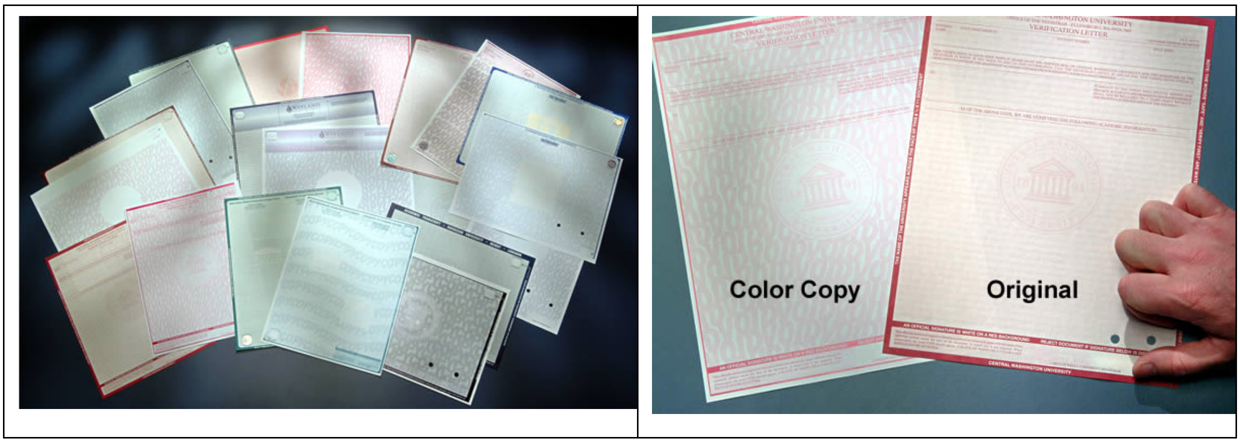


Figure 7 Security documents carrying ThermoSafe™ "Density Change Copy-Void Pantograph" (Verify First Technologies, 2005d)

Anti-counterfeit technologies based on photochromism and reflective colouring materials

Anti-copy has been the holy grail for anti-counterfeit research and development. One of the mechanisms that have been reported is to render the document "uncopyable" by using paper embedded with photochromic materials. (James *et al.*, 1971) Thus, the photochromic materials formed part of the coating formulations applied onto the paper substrate using a conventional coating method. Upon exposure to radiation from strobotron placed closely adjacent to the paper, the paper became coloured matching the colour of the printed image, rendering the printed document uncopyable. Suitable photochromic materials for such applications included phosphotungstic acid and tetrachlor-ketonaphthalene. The only drawback, in terms of practical application, of this mechanism is the need of a strobotron within the photocopying device.

Mullis (1989) and Goman and Sirdesai (1992) reported a phototranschromic ink suitable for use in a printing machine, including a water soluble, inert, non-ionic polymeric resin carrier base having film forming properties, a photo acid or photo base progenitor which releases or takes up protons upon exposure to light, a pH sensitive dye which changes colour in response to a change in proton levels, a water compatible non-ionic wetting agent, a water compatible non-ionic thickening agent, and a neutral water soluble flow aid. Prints produced using such an ink change colour upon exposure to ultraviolet radiation and are of suitable consistency for use in a printing machine.

A typical ink formulation consists of sodium bisulphite, o-nitrobenzaldehyde, polyvinyl alcohol, bromophenol blue sodium salt, meta-cresol purple, polyalkylene oxide-modified methylpolysiloxanes, polyurethane dispersion viscosity modifier and diol ester solvent.

LaCapria (1976) proposed the art of creation of valued documents printed using inks containing specularly reflective colouring materials, such as powdered aluminium, to prevent photocopying using colour photocopiers. Such a method was based on the understanding that modern colour copiers depend upon a colour analysis of the light absorbed by various parts of the document and do not reproduce true colours when they encounter specular reflections from the surface of the document being copied. A specular reflection on the surface of the document being copied results in an image which does not match the colours on the original document, and hence is readily distinguishable from an original.

A typical formulation containing aluminium flakes consists of two parts with Part A consisting of 64% of powdered aluminium, 16% mineral spirit and 20% transparent varnish and Part B consisting of 41.4% chinawood oil, 11.4% of phenol formaldehyde rosin and 47.2% of raw linseed oil. A typical formulation consists of 54.9% Part A and 45.1% Part B. Although not all aluminium flakes will lie flat, a sufficient percentage of these flakes do so to produce scattered specular reflections. The scattered reflections, although randomly located, are sufficiently dense to confuse the copier and interfere with the reproduction of the silver colour of the aluminium.

Warner and Lind (1998) proposed a simpler method for the creation of specular reflection. Thus, a paper substrate is laminated with a metalised layer forming a mirrored surface. A partially transparent black diffraction grating is applied by stochastic screening to the mirrored surface. The diffracting grating forms a random pattern from selected geometric shapes. The partially transparent black stochastic screen forms a diffraction grating on the metalised layer so that when illuminated from the light source of either a specular or diffuse illumination-type photocopier, random interference patterns of light occur at the interface of the metalised surface and the stochastic screen. The diffracted light is not readable by a photocopier drum resulting in the indicia being not legibly reproduced. Thus, the indicia printed on the security document are protected from counterfeiting and unauthorised copying.

Brand protection

Another aspect of anti-counterfeit activities lies in brand protection. Many anti-counterfeit technologies used for the prevention of banknote counterfeit are suitable for application in brand-protection. Such applications would likely take the form of security labels attached upon the package of branded products or directly on the branded products.

For both banknotes anti-counterfeit and brand-protection applications, it is of vital importance that the special features employed are technically extremely difficult to reproduce or expensive to imitate. Patenting anti-counterfeit and brand-protection technologies is not without its drawbacks, as the counterfeiters are far from submitting themselves to the constrain of intellectual property rights. Disclosure of the technical details of an anti-counterfeit technology could significantly discount the value of the technology.

One of the more worrying facts concerning the existing anti-counterfeit/brand protection technologies mentioned above is the public's accessibility to the speciality materials and technologies. Thus, the thermochromic colorants based on pH indication dyes and photochromic dyes are readily available through a number of commercial sources. Provided with such speciality chemicals and details of the technologies, it would not take an experienced ink formulation chemist with strong chemistry background too long to develop inks whose functionality, e.g. colour change, would closely imitate those of the patented anti-counterfeit/brand protection technologies.

One effective approach to achieving robust anti-counterfeit/brand protection technology is to develop smart inks giving unique colour changing characteristics and visual effects that are chemically novel and complex thus difficult to be reproduced. Thus, the features created would be difficult to imitate and technically prohibitive. In terms of anti-counterfeit/brand protection features based on photochromic colorants, the future direction should be development of photo-bleaching colorants, which change from coloured to colourless upon exposure to daylight, scanner or photocopier, as opposed to the existing photochromic colorants which change from colourless to coloured when exposed to short-wavelength radiation.

Another factor that needs to be considered when developing future anti-counterfeit/brand protection features is that details of the technologies developed should not be disclosed to public domain. Instead, technology know-how of new anti-counterfeit/brand protection technology should be kept under strict confidentiality, to minimise the potential of the technology being pirated by the counterfeiters.

Applications of smart inks in product-safety-monitoring

One of the high-added-value applications of smart inks is in the field of temperature and time-temperature indication, such as the best-before-end indicator for food packages.

Best-before-end (BBE) indication is an essential requirement for many food products. To date, the majority of BBE indication is still in the format of a date often inkjet printed on the product package on the packaging line. Such a BBE indication system has a number of disadvantages including:

- The BBE date is an estimate based on a set of presumed environmental conditions that the package may experience. As a result, often the BBE date has to be artificially shortened in order to ensure that the packaged content does not perish before the BBE date. This consequently causes a significant level of waste.
- Even with the best estimate, the package may still experience certain unexpected extreme environmental conditions rendering the packaged content unsafe to consume before the BBE date, therefore causing health problem.
- In order to ensure that packaged content has a sufficiently long shelf life required by the transportation logistics and the retailers, manufacturers may need to include an excessive quantity of preservatives within the packaged content in order to allow them to prolong the BBE date. This results in consumers being exposed to an unnecessarily higher level of synthetic additives.

Such disadvantages could be overcome by the use of time-temperature indicators (TTIs) which, when attached onto the package, could “record” the time-temperature history of the package, thus, providing accurate information on the fitness-for-consumption of the packaged food.

So far, several time-temperature mechanisms have been developed, two of which are based on visible colour-change (pH indicators), and on the rate of diffusion of colour creating chemical on substrate, respectively. (Selman, 1995; Heron, 1998) TTI can be generally classified as ascending indicator and descending indicator with regard to their functions. Ascending indicators record critical rising temperatures, ensuring that frozen products are not exposed to thawing conditions. Descending indicators record critical falling temperatures, ensuring that vulnerable refrigerated products, such as vaccines, are not exposed to freezing conditions.

Commercially, there exists TTIs based on various mode that the information is provided. These include the following.

- Go/No Go Without Delay indicators (Heron, 1998) provide an immediately irreversible response to the change of temperature. The indicator is usually based on either the melting of a solid which is then able to deform a pattern, or the thawing of an emulsion allowing mixing of two reactants to form a visible colour change.

- Go/No Go With Delay indicators (Heron, 1998) only reflect a limited period of exposure above a critical temperature. The response delay helps to reduce false positive indications due to short exposures to temperature abuse. (Selman, 1995; Taoukis, 1991) The mechanism of reaction is usually based on diffusion of either a coloured liquid or a liquid carrying a reactant to cause a visible colour when it passes through the barrier to a wick (cardboard or paper), or semipermeable gel or barrier.

- Time-Temperature Integrators provide a single reading, which can be used to provide a continuous, temperature dependent response. Therefore, it can be used to indicate an “effective average” temperature during distribution which theoretically can be correlated to continuous, temperature-dependent quality-loss reactions in foods. However, it cannot provide the exact change of time/temperature combinations at specific time.

- Multi-temperature Go/No Go indicators consist of several Go/No Go without delay type indicators providing information in a range of temperatures without time element. This kind of indicator can provide different response temperatures.

- Multi-Temperature with Time Element indicators combine several Go/No Go with delay type indicators, which can be both time and temperature dependent to provide the information on the temperature that has been exceeded and the length of exposure. Therefore, this kind of indicator can be used as time-temperature indicator system to monitor the thermal effect on food with contribution of both time and temperature.

The mechanisms employed to create the assemblies mentioned above include the followings.

- Diffusion based indicator, where two reactants (mobile component and stationary component) are located in separated compartments. (Figure 8) Initially, these two components are separated by a barrier film. As the temperature exceeds the active limit, the barrier system will be removed or broken, and mobile component is brought into contact with the stationary component. The rate of diffusion of the mobile component in the stationary component is time-temperature dependent. Therefore, the system can be used as time-temperature indicator. An example of the material that can be used as the stationary phase in diffusion based indicator is cellulose paper, while the mobile phase can be a medium containing non-toxic food colorants.

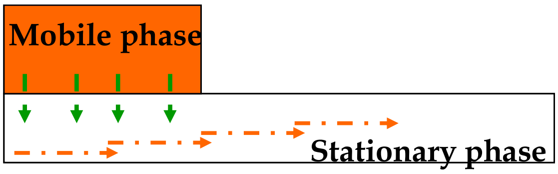


Figure 8 Schematic illustration of the mechanism of diffusion based indicator

- Enzyme based indicator (pH based) functions on the release of an acid as a result of the lipolytic enzyme hydrolyses of the lipid substrate, Figure 9. The acid is brought into contact with the pH indicator to induce the colour change. The indicator is produced by locating the pH indicator in the centre and the lipolytic enzyme and the lipid around the pH indicator.

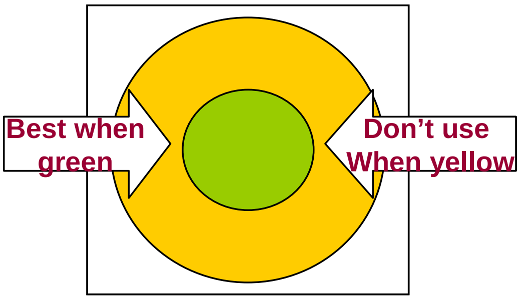
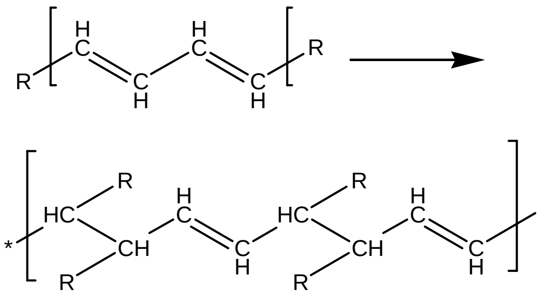


Figure 9 Schematic illustration of the enzymatic based indicator

- Polymerisation based indicators rely on polymerisation of colourless monomers to produce a colour polymer giving a visible colour. The reaction is based on the ability of disubstituted diacetylene crystals (R-C=C-C=C-R) to polymerise through a lattice-controlled solid-state reaction. The reaction proceeds via 1,4-addition polymerisation and the resulting polymer is highly coloured (Scheme 1).



Scheme 1 Polymerisation of diacetylene monomers

Figure 10 illustrates the feature of a polymerisation based indicator. Initially, the central ring containing diacetylenic crystals is colourless so that the red background can be seen at the centre of the label. When the polymerisation occurs, the polymer crystals are chain aligned and are effectively one-dimensional in their optical properties. The colour of the polymer chain is due to the unsaturated, highly conjugated backbone. Eventually, the middle section (the active section) of the polydiacetylene becomes coloured.

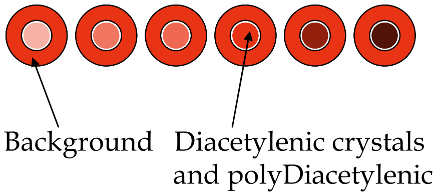


Figure 10 Schematic illustration of a polymerisation based indicator

- Photoactivatable time-temperature indicators comprise either thermally inactive compound or thermally active compound with photosensitive compounds in polymer matrix. (Bhattacharjee, 1987) Upon exposure to actinic radiation, the photosensitive compound will react and form a new compound initiating the thermally reactive reaction. An example can be obtained by combining a diacetylenic compound and a photosensitive compound. On exposure to actinic radiation, the photosensitive compound will form an acid that converts diacetylene to thermally reactive product which responds to time and temperature resulting in colour change.

A number of patents on TTI are worthy of notice. Brown *et al.* (1986) disclosed a temperature indicating composition that is UV curable and can be applied to a recoverable substrate by printing. Baum (1969) introduced a triggering system based on the combination of wax and photochromic colorants. When temperature increases to a certain point, the wax melts leading to exposure of the photochromic colorants thus resulting in the colour change.

Certain thermochromic materials based on inorganic chemistry have been used in the TTIs. Thus, Bohm *et al.* (2002) introduced thermochromic rylene dyes, together with their synthesis routes. Arduengo (1987) reported the synthesis process of arsenic and antimony compounds which displayed thermochromic properties in solvent. Fischer and his colleagues (1996a; 1996b) introduced a novel thermochromic compounds (ring opening system), which can be used for laser image printing since they exhibit no absorption in the NIR range to strong absorption in the NIR range when subjected to heat or heat radiation.

Organometallics have also been employed in TTI. Kostic and Zhou (1989) developed thermochromic compounds containing $[Pt(dipic)Cl]^-$ anion. These compounds were yellow and monomeric at high temperature or in low concentrations and abruptly changed to red and polymeric at low temperatures or higher solution concentrations. Also, the critical narrow temperature range could be changed by altering the solution concentrations. It was pointed out that an ideal product should possess abrupt colour change at a certain temperature.

Schmidhalter (1990) developed copper and nickel dihalide organic complexes which were simultaneously cryogenic and thermochromic that could be used as an indicator for both cooling and heating. Chromic behaviour of organic compounds on decomposition was discussed in some detail.

There have been a large number of patents on the use of macromolecular materials in TTI, indicating both strong interest from the industry and huge potential of this type of product in future market. Of particular interest are polydiacetylene polymers that may be formulated to provide compositions having numerous different colour transition triggering mechanisms. This kind of polymer can be structurally modified to afford more than one intrinsic colour change (e.g. blue to magenta to red or blue to red to yellow) with different triggering mechanism for colour change. (Ribi, 2003a) In such systems, the thermally induced chromic change is the result of the melting transition of side chains appended to the polymer diacetyleneic structure. Various side chains will lead to different thermochromic temperature. (Ribi, 2003b) Yee *et al.* (1980; 1981; 1982) and Baughman *et al.* (1980) described the preparation process in the early stage of the invention of polydiacetylene monomers.

All current TTI technologies suffer the same drawback that is the lack of precision in terms of colour-change in response to time and temperature. This significantly restricted the extent of the application of the existing TTI technologies. One of the future directions in TTI technology should be the improvement of the sensitivity of the TTI assemblies. Any TTI that could record time-temperature history to the precision of ±12 hours and ± 2°C would be a break-through in TTI technology.

Applications of smart inks in medical diagnostic sensor devices

Smart inks have also found applications in the manufacturing of medical diagnostic sensor devices. The benefits of adapting printing technology for the production of such sensor devices include the much increased speed of production and reduced cost of production, as printed sensor devices are often a miniaturised versions of the traditional ones. The heart of printed medical diagnostic sensor devices is smart ink which contains chemically and biochemically active ingredients such as enzymes, anti-bodies, buffers and electron mediators.

One of the more successful applications of smart ink is in the manufacture of dry test strip for use in conjunction with glucose meters. (Lin, 1994) The smart inks concerned are often delivered through inkjet printing, a technology that is particularly useful for the deposition of small quantities of high-cost materials. Hart *et al.* (1996) developed prototype electrochemical lactate electrodes based on lactate oxidase by ink-jet printing. Laboroi (2003) developed various prototype blood glucose sensors (Figure 12) using inkjet printing technology. In both cases, good retention of enzyme activity and good storage stability of the biosensor assemblies were achieved (Figure 13), proving inkjet printing a feasible technology for the fabrication of biosensors.

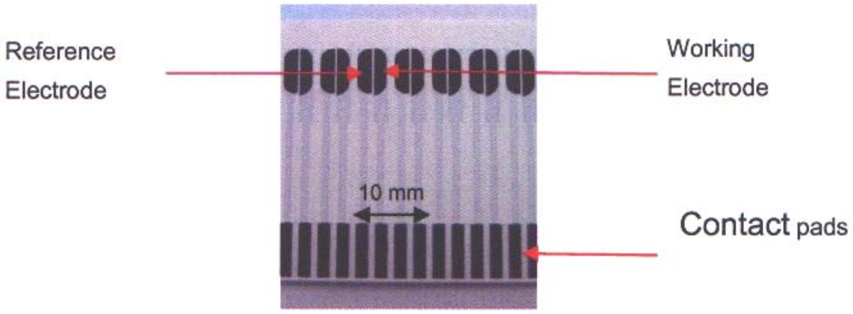


Figure 12 Jet printed enzyme glucose electrodes for medical diagnostic sensor systems

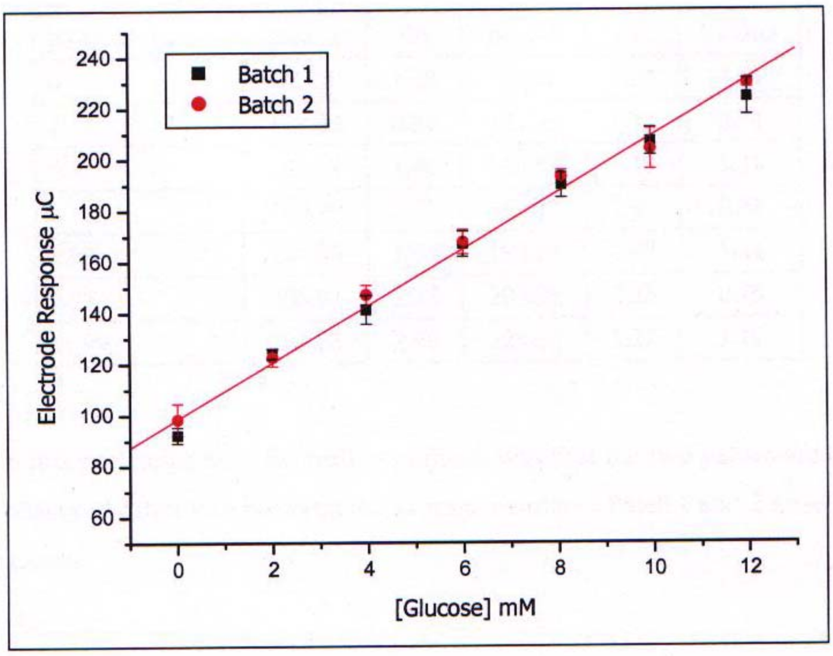


Figure 13 Calibration curves of two batches of jet printed medical diagnostic sensors

The future of smart inks for medical diagnostic sensors lies in the development of smart inks capable of detection of a range of pathologically important biochemicals such as homocysteine for the diagnosis of heart-disease. It is very likely that inkjet printing would be the technology of choice to ensure lower cost and higher speed of production.

Applications of smart inks in the manufacturing of electronic components/ devices

Smart inks have found a significant number of applications in the fabrication of electronic components. (Pede *et al.*, 1998; Jeynes *et al.*, 2002) Typical electronic components fabricated using smart inks, in conjunction with inkjet printing technology, include polymer thin film transistors (Kawase *et al.*, 2003), all-polymer capacitors (Liu *et al.*, 2003) and RC filter circuits (*Chen et al.*, 2003) All of such fabrications involved inkjet printing of smart ink formulations containing at least one conductive polymer, typically poly(3,4-ethylenedioxythiophene).

Kobayashi *et al.* (2000) developed ink formulations containing light-emitting polymers (LEP) for the fabrication of light-emitting polymer display. Thus, poly(para-phenylene vinylene), used as a green or a red emitter, was printed with a conventional inkjet head followed by spin-coating of poly(di-octyl fluorine) to form an electron-transferring layer or a blue emitter. Using this system, patterned electroluminescent (EL) layers on a thin film transistor TFT substrate were fabricated using the inkjet process which display a multicolour image through the TFT–LEP display.

Sumitomo Metal Mining Co. Ltd. (2005) introduced X-100 series transparent conductive ink, which composed of organic solvents, a binder, and well-dispersed micro-particles, manufactured using proprietary powder technology. The X-100 series ink allows clear conductive film to be formed easily and inexpensively on substrates such as plastic and glass using the wet coating method. The film can be formed at low temperatures (80~120°C) and is therefore suitable for printing on plastic films such as PET and PMMA.

Self-assembling inks have also been reported. (Lu *et al.*, 2001) A group at Sandia National Laboratories, California (USA) headed by C.J. Brinker developed smart inks which creates structures on the nanoscale by taking advantage of molecular self-assembly, the tendency of some molecules to form orderly patterns on their own. Such inks contain certain self-assembling molecules, such as proteins, yeasts or plastics and solvent. The inks can be conveniently printing using inkjet printer. As the solvent evaporates, the self-assembly molecules spontaneously organise themselves into elaborate nanostructures, taking on the form of honeycombs or miniature jungle gyms or even structures that look like tumbleweed. Within such structures, ligands - active molecules that exhibit molecular recognition characteristics – can interrogate any gas or fluid, laser light, or electric or magnetic field passing through. Potential applications can be found in monitoring the pH of fluids transported by capillary action and wave-guides to direct laser light.

Three-dimensional images created using inks that carry colloidal particles made of metals, ceramics, plastics or other materials, instead of pigments have been developed by

University of Illinois at Urbana-Champaign and Sandia National Laboratories researchers. (Office of Technology Management UICU, 2005) The fluid that the printer ejects is a smart gel that can be deposited in layers to build into 3D structures. (Figure 14)

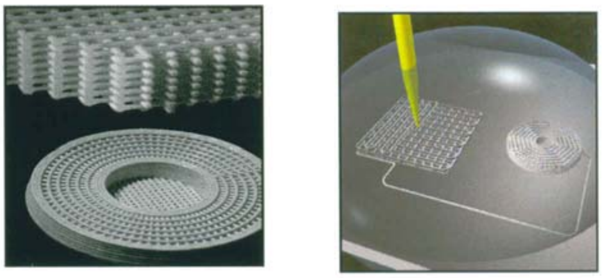


Figure 14 3D structures created by jet-printing of organic inks

The smart organic inks are concentrated colloidal gels with tailored viscoelastic properties designed to provide the self-supporting features needed. Polyelectrolytes were included in the inks to stabilise the colloidal dispersions before printing. Changing the pH or ionic strength would gel the ink. The printed ink adopts a rigid, gel core-fluid shell architecture during image assembly. This facilitates bonding and shape retention of the deposited ink.

Future of smart inks for the manufacturing of electronic components lies in the incorporation of novel materials, particularly those capable of forming nano-structure. RFID is the preferred technology for logistics in the future. As such, market demand for miniature REID, probably based on nano-structures created using novel smart inks, would be increasingly significant.

Summary

Smart inks already play an important part in various industrial sectors. With the increased legislation requirement, greater market demand for smart inks suitable for anti-counterfeit/brand protection and food safety monitoring will undoubtedly emerge in future. The rapid progress in nano-technology will open up opportunity for the development of more intelligent and sophisticated smart inks to meet the already significant market demand. Clearly, the field of smart inks will experience an increasingly rapid expansion in the near future.

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