Printing Processes and their Potential for RFID Printing

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Abstract

This paper explains the basics of a number of printing processes (offset lithography, gravure, flexography, ink jet, electrophotography and screen printing). Characteristics such as the process principles, the type of inks and substrates used, the resolution, but also the limitations of these processes (in terms of regularity, for instance) are tackled. Then, their potential for RFID printing is addressed.

1. Introduction

Printing processes have developed for centuries, mainly with the growing need for information in large volumes and at a low price. The actual spreadout of information started in the 1450's, when Johannes Gutenberg invented a mould allowing the manufacturing of multiple movable types. Characters could then be made by the thousands and re-used to print multiple documents. Typography, as it was called, remained the main printing process until the 1950's, when offset lithography started to spread very fast.
Because printing was an efficient way of reproducing text and images, people have always been looking for ways to print on various materials. Nowadays, one can print not only on paper, board, polymers and metals, but also on glass, textile, ceramics, wood, or even eggs.
"Printed circuits" are well known and have been around for decades, although they are actually obtained by chemically etching areas that remained uncovered (not printed) by a resist layer.
It appears that printing processes could be an efficient and low cost way of producing a number of electronic components such as printed circuits (by printing directly conductive elements without the etching stage), displays (such as OLEDs), RFID antennas, batteries, etc. , thanks to conductive inks or organic polymers. Robustness should also be an advantage of printed electronics [1].
The purpose of this paper is to investigate whether printing processes could enable one to obtain RFID components with the required properties and in a fast and cost-effective way.

2. The main printing processes

Electronic components imply tight requirements in terms of :

- accuracy of position.
- Amount of material deposited, i.e., thickness and content of active particles.
- Resolution.

Each printing process will be described according to these requirements. As far as the accuracy of position is concerned, one deals essentially with a mechanical problem (transportation of the substrate, transfer of the ink from the printing form to the substrate). In other words, even very precise positions, if required, can be obtained by printing processes.

2.1. Offset lithography

Offset lithography is the most widespread printing process for publication. It is also one of the main processes for packaging and can be used on a wide variety of materials (paper, board, polymers, metals). It is accurate, fast and rather economical.
Offset lithography is a "flat" printing process based on the antagonism between water and ink. An aluminium-based plate (typically 0.3 mm thick) is covered with a thin photopolymer layer (1 to 2 µm), the latter being the "image area" (see Figure 1).

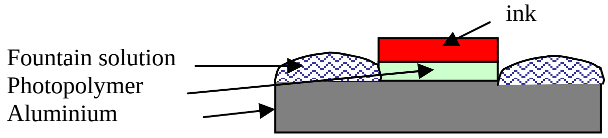

Figure 1: A conventional offset plate.

The desired image is obtained by exposing the monomer film to light, either through a photographic film of directly.
Figure 2 describes the process. The plate is first wetted by an acidic dampening solution. The latter spreads easily on the aluminium surface (representing the "non image area"), due to the high surface energy of the aluminium oxide (around 70 mJ/m²). The dampening solution will wet poorly the image areas, which are non polar and of low surface energy (around 35 mJ/m²).

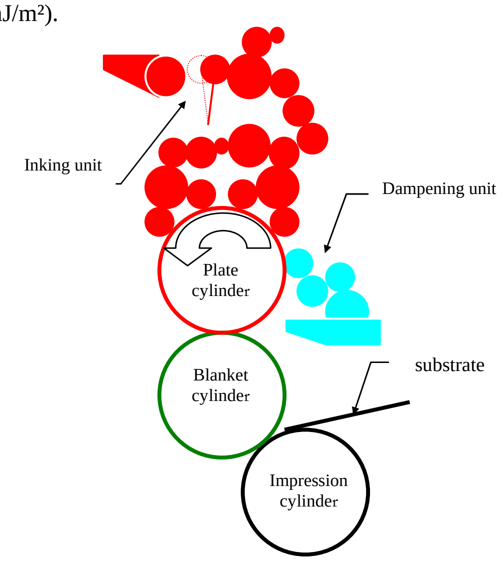

Figure 2: The offset lithography process.

The plate is then inked : the ink will not spread on the wetted areas, but will spread on the image areas, not affected by the dampening solution.
The image is first transferred onto an intermediate elastomeric plate named "blanket" and finally onto the substrate. The blanket allows to reduce the amount of water brought to the substrate. Moreover, its elastomeric properties improve the transfer in case of rough substrates. The name "offset" comes from this double transfer [2].
Offset inks are very viscous (5 to 50 Pa.s). Their surface tension is around 35 mN/m and their polarity is low.
Plates are easy to make and rather cheap. The resolution is excellent, especially when they are obtained through direct exposure to a laser beam.
Among the limitations of this process as far as printed electronics are concerned, the presence of water may affect the materials in presence and thus the conductivity of the resulting ink film. This drawback may be overcome by using waterless offset lithography : in this process, the dampening solution is replaced by a silicone layer covering the non image areas of the plate (see Figure 3). This process is easier to monitor and can reach much higher resolutions than conventional offset lithography (up to 200 lines per cm on paper substrates).

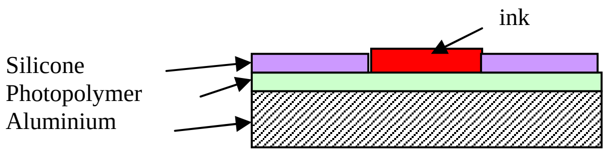

Figure 3: A waterless offset plate.

Another limitation of offset lithography is that the ink film thickness remains low (1 to 2 µm). Therefore, two or more passes may be necessary in order to print thick enough layers. A mechanical accuracy of 2.5 µm is commonly achieved.

2.2. Flexography

Flexography was initially developed for packaging applications (corrugated cardboard).
Flexography is a direct printing process, using a relief flexible plate that applies a fluid ink to the substrate. The ink usually comes from an ink chamber, in contact with a metering roller called "anilox" and closed by two doctor blades (see Figure 4). The metering roller surface contains cells of regular size and shape. The number of cells per centimetre varies from 40 to 230, according to the ink film thickness and to the resolution needed on the plate. Indeed, the screen ruling (number of cells per cm) of the anilox must be around 3.5 times that of the plate (number of dots per cm to be reproduced) [3].
The doctor blade wipes the excess ink from the surface of the anilox, leaving only the needed amount within the cells.
The plate thickness goes from fractions of a millimetre to several millimetres, depending on the substrate to be printed.
The viscosities of flexographic inks vary from 0.01 to 0.1 Pa.s. Inks may be water-based, solvent-based or UV-curing.

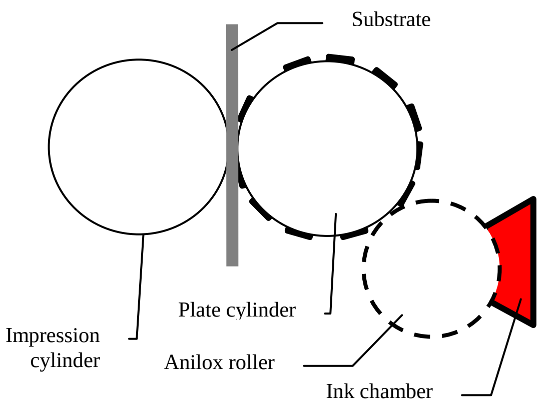

Figure 4: The flexographic process.

The flexographic process is able to print on a very wide variety of substrates : paper, board, corrugated cardboard, flexible and rigid polymers, metals, glass, etc. The printed ink film thickness goes from 6 to 8 µm, which is more suitable for printing electronics.
The flexographic process now reaches resolutions of 60 lines per centimetre, when thinner, more rigid plates are used.
Among the limitations of this printing process, a pattern is always visible on the edges of the printed areas. This pattern comes from the squashing of the photopolymer plate on the substrate, despite the low pressure applied. Therefore, there will be an irregularity on the edges, which may affect the way printed electronic components work. This squashing may also generate a slight inaccuracy of position, if the pressure and substrate position are not properly controlled.

2.3. Gravure

Gravure is an intaglio process where an engraved cylinder transfers a liquid ink held by its cells to the substrate, under very high pressure (see Figure 5). Publication gravure is especially well adapted to very long runs (over 500,000 impressions), due to its excellent consistency. This printing process is also mandatory in decorative printing, since it is the only seamless conventional printing process. Gravure is also widespread in packaging (cartons and polymers).

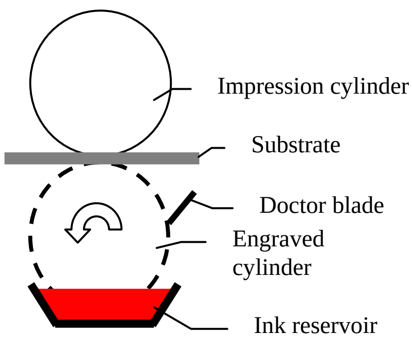

Figure 5: The gravure process.

A steel-based cylinder is covered with a thin nickel layer, then electrochemically covered with a thick copper layer. It is then engraved (usually through an electromechanical process). The resulting cells may vary both in width and depth (the latter can reach 40 µm in the dark areas) [4]. After engraving, the cylinder is covered with a thin chrome layer, allowing hardness and resistance to wear. It is then ready for printing.

In order to print, the cylinder steeps and rotates in an ink reservoir (which may be an ink chamber). The excess ink is wiped away by a doctor blade and the ink remaining in the cylinder cells is transferred to the substrate under pressure against the cylinder.

Gravure inks may be water-based, solvent-based or even UV-curing. Their viscosities vary from 0.01 to 0.05 Pa.s. The printed ink film thickness goes from 8 to 12 µm, which is interesting for electronics applications.

However, this process shows two limitations. First, the pressure required to print is so high that it limits its applications to flexible substrates. However, offset gravure does exist and could overcome this difficulty in most cases (an intermediate, compressible cylinder is inked under pressure and transfers the ink to the rigid substrate).

The second limitation of gravure comes from its very principle : since the image is built from separate cells, there is no way to print a straight line without observing a jagged line. Although laser engraving has drastically reduced this phenomenon (thanks to its ability to engrave up to 1,000 lines per centimetre – versus 100 lines per centimetre with electromechanical engraving), this is to be taken into account when printing electronic components, in order to avoid any possible edge effect.

2.4. Screen printing

Screen printing is a stencil process : the ink is transferred to the substrate through a stencil covering a fine fabric mesh of threads. The latter are stretched on a frame, allowing pressure to be applied to the stencil by a squeegee [4].

The ink is poured on the stencil and the squeegee is drawn across the frame, forcing the ink through the stencil (see Figure 6). Screen printing may also be a rotary process : in this case, the mesh has a cylinder shape, the ink is poured inside the cylinder and the squeegee, also within the cylinder, forces the ink out of it, through the stencil.

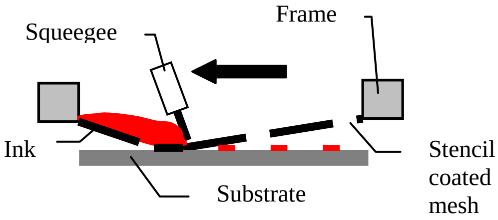

Figure 6: The screen printing process.

Screen printing inks are viscous (0.1 to 10 Pa.s) and allow very thin to very thick ink films (from 20 nm to 100 µm). This is why it has been used for a long time to print circuits and remains especially interesting for electronic printing. Inks may dry through solvent evaporation or be UV- or electron beam-cured.

Among the limitations of screen printing, its maximum resolution remains usually under 50 lines per centimeter and its speed is low in comparison to other conventional printing processes. But the speed should not be too much of an issue as soon as printing electronics prove to be efficient in producing electronic components.

2.5. Ink jet

Ink jet has been the most developing printing process in the last ten years. Its versatility remains without competition : this digital, non impact printing process can print directly from computer data onto virtually any substrate, of any size. Naturally, this requires very complex ink formulations. The latter may be water-based, solvent-based, hot melt or UV curing. Their viscosities are around 10 mPa.s.

The ink jet process may be of two types : continuous ink jet and "drop on demand" (DOD) ink jet.

In the continuous ink jet process [1], the droplet generator is made of a reservoir containing ink under pressure and undergoing a vibration. The vibration increases the pressure inside the reservoir, which ejects a stream of fine droplets out of a nozzle. The droplets pass through a charged electrode and can then be deflected in two directions by two perpendicular electric fields. The droplets which are not to be printed are deflected into a gutter and recycled. The resolution is limited to 60 lines per centimeter, which remains rather low for printing electronics.

In the DOD process [1], one single ink droplet can be jetted from the reservoir through the nozzle (see Figure 7). This happens when the pressure within the reservoir increases, either due to the vibration of a piezo element (piezo system) or to a bubble resulting from the rapid evaporation of the heated ink (heat system).

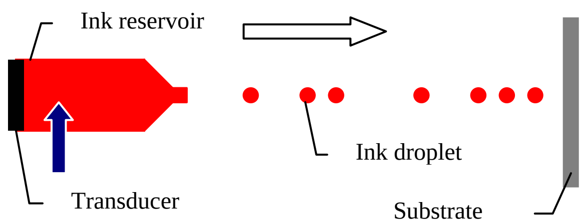

Figure 7: The ink jet (DOD piezo) process.

The sizes of DOD droplets may now be under 5 pico litres, *i.e.* a diametre of 21 µm, which allows an excellent resolution.

However, there is always a risk of placement errors : undesirable "satellite" droplets reach areas that should not be printed. Placement errors of 10 µm at a 1 mm distance from the print head are standard nowadays [1]. Edge effects are also possible, especially with thermal inkjet.

2.6. Electrophotography

Electrophotography, also known as "xerography" or "laser" printing, is the second main digital printing process. However, it has not found applications in printing electronics. There are two main reasons for this :

- the "toner" used as the ink to be printed (in the form of a powder or liquid dispersion) must be charged and transferred electrostatically, which may raise issues when dealing with conductive elements.
- The transferred toner is then fused onto the substrate, which may also raise problems in some applications.

Table 1 gives a synthetic view of the characteristics described for each process studied.

Table 1: Some characteristics of printing processes

Process	Offset lithography	Flexography	Gravure	Screen Printing	Ink jet
Printing form	Flat (Al plate)	Relief (polymer plate)	Engraved cylinder	Stencil + mesh	None (digital)
Substrates	Papers, boards, polymers, metals	Papers, boards, polymers, metals	Coated papers & boards, polymers	All substrates	All substrates
Ink film thickness (µm)	1-2	6-8	8-12	20 nm to 100 µm	Depends on ink
Ink viscosity in Pa.s	5-50	0.01–0.1	0.01–005	0.1–10	10^{-2}
Resolution (lines/cm)	100 (conv.) 200 (waterless)	60	100 (conventional	50	60 (continuous) 250 (DOD)

3. Conclusion

As mentioned in the introduction, printing processes may enable electronic components manufacturers to produce them in an efficient and cost effective way. A lot of development is going on and some solutions already exist.

As far as RFID is concerned, printing antennas simultaneously with board packages is already foreseeable and could save one step along the line, all the more so as papers or board containing chips are already produced.

The large variety of printing processes may eventually lead to printing all components of an RFID device. The applications in the packaging market could then be countless.

References

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