Using of flexographic printing plates for producing an organic field effect transistor

Khaled Talaat Youssef
Assistant Prof., Printing, Publishing and Packaging Department,
Faculty of Applied Arts, Helwan University, Egypt

Abstract:

Nowadays the electronic industry companies is working as much as possible to use printing techniques to produce function devices. Function devices may be electronic component, integrated circuits, solar cells or OFET. Function printing means printing clean structures and clean surfaces with highest precision.The major challenge that exits today to use of flexography printing technology to produce function devices and in the identification, characterisation and optimization of the printed structures and surfaces. Flexography is characterized by flexible and elastic printing plates, they are characterised by a topological difference between printing and nonprinting areas.
This research aims to investigate the effect of using flexographic printing plates to print of source/drain electrode structure as one of component of OFET and the basic challenge for the circuit fabrication is the morphology and topography of the source/drain electrode structure. As a result of an experimental study, it has been proven that the flexographic digital plates are used to print thinner lines of source/drain structures in compared with the other types of plates. The lower value of surface roughness were with Nyloflex plate and the flexographic digital plate so they are suitable to print electronics to get smooth layers. For printed electronics, it's very important to print thick film to ensure good conductivity of ink so it must use anilox rolls have rough screen rulings and big cells depths. The occurrence of "viscous fingering" can be avoided by optimization of the ink formulation (e.g. viscosity and surface tension).

Keywords:
- ***Function devices,***
- ***Organic Field Effect Transistors,***
- ***OFET,***
- ***Organic electronics,***
- ***Flexographic printing,***
- ***Morphology,***
- ***Topography,***
- ***Roughness***

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Introduction

The use of organics in printed electronics is based on the combination of new materials and cost-effective, large area production processes that open up new fields of application. Thin, light-weight, flexible and environmentally friendly that's what organic electronics means. It also enables a wide range of electrical components that can be produced and directly integrated in low cost reel-to-reel processes. [Klaus Hecker, OE-A, 2007]

For the printing of polymer chips, there prevail completely different preconditions. First, continuous-line structures are required to the drain/source electrodes with resolutions in the micrometer range. The semiconductor and the insulator have to be stacked upon each other, as very thin, homogeneous, defect-free layers, and the gate structure must be applied as accurately as possible upon the drain-source structures. Second, the rheological behaviour of the dissolved polymers like viscosity, adhesion, and coating behavior, can differ by orders of magnitude from those of conventional printing inks.. Unfortunately, the electrical performance depends very critically on the purity of the solved polymers, and thus the functionality would be reduced severely. Finally, the electrical overall performances of the materials and the whole setup must be sufficient for microelectronic.[MacDiarmid A.G.,2003]

During the last years, the research has increasingly concentrated on the processing of functional polymers for the development of electronic devices. Researchers hope to realize extremely cost-effective applications on flexible substrates, such as plastic foils or paper in the future, in order to equip and embellish many daily life products as ''smart objects''. Among other functions, it is primarily electronic circuits based on organic field effect transistors (OFETs) that are of interest. In the last years, a great number of methods for the processing of material layers necessary for OFET circuits have been proposed which are frequently borrowed from traditional electronics production. However, the solubility and dispersibility of functional polymers in various solvents suggest applying them as formulated inks which can be deposited into patterned layers by means of printing techniques. Some research groups have adapted methods from printed circuit board production, such as screen printing and pad printing , while many other groups have used inkjet printing. By combining these methods in different ways, it has been possible in the past to show that comparatively complex circuits based on organic semiconductors with hundreds or even thousands of transistors are possible and that microsecond switching speeds can be achieved.[Huebler A.C., et al ,2007]

This research aims to investigate the effect of using flexographic printing plates to print of source/drain electrode structure as one of component of OFET and the basic challenge for the circuit fabrication is the morphology and topography of the source/drain electrode structure.

Literature Review

Structure of the OFETs:

The organic field effect transistor (OFET) is, like the inorganic one, a three-terminal device in which the current flow through two terminals is controlled at the third. The two electrodes, through which the current flows, (fig. 1.1) are called source (S) and drain (D). Parameters for defining their geometry are: the distance which parts them, called channel length (L), and the length of overlapping between them, called channel width (Z). The region between S and D is filled with the semiconductor (Fig. 1.2), which provides the switch able electrical connection between S and D. The third electrode, called gate (G), is separated from the semiconductor by an insulator, and, together with this insulator, acts as a capacitor. [Alessandro Manuelli, 2006]

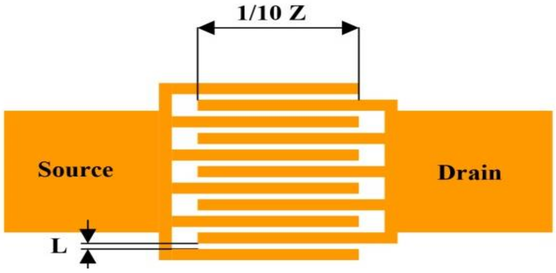

Figure 1.1 Typical layout of inter-digital drain-source electrodes

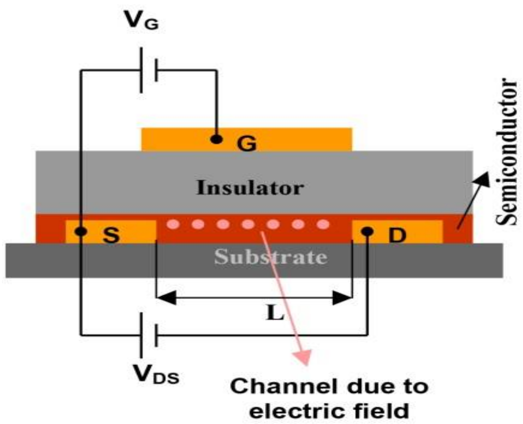

Figure 1.2 Schematic representation of a top gate FET with bottom contacts

Flexography:

Today, the whole packaging sector and other areas of the printing industry would be unthinkable without this highly economical quality printing process. This is attributable primarily to the high flexibility flexo offers, its qualification for a wide range of materials, the large and variable range of print repeat lengths, the different press widths available, it's quite extraordinarily high production speed and it's applicable to (web) R2R printing. [Neumann R., 2001]

Flexographic printing process is a rotary relief method of printing. A schematic of the process can be seen in Figure 2. It uses a printing plate made of rubber, photopolymer, or some other flexible materials. Recently photopolymers are also being used to increase the resolution and lifetime. The image pattern is raised on the plate like the raised areas on a rubber stamp. The plate is attached to a plate cylinder so that it can print in a rotary fashion. Ink is applied to a raised image on the plate using an engraved roller called anilox. The anilox roller has small cells or wells all over its surface, which transfer a precise volume of ink. Excess ink is wiped off by a doctor blade before printing. This helps in depositing a controlled amount of the ink to the substrate. Only the raised part (image part) on the plate receives the ink and the pattern is transferred to the substrate by the pressure of the impression cylinder. Non-image areas are below the printing surface and do not reproduce. The thickness of the film can be adjusted by controlling the rotating speed and the pressure applied on the substrate. [Anupama Karwa,2006] The improved quality of flexographic prints in recent years is mainly attributed to the developments in printing plates ,anilox rollers, and inks.

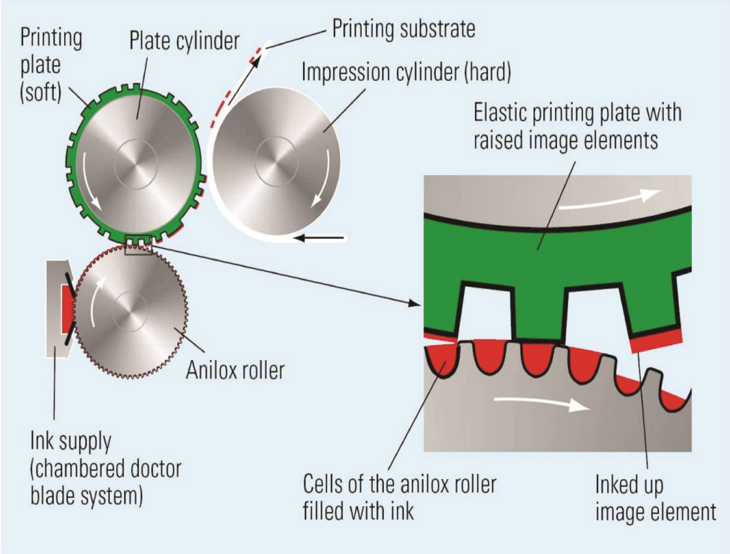

Figure 2 :schematic of a Flexograhic printing process

Flexographic printing plates

Flexographic printing plates are classified into conventional plates that mainly made from photosensitive monomers and a number of additives, such as photo initiators and plasticizers, to obtain high level of their quality [Thompson, B., 2004]. When they exposed to UV radiation through film negative, photo polymerization occurs and exposed parts of the plate become insoluble in defined processing solution [Poljacek S. M., et al, 2013]. The second type of plates and one of the most present printing plates is digital plate that bases on the LAMS (laser ablated mask) technology, the direct to- plate (digital) imaging process is accomplished without the use of a film negative. Plate manufacturers have accomplished this by adding an integral black carbon masking material to the photopolymer plate material. During the digital plate imaging process, a powerful laser removes (ablates) the carbon masking material from the plate in image areas. After the mask has been imaged by the laser, the exposure and finishing processes are very similar to analog processing [Dean Gilbert and Frederick Lee,2008]. The third type of plates is commonly applied for the digital 3-dimensional structuring of Flexo plates. The process is the direct thermal ablation of the non-printing surface material of the plate with a high power, external modulated cw CO_2 laser, followed by cleaning.[Guido Hennig, et al,2006]

Methodology:

The following section describes the effect of using the different types of flexographic printing plates on printing quality of electronic circuits as one of function devices; there are several process parameters which may be analysed, including morphology and topography of the printed structures and surfaces.

Materials and procedure

Printing test form:

The printing form consists of source/drain structures with channel lengths L between 100 – 400 µm (0.1 and 0.4 mm), and finger width F = 1600 – 1900 µm (1.6 – 1.9 mm) (fig.3).

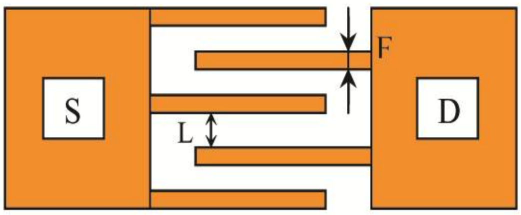

Figure 3: Source-Drain structure

The printing machine:

All tests were performed on FAG FLP 21/1 (Modulatable Flexo Lab Printing Machine), the printing speed was 22m /min

Anilox Roll:

The anilox rolls used were anilox1and anilox2; the next table no.1 shows their specifications.

Table 1 The specifications of anilox rolls

Specifications	Anilox1	Anilox2
line screen l/cm	140	120
The angle of cells °	60	60
anilox volume cm3/m2	8.0	9.1
Cell depth µm	20	20

The flexographic plates:

The flexographic plates used were varied in four types that represented in table2

Table 2 the specifications of plates used

Type of plate	The thickness mm	The hardness shore	The mounting tape mm
Analogue HIQS (Dupont)	1.14	65	0.38 mm soft
Digital DPI (Dupont)	1.14	65	0.38 mm soft
Direct engraving CONTI Laserline (ContiTech)	1.14	45	0.38 mm hard
Nyloflex Gold (Flint grp.)	1.16	65	0.38 mm soft

The Printing substrate:

PET (ethyleneterephthalat) foils, the thickness is 100 µm

The printing ink:

The general description of it aqueous dispersion of PEDOT (Poly(3,4-ethylendioxythiophene)-poly(styrenesulfonate) available under the trade name Clevios™, containing organic solvents and polymeric binders, blue liquid.

A test form consists of source/drain structures with channel lengths was generated by Adobe Illustrator CC software and was printed by Modulatable Flexo Lab Printing Machine on PET foils by using four types of flexographic plates and PEDOT ink. Because of the high transparency of the ink it's difficult to make the measurements for prints, so it was added copper phthalocyanine tetrasulfonic acid tetrasodium salt 60% to the mixture of ink but by using very little amount of this material (about 2gramm to mixture), this material confers blue colour to ink and don't affect on the conductivity of ink mixture. The pressures between plate cylinder and anilox cylinder, and the pressure between the plate cylinder and impression cylinder are adjusted to get best results that it used less pressure on the plate and more pressure on the impression cylinder to transfer more ink and obtain good results. After printing the printed layer was dried at 120C° in hot air. The printed layers were evaluated using Cellcheck CIL-ZX-USB optical microscopy supported by Metric software and ZYGO interferometer device.

Results and discussion

The next figures no.4,5 show the difference between the printed finger widths with anilox 1,2. The higher value of lines widths with analogue plate following that Nyloflex plate than lines widths of other plates. The best results of widths closed to the nominal lines are with digital plate and direct engraved plate. Whenever the screen ruling of anilox is high the line width value is closed to the nominal lines widths with digital plates compared to the direct engraved plate.

As we head to the bigger widths the best results that very closed to the nominal widths are with the digital plate.

The digital plate then direct engraved plate gives the best results according to resolution and sharpness edges of lines of source/drain structures compared to the others plates especially with the higher screen rule of anilox (140 l/cm).the worst plate in resolution and sharpness of lines is analogue plate.

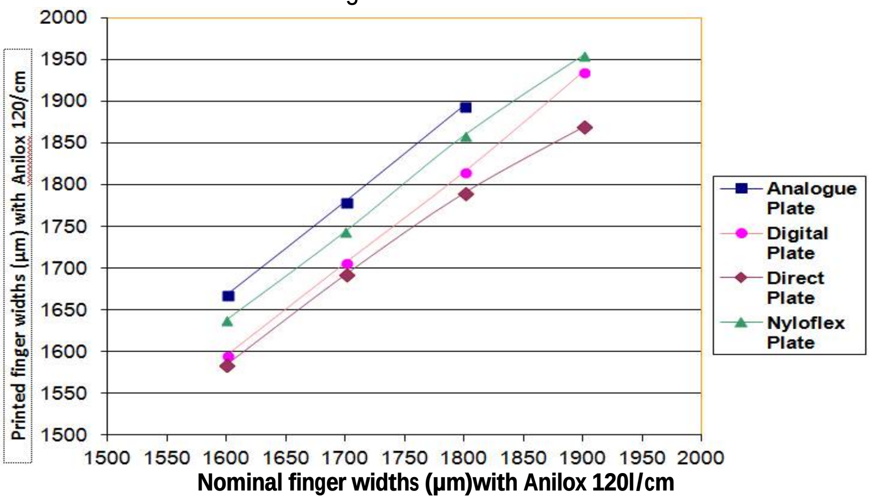

Figure 4: the comparison of printed width for anilox 1

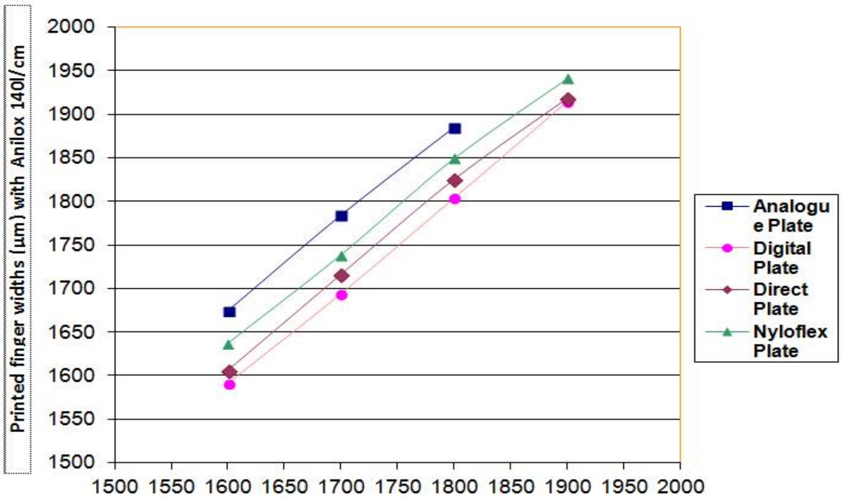

Figure 5: the comparison of printed width for anilox 2

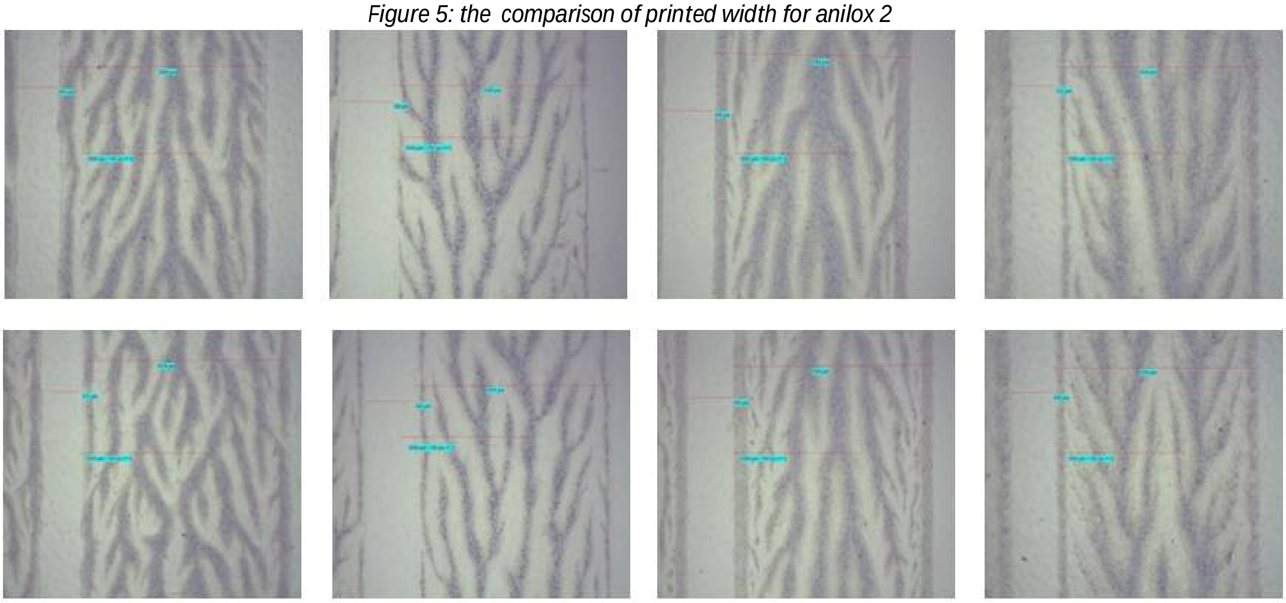

Figure 6: the pictures up from left to right showed the comparison between printed width1.6mm started analog plate then digital plate then direct engraved plate finally nyloflex plate, all pictures with anilox 1.
The pictures down left to right showed the comparison between printed width1.6mm started analog plate then digital plate then direct engraved plate finally nyloflex plate, all pictures with anilox 2

These results showed that with the finest screen ruling of anilox roll, the surface roughness will be lower because of the printed structures by screen ruling 140L/cm of anilox roll were exhibited a finest branched inhomogeneous morphology figure 6. This morphology is typically observed due to the phenomenon of so-called "viscous fingering" which occurs when a highly viscous fluid is displaced by a less viscous one. It can be observed when two parallel plates with a liquid in between are pulled away from each other, so that the surrounding air displaces the embedded fluid . Under certain conditions the air is entering in a non-isotropic way, which causes a finger-like pattern at the air–liquid interface. [K. Reuter ., H. Kempa, N. Brandt, M. Bartzsch, A.C. Huebler,2007]

The lower value of surface roughness was with Nyloflex plate with anilox1 or 2 , the second lower value of surface roughness with digital plate.The higher value of surface roughness was with analogue plate then direct engraving plate.(see table 3 and fig.7,8)

Table 3 the roughness of plates used

Plate type	**Surface roughness µm**	
	With Anilox1(140 L/cm)	With Anilox1(120 L/cm)
Analogue HIQS (Dupont)plate	0.035	0.031
Digital DPI (Dupont) plate	0.022	0.020
Direct engraving CONTI Laserline (ContiTech) plate	0.032	0.025

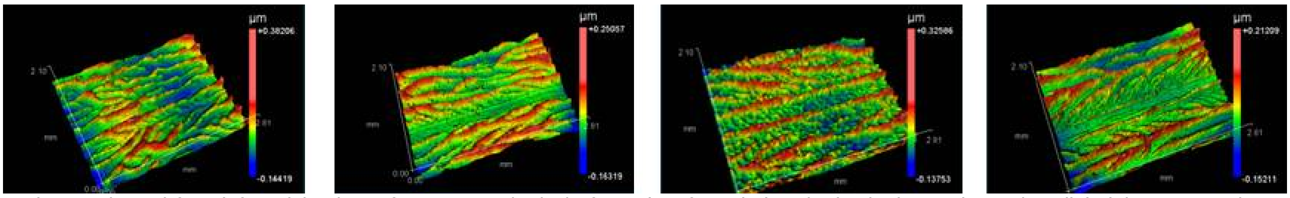

Figure 7 showed from left to right *The surface topography (3D) of samples after printing obtained using analogue then digital then engraved finally nyloflex plates with anilox1*

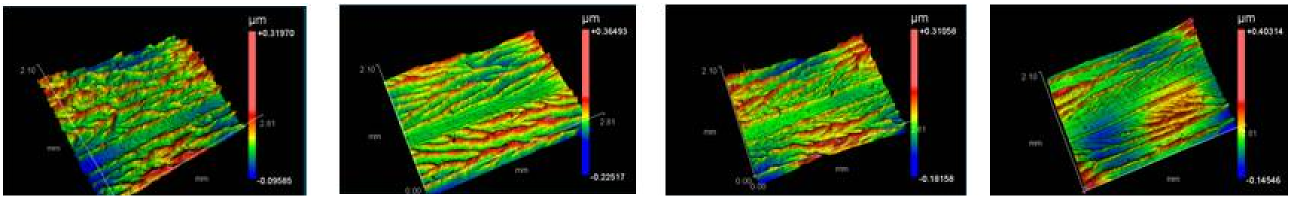

Figure 8 showed from left to right *The surface topography (3D) of samples after printing obtained using analogue then digital then engraved finally nyloflex plates with anilox2*

5- Conclusion

The research was performed a set of experiments in order to determine the influence of varied flexographic printing plates parameters on morphology and topography of flexographic printed layers of source/drain structures. The following conclusions have been drawn:

- The flexographic digital plates are used to print thinner lines of source/drain structures in compared with the other types of plates.
- The lower value of surface roughness was with Nyloflex plate and the flexographic digital plate so they are suitable to print electronics to get smooth layers.
- With printed electronics, it's very important to print thick film to ensure good conductivity of ink so it must use anilox rolls have rough screen rulings and big cells depths.
- The occurrence of "viscous fingering" can be avoided by optimization of the ink formulation (e.g. viscosity and surface tension).

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