THE STUDY OF FLEXOGRAPHIC PRINTING FEATURES OF CONDUCTIVE ELEMENTS ON POLYMER SUBSTRATES

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Abstract

The microgeometric parameters and conductive properties of chip elements printed on polymer films using flexographic method were examined. Critical dimensions of stable reproducible line elements for different types of printing plates were experimentally defined by SEM. The special resolution is 30±5μm under observance of a correct plate forming was found. Using commercially available compositions contained silver and carbon nanoparticles the advantages of the first type composition due to better electrical resistivity and element surface homogeneity are shown.

Key words: *flexography, polymer films, spatial resolution, conductive inks*

1. INTRODUCTION

After numerous test trials of chip conductive elements using ink-jet printing, some problems which are widely discussed in scientific literature were detected (Kuznetsov 2000, Radivojevic 2006, Fadeykina 2008, Reinhold 2009, Jasper 2009). Recently, a series of articles were published, where flexography and gravure printing were used for conductive elements production (Hübler 2012, Deganello 2012, Maksimov 2013, Hongki 2014, Chang 2014, Janghoon 2015, Younsu 2016, Giuliano 2016).

A flexography feature is an image transmission from a flexible polymer plate through an engraved anilox roll to a flexible (polymer) substrate (fig.1). This printing method is the most suitable for manufacturing of chip and mass-produced micro-scale conductive networks.

Main critical components, which influence the size and the uniformity of the elements, are a line width on a printing plate, characteristics of the used ink (conductive in the case under consideration) and anilox roll parameters.

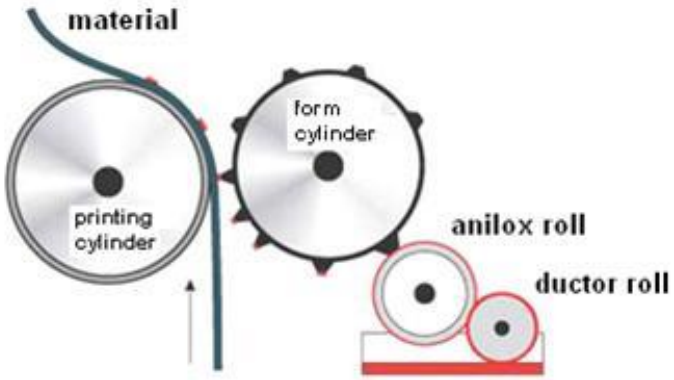


Figure 1. Scheme of flexo-printing

There are two widely used procedures of flexographic printing plate producing: traditional and so-called NExT. A feature of the last ones is an additional UV-source application in an exposure device. It is generally believed that the more intense UV-beam steps up polymerization process, by reducing an oxygen inhibition, that leads to getting of a demanding shape and a slope angle of dots or lines on the printing plate.

In general, silver- and carbon-contained inks are applied as conductive ones. Their electrical conductivity depends to a greater degree on a matrix polymer, therefore, as a rule, two polymer classes are used: PEDOT: PSS and polyaniline, due to their ability to conduct electricity (Chang 2014).

The range of the values of the printed capacitors, resistors and inductors are large: respectively, 224 pF/cm^2 to 1.1 pF/cm^2, 3.3 kΩ/mm^2 to 800 kΩ/mm^2 is sufficient for many applications, including RFID. These large ranges are desirable for sake of generality for the efficacious design and realization of analogue and mixed-signal circuits/systems. These data were listed for 100 μm lines (Chang 2014)..

The influence of the third critical components of the flexographic process - anilox roll parameters on a printing result is also discussed in a literature (Deganello 2012). Increased anilox volume was shown to have a large impact on the printed film thickness, with increased anilox volumes producing tracks of increased thickness, thus, conductivity, with limited effect on the track width and subsequent area coverage. The produced tracks display a very smooth convex shape which is an important factor for the development of functional devices, allowing more accurate and thinner over-coating. The anilox volumes required for the production of highly conductive tracks were shown to be greater than those conventionally employed in graphics printing.

The basic task of our study is the evaluation of the flexographic printing spatial resolution, therefore, we need to get as low as practicable line width both on the printing plate and substrate without sacrificing of their ability to conduct electricity.

2. OBJECTS AND METHODS

For conductive elements production the following materials were used:

- two types of commercially available ink: SunChemical Silver 26-8204 (**I1**) and Graphite 26-8203 (**I2**). Their parameters are presented in table 1;
- two types of substrates – a polyethyleneterephtalate film with 190 μm thickness (**PET**) and a polypropylene film (**PP**) with 100 μm thickness (FASSON PP TOP WHITE-S692 BG-42);
- two types of photopolymer printing plates – a DuPont plate DPR 045 (**P1**) for the traditional exposure process and a FlintGroup plate (**P2**) for the NExT technology. The prints were produced using Gallus RCS 330 printing machine.

Table 1. Conductive ink parameters

	I1	**I2**
Pigment Matrix polymer	Silver Thermoplastic polymer	Carbon (soft black) Thermoplastic polymer
Properties		
Dynamic viscosity μ (at 25°C), Pa·s Density, g/cm^3 Dry solid, %	32±2 2.2±0.2 70±2	120±5 1.2±0.2 47±2
Electrical resistivity, Ω/mm^2	~ 10^{-2}	~ 10

The evaluation and measurements of plates and prints were carried out by the optical microscope M-Service with FlexoCheck software and by the field emission scanning electron microscope JSM 7500F (Jeol) at the secondary electron detection mode at the acceleration voltage 1 kV.

Test-plates for two exposure processes (5x5 cm) were made. Lines width was varied from 10 to 100 μm with an interspace 100 μm.

The measurements of printed elements electrical resistivity were obtained using a four-point probe method.

3. EXPERIMENTAL RESULTS

SEM-images of printing plates, which were produced using traditional and NExT exposure processes, are presented in fig. 2 (a-d). It is clear that a profile of printing elements of the traditional imaged plate has a smoothed shape with a pike and a misplaced center. As a result, a real printing element width is varied from 8 to 18 μm at the pre-assigned value 10 μm. Therefore, the shape of the elements printed using this plate and **I1** is unstable (fig. 2e). Some elements have intermittent and wavy nature with the width, which is varied from 8 to 47 μm.

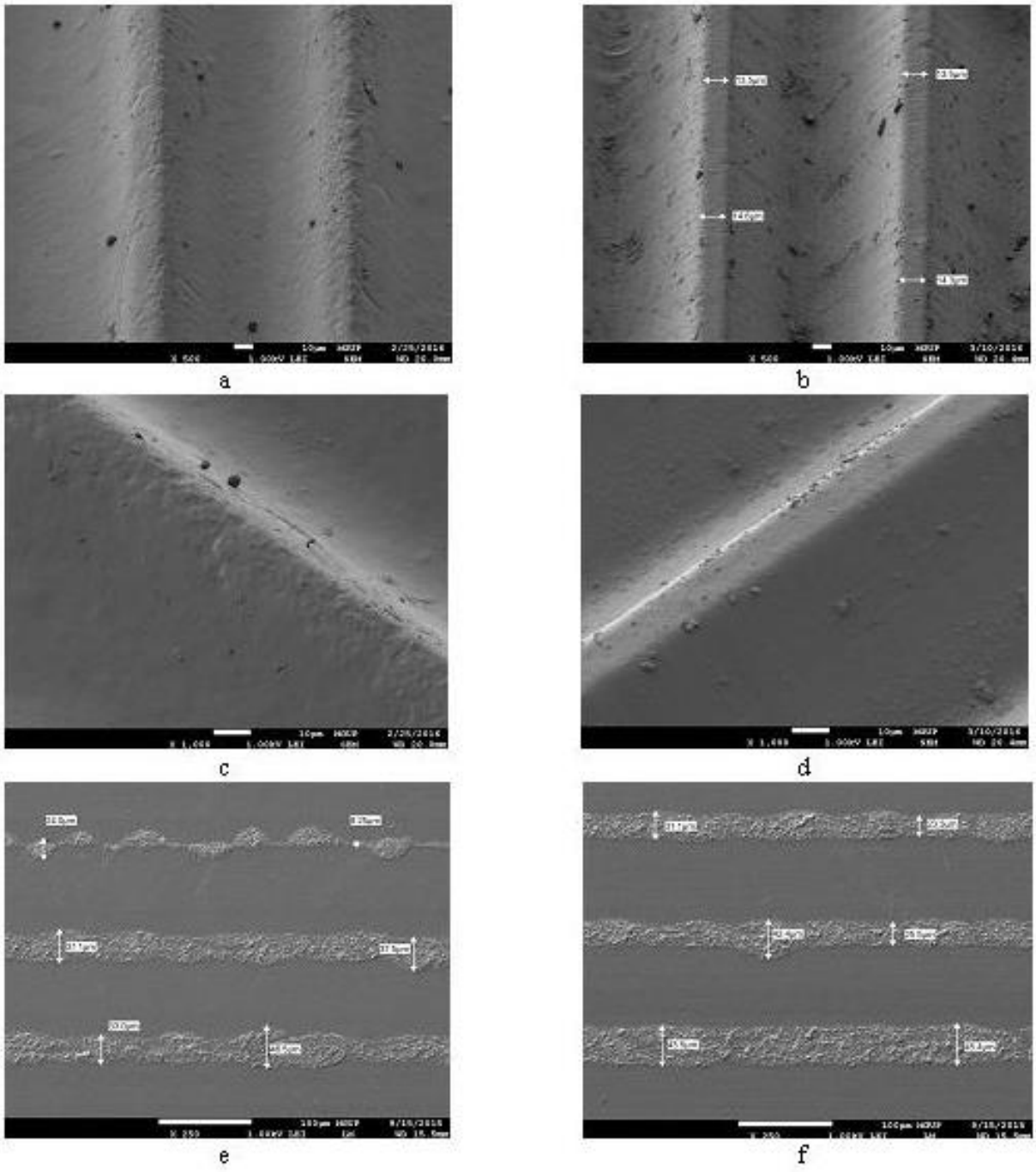


Figure 2. SEM-images of printing plates P1 (a, c), P2 (b, d), flexo-printed elements using P1 (e) and P2 (f)

A profile of printing elements of the NExT imaged plate **P2** has a regular dovetail shape with a flat top and slope angle of planes which is about 50°. Elements width is also different from the pre-assigned values: 13.5-14.5 μm, but a spread of range is less than for **P1**. Values of printed elements width are varied from 23 to 45 μm (fig. 2f).

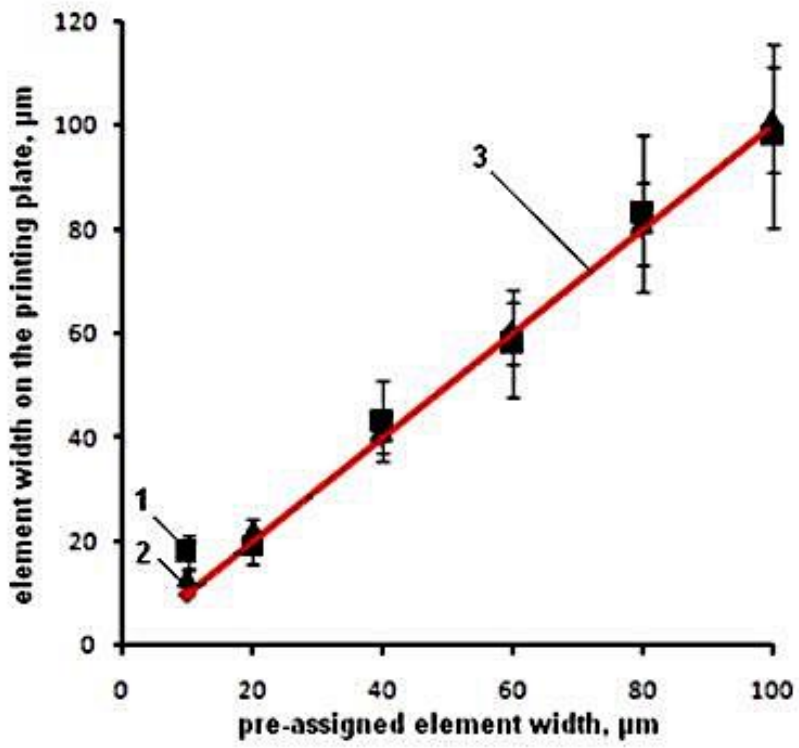


Figure 3. Dependency graph of elements width on a printing plate as a function of the pre-assigned width, where 1 – P1; 2 – P2; 3 – an ideal curve of elements reproduction

For comparing, results are graphically presented in fig. 3: it is clear that the lower elements width, the bigger their distortions are.

So, we can conclude that using **P2** is more preferred then **P1**, but it is demanded to make pre-distortions in a layout file and additional correcting of printing process parameters.

According to the SEM-analyse of conductive ink structures, **I2** has a two-phase structure – carbon nanoparticles and big (some decades μm) flat flakes, graphite probably (fig. 4 a, c). The ultrasonic treatment of the **I2** to get a homogeneous structure was not successful.

The **I1** structure is much more homogeneous, the size of separate silver particles is 200-400 nm, and the size of agglomerates is less 2 μm (fig. 4 b, d).

After printing process the **I2** structure is not significantly changed: both homogeneously distributed carbon nanoparticles, which form a thin layer; and separately distributed graphite flakes were saved (fig 4 c). A structure of the elements printed using **I1** consists of silver particles, which are separated by matrix polymer (fig 4 d). Layers thickness can be evaluated as about 1.5-2 μm

The results of spread value measurements – an elements width growth during a printing process due to high pressure in a printing contact zone – are presented in figure 5. These data indicate that in case of printing on a harder material as a **PET** film the element spread is lower than at printing on a **PP** film.

Anilox roll parameters also play a significant role in element spread value growing. It was defined that a 400/3 anilox roll is preferred than 200/6 ones because in the first case the element spread is 0.95-1.7 whereas in the second case – up to 2.3. A correlation between the volume of engraved anilox roll units and the shape of elements boundary was not found.

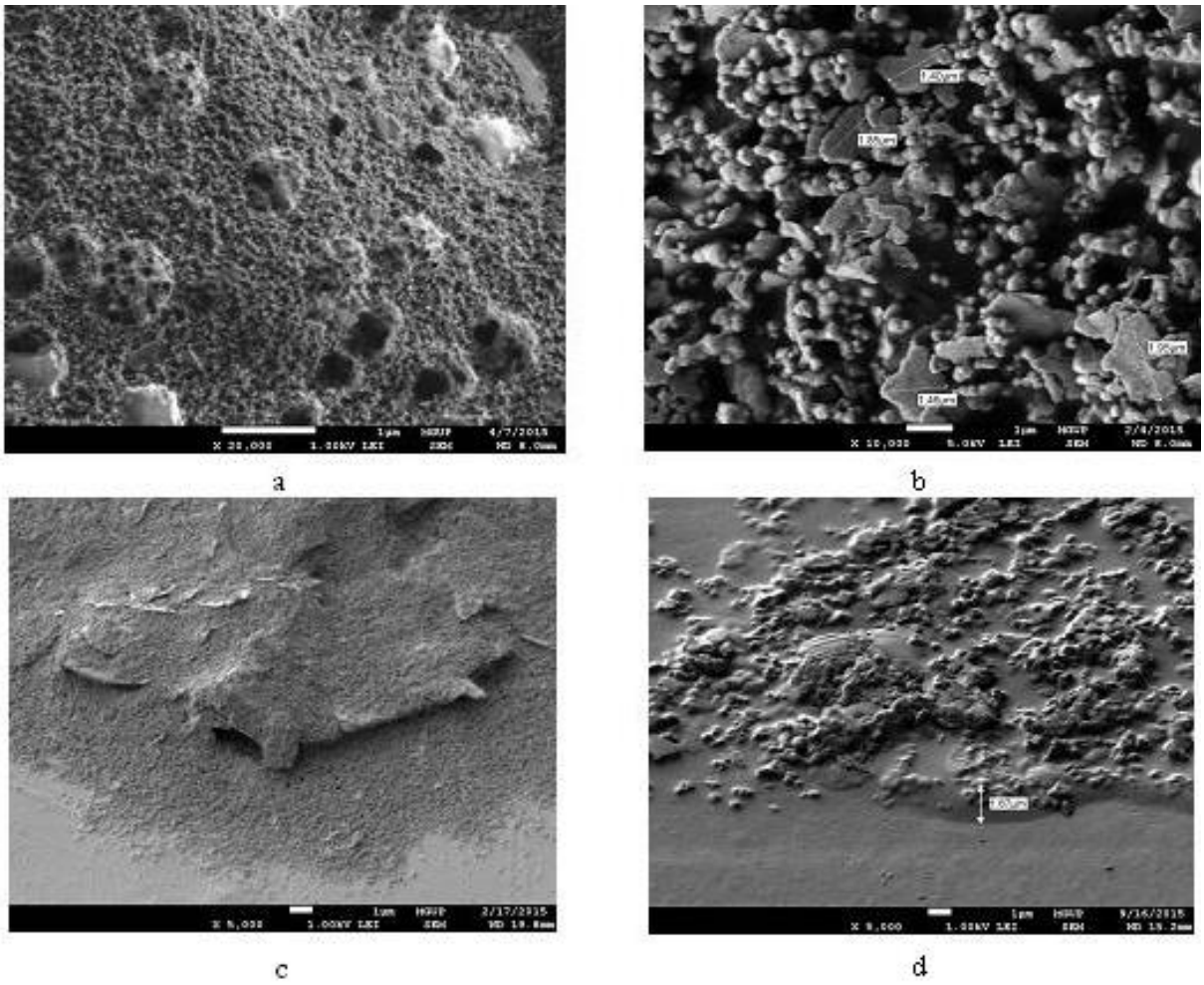


Figure 4. SEM-images of carbon- (a) and silver- (b) contained ink structures and edges of printed elements (c and d respectively)

Note that in both cases silver conductive particles were distributed quite homogenously. It is allowed to get electrical resistivity values of the elements printed using **I1** in order $2\text{-}3\cdot10^2$ Ω/mm^2 (about 10 Ω/mm^2 for the ink). In the case of the elements printed using **I2**; their electrical resistivity was dramatically increased in comparison to the initial ink value: ~10^4 Ω/mm^2 and ~10^{-2} Ω/mm^2 respectively (table 1). Two orders increasing of electrical resistivity values of **I1** printed elements is probably a result of dividing of conductive particles by matrix polymer. For the elements printed using **I2** it depends on the clear two-phased ink structure

It should be note that such measurements were obtained for elements with a real width 30±5μm in the absence of adjacent element contacting, which is often appeared in case of ink-jet printing.

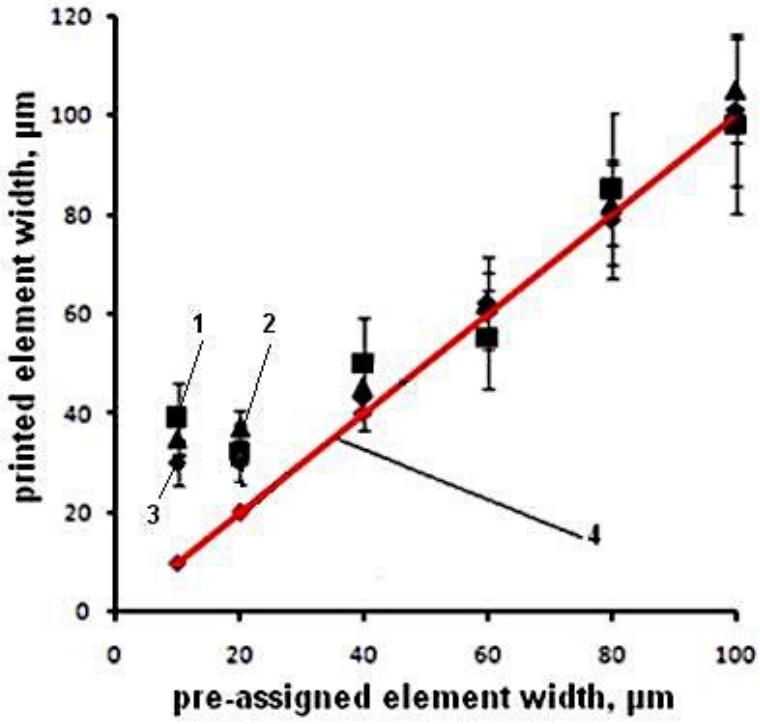


Figure 5. Dependency graph of printed elements width as a function of the pre-assigned width, where 1 – printed on a PP film using P1; 2 – printed on a PP film using P2; 3 – printed on a PET film using P2; 4 – ideal curve of elements reproduction

4. CONCLUSION

In the study the special resolution of flexographic method for printing of chip elements on polymer films was evaluated. It was defined that the critical dimension of stable reproducible conductive elements is 30±5µm at electrical resistivity values in order 0.1 kΩ/mm^2 for silver-contained inks. Structure features of commercially available conductive inks and variety of printing plates production methods were examined. It was found out that using NExT exposure processes is more preferred than traditional ones, but it is demanded to make pre-distortions in a layout file and additional correcting of the printing process parameters. It was also determined that anilox roll parameters play a significant role in element spread value growing.

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