Cost Action - FP1405 ActInPak -STSM report

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1. Introduction and context

The project is collaboration between the LGP2, Grenoble and the University of Pardubice, Czech Republic. The common interest of both laboratories is flexible printed electronics. Printed electronics consists in using conventional printing processes to implement conductive tracks or layers. One part of LGP2 activity is dedicated to functionalization by printing processes and functional ink formulation. The University of Pardubice activity is dedicated to the printing science with a part focused on conductive inks applications in printed electronics devices (displays, sensors…) with pilot scale printing machines.

The goal of the STSM was to evaluate the use of a new hybrid nanowires/nanocellulose ink developed in the LGP2 by (i) integrating new conductive hybrid inks of silver nanowires/nanocellulose in opto-electronics devices by screen printing and (ii) evaluate the industrial roll to roll screen-printing of the ink. The main idea of the project is to profit the ink opto-electrical properties (conductivity/transparency) to allow increased performances in devices such as displays or sensors and evaluate the ink processing in roll to roll screen-printing for an industrial production of these devices.

2. Materials and methods

2.1 Materials

The nanowire-nanocellulose ink was provided by the LGP2 and the others functional inks and substrate by University of Pardubice. Two inks were tested, one dedicated to be integrated in electroluminescent display (alcool and water based) and one dedicated to rotary screen-printing (100% aqueous based).

2.2 Methods

2.2.1 Electro-luminescent device structure

Electro-luminescent (EL) devices are multilayers components following the structure presented in Figure 1. The EL device is composed of a phosphor based light emitting layer and a dielectric layer sandwiched between a transparent conductive anode and a silver based cathode. The nanocellulose-silver nanowires ink would be used as the transparent conductive anode.

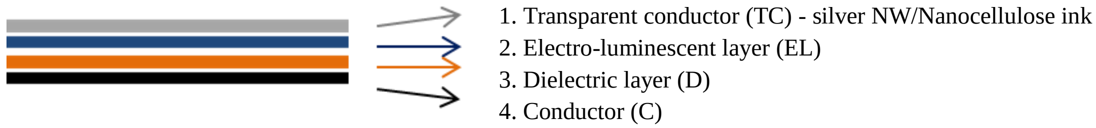

Figure 1: EL displays structure

2.2.2 Printing

The printing of EL devices has been made on laboratory screen-printing press. All the layers were printed using screen-printing with a drying step (120°C-5 min) between each layer. Screen-printing is a printing process where the ink is passing through a screen-mesh on a substrate, as illustrated in Figure 2.

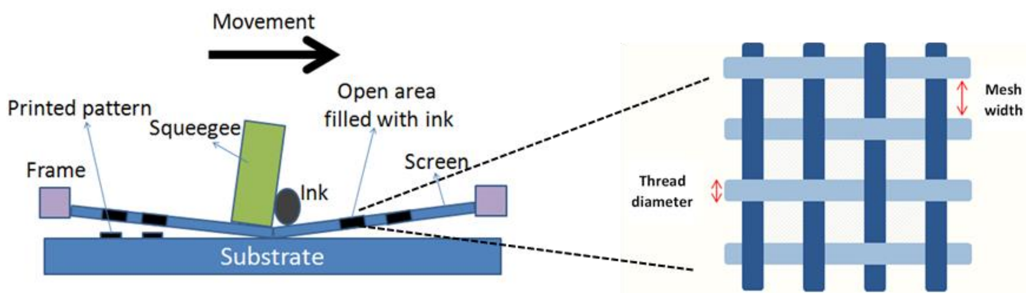

Figure 2: Screen-printing process description

Screens were fabricated in the University of Pardubice using a 90l/cm mesh for the TC and EL layers and a 120 l/cm mesh for the dielectric and conductor layers. Printing has been made on PET polymeric foils.

Rotary screen-printing has been done on industrial printing roll to roll press with an University of Pardubice industrial partner.

3. Results

3.1 Electro-luminescent displays

The goal was to evaluate the integration of the nanowire ink into electro-luminescent devices. First work plan was set to evaluate the influence of several parameters (dielectric layer thickness, phosphor layer thickness, conductor nature) on the produced displays according to the structure in Figure 1. However after characterization of the sample, it appears that most of the samples do not light in the middle as illustrated in Figure 3 (white arrows).

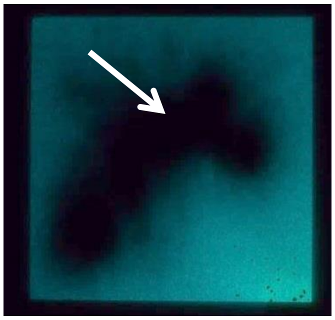

Figure 3: Electro-lumiscent display under current according to structure TC/EL/D/C

This effect, only visible in the middle of the sample, was probably due to a dissolving of the silver nanowires-nanocellulose TC layer by the EL layer containing cetones. As the middle of the TC layer was probably not as dried as the edge, the dissolution of the TC layer might happened by reacting with the EL up-layer. In order to avoid the defect, samples have been printed again with a different structure by inverting the electroluminescent layer and the dielectric layer. With this structure, two parameters were evaluated: the number of TC layer (1 or 2) and the number of EL layers (1 or 2). Using this structure, the printing was good and the luminescence of the displays is correct (Figure 4-b).

3.1.1 Printing

The printing of the silver nanowires-nanocellulose ink on the lab scale screen printing machine appears to be correct. However, the rheology of the ink can be improved since it appears that the ink behavior during the printing is not optimal. Indeed, the ink possess a high viscosity and, although presenting a shear-thinning behavior, the filling of the screen during the printing is not homogeneous. A lower ink viscosity might improve this filling and allow a better printing.

Another point is the drying of the ink. Indeed since the ink is aqueous/alcool based, the drying occurs very fast leading to mesh clogging. Although this point was already discussed and solved by addition of ethylene glycol in the ink, it seems that the added proportion were not high enough to slow down the drying within the mesh. Further improvement should then be done toward this issue that can be solved by using surfactant instead of alcohol or increase the amount of ethylene glycol in the ink.

3.1.2 Characterization

- **Photograph of the samples**

The samples were first characterized using photographs to then evaluate the homogeneity of the luminescence. An example of the obtained sample is presented in Figure 4

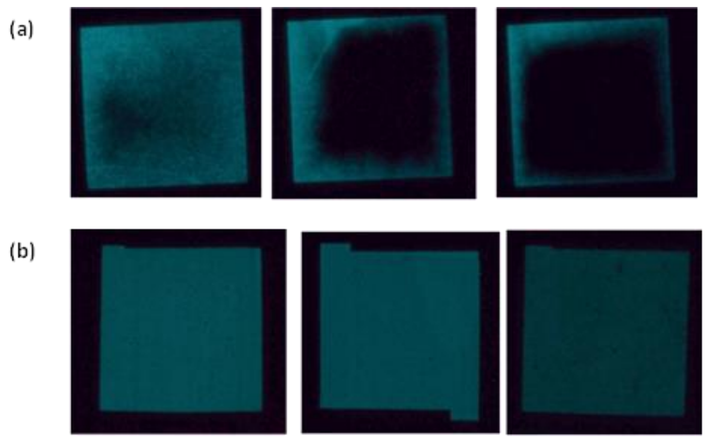

Figure 4: Photograph of the EL displays with (a) the first TC/EL/D/C structure and (b) the change TC/D/EL/C structure

- **Spectrophotometric and brightness measurement**

Brigthness and absorbance spectra were characterized for each working display of the TC/D/EL/C structure. The brightness of the samples appears very low as compared to the one measured with the previous structure C/D/EL/TC (not presented here since the lightening was not homogeneous). This might be due to the change in the structure (inverting the dielectric and electroluminescent layers). These performances are not as good as expected and are lower than the ones obtained using conventional transparent conductive materials. This might be due to a lower transparency of the nanowires-nanocellulose ink as compared to conventional material. Further tests should be done for improving the obtained performances by using the first structure (TC/EL/D/C) with (i) a longer drying time for the nanowires-nanocellulose TC layer to have a completely homogeneous drying or (ii) using another electro-luminescent ink.

Regarding the influence of the studied parameters, it should be noticed that the printing of two EL or two nanowires-nanocellulose TC layers does not lead to better luminescence results, as illustrated in the absorbance spectrum in Figure 5.

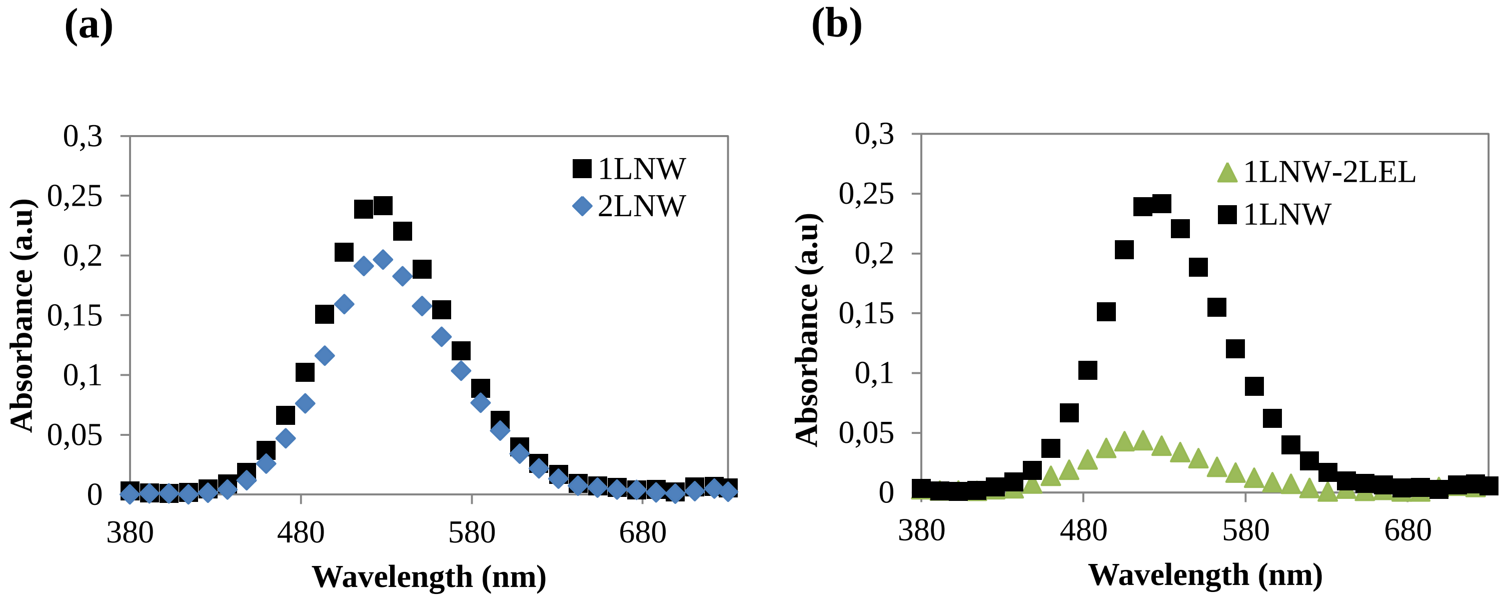

Figure 5: Absorbance spectra of (a) the EL display with 1 or 2 layers of silver nanowires-nanocellulose ink and (b) with 1 or 2 layer of EL layers

3.2 Industrial rotary screen printing trials

Industrial trials using the silver nanowires-nanocellulose ink have been performed with an industrial partner of the Pardubice University. It appears that the ink is suitable for rotary screen-printing, allowing a good printing. However, after some minutes of printing, the ink dries fastly within the screen. This leads to the presence of printing defects within the film. Thus, it appears that the ink formulation for industrial printing should be improved by using additives for retarding the drying. Rheology of the ink can also be adjusted to be more fluid. However, the obtained printed patterns were conductive and transparent, confirming the possibility of processing transparent conductive layers using rotary screen printing.

4. Conclusion and perspectives

The printing experiments in the Pardubice University have allowed the printing of EL displays and the evaluation of industrial rotary screen-printing using the silver nanowires-nanocellulose inks provided by the LGP2.

Integration of the ink in EL displays was functional but the obtained performances of the devices were lower as the ones expected. Others trials in the printing of EL displays will be done for obtaining better performances in term of luminescence.

Industrial rotary screen-printing was tested using the nanowires-nanocellulose ink. Although some improvements should be done toward the ink formulation regarding the drying speed and the ink rheology, conductive transparent layers were obtained. The silver nanowires/nanocellulose ink formulation will be improved for reducing its drying time and adjusting its rheological behavior. Some others trials would then be performed once the ink is improved.