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Inkjet printed structures sintered with intense pulse light

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Anotace:
V tomto článku je zkoumána možnost využití intenzivního pulzního světla pro spékání stříbrného inkoustu nanášeného na PET (Polyethylentereftalát) substrát Inkjet tiskem. Natištěné struktury byly postupně osvěcovány různými kombinacemi délky a energie pulzu. Zkoumán byl také vliv vícenásobného osvícení jedné struktury na změnu výsledného odporu. Výsledky spékání intenzivním pulzním světlem byly porovnány s konvenční laboratorní sušárnou. Bylo zjištěno, že pomocí intenzivního pulzní světla lze dosáhnout hodnot výsledného elektrického odporu o 83 % nižších v porovnání s laboratorní sušárnou.

Annotation
The possibility of using intense pulsed light to sinter silver ink deposited on a PET (poly(ethylene terephthalate)) substrate by Inkjet printing is investigated. Variations of pulse length and energy are sequentially applied to the printed structures. Furthermore, the effect of multiple illuminations of a single structure on the change in the resulting resistivity is studied. The results of sintering with intense pulsed light are compared with a conventional laboratory oven. It was found that by using intense pulsed light, values of the resulting electrical resistivity could be achieved 83% lower compared to the laboratory oven.

INTRODUCTION

Inkjet printing becomes in recent years very popular thanks to its precision of material deposition and relatively fast fabrication. The main advantage of this technology is fabricating effectiveness with no wasting of the material what it makes a more ecological and economical deposition method [1], [2], [3]. Sintering of printed structures also goes hand in hand with printing. Besides common sintering techniques as an oven or hot plate, intense pulse light (IPL) becomes still more popular because it is a very fast and more appropriate method for protecting the substrate rather than conventional thermal sintering process [4], [5].

METHODS AND RESULTS

Substrate preparation

Samples were printed on a PET foil Mitsubishi Novele™ IJ-220 which is a flexible transparent substrate suitable for Inkjet printing up to 140 °C. The surface of the substrate is pretreated from production and modified to be adhesive and allows fast ink drying, which is a very important feature of this substrate.

Printing

The silver nanoparticle ink ANP DGP 40LT-15C from Sigma-Aldrich (silver nano-dispersion, product number 736465) was used to print all the tested structures with inkjet material printer Fujifilm Dimatix DMP-2831. During the printing, platen temperature was set to 40 °C and the structures were printed with a resolution of 1016 dpi (25 μm drop spacing) and 2 kHz jetting frequency. Cartridge was heated to 35 °C. The structures were printed in 3 layers to obtain optimal shape and morphology of printed structures. The printed structures were sintered with the Xenon X-1100 IPL system and laboratory oven Memmert UF 30Plus. Measurement was performed with multimeter Keysight 34465A with a 3D printed contact holder. The thickness of silver layers printed on PET foil is about 350 nm estimated with Scanning electron microscopy (SEM) FERA3 TESCAM, see Fig. 1.

Printed structures

For printing and subsequent analysis was prepared structure with four connecting pads for four probe measurement. The width of the printed line was 200 μm and was printed with 3 layers. The dimensions of the connecting pads were 1,5 mm x 1,5 mm. The prepared structure with dimensions can be seen in Fig 2.

Sintering

For each IPL setup, a set of five structures was printed and sintered simultaneously. Before sintering, it was necessary to let the printed structures completely dry. Therefore, the structures were dried for 24 hours in the exicator. In case that we skip the drying procedure, the structure could be damaged due to a residue of the solvent and moisture in the printed layers.

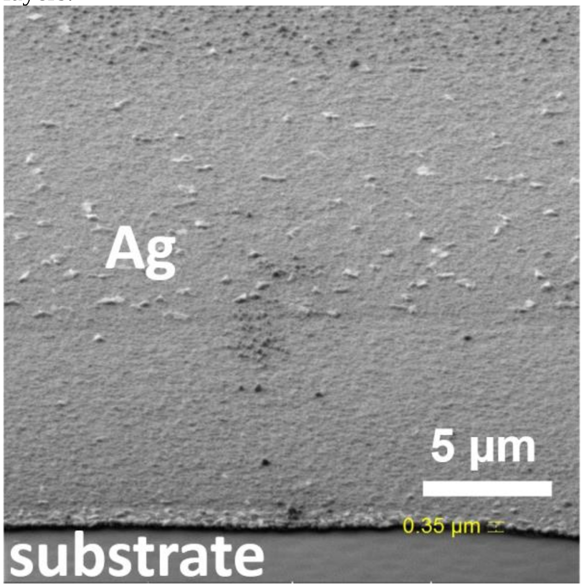

Fig. 1 SEM picture of a printed silver layer

The combination of the applied energy and the length of the pulse was studied. The values of the pulse length were chosen from 100 µs to 600 µs with 50 µs steps and the energy changed from 100 J to 300 J with 50 J step as well. From the combination of these two parameters, it was made a table with three areas which represent three possibilities: 1) Low energy in long pulse duration – the lamp will be not activated because of too low energy. In Tab. 1 this is represented by the windows with "N/A". 2) Good combination of pulse duration and applied energy – the structures are sintered and can be measured their resistance. In Tab. 1 this represents an area with measured values of resistance. 3) The applied energy is too high and the structures are damaged. This represents an area in Tab 1 with "D".

Tab. 1 Achieved values for energy and pulse duration combination

		Pulse duration *(µs)*								
		100	150	200	250	300	350	400	500	600
Energy (J)	100	9,13 Ω	15,4 Ω	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	150	D	4,9 Ω	4,8 Ω	6 Ω	19 Ω	N/A	N/A	N/A	N/A
	200	D	D	2,9 Ω	3,5 Ω	4 Ω	4 Ω	4,4 Ω	N/A	N/A
	250	D	D	D	D	D	D	D	3,5 Ω	4,12 Ω
	300	D	D	D	D	D	D	D	D	3,5 Ω

Oven

The results were also compared to a standard laboratory oven. The conditions were set to 30 min at 120 °C. This temperature was chosen due to possible damage to the substrate. With temperatures above 120 °C, the PET foil starts to degrade (for example: due to the expansion of the material, the substrate may start to curl) and can affect the sintered structures. The measured resistivity of samples sintered in the oven was approximately 12 **Ω** what is up to 6 times more compared to the IPL. Furthermore, it was investigated the influence of time on the final resistance. 30 min, 60 min, and 90 min were selected as tested intervals. It was proved that there is change only about 5 % between these three time periods and therefore it is no more effective to prolong the sintering time.

Multi pulse sintering

Structures were further tested for sintering with multiple pulse irradiation. The combinations of pulse length and energy were set as in the first experiment and for each combination, the structures were flashed 6 times. After each flash, the structures were measured. It was proved that for low energy (100 J and 150 J) there is an effect of a gradual reduction of resistivity with approximately 30 %. When increasing the energy of pulses, the effect of additional pulses is not significant and the change of resistivity is about 8 %. A plot with measured values can be seen in Fig. 3.

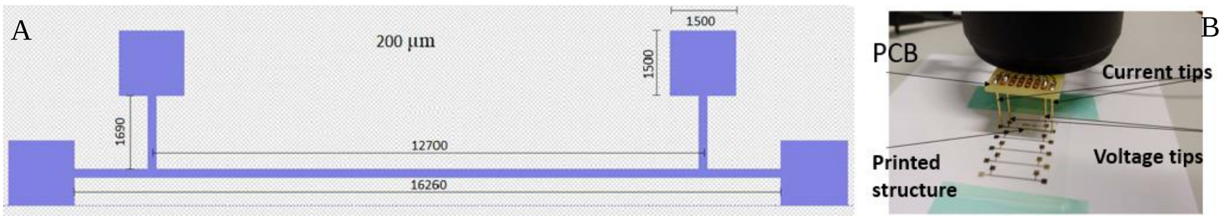

Fig. 2 Layout for four-probe measurement (A) and measurement setup (B)

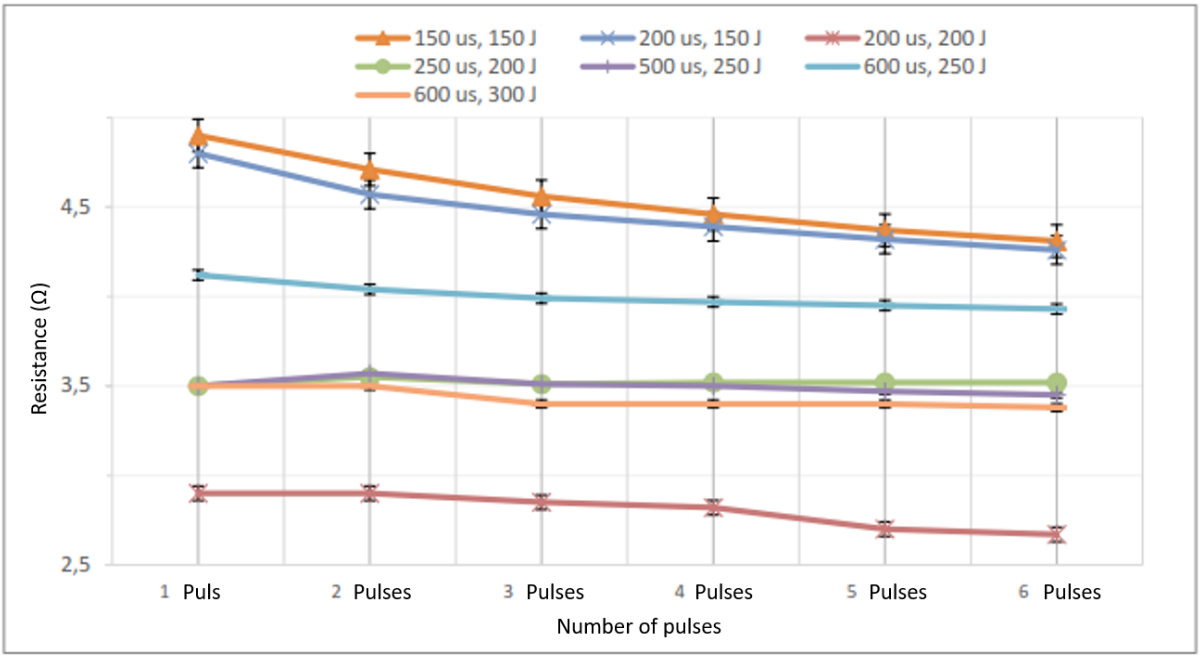

Fig. 3 The effect of the number of pulses on the resistivity for energy 150 J – 300 J

CONCLUSION

It was established a sintering process for Inkjet-printed structures with silver ink. All samples were printed with the same conditions and subsequently sintered with IPL to find the most appropriate setting. It was observed that there is only a narrow space of the settings which can be applied on printed structures without its damage. It was experimentally proved that we can obtain the best result of resistance (2,9 Ω for tested structure) with 200 J and 200 µs of one IPL pulse. The results of IPL sintering were then compared to the laboratory oven. It was observed that with IPL can be reached values of resistivity about 83 % lower than with the oven. The results are still preliminary and further research will be continued.

ACKNOWLEDGMENT

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