Low cost Inkjet printing system for organic electronic applications.

Konrad Futer, a Institute Tele- i Radiotechniczny, Institute of Metrology and Biomedical Engineering WUT

Abstract

This work shows in details the design and performance of precise ink jet printing system which has been constructed for organic electronic technology analysis. The printing system was designed for laboratory investigation of inks and substrates compatibility. Printing system has been tested by its precision and abilities by fabrication electronic elements. PEDOT: PSS, Sun Tronic U6415, Nano silver based inks were tested. Glass, alumina ceramic, PEN foil and paper were tested as substrates. Printer was design in order to solve disadvantages of commercial systems. It has improved software with user friendly graphic interface, improved accuracy and precision. New drop watch solution has been develop.

In the investigation, compatibility of materials and inks was tested. Methods of making inks and substrates compatible, by setting the substrate temperature, ink jet printhead voltage and geometry, were studied. Printed lines after sintering process become conductive. Ohmic resistance of lines was measured and their quality was evaluated.

According to analytics prediction printed electronics will be developed rapidly in the next few years. It will play a crucial role in the future in a production of cheap, flexible consumer products. Each printing techniques brings variety of advantages, by using large scale flexography the price of final product can be lowered down more than two orders of magnitude according to single scale production. By combining layers printed with different inks, conductive, semi conductive and dielectric, complicated electronic structures can be manufactured. Organic electronic will never compete with silicon based electronic on field of efficiency or integration scale, this is not the way it’s evolves into. Organic electronic elements can fill the market niche with flexible, low cost simple electronic devices. Main targets are “smart clothes” – sensors integrated clothes for firefighters, one time usage low cost biosensor – paper glucose sensor for diabetics and other basic but very useful devices. [1] Low cost RFID antennas can bring more wireless applications of sensors to new areas of applications. [2] Screen printing can be found very useful for material science, flexibility of process variables gives an opportunity to optimize paste properties easily. Variety of substrates material can be tested using screen printing, there are no limitations to flexibility or hardness as in flexography are. In ITME and ITR screen printed organic electronic investigation are being carried. Applying this method in ITR are being printed UHF RFID antennas on flexible substrates using organic and nanoparticle pastes[3]. Investigation of using CNT [4] based screen printable pastes as conductive material for flexible, transparent electrode applications have been also carried in ITME [5]. Third mentioned technique Inkjet is widely described in following article. Basic advantage of this technique is that additional tools are not needed for printing different patterns. It is very useful technique for rapid prototyping of electronic devices. [6]Inkjet printing is a simplest way to print the pattern in small series or even only one time. This method bases on jetting single, pico litter volume drop of an ink “on demand”. Jetting single, round drop on demand is a critical variable of inkjet printing process.[7]Most common inkjet print heads are based on piezoelectric ceramic, electric pulse, sent from the driver, deform piezoelectric element which generates acoustic wave inside print head. Reaching nozzle edge wave generates drop.[8] There are print heads based on other that piezoelectric actuators, acoustic wave can be generated by small heater. Heater rapidly boils ink inside of the print head for a very short period of time, vapor bubble rapidly gain volume and rapidly disappears. This rapid volume change squeeze out drop through the nozzle.
1. The design of Inkjet printer

In this paper the design of piezoelectric print head based inkjet printer is described. It has been designed and built in Tele & Radio Research Institute (ITR). It is a small and low cost inkjet printer. The issue was to design flexible, low cost printing system to support material science investigation, technology optimization and new technology development. New printing system should have printing abilities no lower than commercial printers and low cost couldn’t be an excuse. Commercial available printing systems has already been found inaccurate for some task realized in R&D units or in small laboratories. Those disadvantages, commonly described by the users were supposed to be removed from new designed printing system. Built printing system, is based on MicroDrop, piezoceramic PZT print head system [9]. This specific system gives the highest spectrum of compatible inks. It is possible to use inks with pH in the range 1-12, viscosity 1-12 cPs. Nozzle diameters in this printer are 50 µm and 100 µm, drop volume is in range from 35 pl to 85 pl. Printhead has a heater, build in, that allows to heat up ink inside of the nozzle up to 100˚C. Printhead is controlled by attached driver unit. Generated electric pulse deforms piezoelectric actuator inside of the printhead. Operator controls the right pulse shape to get single “drop on demand” (DoD). Amplitude, length and delay of the pulse can be also set according to optimize drop shape. Amplitude can be set in range 0-250 V, length from 10 – 300 ms, and delay from 1000 to 9999 µs. Control unit generates strobe signal for the strobe light. This gives the ability to observe drops in still – “frozen” position using simple CCD camera. This system is also called “Drop Watcher”. Delay of the strobe light signal can be adjust to freeze the right moment of the drop forming process. Commercial drop watch systems does not allow to freeze the picture Therefore, adjusting and optimization is less accurate then. Drop forming sequence taken by the strobe light CCD camera in different time delays is shown in Fig. 1.

2. Printing tests

Printer abilities has been tested by printing patterns on most use substrates and by using variety of inks. To test precision and accuracy specific pattern was designs. An array of single dots, dot lines, horizontal and vertical. For system tests nano silver based ink was used, this ink is a commercial ink provide by Amepox[14]. Dot spacing was 0,15 mm, dot diameter 100 µm. Printhead impulse was set to 110 V and 50 µs. Substrate temperature was 65 °C. As a substrate glass was used. 10 exact patterns has been printed. Specimen were measured by using optical microscopy (see fig. 4). Diameter, spacing and position of each dot was measured and analyzed. Dots diameter was 100 µm ± 4 µm, horizontal spacing 150 µm ± 2 µm, vertical spacing 150 µm ± 4 µm, position error 5 µm (as a distance from theoretic position to printed dot center), shape error 11 µm (as a standard deviations from ideal round shape).(Fig.2.)

Shape precision and jetting accuracy was also investigated. As a substrate for this test, glass was used. Single drop was jetted one more time on the printed pattern. As it can be seen, dots from the second layer are deposited precise on centers of first layers dots. This proves very high printing precision. Second layer dots exhibit smaller shape error, less than 3µm from model circular shape. However second layer dots have smaller diameter, the average diameter is 92 µm. This is caused by different surface tension on clean substrate surface and printed dots surface.

3. Line printing investigation

Line printing ability was investigated. Using built printing system conductive lines were printed on ceramic substrate. As ink, nano silver based ink was used. Line printing tests were divided into four categories by quantity of layers. Lines were printed on substrate heated to four temperatures, 40°C, 60°C, 80°C, 100°C. The issue was to find optimal parameters for printing conductive lines using nano silver based ink. Results of this test can be seen in tab. 1.
Blur edges of prints are caused by the structure of ceramic substrate. First layer of ink soaked in the porous substrate and deform the edge. Second layer of ink forms a line, solvents evaporates fast enough, to prevent dots from spilling on the first layer. Different line structure, width and morphology can be achieved by using different combination of parameters. Due to the test, best results can be obtained by printing on ceramic substrate heated to 80 °C with three layers. All printed patterns were sintered in 350 °C for one hour. In this process organic ink ingredients evaporates, and lines became conductive. After sintering resistance of lines was measured. The lowest resistance has lines printed on substrate heated to 60 °C with four layers. Resistance of this line is 0,063 Ω, lines with five layers and more, has higher resistance. It is caused by surface cracks, lines with four layers and more has long, wide surface cracks. Resistance value for line with five layers is 0,083 Ω, six 0,097 Ω. (see fig. 3).

Lines after sintering process can be seen in table 2. The “Coffee Ring” effect is strongly present. With line with three layers “Stack Coins” effect is observed. For four layer line none of these effects is present, but “Halo” effect shows up. Halo effect is caused by porous structure of surface of alumina ceramic substrate that was used in this experiment.

<table>
<thead>
<tr>
<th>Layers</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance</td>
<td>1,29 Ω</td>
<td>0,85 Ω</td>
<td>0,06 Ω</td>
</tr>
</tbody>
</table>

4. Conclusions

Achieved results show, that precise inkjet printing system for organic electronic has been build. The advantage of this system is that it is low budget. Parameters of the new built system meet the commercial Inkjet printing systems, but it has been reached with ten times smaller budget. Developed new software makes pattern design easier for user, and graphic interface is more clear and friendly. Accuracy of the system was improved by using optimized maximum speed calculation algorithm. Printing precision of the printer is lower than 5µm and dot shape precision is not higher than 4µm. 100 µm ±5 µm lines can be printed using this system, this meets most requirements for manufacturing simple electronic devices. Moreover substrate stage design gives higher standard of temperature stability. It improves heat transfer and even distribution on substrate surface for low heat conductive materials like ceramic or paper. New drop watch solution adopted in this system uses CCD camera directed at printhead nozzle, makes drops observation during printing possible. This gives drops control feedback while printing process available. All these features sums up in high flexibility of printing system which opens new areas of possible usage of inkjet printers in electronic industry. Printed nano silver lines become conductive after sintering process. Sintering was executed by firing specimens in 350 °C for one hour. It is planned to investigate resistance sintering, as low temperature process, ready to print conductive lines on substrates fragile for high temperature firing. Printed conductive lines after firing have resistance 0,063 Ω. This values and precision makes this system ready for printing.
Radio Frequency Identification antennas, sensors, precise MEMS devices, conductive lines and pads or transistor electrodes. It is planned to manufacture organic electronic circuits using this system, OFET (Organic Field Effect Transistor) based logic structures and OLED / PLED screens. System has now entered the final test stage were its abilities will be investigated in small scale production line. It is ready to fabricate elements on semi commercial scale, and new materials for new applications are being developed.

References
[1]. M.Sibinski, M.Jakubowska, M.Sloma „Flexible Temperature Sensors on Fibers” Sensors 2010, 10(9), 7934-7946
[8]. H.Wijshoff „The dynamics of the piezo inkjet printhead operation”, Physics Reports 2010

Authors:

Konrad FUTERA1,2
1Instytut Tele- i Radiotechniczny ul. Ratuszowa 11, 03-450 Warsaw, 22 619 22 41, Konrad.futera@itr.org.pl
2 Institute of Metrology and Biomedical Engineering Warsaw University of Technology ul. Św. Andrzeja Boboli 8, 02-525 Warszawa, e-mail: k.futera@mchtr.pw.edu.pl