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***Katarzyna Piłczyńska, Stefan Jakucewicz****
*Institute of Mechanics and Printing*
*Warsaw University of Technology*

# PRINTING ELECTRONICS USING INK-JET TECHNIQUE

*The article presents the possibility of printing electronics using digital ink-jet technique. Materials such as three-dimensional parts and multi-layer devices need to be printed in a different way than plastics and papers. However there are special ink-jet machines which have been adapted for electronics printing. Thanks to the modernization of digital devices, higher resolution has been also achieved. This issue is very important, especially in printing electronics.*

***Key words: ink-jet printing, digital printing, UV-curable inks, ink-jet printer, printed electronic, nanogold inks, nanosilver inks, nano-carbon inks***

**Introduction**. Ink-jet is a digital method of printing, used mainly for carrying out shorter runlenghts of tasks such as: brochures, catalogues, advertising, packaging and books. This constitutes a very important issue nowadays since the digital printing market was estimated to grow by 71% from 2008 to 2013 year [1]. Furthermore, thanks to the newest solutions in machine and ink production, the quality of printing has improved. This is the reason why, ink-jet can be used also in electronics manufacturing services. This branch of industry has been also developed recently. Using low-cost and not complicated way of printing, it has become more economical and environmentally-friendly.

**Ink-jet technique.** This digital method of printing was invented in Siemens-Elema (Sweden) in 1952. The invention was called Minograf, with capillary nozzle ink-jet. Minograf was modernized in 1963 by Richard Sweet (Stanford University), who made from this first continuous ink-jet printing system.

Regarding the drop on demand method, it was invented in the late 1940's by Clarence Hansell at Radio Corporation of America.

Digital ink-jet printing devices can use different types of ink. The most popular are:

- Aqueous;
- UV-curable;
- (Eco)solvent-based;
- Oil-based;
- Hot melt [2].

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For electronics printing, the most common is the one with UV-curable inks. It is connected with the type of material suitable for manufacturing of three-dimensional parts and multi-layer devices. Such materials aren't porous and they aren't able to absorb water or solvent. UV-curable inks are cured with ultraviolet light. There is no evaporation needed. The advantage of this method is also instant drying. That's why this technique can be used irrespective of substrate.

**Special designed machines.** According to create prototypes in the least expensive way, there are made some investigation to develop special ink-jet machines. Tele- and Radio Research Institute in Poland has built a printer based on piezo-electric printing head.

- The parameters of this ink-jet printer are:
- 50 μm nozzle diameter,
- 35 to 55 pico litters drop volume

Possibility of using organic and inorganic inks

The whole process is controlled via two CCD cameras. The operator of machine is able to change drop size and shape. This ink-jet machine is shown on Figure 1.

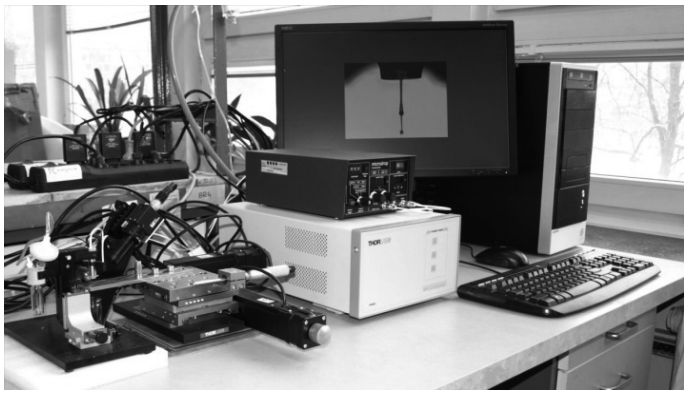

Fig. 1. Ink-jet printer constructed in Tele- and Radio Research Institute [3]

During the research of Institute, drops were jetted on three types of substrates: glass, paper designed for electronic and casual photo paper. Printing on papers was more problematic – especially photo paper is not suitable for this ink-jet printer. However jetting drops on flexible materials gave the best results. What is more, they aren't expensive, that's why manufactured electronic can be more economical [3].

**Printed electronic.** In the process of manufacturing printed electronic, precision and selectivity of jetting are crucial. Resolution, layer thickness and its electric, optical and mechanical properties depend on way of jetting ink. First of all, layers are jetted in liquid form so they have to be cured, however with not very high temperature [4].

Growth figures for this application are estimated to be a $57 billion market by 2019 (see Fig. 2) [5].

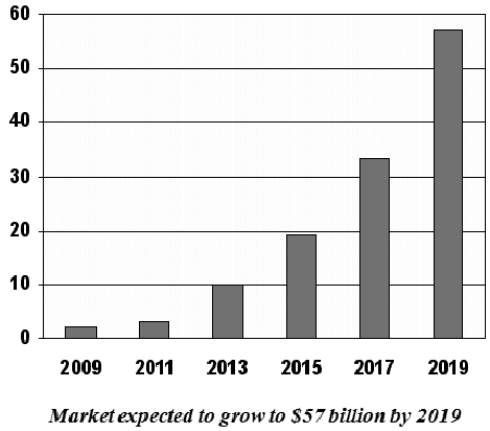


Fig. 2. Global market for printed electronics ($ billions) [5]

There are different substrates used for printed electronic. Their main features are:
- Flexibility
- Non-absorbance
- Transparency

The first one is the most important – printed electronic is also called elastic electronics. The second feature is also crucial because absorbance can provide to problems with layer rheology and its equal curing. Transparency is not always desired.

The most useful materials for printed electronic are: glass (Fig. 3), polymers and papers coated with polymer. There is an investigation of preparing textures for this application. However such materials are difficult to use in electronics because of their high absorbance, porosity, unequal surface and shrinking tendency.

As it was mentioned before, photo paper cause also problems in electronics printing. It is connected with its porosity and unequal surface. This is the reason of unequal ink absorption. Due to this fact, on paper surface there are places without any ink what causes breaks in conductive path.

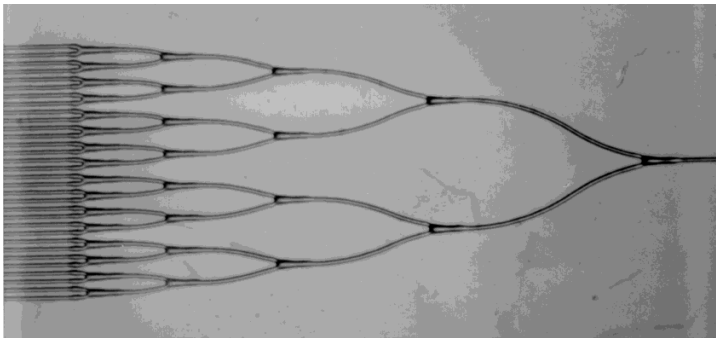

Fig. 3. Thirty-two channel splitter printed onto glass using inkjet technology. The individual waveguides are 100-μm diameter [6]

**Inks for printed electronic.** In ink-jet method, inks should have low viscosity (2÷25 mPa·s) what enables to jet it on a surface without any problems. Surface tension is also an important issue – ink should have $3 \div 4 \cdot 10^{-6}$ N/m. Due to appropriate viscosity and surface tension, drops are able to form globules and they don't change their shape.

Inks for printed electronic usually are made of conductive polymers such as polyaniline, PEDOT:PSS and nanomaterials dispersed in solvents or sometimes in polymer resin solution. The most popular inks are the ones containing metal nanoparticles, such as nanogold (1÷5 nm, see Fig. 4), nanosilver (1÷5 nm, see Fig. 5) and nano carbon in nanotube form. [4]

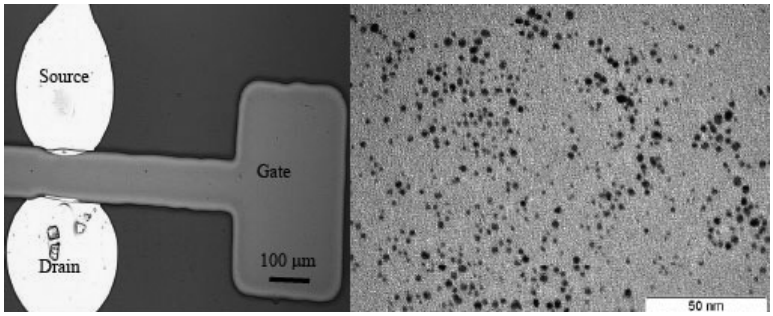


Fig. 4. An ink jet printer TFT device with NMTI nanogold inks (on the left) and TEM image of NMTI Gold nanoparticles ~5 nm (on the right) [7]

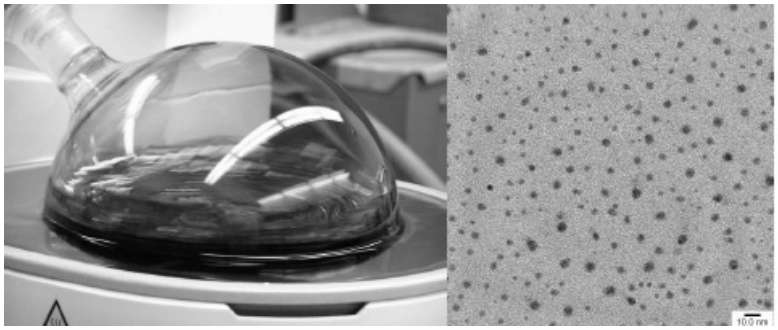

Fig. 5. Nanosilver conductive inks produced by NMTI's proprietary technology (on the left) and TEM image of NMTI silver nanoparticles (on the right) [8]

Carbon nanotubes have become more popular nowadays because of their diverse applications. They are characterized by good mechanical, thermal conductive and electrical properties. Ink made of carbon nanotubes creates transparent and conductive material which can be used as foldable electrode. The research done by P. Lee and S. G. Keem showed that conductivity and transparency can be determined by changing the pitch of the printed line (see Fig. 6). Due to increasing of pitch size, the transparency of electrode becomes higher [9].

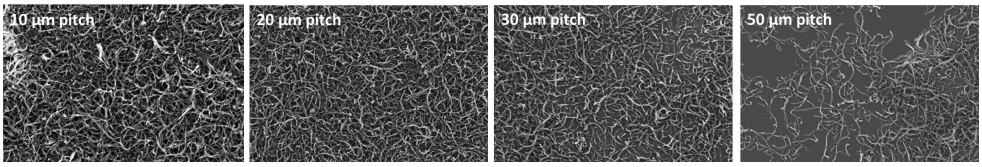


Fig. 6. The SEM images of carbon nanotubes percolation network with different pitch sizes [9]

**Summary.** Although in electronics the most popular technique is screen printing, ink-jet method has become a cheaper alternative. They are done a lot of investigations connected with modern printers which enables to create prototypes, electrodes, Random Access Memory, OLED lights and displays, sensors etc. Such products made by using ink-jet method can have also appropriate conduction as long as the resolution of printing is high and materials are characterized by features described in this article.

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## ДРУК ЕЛЕКТРОНІКИ З ВИКОРИСТАННЯМ СТРУМИННИХ ПРИНТЕРІВ

*У статті розкрито можливості електронного друку з використанням цифрової техніки — струминних принтерів. Такі матеріали, як тривимірні деталі й багатошарові пристрої, повинні бути надруковані по-іншому, ніж на пластику та папері. Підтверджено, що існують спеціальні струминні машини, які адаптовані для друку електроніки. Завдяки модернізації цифрових пристроїв було досягнуто високої роздільної здатності. Сформульована проблема дуже важлива, особливо в друці електроніки.*

## ПЕЧАТЬ ЭЛЕКТРОНИКИ С ИСПОЛЬЗОВАНИЕМ СТРУЙНЫХ ПЕЧАТНЫХ УСТРОЙСТВ

*В статье представлены возможности печати электроники с использованием цифровых струйных устройств. Такие материалы, как трехмерные детали и многослойные устройства, должны быть напечатаны по-другому, чем на пластике и бумаге. Существуют специальные струйные машины, которые были адаптированы для печати электроники. Благодаря модернизации цифровых устройств достигнуто высокое разрешение. Эта проблема очень важна, особенно в электронике.*