Preliminary Study of Resistive Sensors in Inkjet Technology for Force Measurements in Biomedical Applications

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***Abstract*—The research aims to the development of sensors for strain measurements using inkjet technology for biomedical applications. The process of inkjet printing is based on the emission of a fixed quantity of material in liquid phase, usually called ink, in the form of small drops, contained in a chamber through a nozzle. The emitted drop falls on a substrate, forming a pattern. The solidification of the liquid can occur through the evaporation of the solvent, chemical modifications (eg by cross-linking of polymers) or crystallization. Often post-processing treatments are required, such as thermal annealing or sintering. For the realization of the sensors, the nanocrystalline silver ink, which is a biocompatible ink, was chosen. The substrate is Kapton and several studies demonstrate its biocompatibility. A preliminary analysis of the material and its compatibility with the chosen printer, the description of the developed devices and finally the experimental results with the calculation of the relative Gauge Factor are reported. The research allowed to study, in a preliminary way, light, thin, flexible, inexpensive, and biocompatible sensors for applications inside the human body.**

***Index Terms*—Inkjet printing, strain measurement, biomedical application, resistive sensor.**

I. Introduction

The printed electronics include a variety of low-cost methodologies and processes, characterized by high volume and high throughput in the production. The techniques and processes for printing of electronic devices and circuits are based on traditional printing methods, such as screen printing, flexography, lithography, inkjet printing, etc. Inkjet printing is a promising technique to develop low-cost electronic devices and sensors and has gained the interest of the scientific community for its design flexibility, low cost and the new possibilities in the field of sensors. The deposition of electrically functional electronic inks is a common characteristic for printed electronics methods. The inks can be organic or inorganic and the substrate can be flexible for placing on curved surface. Some common characteristics and differences exist between inkjet and screen printing technologies. Screen printing technique consists in the deposition of a thick ink in a single pass, and the desired design is obtained using an expensive mask. This is a low resolution method. Otherwise, inkjet printing is a non-contact method in which small droplets of functional or conductive material are deposited accurately on the substrate, guaranteeing high resolution and high flexibility in the geometry of the ink trace and in the application which the produced device is used for.

Currently, academic research and industrial innovation focus on the study of the process feasibility and of the inks performance in order to select the best materials for the particular application. To test the flexibility of the inkjet printing method, Kang et al. [1] realized some inkjet-printed passive components, such as resistors, capacitors and inductors. Using different types of ink, the authors could obtain dielectric, conductive and ferromagnetic layers in order to realize the passive components. Finally, they produced a low pass filter, printing a RC electrical circuit. The process of deposition depends on substrate, ink and application. For example, inkjet printing requires a low viscosity ink, which can be of different types. In many cases, additives are added to the ink in order to reduce its viscosity during the deposition process. In this way, the sintering or annealing processes are employed to increase the stability and the conductivity of the ink. The time and the mode of drying are important and depend on the ink. For example, T. Öhlund et al. [2] deposited a silver nanoparticle ink on a range of commercially available paper substrates with varying compositions, in order to select or construct a substrate paper for optimizing electrical performance in paper electronics applications. A. Chiolerio et al. [3] investigated the best process using the silver ink on a Kapton substrate in order to realize a chipless RFID (Radio Frequency Identification), varying the drop step size, the number of printed layers, the trace cross-size and the annealing process. In particular, they concluded that the low power Diode Pumped Solid State (DPSS) laser assisted configuration gives generally better results with respect to the tradition hot-plate. The inks used for inkjet printing differ in propriety and deposition methods. PEDOT:PSS (poly(3,4-ethylenedioxythiophene)) poly(styrenesulfonate) and silver nanoparticle ink are frequently used in printed electronics. J. Rausch et al. [4] tried to use PEDOT:PSS to realize a strain sensor, while B. Andò et al. [5] proposed a strain sensor based on silver ink for

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deformation measurements. A humidity sensor [6] was fabricated on polymeric foil PET (Polyethylene terephthalate) using all additive processes and silver ink. K. Crowley et al. [7] detailed the fabrication and the sensor performance for ammonia gas analysis using the inkjet-printed deposition of polyaniline nanoparticle films.

In our paper, a preliminary study of the inkjet printing method is presented. The ink and the substrate are chosen according their biocompatibility characteristics. The silver nanocrystalline ink has selected as conductive material and the Kapton has chosen as flexible substrate. In the case of implantable medical devices, the material biocompatibility is an important aspect: the device proposed in this paper is a Kapton substrate and a nanocrystalline silver ink, both tested in the literature. A. P. Supp et al. [8] and R. Rustogi [9] tested the absence of cytotoxicity of the nanocrystalline silver in vivo. The Kapton biocompatibility is confirmed by Y. Sun et al. [10]. To test the performance of these materials, we have printed different geometric patterns. In particular, we have developed a sensor for medical devices, printing multilayers of the same ink. The printed sensor pattern is similar to the traditional strain gauge. The resistance response under stress and the temperature influence are tested.

II. System Description

The instrumentation required for the sensor development consists of a commercial inkjet printer and a series of refillable cartridges. The selected printer is the Epson Stylus SX430W, a common commercial printer. It has 4 separate cartridges with 128 nozzles for black and 42 nozzles for each color; it has a print resolution of 5760x1440 dpi and can print with different qualities. Then, the printer decides that the amount of ink will be used. The used ink (Aldrich-719048) is based on silver nanoparticles, with size less than 150 nm, in this way the particles go through the nozzle. In respect with PEDOT:PSS, the silver ink is simpler to use and it causes clogging nozzle less frequently. In this way, it's possible to use the cartridge until the silver emptying, guaranteeing a more reproducibility of performance. The viscosity is around 10 cps and the tension surface 30 DYC. The ink is 20% wt dispersion in ethanol and ethanediol. An annealing process is necessary in order to evaporate the solvent and form a continuous percolating structure that allows for conductivity. The substrate chosen for the sensor is made of Kapton sheets of thickness 25 microns. The strain gauges were made with the classical structure of a serpentine extensometer resistance (Fig. 1). After printing three layers superimposed via inkjet and being subjected to annealing which consists in heating the sample at a temperature of 150 °C for 30 minutes. The gauge was contacted at its ends with the silver paste (Dupont 5028). In this way, it was possible to weld the wires to the device, without changing its structure or risk of damage due to high temperature reached during the welding.

In Fig. 1 a picture of the final device is reported. The chosen pattern is similar to a traditional strain gauge, used for deformation measures of an object. A traditional strain gauge is usually made of metallic foil. With respect to the printed strain gauges, conventional strain gauges are larger and are less suitable to be attached on curvilinear surfaces and to measure large deformations. An enlargement of the proposed device is shown in Fig. 2. The picture is obtained using an optical microscope at 50x and shows the deposition realized by the inkjet printer. The figure shows a part of the border of the track and the drops deposited by the printer can be seen. The deposition leaves some areas not covered by the ink and to overcome this aspect more than one deposition can be performed.

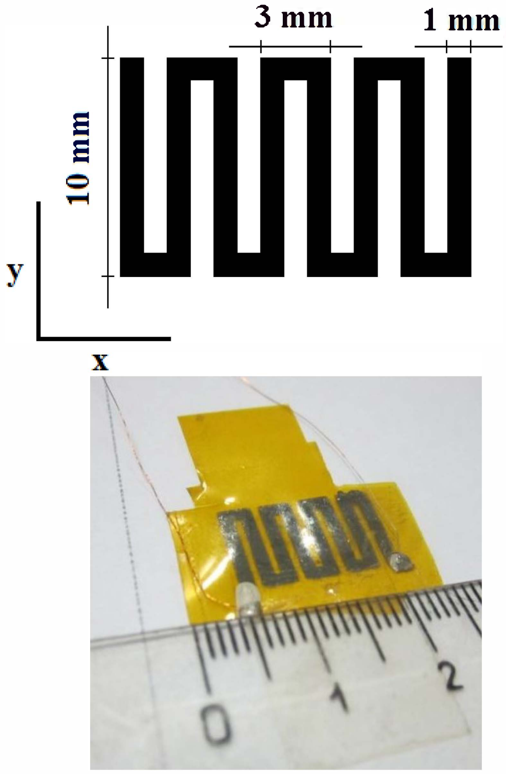

Fig. 1. Images of the realized strain gauge and dimensions.

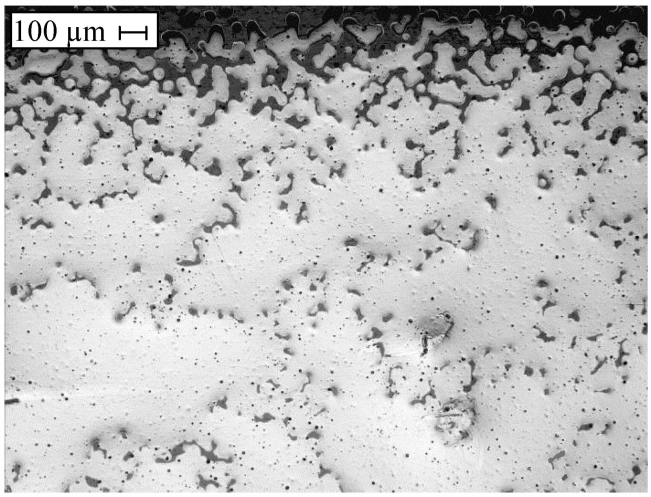

Fig. 2. Images of the realized depositions.

III. PRELIMINARY EXPERIMENTAL RESULTS

Different conductors of rectangular shape having a different length (from 2 mm to 25 mm), but equal width (3 mm) and thick (three layers of print), were made with the printing process described in the previous paragraph. The resistance of the conductors was measured with the classical 4-wire connection using a multimeter (HP34401A) and then the average value of the resistance was calculated, which is about 7.4 Ω/cm (Fig. 3). This value is in agreement with that measured for the gauge realized (about 498 Ω). Tests were then performed to evaluate the temperature dependence. The thermal drift of the gauge at rest was derived using a climatic chamber Perani UC 150/70. The measurements were carried out in conditions of constant humidity at 20% and by varying the temperature from -20 °C to 90 °C, with a step of 5 °C (Fig. 4). The trend of the resistance value as a function of temperature is linear; it also follows the classical behavior of the metal conductors. The sensitivity with respect to temperature is of 0.042%/°C.

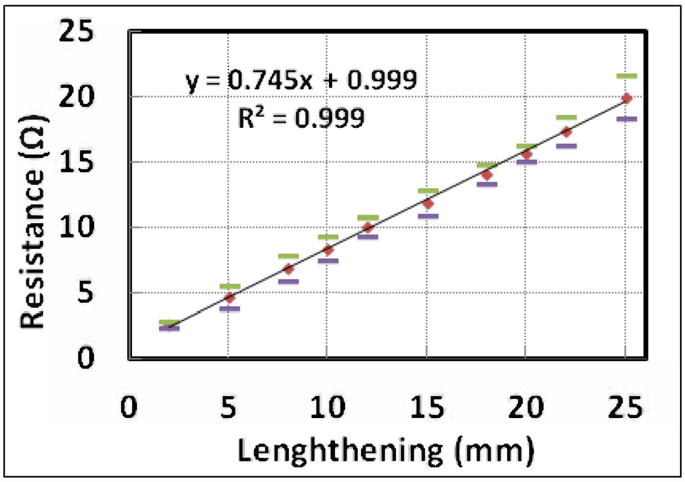

Fig. 3. Resistance values for different lengths of conductor.

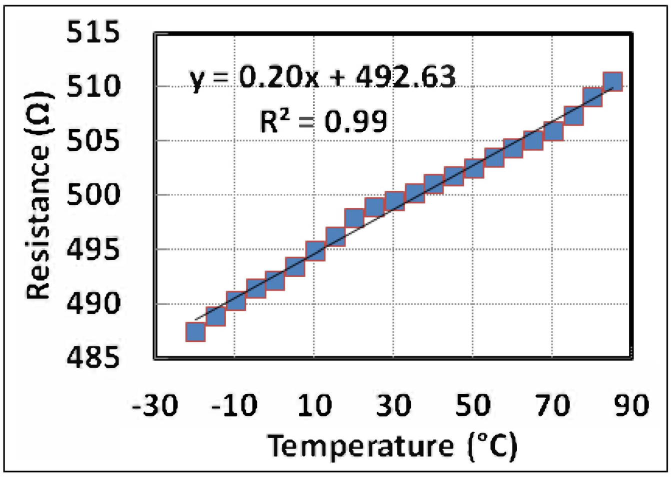

Fig. 4. Variation of the strain gage resistance vs. temperature.

The strain gauge has been subjected to deformation by an experimental setup consisting of a micrometer screw (Fig. 5) and the corresponding resistance values were measured.

The gauge has been progressively stretched along the direction of its y-axis with a pitch of 50 micrometers. The data relating to the calculation of the GF (Gauge Factor) are shown in the graph of Fig. 6. The Gauge Factor is about 6.2 Conversely, the GF of the metallic strain gauges is about 2 and the GF of the semiconductor strain gauges is higher (around 200).

The hysteresis was also studied (Fig. 7). The hysteresis error is about 36% relative to the output span.

The research work has allowed us to realize a biocompatible strain gauge with the inkjet printing technique. Further research work for improving reproducibility and resolution is ongoing.

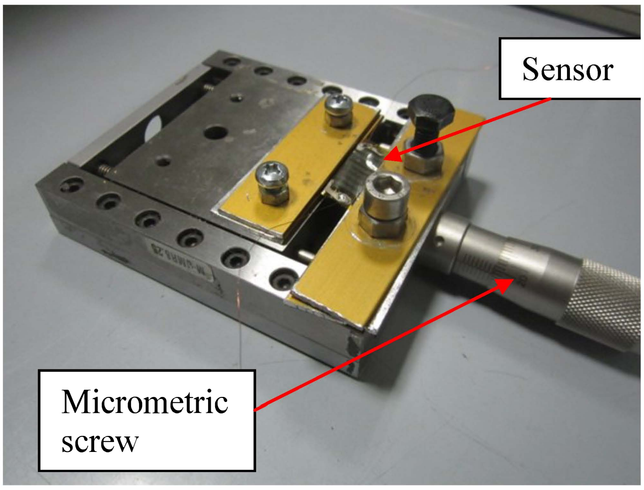

Fig. 5. Images of the realized strain gauge and dimensions.

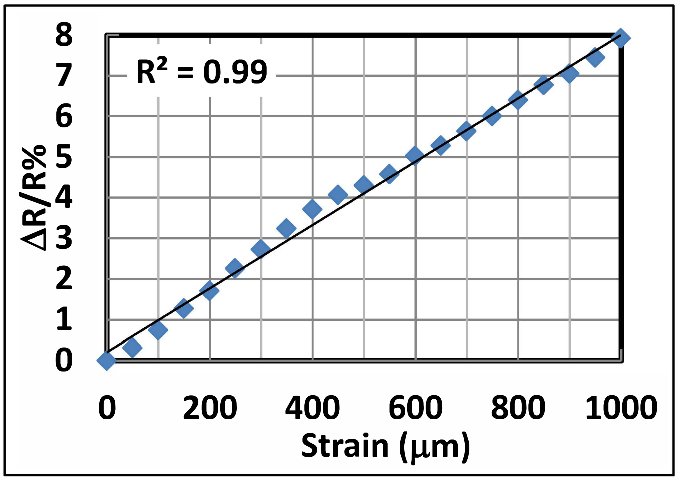

Fig. 6. Percentage change of the resistance vs. strain.

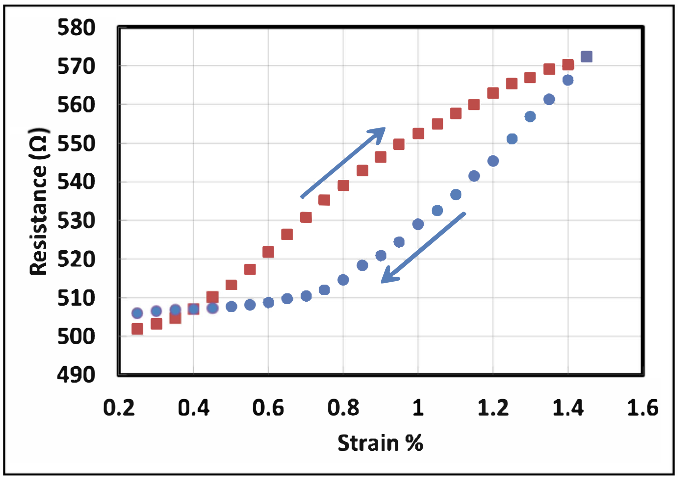

Fig. 7. Hysteresis loop measured at different strain values.

IV. Conclusions

The research reported in this paper has studied in a preliminary way the possibility of design, build and test biocompatible sensors realized through inkjet technology using commercial printers. The preliminary experimental results has shown the sensor behavior achieved by varying the temperature. In addition, some tests have been performed by varying the applied strain and measuring the resistance and the results show a high gauge factor. An analysis of the values obtained experimentally is in progress. Experimental trials are underway to evaluate both different geometries and different deposition parameters.

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