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RESISTIVE STRAIN SENSORS OBTAINED TRHOUGH INKJET PRINTING PROCESS

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Abstract. *Resistive strain gauges are a popular and reliable method for determining localized strain in manufacturing and engineering industries. Common commercially available strain gauge structures are manufactured using conventional photo-resist and acid etching processes. The disadvantages associated with these techniques are generation of toxic effluents and the slow speed of production. Moreover, the commercially available strain gauges should be attached to the test sample through the use of fast-acting glue. It can be an issue when flexible polymers are analyzed. Within this scenario, printed electronics can be and option to produce such strain sensors since it has already demonstrated its capability also for manufacturing of high-speed electronics and low cost products through an additive process. The technology also allows the printing of a sensor directly over the tested sample. This method can increase the sensor sensibility since the fast acting glue influence is removed. Markets of printed electronics are growing rapidly and it is estimated that in the future the business will grow even bigger than the silicon technology. Products based on printable electronics might include ultra cheap radio-frequency identification tags (RFID), inexpensive and disposable displays/electronic paper, interior connections, parts of electronic assemblies (e.g. PWB and phone chassis), sensors, memories, and wearable user interfaces. This paper reports the design and manufacture of a resistive strain sensitive structure fabricated using the inkjet printing process. The main objectives were the obtention of a resistive strain gauge with commercial resistance and also analyze the printing process and the resulting microstructure. For this purpose, strain gauges were printed over polyimide substrates using a Dimatix. The ink was a silver based suspension and the curing conditions were controlled in order to obtain the desired resistance. The electrical response of the strain gauge under strain was verified. After a microstructural analysis though SEM it was possible to observe a large amount of porous within the trace. These porous affected the trace resistivity and could be an issue to the mechanical properties, adhesion for instance, of the strain sensor. Nevertheless, it was possible to obtain strain sensors through the printing of conductive material.*

Keywords*: Printed Electronics, Strain gauge, Polyimide*

1. INTRODUCTION

Resistive strain gauges are a popular and reliable method for determining localized strain in manufacturing and engineering industries. According to Perry and Lissner (1962), average unit strain, capable of being determined using strain gauges, can be summarized as the “total deformation of a body in a given direction divided by the original length in that direction”. The operation of resistive strain gauges relies on the change in resistance of a conductor when a load is applied.

Manufacturing techniques for resistive strain gauges have changed over time from thin diameter wire cemented in a grid formation on paper backing materials, employed for SR-4 structures, to photo resist, acid etched grids formed on alloy clad polymer substrates. Gareth *et al* (2007) observed that disadvantages associated with the later manufacturing technique include the production of toxic waste material and slow speed of fabrication.

Most of the conventional pressure sensors consists of a sensitive wire or foil as strain gauge material, attached by an adhesive to the component. As the adhesive and backing material are in the force path, the accuracy of measurement is limited by the thickness and characteristics of these materials (Rajendra *et al.*, 2005).

Business around printed electronics is expected to have a vigorous growth in next few years. Printed electronics is estimated to have even bigger market than the silicon technology nowadays. Products based on printable electronics might include ultra cheap radio-frequency identification tags (RFID), inexpensive and disposable displays/electronic paper, interior connections, parts of electronic assemblies (e.g. PWB and phone chassis), sensors, memories, and wearable user interfaces. Additive technologies offer lower cost, less production steps, and capability for mass production. Printed electronics takes advantage of nanosciences and material development, piggybacking them onto printing technologies which have developed quite much during past years (Bonadiman *et al.*, 2008**).**

Conductive traces can be obtained through the arrangement of dots that are deposited in the substrate, with some overlapping. There are several parameters that must be controlled in order to achieve appropriate dispensing. These parameters are distributed in the ink, in the inkjet head, as well in the substrate (Bonadiman *et al.*, 2008). Moreover, the curing (sintering) process is also extremely important. It will define the traces microstructure, thus it will impact in the electrical and mechanical proprieties of the device.

Strain sensors without adhesive application were obtained through different techniques as anodization (Rajendra *et al.*, 2005) and lithography (Gareth *et al.*, 2007). However, ink jet printing technology arises as a low cost and flexible technique. Since it allows the non contact printing, it is possible to create strain gauge over complex surfaces and change its layout easily.

Within this scenario, printed electronics can be an option to produce such strain sensors since it has already demonstrated its capability also for manufacturing of high-speed electronics and low cost products through an additive process. The technology also allows the printing of a sensor directly over the tested sample. This method can increase the sensor sensibility since the fast acting glue influence is removed.

This paper reports the design and manufacture of a resistive strain sensitive structure fabricated using the inkjet printing process. The main objectives were the production of a resistive strain gauge with commercial resistance through printed technology process and also evaluate the printing process and the resulting microstructure.

2. EXPERIMENTAL PROCEDURE

2.1. Strain Sensor Printing

Strain sensors were printed through ink jet technique on polyimide flexible substrate. For this purpose a specialized ink jet printer (Dimatix) and a suspension containing silver nanoparticles were applied. The ink used was acquired from a known supplier, and has 50% of metal content in polar solvent. Surface tension is 27.9 mN/m. The substrate was Kapton® polyimide film.

The conductive particles, within the suspension, are covered with dispersing agents which improves the ink stability proprieties. After printing process, the dispersing agent must be removed in order to allow the contact between conductive particles and, consequently, the sintering process. This principle is shown in Fig. 1.

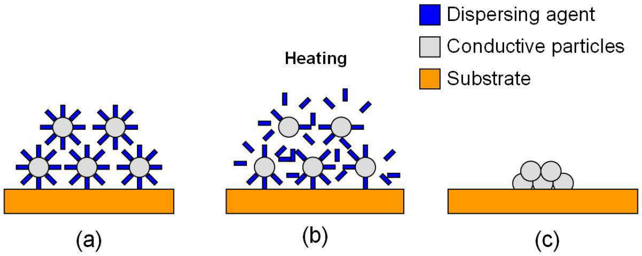

Figure 1. Sintering process (Caglar *et al.*, 2008).

Prior to the printing process, the ink was submitted to an ultra-sound treatment during 10 minutes in order to minimize the metal particles agglomeration. This process also minimized the clogging effect in the cartridge nozzles since the cartridge nozzles apertures have about 22µm. The polyimide substrates were treated using a cleaning solution (HFE 7100 3M). After this procedure, the polyimide sheets were placed in the printer plate which was maintained at 60°C. Figure 2 shows the printed strain sensor layout. Ink drops of approximately 60µm were deposited on the substrate with 10µm spacing. The printing conditions were based in previous work (Marques *et al.*, 2007). After the printing process samples were kept on the printer plate until the ink dries completely completely.

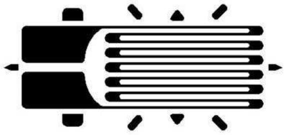

Figure 2. Printed strain sensor layout.

Samples were submitted to a controlled sintering process. Curing process was held in a muffle oven at 210°C. The final resistance (120Ω) was controlled though online resistance monitoring.

2.2. Microstructure Evaluation

In order to evaluate sensors microstructure two groups of samples were selected and then submitted to metallographic preparation. One group of samples was cured in the same conditions as mentioned previously. The second group of samples was not sintered. These samples only were submitted to a drying process at 60°C during 10 minutes. In both cases, the layout was defined as a rectangular pad. It was defined in order to facilitate the microstructure analysis proceeding.

The Ag microstructure was analyzed through Scanning Electron Microscope (SEM). The pad was scratched in order to set the Ag layer perpendicular to the SEM beam. After that a carbon coating was applied over the pad in order to prevent image saturation.

The materials microstructure was evaluated

2.3. Electrical Response Tests

The electrical signal generated by the printed strain gauge was evaluated in order to compare the results with commercial strain gauge. The main goal was to evaluate if the printed sensors has a similar behavior when compared to the commercially available sensors, i.e., if it is able to recognize the substrate deformation.

Conventional strain gauge was bounded on a polyimide flexible substrate. Both, printed and commercial strain sensors were submitted to bending tests. The schematic representation of the performed bending test (Test A) is show in Fig. 3.

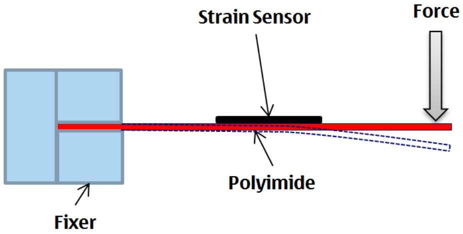

Figure 3. Bending Test Schematic Representation (Test A).

A second bending test was performed. In this test the two extremes of the polyimide were fixed (Test B). The Scheme is shown in Fig. 4.

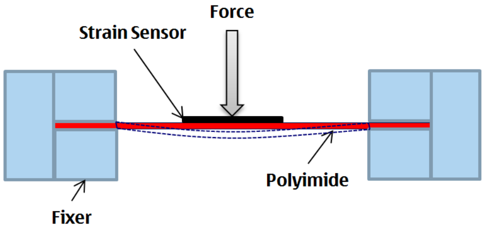

Figure 4. Bending Test Schematic Representation (Test B).

3. RESULTS AND DISCUSSION

3.1. Strain sensor printing

It was possible to print strain sensors directly on polyimide substrate (Fig. 5). The strain gauge dimensions are limited by the input drawing which is limited by the trace resolution. However, this one is related to a complex interaction between the ink, the substrate and the printing conditions (Bonadiman *et al.*, 2008). The available ink and equipment allows traces with about 60µm length, thus, the selected layout was within this limit. Samples found do have electrical continuity, thus, being able to be cured.

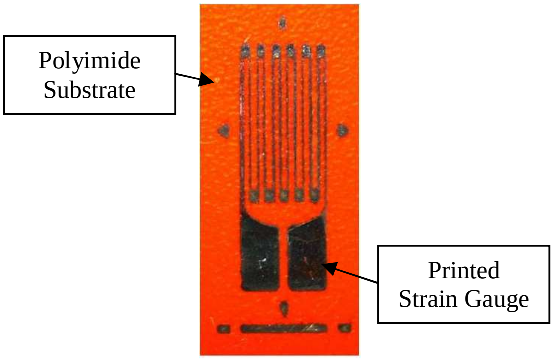

Figure 5. Printed strain gauge on polyimide substrate.

3.2. Microstructure Analysis

3.2.1. Dried Samples

Through the SEM analysis was possible to observe that the non-cured samples microstructure shown small pores on the Ag pad surface. These pores were located in the bottom surface of the pad which was in contact with the Polyimide (Fig. 6). These pores could be an issue to the sample mechanical behavior.

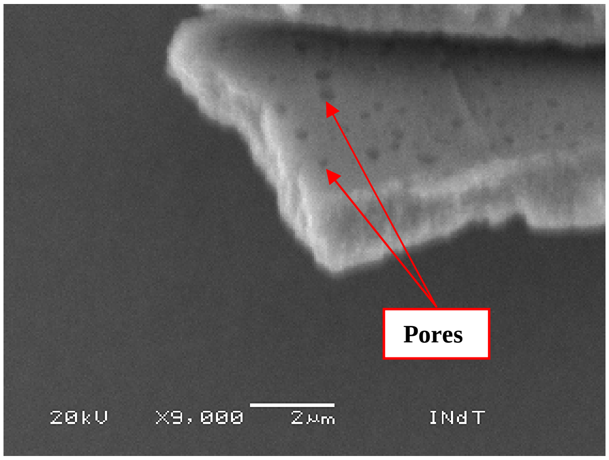

Figure 6. SEM image of Ag printed pad. It is possible to observe small pores in the surface which was in contact with the polyimide.

Despite the fact that the sample it is not cured, it was not possible to observe a reasonable amount of pores in the bulk material (Fig. 7). Possibly it is caused by the easy arrangement of the metal particles due to the presence of low viscosity materials coming from the ink composition. Moreover, the presence of surfactants and elements from the ink may mask the pores.

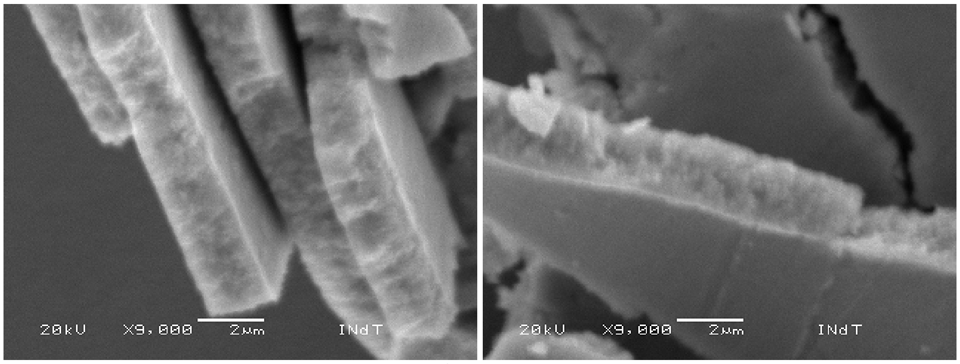

Figure 7. SEM images of the traces bulk material. It was not possible to observe a considerable amount of pores.

3.2.2. Cured Samples

The curing process, more precisely, refers to the sintering process. This is a process of forming objects from a metal powder by heating the powder at a temperature below its melting point. During the hitting procedure, the particles composing the powder, join together to form a single solid object (Fig. 8). Moreover, the process is time and temperature dependent. Thus, with the increase of the time and temperature the sintering process is more effective inducing the pores reduction, thus increasing the material densification.

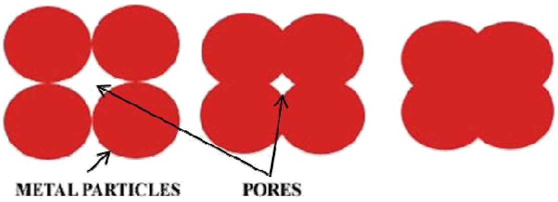

Figure 8. Sintering process schematic representation. With the increase of the time and temperature the amount of pores reduces.

After the curing process it was possible to observe a large amount of pores in the trace bulk material (Fig. 9). Probably, the pores were originated from the gases expelling during the curing process. Since the applied ink is composed not only by metal particles (only about 50%wt of the composition), but also composed by a certain amount of surfactants and chemical solutions (with low evaporation temperature), the evolution of gases was expected. In order to increase the trace densification, a pressurized sintering process would be needed.

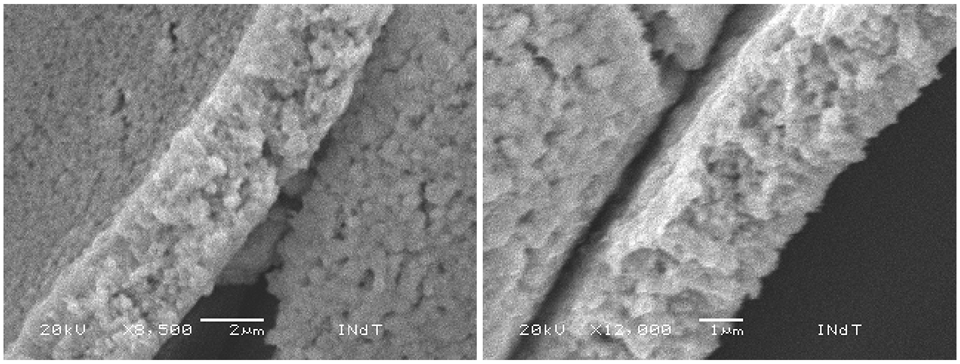

Figure 9. SEM images of the pad bulk material. It is possible to observe a large amount of pores in the trace bulk material.

Curing process had a high influence over the traces resistivity. After sintering, the material reduced considerably its resistivity. However, the resistivity found to be one magnitude order higher (16 µΩcm) when compared to the silver bulk resistivity (1.6 µΩcm) . Probably it is due to the large amount of voids in the trace structure. Moreover, since the material was obtained through sintering of metal nanoparticles, the microstructure probably has a high amount of grain boundaries. It can interfere in the electrical conductivity.

3.3. Strain Sensor Electrical Signal Evaluation

Fig 10 shows the electrical comparison between the printed and the conventional strain sensor when submitted to the Test A. It is possible to observe that the printed strain gauge has a more sensible response to the induced force.

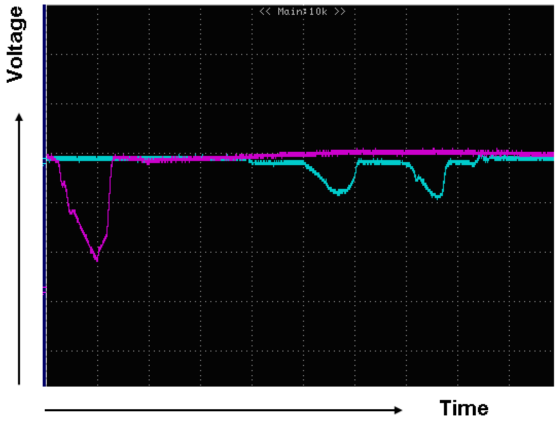

Figure 10. Electrical response comparison between printed and conventional strain sensor during Test A (blue line – conventional sensor; pink line – printed sensor). Grid squares corresponds to 1V variation.

Fig 11 shows the electrical response during Test B. Again, it was possible to observe a more sensible response of the printed sensor when compared to the conventional.

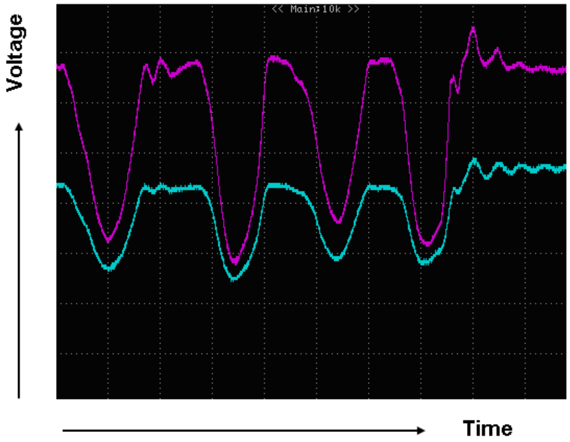

Figure 11. Electrical response comparison between printed and conventional strain sensor during Test B (blue line – conventional sensor; pink line – printed sensor). Grid squares corresponds to 1V variation.

During a stationary state it was possible to observe changes in the signal of the printed strain gauge (Fig. 12). These changes in the signal of the printed strain gauge could be related to the air flow influence. Since the printed sensor is extremely sensitive, a vibration in the system could have caused these signals. Moreover, another possible influence is the variation due to temperature changes since the electrical signal seems to change even with small temperature variations. One possible solution would be the application of a cover layer over the printed samples.

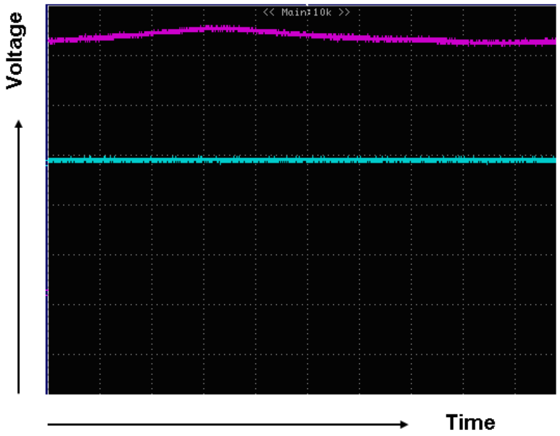

Figure 12. Electrical signal during stationary state (blue line – conventional sensor; pink line – printed sensor). Grid squares corresponds to 1V variation.

4. CONCLUSIONS

It was possible to print strain sensors directly on polyimide substrate. The strain gauge dimensions are limited by the input drawing which is limited by the trace resolution. However, it is related to a complex interaction between the ink, the substrate and the printing conditions.

It was not possible to observe a reasonable amount of pores in the bulk material of non cured samples. Possibly it is caused by the easy arrangement of the metal particles due to the presence of low viscosity materials coming from the ink composition. However, cured samples shown a large amount of pores within the trace bulk material. Probably, the pores were originated from the gases expelled during the curing process. It was expected since the applied ink is composed not only by metal particles, but also composed by a certain amount of surfactants and chemical solutions.

The electrical bending tests showed that the printed strain gauge has a superior sensibility when compared to the conventional sensor. However, in stationary state the printed strain gauge presented changes in the generated electrical signal. Probably it is related to this high sensibility which can sense small vibrations and also changes in the temperature

5. ACKNOWLEDGEMENTS

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6. REFERENCES

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