ELECTRO-MECHANICAL PROPERTIES ANALYSIS OF INKJET PRINTED STRAIN GAGES

Jairo Quintero, ext-jairo.quintero@nokia.com
Renato Bonadiman, ext-renato.bonadiman@nokia.com
Rafael Drumond Mancosu, ext-rafael.mancosu@nokia.com
Nokia Technology Institute, Avenida Torquato Tapajós, 7200, Manaus, Amazonas, Brazil.

Antonio Wesley Carvalho Oliveira
Universidade Federal do Amazonas, Núcleo de Pesquisa e Extensão em Engenharia de Produção / NUPEP. Av. Gen. Rodrigues Octávio Jordão Ramos, 3000, Manaus, Amazonas, Brazil.

Abstract. This paper reports Conventional strain gages (SGc) are precision electrical resistors widely used in research field for determining strain of products and manufactured structures. The operating principle assumes that the strain on the object under investigation is transferred without loss to the strain gage. The most common type of strain gage consists of an insulating flexible backing which supports a metallic foil pattern, so that can be bonded to the surface of the object under investigation by a very strong quick-setting adhesive. Commonly the fast-acting glue is based on Cyanoacrylate material, which has a low shearing strength. In addition, in some cases Cyanoacrylate application changes the stiffness of material under investigation and affects the sensibility of the strain gage. Thus, the usage of conventional stain gages on polymer thin films is some how limited due to problems caused by reinforcement of the polymer as consequence of the quick-setting adhesive. To overcome these problems a method has been developed whereby a strain-sensitivity circuit can be printed direct onto polymer surface. Through optimizing the printing conditions, ink, formulation, ink-curing conditions and the electrical circuitry it has been found that these printed strain gages can provide very convenient and accurate outcomes for measuring strains in polymers. This paper reports the specification (e.g. gage factor and sensibility) of the strain gage printed (SGi) directly over polyimide substrates and its response when subjected to mechanical tests (four-point bend and tensile strength tests). A commercial strain gage was placed at the same position in order to compare the strain gage printed effectiveness. The main purpose of this work was to compare the electrical strain gage printed over the polyimide film with conventional strain gage. Printed strain gage resistance showed significant instability probably due to the inkjeted material applied. Despite this fact, it was possible to obtain a similar electro-mechanical response when compared to conventional strain gages.

***Keywords**: Printed Electronics, Strain gauge, Polyimide*

1. INTRODUCTION

The basic function of the semiconductor strain gauge is based on transforming the changes of dimensions in certain direction to charges of its electric resistance. The change of strain gauge dimensions is caused by deformation of the measured object. Transformation in determined by the so-called deformation sensitivity *K* (gage factor) that is generally defined according to the equation 1.

$$K = \frac{\Delta R / R}{\Delta l / l} \tag{1}$$

where R denotes the strain gauge resistance, *ΔR* is the change of strain gauge resistance at deformation (Husák *et al.*, 2002).

According to Hay *et al* (2007) common commercially available strain gauge (SGc) 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.

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**).**

Within this scenario, printed electronics can be an option to produce 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. Hover, questions regarding the strain sensor behavior during mechanical stresses still remain.

The acquisition the system converts the mechanical deformation into electrical signal in order to allow physical interpretation such as force, pressure, torque, displacement, deformation, among others. The main purpose of this work was to compare the electrical strain gage printed over the polyimide film with conventional strain gage.

2. EXPERIMENTAL PROCEDURE

2.1. Convencional Strain Gauge (SGc)

The SGc were cemented onto polyimide surface by using quick setting adhesive (Super Bonder, Loctite). The polyimide surface was cleaned and neutralized through the use of a special cloth and neutralizer MN5A-1. The SGc were carefully positioned at the center of the specimens in order to avoid any misalignment. Specimens were conditioned at environmental temperature. Five specimens for tensile-strength test and five for four-point bending were provided to be subjected to mechanical tests. Some strain sensor characteristics are shown in table 1.

Table 1. SGc characteristics.

Nominal resistance	119.6 ± 0.4 Ω)
Gage length	5 mm
Gage factor	K = 2.10
Model and supplier	KFG-5-120-C1 Kyowa

2.2. Strain Sensor Printing Process

Strain sensors were printed through ink jet technique on polyimide flexible substrate. For this purpose a specialized ink jet printer (Dimatix DMP-2800) 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.

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. Fig. 1 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.

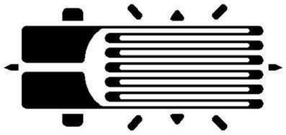


Figure 1 – Printed strain sensor layout.

Samples were submitted to a controlled sintering process. Curing process was held in a muffle oven at 310°C.. The final resistance (120Ω) was controlled though online resistance monitoring by the curing time control.

2.3. Printed Strain Gauges (SGi) Mechanical Characterization

2.3.1. Mechanical properties Polyimide film

Polyimide films are formed from biphenyl teatracarboxylic dianhydride (BPDA) monomers which are very resistant to heat. This material is widely employed on electronic products mainly in flexible cables as an insulating film.

Polyimide is thermally stable, has good chemical resistance and mechanical properties. The polyimide mechanical properties are presented on Table 2.

Table 2. Polyimide mechanical properties.

Young's modulus (E)	2382 MPa
Yield strength	50 MPa
Tensile strength	210 MPa
Elongation at break	0.68 %
Density	1430 kg / m³

2.3.2. Specimen Set-up

Samples submitted to the mechanical tests consist in a flat strip (100 mm x 25 mm) with thickness of 0.1 mm Fig. 2 (a). SGi and SGc were precisely positioned at the center of the flat strip.

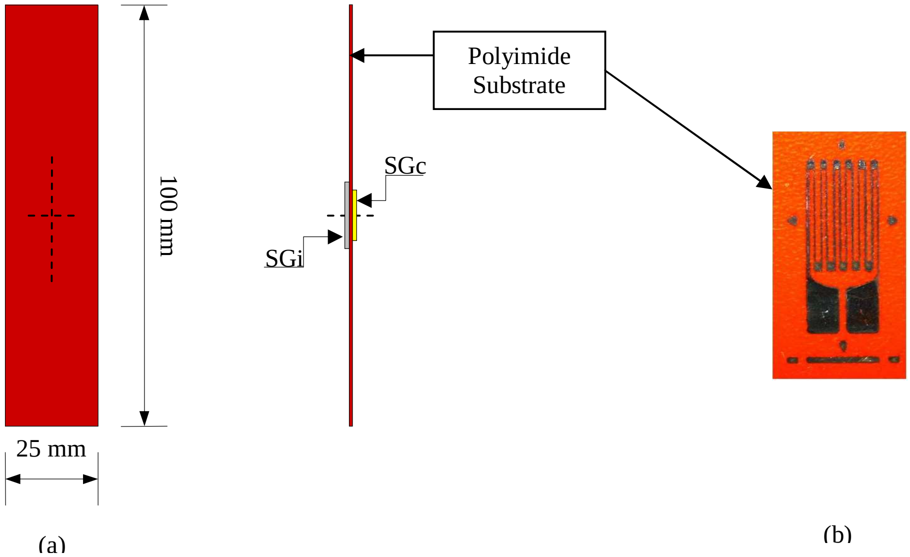


Figure 2 – (a) especimem set up, (b)Printed strain gauge on polyimide substrate.

2.3.3. Tensile-strength tests

Specimens with SGi and SGc were positioned between grips of the universal machine Instron 8874, distant 50 mm. Grips were tightened evenly and firmly in order to guarantee no slipping of the specimen. Loading was monitored in response of grip separation applied at constant speed of 0.25 mm/s. Testing was conducted until fail of one of the strain gauges fail. Total of five specimens were subjected to tensile strength test. Data acquisition from SGi and SGc were captured by using a strain meter and oscilloscope. The SGc was submitted to tensile strength in order to validate the testing method.

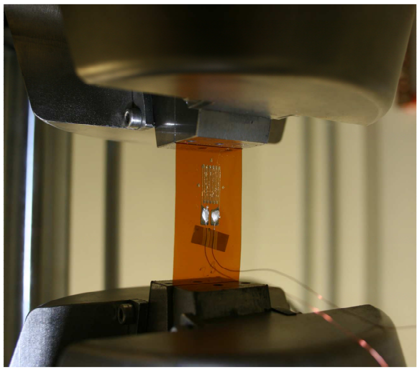
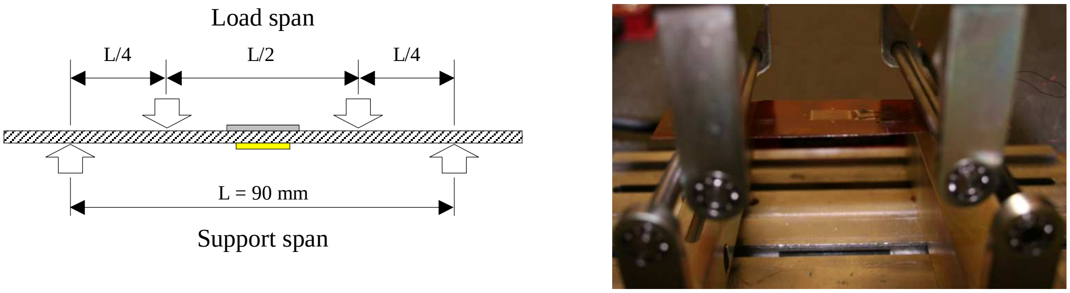


Figure 3 – Polyimide film with SGi between grips for tensile strength test.

2.3.4. Four-point Bending Test

Four-point bending tests were conducted on polyimide specimens with SGi and SGc by using a universal tester machine (Instron model 5564). The bending fixture was set on the test equipment in accordance with Fig. 4 (a). Specimens were set with SGi at up position and SGc in down position. The upper rollers were approached to the sample surface until loading variation occurrence. Signal monitored by strain gauges were collected by using a strain meter and oscilloscope. Cyclic displacement was applied and five specimens were submitted to bending test.



(a) (b)

Figure 4 – (a) Four-point bending setup; (b) Polyimide film with SGc and SGi under bending test

3. RESULTS AND DISCUSSION

3.1. Gage Factor K

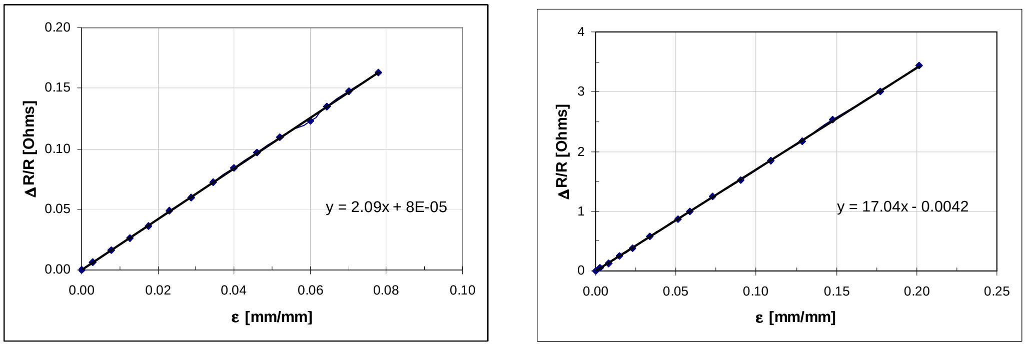
The Gage factor (*K*) indicates the relation between the specific changes in resistance and the specific elongation of the measuring specimen. The value of *K*, which varies between 2 and 6 for metals, can have values of about 180 for semiconductor strain gauges.

The gage factor of the conventional strain gage is 2.10 ± 0.1. However this value was evaluated during tensile strength test in order to validate the method applied to calculate the *K* values. The procedure consists in to monitor the electrical resistance and deformation of the SGc and SGi. Table 3 present the average of the Gage factor acquired after 5 experimental analyses.

Table 3. Gage factor acquired through experimental analyses.

Conventional strain gauge - Kc	**Printed strain gauge - Ki**
2.09	17.0

Fig. 5 shows the gauge factor for both, conventional (a) and printed strain gauges (b). These curves were determined by the linear portion of the tensile strain test. The curves slopes indicate the *K* constant value for both curves. It is expected a higher sensibility of the printed strain gauge since the *K* factor of the SGi is higher when compared to the SGc.



(a) **(b)**

Figure 5 – Gage factor K of the SGc (a) and SGi (b) obtained by experimental evaluation.

3.2. SGi Tensile Stress Test

Fig. 6 shows the SGi response and the maximum deformation during the tensile stress test. It was observed a non linearity in the first portion of the curve. Probably it is related to sample accommodation (yellow rectangle – Fig. 6) in the testing equipment right after the test start. The conventional strain gauge showed the same non linearity, however since the SGc curve was obtained in order to validate the testing method it is not presented in this paper. The strain gauge seems to "sense" very small deformations of the substrate, different from the conventional strain gauge. The relation between the linear deformation and the test time is approximately linear in the second part of the curve (after accommodation), i.e., the deformation rate remains almost constant during the test. This behavior indicates a high reliability in the SGi response. The maximum deformation obtained for this specimen was 12500 microstrains during a 15 seconds test.

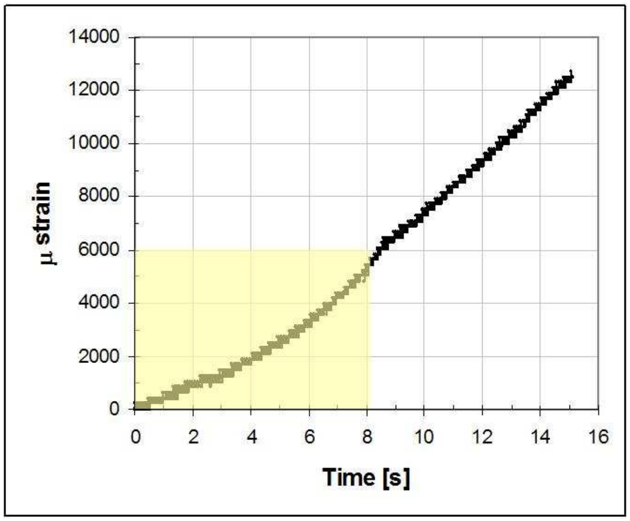


Figure 6 – SGi behavior during tensile stress test.

3.3. SGi Four-point Bending Test

It is possible to observe, in Fig. 7, the elastic behavior of a SGi during the four-point bending test. For small deformations the polyimide and the SGi showed the same mechanical response. The variation in the maximum and minimum strain probably is due the sample dislocation during the four-point bending test.

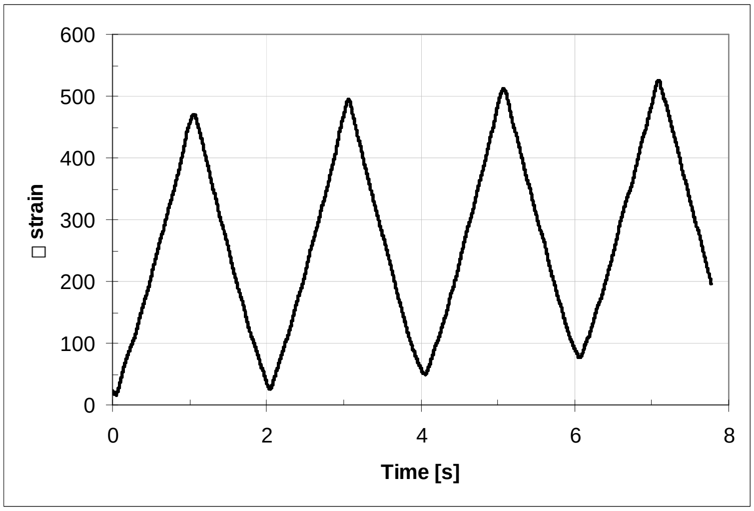


Figure 7 – SGi behavior during four-point bending test.

4. CONCLUSIONS

Printed Strain Gauges found to be extremely sensible. The gage factor observed was 17, far above the *K* observed in commercial strain gauges (about 2).

During tensile stress tests it was observed a non linearity in the first portion of the curve. Probably it is related to the printed strain gauge high sensibility since it was possible to observe a sample accommodation in the testing equipment right after the test start. The strain gauge seems to “sense” very small deformations of the substrate, different from the conventional strain gauge which did not show this behavior.

The relation between the linear deformation and the test time is approximately linear in the second part of the curve (after accommodation), i.e., the deformation rate remains almost constant during the test. This behavior indicates a high reliability in the SGi response.

After the four-point bending test it was possible to observe that, for small deformations, the polyimide and the SGi showed the same mechanical response.

5. ACKNOWLEDGEMENTS

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