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Behaviour of an Electrospun Sputtered Strain Gage Working in Various Supplying Conditions

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***Abstract* – In the paper, the characteristics of a strain gage sensor built using electrospinning and sputtering technologies, working under dc and ac supplying conditions are presented and discussed. Using the above technologies instead of classical deposition techniques may lead to increasing the sensor sensitivity because of enhancing the Poisson effect on the metallized nanofibres. Even if the manufacturing technology is not yet well established, it is much promised as idea, as the sensitivity of the sensor is proved to increase several hundreds of times with respect to the classical similar devices available on the market.**

Keywords – strain gage, electrospinning, sputtering, characteristics, sensitivity

I. INTRODUCTION

Strain gages are devices for measuring deformation of a surface. Their utility is proved in many applications for measuring directly the deformation of indirectly other quantities like force, weight, vibration, momentum, tilt, pressure, etc. It is well known that, on the market, two types of strain gages are available: metallic strain gages and semiconductive ones [1]. The first type exhibit gage factors GF (relative variation of resistance with respect to elongation) of about 2, whereas the semiconductor gages have the GF of about 200. Other attempts are reported in literature for employing new techniques of manufacturing strain gages using 2D and 3D printing on flexible supports, nanowires, nanoparticles, thin films, etc. [2-4].

In this paper, a new idea and a prototype of a strain gage whose construction is based on electrospinning and thin film (sputtering) technologies are presented. The device behaviour in terms of transfer characteristics when supplied with dc and ac current have been traced and discussed. Some benefits and drawbacks of the proposed method are concluded. Even if the technology is not well defined yet, this may be a good promise for significant improvement in the future of the strain gages performances.

Electrospinning is a technology by which polymeric nanofibres with diameters as small as several tens of nanometers are obtained [5,6]. In principle, a high voltage electrical field is applied between a nozzle and a collector. In this field, a polymeric solution is jetted under pressure through the nozzle, being electrostatically directed and "wiped" towards the collector. In such a way, the drop of polymer is pulverized and transformed in thousands of small fibres that are deposed on the collector surface as a tissue of nanofibres. A schematic of this process is depicted in Fig. 1.

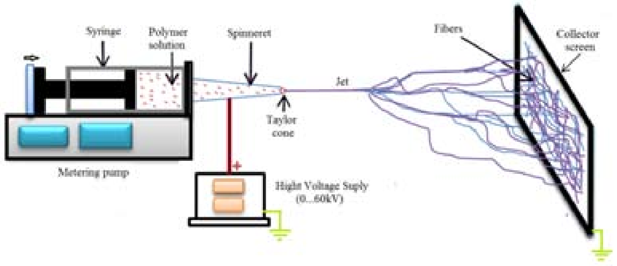


Fig. 1. Schematic of the electrospinning process

Sputtering is a technique for obtaining deposition of thin films on metallic or non-metallic objects [7-9]. This may be accomplished by cathode pulverization with magnetron of by resistive thermal evaporation. In our application we utilized the second method, thermal evaporation. According to this technique, the material is melted by Joule effect in high vacuum (p < $5x10^{-5}$ Torr). In such conditions, the atoms become free to move in the enclosure, depositing on the surfaces as a thin film. The film thickness is measured using a quartz microbalance system, being controlled by several parameters.

II. SENSOR CONSTRUCTION

The sensor construction is described in details in [10] Briefly, it consists of a flexible support of cooper plated textolite on which the metallic contacts have been etched (Fig. 2). On this surface, a layer of about 10 μm of polymeric nanofibres tissue has been first deposited by electrospinning, after which a metallic film of several nanometers has been added by thermal evaporation so that it covers the polymeric fibres on a certain extent, thus obtaining very thin metallic fibres randomly disposed on the surface. The metallic film thickness is strictly controlled so that it covers the nanofibres, and especially the microcontacts between them. In such a way, the Poisson effect occuring in an ordinary strain gage is thousands times amplified by the very small dimension of the wires which form a complex structure of electrical serial-parallel connections.

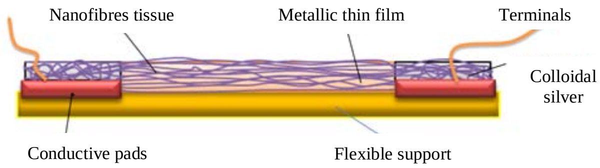


Fig. 2. Illustration of the strain gage construction

Using the above sketched method, the research team developed two types of strain gages which differ by the way the nanofibres tissue has been fabricated. The first method consists in direct deposition of the nanofibres onto the flexible support by electrospinning, after which the fibres metallization was carried up over the open surface (Fig.3). In the second method, the electrospinning deposition was made as a freely suspended tissue on a metallic frame, after which the metallization was performed on both sides of the tissue, as shown in Fig.4. In this case, the metallic film is deposited on both sides of the tissue, thus obtaining a better coverage of the nanofibres surface (Fig. 4). The metallized tissue is then glued on the sensor surface. In both cases, the electrical contacts of the active element with the cooper pads are made using colloidal silver (Fig. 5).

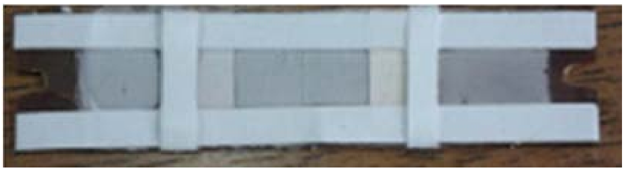


Fig.3. Electrospinning made directly on the textolite support

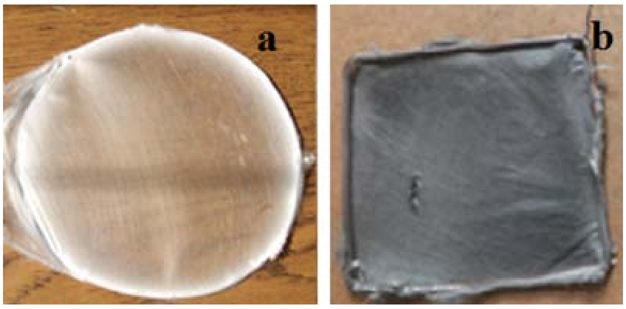


Fig.4. Nanofibres tissue obtained on a freely suspended frame (a – non-metallized and b – metallized)

When the gage is bonded on the surface to be measured, a resistance variation occurs when the surface is deformed because of the Poisson effect happening in the nanofibres surface, exactly like at the classical metallic strain gages, but much amplified because of the big number of wires connected between the electrodes.

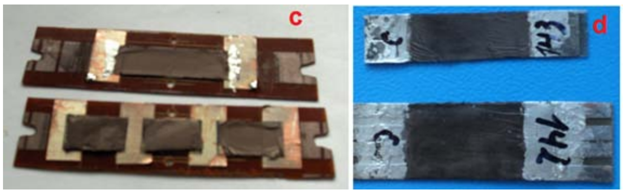


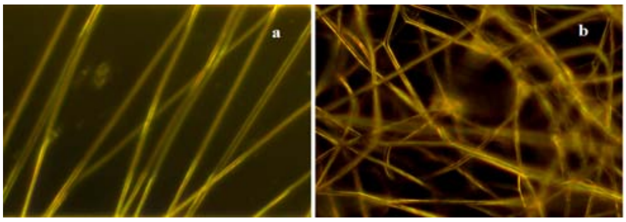
Fig.5. Strain gages obtained using a) the first method and b) the second method

Ideally, this phenomenon should lead to a high increase of the sensor sensitivity and efficiency. In the next sections will show, however, that important impediments and negative influences affect the sensor behaviour, for which mitigation and compensation measures might be taken especially during the manufacturing process in order to make sensor functional.

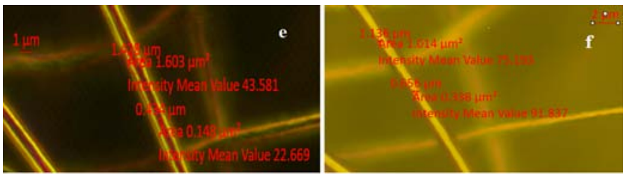
Details regarding the technological parameters utilized when manufacturing the device, together with some practical advices are given in [10].

III. RESULTS AND DISCUSSION

The analysis of the structure and morphology of the microfibres has been performed using a Karl Zeiss AXIO.Lab.A1 microscope. In Fig.6, some pictures of the nanofibres structure are presented.



a) *b)*



c) *d)*

Fig. 6. a) Nanofibres oriented in the space between electrodes, b) Nanofibres random deposited on the pads, c) Nanofibres covered by a 500 nm layer of manganin and d) 250 nm of constantan

We found that the thickness of the metallic film is a very important parameter, as the contact between fibres depends on it. For thicknesses less than 300 nm, the imperfect contacts lead to a very low signal to noise ratio, especially when the sensor is supplied in dc. For thicknesses more than 800 nm, the nanofibres lose their elasticity and microfissures appear on the surface when bending, leading to a large hysteresis of the sensor characteristic. The optimum thickness is comprised between 300 and 800 nm, depending on the metal utilized.

IV. CHARACTERISTICS

An experimental setup sketched in Fig.7 has been utilized for tracing the sensor characteristics.

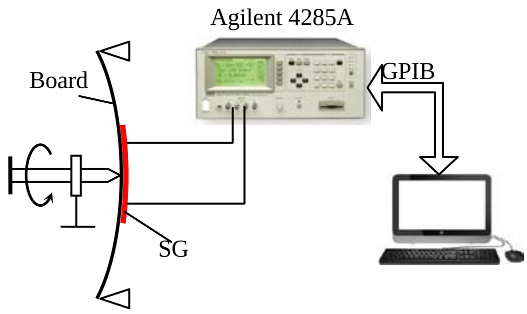
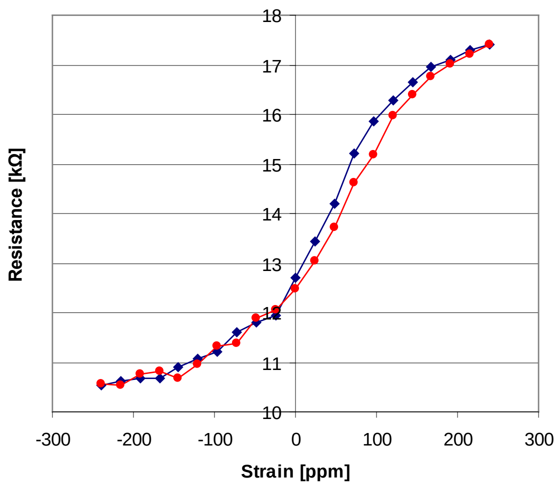


Fig.7. Experimental setup for tracing the sensor characteristics

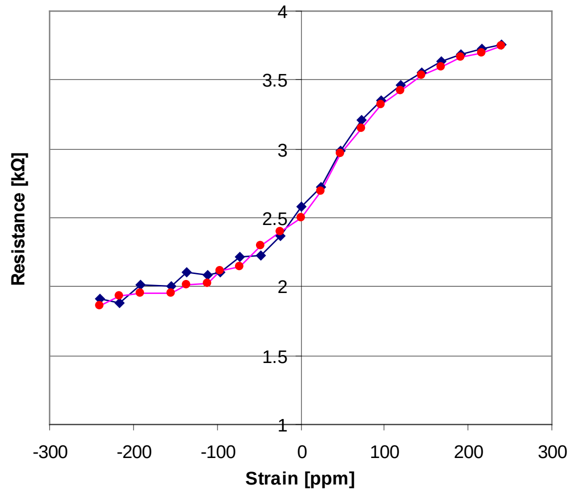
The strain gage is bonded on the flexible surface whose deformation is strictly controlled and known. Experiments were performed when the gage was supplied in dc and ac current. The characteristics R (Z) = f(ε) have been traced when varying the following parameters: nanofibre diameter, tissue density, metallic film thickness, metal type and distance between electrodes. Two types of tests were performed, depending on the current that supplied the sensor: dc and ac.

A. Behaviour in direct current

The sensor has been first supplied in dc and its resistance was measured for different values of currents, comprised between 0.1 and 0.5 mA. Detailed information regarding these characteristics are provided in [10]. Part of them are displayed in Fig.8.



a)



b)

Fig.8. Dependence R(ε) for a strain gage supplied in dc, I = 0.2 mA, having: a) D = 653 nm, ρ = 860 nanofibres/mm3, covered by 130 nm of manganin and b) D = 749 nm, ρ = 1015 nanofibres/mm3, covered by 175 nm of nickel.

Analysing the dc characteristics of the strain sensor, we have drawn the conclusion that the nanofibres diameter and density affect positively the sensor sensitivity but negatively the measurement stability because of the micro-contacts contribution. Also, the metallic layer thickness causes improving stability and signal to noise ratio due to decaying the influence of the micro-contacts, as they became soldered for larger thickness of the metallic film. We also noticed that sensors covered with magnetic metal are more sensitive and also more unstable than those covered with non-magnetic materials, but we think this is not a rule. Increasing the distance between electrodes leads to increasing the value of the resistance.

B. Behaviour in alternative current

In this series if tests, the sensor was supplied with ac currents of different frequencies and intensities and its impedance, *Z*, was measured with respect to the strain *ε* using the same experimental setup. The impedance was measured with an Agilent 4285A automatic bridge. Finally, the gage constant (GC) was calculated in order to draw conclusions regarding the sensor efficiency. To this aim, the following formula was used for calculating *GC*:

$$GC = \frac{\frac{Z_\varepsilon - Z_0}{Z_0}}{\varepsilon[ppm]} 10^6 \qquad (1)$$

where Z_0 and Z_ε are the sensor impedances in relaxed state and after deformation respectively, and *ε* is the strain.

In Fig. 9 the characteristics of a strain gage built using the second method in which the sensitive layer was fabricated separately and bonded onto the sensor surface are presented. The distance between the electrodes was 10 mm, the metal was manganin, the fibres diameter was about 700 nm and the density 970 nanofibres/mm^3.

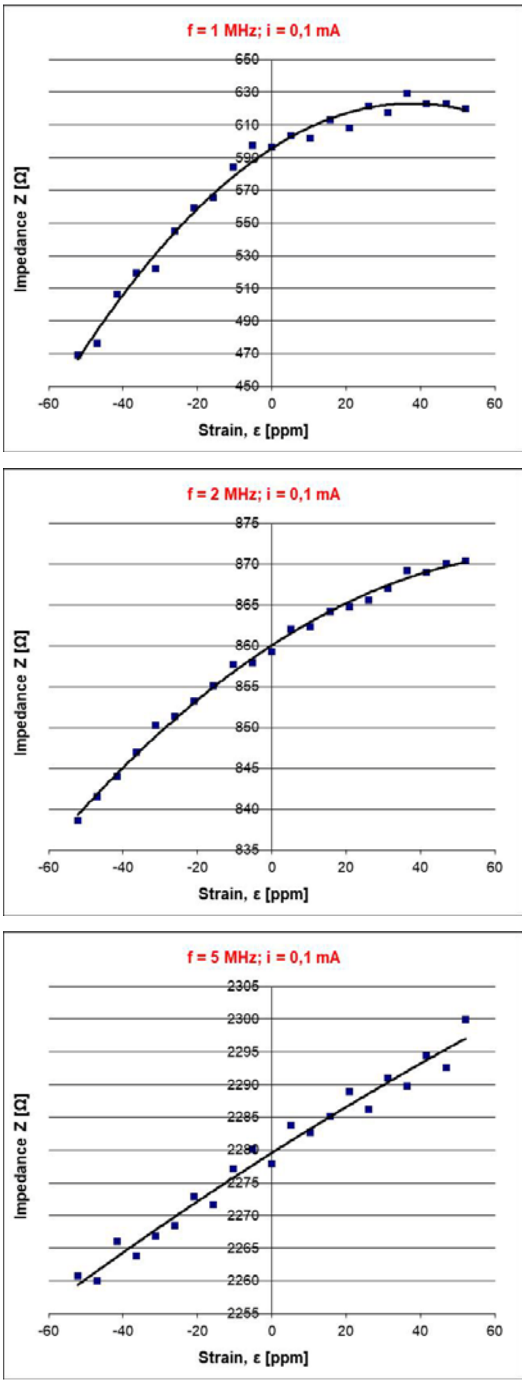


Fig.9. Dependence Z(ε) for a strain gage supplied in ac, i = 0.1 mA, for 3 different frequencies

One may notice from these characteristics that the linearity improves as the frequency increases, with the drawback of a higher dispersion of results. Current intensity does not affect significantly the sensor performances. Fig.10 depicts the variation of GC, also reported to frequency.

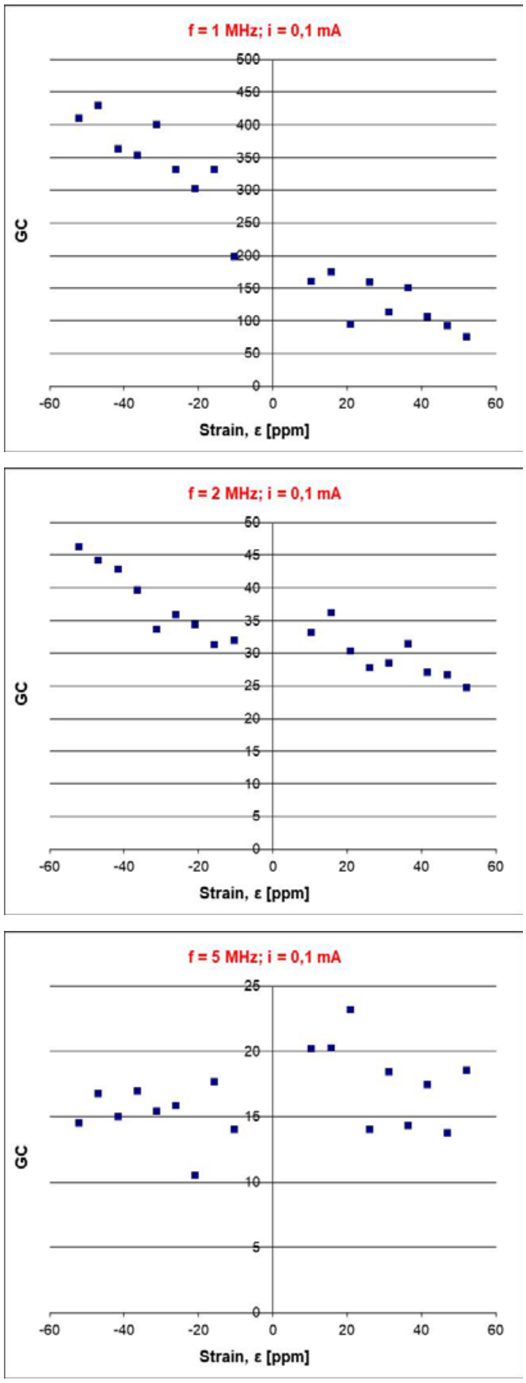


Fig.10. Dependence GC(ε) for a strain gage supplied in ac, i = 0.1 mA, for 3 different frequencies

From the above figures one may deduce that the frequency significantly influence the gage quality, assessed in terms of gage constant. Obviously, this parameter should remain constant over the whole measurement range of the sensor. Though, working at lower frequencies implies a quite linear variation of GC with strain, whereas increasing frequency leads to increasing the dispersion of GC values over the measurement range, but to maintaining them on a more horizontal regression line.

V. CONCLUSIONS

A new possibility of building strain gages based on electrospinning and sputtering technologies is presented in the paper. Several manufacturing attempts reveal the possibility of perfecting the method, as the characteristics traced for the device supplied in dc and ac currents show good promise for improving metrological parameters such as sensitivity and linearity. Further research will be done with the aim of amelioration some severe problems encountered especially related to nanofibres orientation along the gauging direction and to finding the optimal thickness of the metallic film in order to increase the signal to noise ratio.

VI. ACKNOWLEDGMENT

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