Piezoresistive behaviour of polymeric composites and their possible integration in active sensors based on OTFTs

G. Latessa[a)], F. Brunetti[a)], A. Reale[a)], G. Saggio[a)], A.Di Carlo[a)]

E. Tamburri[b)], F. Toschi[b)], V. Sessa[b)], M.L. Terranova[b)]

[a)] *Department of Electronic Engineering, University of Rome "Tor Vergata", via del Politecnico 1, 00133 Rome (Italy)*

[b)] *Dept. of Chemical Sciences and Technologies, University of Rome Tor Vergata, 00133 Rome, Ita*

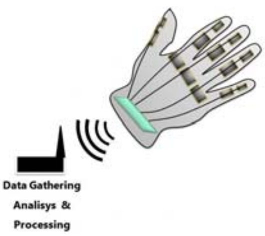
The use of polymeric composites as piezoresistors integrated with organic transistors represents nowadays a challenging field of research. In fact, thanks to their low cost processing and the demonstrated good performances, they can be competitive as "smart sensors" in tanks, pipelines and smart textiles [1].

In this context we focused our attention on the realization of flexible polymeric composites based on carbon nanotubes that could be integrated on a transistor based large area sensor. It has been already demonstrated the piezoresistive behaviour of carbon nanotube materials [2] but the use of polymeric nanocomposites is of particular interest due to the possible integration with polymeric transistors for the realization of strain and pressure sensors [3]. We have developed a method for the synthesis of polymeric nanocomposites based on electropolymerization that allows to include carbon nanotubes inside a polymeric matrix made of PEDOT:PSS. This composite shows a better piezoresistive behaviour compared to the polymeric one due to the presence of carbon nanotubes. This technology was used to pattern our piezoresistive sensors on specific layouts that are compatible with the realization of O-TFT on plastic flexible substrates. The integration of the two structures will give both the sensor and the readout system.

This work is included in an ASI (Italian Space Agency) project, called DCMC (Disturbo Controllo Motorio Cardio-Respiratorio). The goal is the realization of a goniometric glove for hand posture obtained with the vulcanization of the sensors in a textile material that is controlled using a wireless system.

Required characteristics:

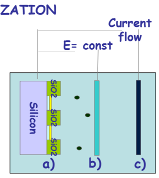
- ✓ The sensors are put on the foremost junctions of the hand
- ✓ The wire-contacts carry the signals until an electrode
- ✓ The signal is processing on a external circuit
- ✓ The relation between the external circuit and the glove is a wireless communication

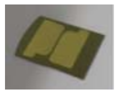


Samples realization

POTENTIOSTATIC SELECTIVE AREA ELECTROPOLYMERIZATION

We grow the polymer using a potentiostatic electropolymerization on a patterned silicon/silicon oxide wafer covered with gold contact. The polymer grows only where are the conductive areas.





Substrate for the polymerization

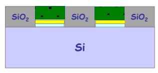
Monomer: EDOT 1mM

Electrolyte: POLY(SODIUM 4-STYRENE SULPHONATE) 2mM

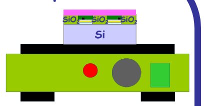
Solvent: CH_3CN/H_2O 1:1

In the case of the CNTs based samples we dissolved in the solution 5mg of nanotubes.

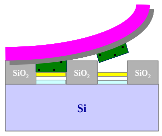
Peeling Technique



1- Substrate with composite



2- Spin coating and annealing of polymeric solution for flexible support

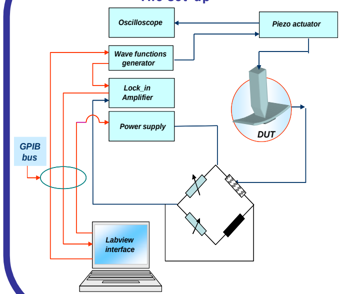


3- Peeling off of the polymide film with the composite

4- Flexible Substrate

Microscopic deformation Measures

The set-up



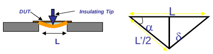
The DUT (Device Under Test) is deformed by an insulating tip that is mechanically controlled by a piezo-actuator. The deformation induces a variation of a resistance in the wheatstone bridge that generates a ΔV. The obtained signal is measured with a lock-in amplifier in order to limit the noise effect.

This set-up allows us to measure the Gauge Factor (GF) that is the ratio between the electrical measurable response (resistance fractional change) and the mechanical interesting quantity (axial strain). This parameter is used for the estimation of the quality of a piezoresistor.

$$GF = \frac{\Delta R / R}{\varepsilon}$$

$$\varepsilon = \frac{\Delta L}{L} = \frac{L' - L}{L} = \frac{2\sqrt{\left(\frac{L}{2}\right)^2 + (\delta)^2} - L}{L}$$

$$\frac{\Delta R}{R} = \frac{\Delta V}{V_{in}} \frac{(1+\beta)^2}{\beta}$$

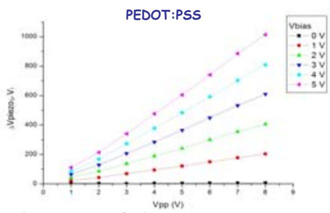


$$\beta \approx 1$$

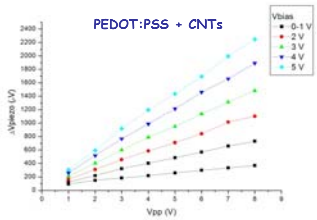
The geometrical deformation is modeled with a triangle. From a trigonometric formula we can obtain the value of ε.

Sensor response

PEDOT:PSS

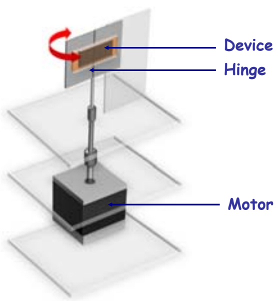


PEDOT:PSS + CNTs

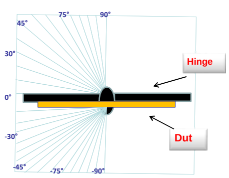


The response of the sensor raises proportionally to applied deformation (V_{pp}) both in the case of PEDOT:PSS and in the case of PEDOT:PSS+CNTs. Increasing the bias of the Wheastone bridge (V_{bias}) the linear behavior of the sensor is maintained Typical measured GF is around 3-14. In the case of CNTs based composite the effect of the deformation is more evident, however, the samples still suffer of a low repeatability due to the difficult dispersion of CNTs in solution.

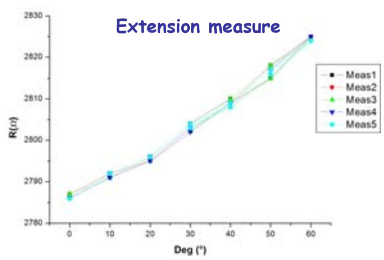
Macroscopic deformation Measures



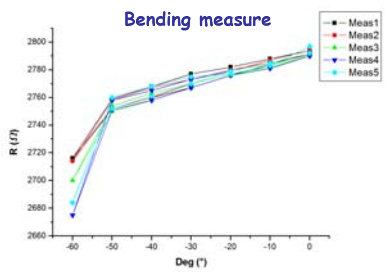
Top View



Extension measure



Bending measure



This set-up consists of an hinge controlled by a step-by-step motor. The sample is mounted on the hinge and can be extended or bent. The movement of the engine is controlled via PC; with a lab-view program we can measure the variation of the resistance in dependence of the macroscopic movement of the sample.

We characterized PEDOT:PSS based samples.

The typical measured resistance without any applied deformation is in the range of 1-15 Ω.

The effect of the extension on the sample is the increase of the resistance, while the bending induces a decrease. In both measures we obtained a reproducible behavior during repeated measures; negligible hysteresis is observed.

Conclusions

In this work we focused the attention on the study of the piezoresistive behavior of films of polymeric composites (PEDOT:PSS and PEDOT:PSS+CNTs) for the realization of a goniometric glove.

On those samples we evaluated both the effect of microscopic and macroscopic deformation. In the case of microscopic bending we found that the use of CNTs improves the performances of the piezoresistor. For the macroscopic deformation we studied both the effect of the extension and the bending of the samples. We obtained a reproducible response during repeated measures and the samples showed an opposite behavior in dependence of the applied deformation.

Since the used technique is compatible with the technology for the realization of O-TFT on plastic flexible substrates [4], this is a preliminary step for the realization of an integrated sensor with the readout system.

References

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[3]F.Brunetti et al., Nanotechnoloy II ed. P. Lugli, L.B. Kish, J. Mateos - SPIE 2005, vol 5838 77-84
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Contact:: giuseppe.latessa@uniroma2.it

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