

EUROSENSORS 2015

Capacitive strain sensors inkjet-printed on PET fibers for
integration in industrial textileA. Vásquez Quintero^a, M. Camara^{a*}, G. Mattana^a, W. Gaschler^b, P. Chabreck^b,
D. Briand^a, N.F. de Rooij^a^a*Ecole Polytechnique Fédérale de Lausanne (EPFL), Institute of Microengineering (IMT), Sensors, Actuators and Microsystems Laboratory (SAMLAB), Rue de la Maladière 71b, 2000 Neuchâtel, Switzerland*^b*SEFAR AG, Töberstrasse 4, 9425 Thal, Switzerland*

Abstract

We report on printed strain sensors on several meters long PET fibers for integration in textile at large scale. The sensors are made by locally inkjet printing capacitive transducers on cylindrical PET fibers used in industrial textiles. Sensor measurements were performed for strains up to 1%. 10 meters long functionalized PET fibers were woven with metallic interconnect fibers using large scale industrial weaving machine and resulted in a 1 m² smart textile demonstrator. Applications are foreseen in predictive maintenance of industrial textiles and in the automotive industry.

© 2015 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the organizing committee of EUROSENSORS 2015

Keywords: Capacitive sensor, Strain sensor, Smart textile, Inkjet printing, Fibers

1. Introduction

The integration of sensors into fabrics based on standard cleanroom processing of devices onto polyimide flat stripes was previously demonstrated [1]. Integration was performed on small area due to the production of the stripes limited to the size of silicon wafers. We have also reported on the weaving of printed sensors compatible with large area manufacturing [2]. However, flat stripes have shown to be problematic for weaving in comparison to the use of cylindrical fibers. Here we report on the use of inkjet printing to functionalize locally cylindrical long textile fibers for large area manufacturing of textile.

* Corresponding author. Tel.: +41 21 695 45 76
E-mail address: malick.camara@epfl.ch

2. Design and Fabrication

Capacitive strain sensors were designed on PET fibers ($\phi=50$ to $200\ \mu\text{m}$) based on a model developed in Matlab to predict capacitance values and especially response to strain. The sensor consists in a stack configuration made of inkjet printed silver electrodes (sub- μm in thickness) with in-between a Parylene layer ($2\ \mu\text{m}$ -thick) used as dielectric. Sensors fabrication on 10 m long PET fibers is shown in Figure 1.

Fibers were covered with silver using inkjet printing on both sides of the fiber to cover the whole circumference (Fig. 2). After the thermal annealing of the ink, Parylene was deposited on the fiber. A second silver layer was then inkjet printed and sintered to form the stack capacitor. Devices were woven for the first time as shown in Fig. 3 to form a $1\ \text{m}^2$ smart area in which several of these structures can be implemented in an array. For ease of measurement and to limit the influence of parasitic capacitances, sensors were designed with a length of few centimeters to achieve values of tens to some hundreds of pF.

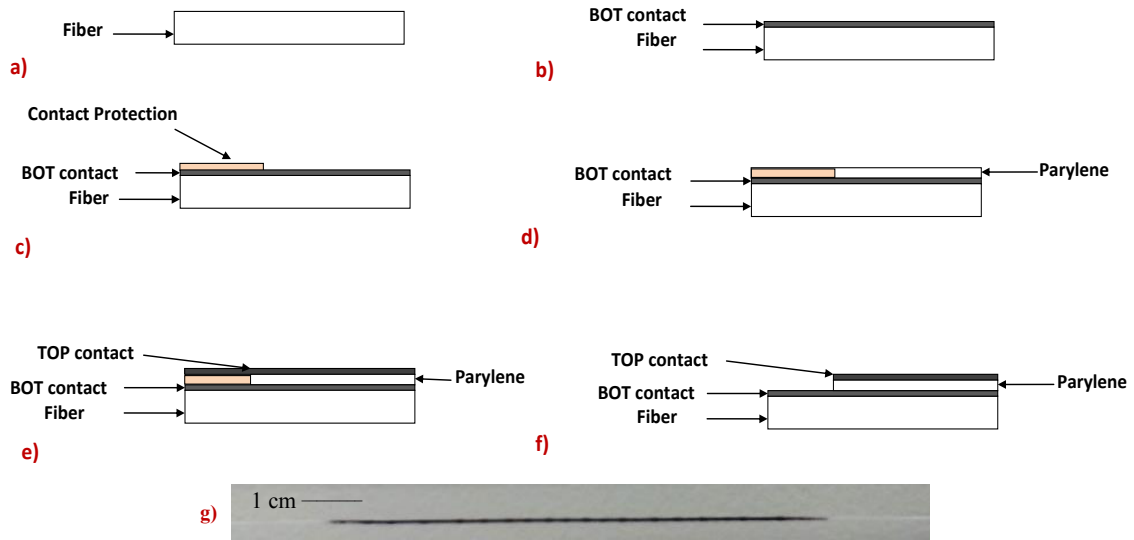


Figure 1: Schematic and process flow of sensor on PET fiber. a) PET fiber; b) Inkjet printing of bottom contact; c) Protection of bottom contact; d) Deposition of parylene; e) Inkjet printing of top contact; f) Removal of contact protection and g) Optical image of a printed sensor on 200µm PET fiber.

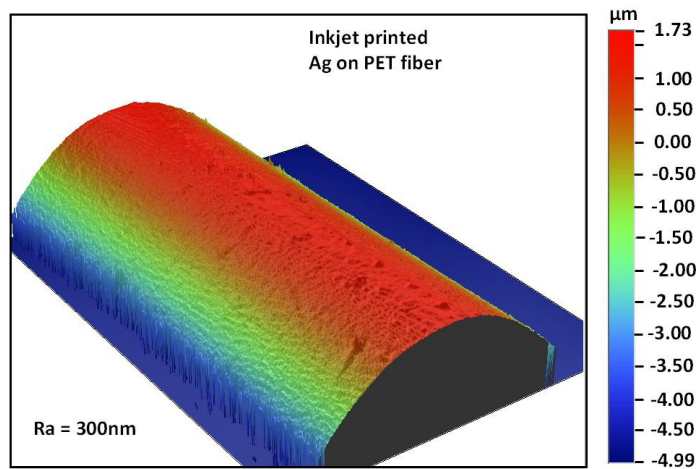


Figure 2: White light interferometer image of the inkjet-printed silver on 200 μm -wide PET fiber.

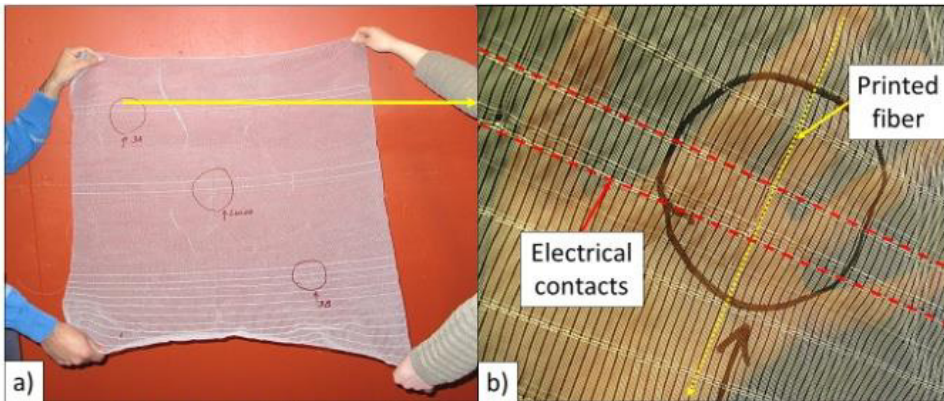


Figure 3: Optical images of a 1x1 m² woven textile using the PET-based fibers, indicating the printed capacitive sensor and the electrical contacts within the textile.

3. Results and discussion

Following the fabrication, the sensors were firmly attached to a pull-tester Instron 4400 in order to perform the electro-mechanical characterization. The PET fiber changes its dimensions as it is pulled which in turn changes the capacitance value of the sensors. The pull test involved a maximum strain of 1% ($\Delta L/L_0$) at a rate of 0.2 mm/min, which was below the plastic deformation region of the PET fiber (plastic deformation was found to appear at 2 % of strain). The applied force as well as the capacitance of the sensor was monitored and registered with the pull-tester dedicated software (i.e. Bluehill 3) and the LCR meter E4980A from Agilent, respectively. Figure 4 shows the change in capacitance versus applied strain (black triangles), and the resultant stress in the fiber (red squares). The linearity of the stress/strain curve corroborates the elastic region of the polymeric structure, with a maximum value of 40 MPa at 1 % of strain. The capacitance change depicts a maximum value of 0.7 % at 1 % of strain. The dynamic measurement of one strain cycle is presented in figure 5, with capacitance values ranging in the 60 pF.

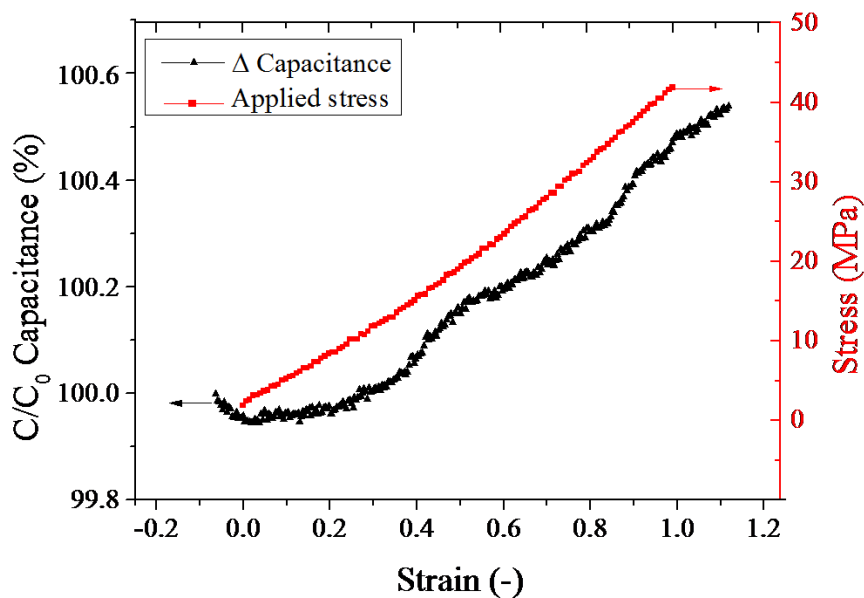


Figure 4: Response of a printed capacitive sensor on PET fiber up to 1% of strain and comparison with the modelling results.

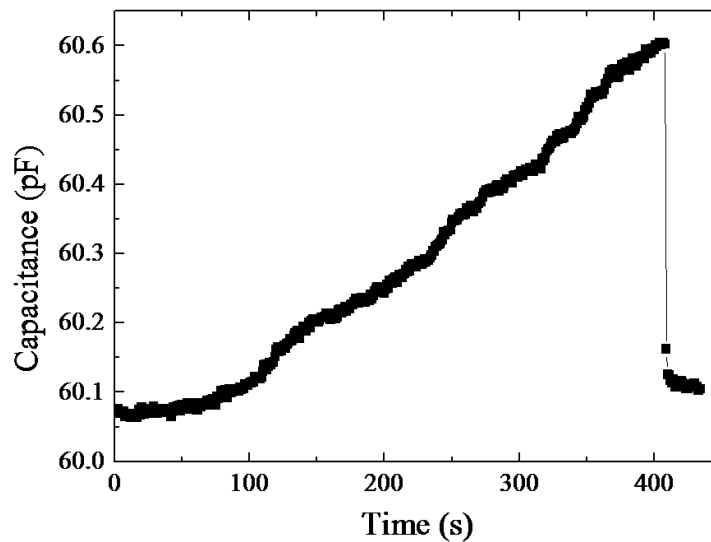


Figure 5: Dynamic capacitance measurements of the printed devices on PET fibers following 1 tensile cycle up to 1% of strain.

4. Conclusion

We are now investigating the maximum strain that could be reached before attaining an irreversible plastic deformation of the PET fiber as well as the cross-sensitivity to bending and humidity. The optimization of the weaving process and the functionalization of fibers are also under consideration for improving the robustness of sensoric textile manufacturing. The process could be extended to the fabrication of other capacitive (humidity, vapour) sensors as well to the fabrication of other electronic components (resistors and transistors).

References

- [1] C. Ataman, T. Kinkeldei, G. Mattana, A. Vasquez Quintero, F. Molina-Lopez, J. Courbat, K. Cherenack, D. Briand, G. Tröster, N. F. de Rooij, A robust platform for textile integrated gas sensors, *Sensors and Actuators*, B177 (2013) 1053-1061.
- [2] G. Mattana, T. Kinkeldei, D. Leuenberger, C. Ataman, J. J. Ruan, F. Molina-Lopez, A. Vásquez Quintero, G. Nisato, G. Tröster, D. Briand, N. F. de Rooij, Woven temperature and humidity sensors on flexible plastic substrates for E-textile applications. *IEEE Sens. J.* 13 (2013) 3901-3909.