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Inkjet Printed Flexible Piezoelectric Sensor for Large Strain Applications

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Summary:

In this work, we design, fabricate and experimentally characterize a fully inkjet-printed piezoelectric sensor tailored for applications requiring significant deformations. In particular, inkjet-printed silver layers constitute the top and bottom electrodes, while a P(VDF-TrFE) layer is employed as active material. Cycling loading tests consisting in a controlled bending of the sensor in the range 0°- 90° are finally performed and an output signal of 0.5 V is measured, thus demonstrating the correct functioning of the sensor and the reliability of the proposed manufacturing process.

Keywords: inkjet printing, piezoelectric, flexible sensor

Introduction

Flexible piezoelectric sensors represent a particularly challenging yet extremely useful family of sensors, with a wide range of applications. For example, they can be employed to give a proprioceptive perception to passive structures, such as robotic joints or structural components, as well as many other structures of different sizes. In this context, piezopolymer-based devices are conquering more and more the smart devices scene due to their high flexibility, biocompatibility, low weight, ease of processing and high sensitivity [1]. From the fabrication point of view, Additive Manufacturing (AM) techniques can be considered as a promising solution for the on-demand production of the next-generation of these devices. In particular, Inkjet printing (IJP) is highly attractive thanks to its capability to pattern in a costless and fast way, to its scalability and to its compatibility with the materials employed in piezopolymer-based sensors manufacturing [2].

The present experimental study focuses on the design, fabrication, and preliminary testing of a fully inkjet-printed piezoelectric sensor tailored for applications requiring significant deformations. The innovation lies both in the use of a unique combination of materials and in the use of IJP for their deposition. The findings highlight the potential of this novel materials combination and manufacturing approach for the creation of highly sensitive piezoelectric sensors suited for large-strain scenarios and adaptable to various requirements.

Sensor production

The sensor design incorporates two electrodes, top and bottom, with a P(VDF-TrFE) active layer in between. A Polyimide (PI) sheet was used as substrate (see Fig. 1.I). On its surface, the bottom electrode was inkjet-printed using a commercial silver (Ag) nanoparticles dispersion (see Fig. 1.II). Then, the active layer was printed (see Fig. 1.III) using a customized solution of 0.7 % wt. P(VDF-TrFE) dissolved in a 70/30 % wt. mixture of dimethyl sulfoxide (DMSO) / methyl ethyl ketone (MEK). Finally, the top Ag layer was printed analogously to the bottom electrode (see Fig. 1.IV). Each layer underwent annealing and plasma treatment was applied to enhance the surface compatibility of the layers.

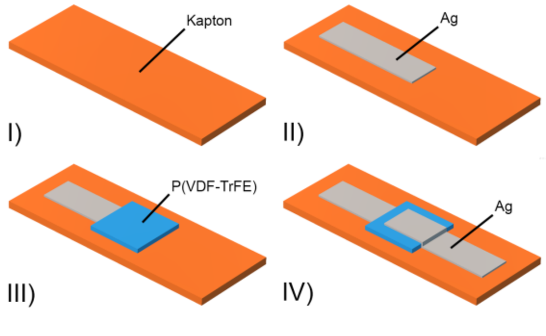

Fig. 1. Piezoelectric sensor fabrication process

Results

Figure 2 shows the SEM cross section of the printed layers constituting the sensor. The thickness of the Ag layers was around 1.4 µm, while for the P(VDF-TrFE) layer it was 2.5 µm.

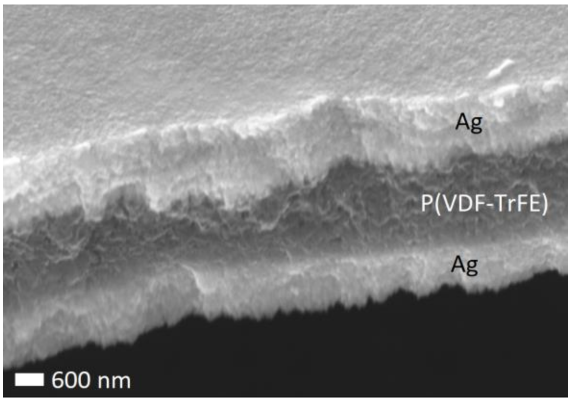

Fig. 2. SEM section of the inkjet printed layers.

The three layers looked compact, continuous and adherent. Bending tests at different radii of curvature were conducted in both concave and convex modes to evaluate the surface compatibility and adhesion of the different layers. As a result, no mechanical delamination or resistance variation were observed at radii ≥ 1 cm. In addition, the sensor was abruptly folded at 180° to verify its adhesion to the PI substrate under extreme conditions. This time micro-cracks were observed on the surface of the electrode, but mechanical delamination was again not observed and the layers maintained their properties. The electro-mechanical response of the proposed sensor was evaluated. Prior to the test, the active material was poled at an applied DC voltage of 40 V for 35 minutes at 80 °C [3]. Then, the sensor was mounted in an Arduino driven setup able to bend it in a controlled way. Figure 3 shows the result obtained applying 10 bending cycles up to 90° at 400 cycles/hour.

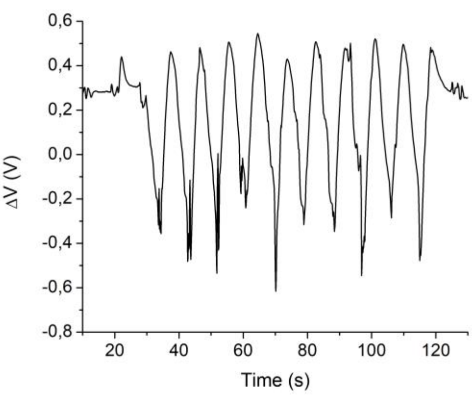

Fig. 3. Electro-mechanical response of the sensor (10 cycles, speed = 400 cycles/hour).

Regardless of the number of cycles applied, the waves roughly maintained the same shape. This is particularly relevant and important because it proves the repeatability of the signal even after a consistent number of cycles and at different bending speeds, confirming the results observed in literature [4]. All the obtained waves have indeed the same amplitude of about 0.5 V, and the signal comes back to the initial offset value when the machine is stopped. The flat position is also recovered after the last loading cycle, demonstrating the reliability of the device. The signal trend exhibits irregularities at the maximum bending angle, probably because of the non-linear behavior of P(VDF-TrFE) at large deformations.

Conclusions

The silver layers and the P(VDF-TrFE) active layers were successfully printed one on top of the others. The outstanding adhesion and mechanical properties of the printed bottom electrode were demonstrated by the controlled bending tests and the morphological analysis conducted afterward. By poling the devices, we confirmed the poling electric field value of 20 V/µm reported in literature also for the DMSO/MEK at 70/30 % wt. and P(VDF-TrFE) at 0.7 % wt. solution. The sensor was bent cyclically in a controlled way from 0° to 90°. The output signal showed a maximum amplitude of 0.5 V, with the waves of the single sensor maintaining the same shape after each cycle.

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