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Enhanced printed temperature sensors on flexible substrate

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ABSTRACT

In this paper we present the development of enhanced printed temperature sensors on large area flexible substrates. The process flow is a fully screen printed technology that uses exclusively solution-processed materials. These Screen printed temperature sensors are based on resistive pastes integrated in a Wheatstone bridge circuit. Substrate is a commercial Poly Ethylene Naphtalate (PEN) with a thickness of 125 μm. Functional temperature sensors are demonstrated and characterized with good electrical properties, showing a good sensitivity of 0.06 V/°C at V_{in}=4.8 V. This sensitivity is enhanced by the annealing and the O_2 plasma treatment. Based on this temperature sensor, we have developed a demonstrator for human body temperature detection.

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1. Introduction

Recently, many developments in the field of organic components have emerged; in particular, the realization of organic thin film transistors (OTFT) on flexible substrates [1,2]. Also, many studies on the development of passive components and sensors have been published [3,4]. Nevertheless the materials used in this type of devices must be stable and have to be studied deeply, in order to understand them, and to enhance the passive components such as sensors. Moreover, the integration of these materials on flexible substrates is sometimes complicated due to the low glass transition temperature (T_g) of the substrate materials such as Polyethylene Naphtalate (PEN) and Polyethylene Terephtalate (PET). Despite these limitations, these two substrates have been widely used for the development of organic technologies because of their favorable mechanical properties [5]. This paper details the process fabrication and characterization of printed temperature sensors. In literature, many studies on temperature sensors used as electronic skin, biomedical thermal imaging and structural temperature monitoring have been reported [6], but there are very few papers on printed temperature sensors on plastic substrates. In this work, we talk about the physical principles of resistive temperature sensors in order to ease their integration into a sensor array. The behavior of our specific inks have also been characterized in order to integrate them into an optimized circuit for temperature detection; finally, we report as well the layout of printed temperature sensors for process fabrication, their characterization results and integration in a demonstrator.

2. Technology and integration

2.1. Design and process fabrication

We fabricated our temperature sensors by screen printing techniques of two different sensitive pastes: Positive Temperature Coefficient (PTC) and Negative Temperature Coefficient (NTC) inks on PEN and/or PET substrates. These two printed pastes could either be used as a simple resistive sensor [7], or be integrated into a Wheatstone bridge to achieve a higher sensitivity [8]. The substrate of choice was PEN TEOENX Q65FA from Dupont teijin with a smooth surface. A thin layer (30 nm thick) of gold is sputtered and then etched to define electrical connections. The first sensitive PTC layer is deposited by screen printing with a thickness of 8 μm and is then annealed at 130 °C for 30 min. The second sensitive NTC layer, which is a metallic oxide based on antimony tin oxide (ATO), is also printed and then cured at 130 °C for 30 min. The final thickness of the layer is 10 μm. Then, we make an oxygen O_2 plasma treatment (power = 120 W, O_2 flow = 50 sccm) for 1 min. This treatment enhances in our case the Temperature Coefficient of Resistance (TCR) of the Antimony tin oxide (ATO), which is necessary to have a high sensitivity. The final process step consists of the deposition of a dielectric

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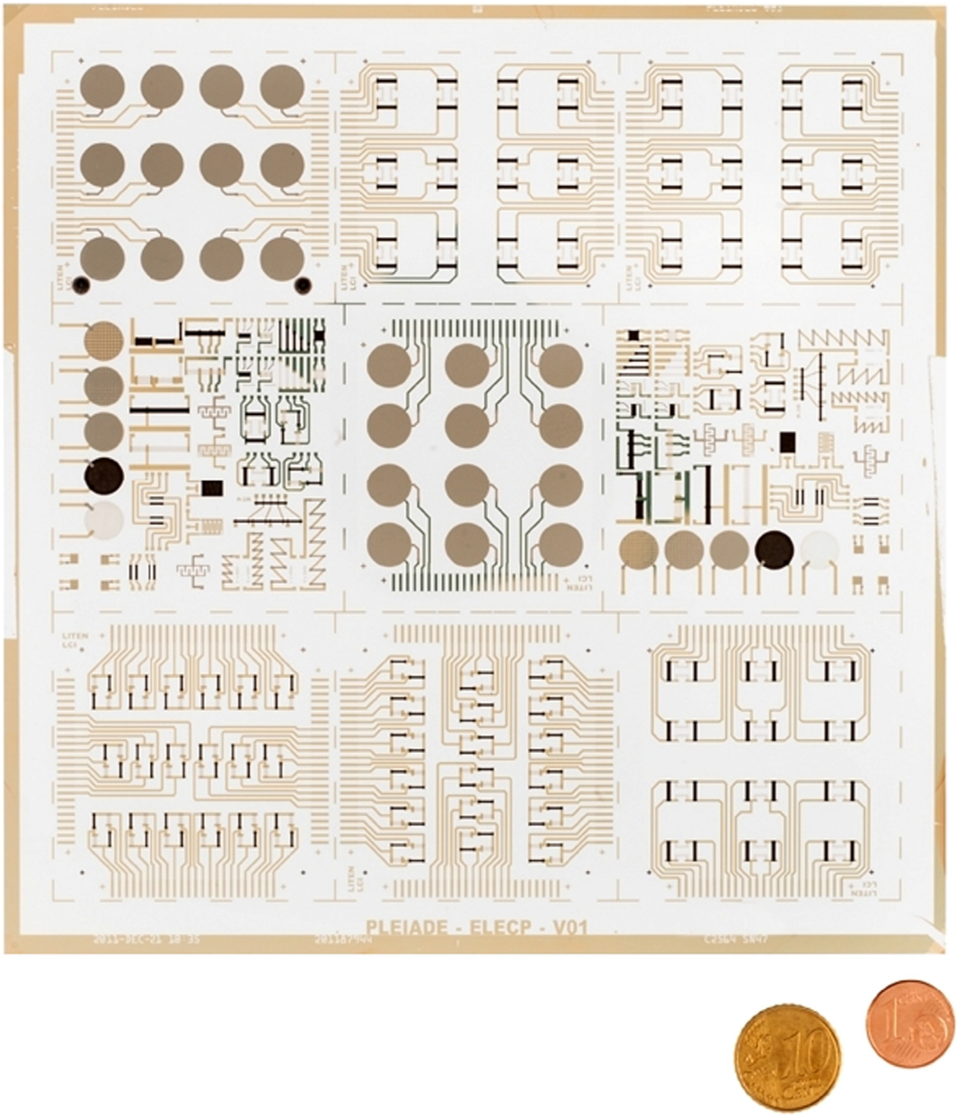

Fig. 1. Image of printed sensors on 15 cm × 15 cm PEN foil

passivation layer (CYTOP like fluropolymer) by screen printing, which is then cured at 100 °C for 20 min. This fluoropolymer is hydrophobic to prevent from humidity and to give more stable and reliable sensors. Its thickness was between 1 and 2 µm. Different test structures and designs have been laid out for standard electrical test and temperature sensor measurements. Fig. 1 shows fabricated sensors on 15 cm × 15 cm PEN substrate.

2.2. Characterization of the sensitive inks

In order to define the process flow of our printed temperature sensors on PEN substrate, we initially characterized by thermogravimetric analysis (TGA) both PTC and NTC pastes to determine their solvents boiling point and their maximum temperature before degradation. TGA tests are done under nitrogen gas with a rate of 10 °C/min for the temperature. Fig. 2a shows the TGA curve of the NTC paste: one can show that the solvent vanishes around a temperature of 180 °C which correspond to 56% of the total weight. The NTC paste starts to degrade around 329 °C. Fig. 2b presents the TGA curve of the PTC ink: complete evaporation of the solvent occurs at 232 °C which correspond to 62% of the total weight. The degradation of this ink is observed between 351 °C and 461 °C which correspond to a 13% of the total weight.

2.3. Single temperature sensor structure and characteristics

To achieve a high sensitivity, the PTC and NTC inks have been integrated in the Wheatstone bridge circuit. These inks have a temperature coefficient of resistance (TCR) of 0.05 °C^{-1} and 0.006 °C^{-1} respectively for PTC and NTC resistive pastes in the temperature range of 20–80 °C. The Wheatstone bridge temperature sensor is supplied with V_{in}=4.8 V. The output voltage (V_{out}) of the sensor was then measured in the temperature range of 20–80 °C. Fig. 3 depicts the schematics (a), lay-out (b) and a photography of the printed temperature sensor (c).

The output voltage ($V_{out}=V_G$) and the sensitivity ($S=dV_{\mathrm{out}}/dT$) of this temperature sensor are given by the formula (1) and (2) respectively [9]:

$$V_{out}=V_{in}\times\left|\left(\frac{n\times[R_{NTC0}-R_{NTC1}\times T]-p\times\left[R_{PTC0}+(R_{PTC1})\times e^{\left(\frac{T}{K}\right)}\right]}{n\times[R_{NTC0}-R_{NTC1}\times T]+p\times\left[R_{PTC0}+(R_{PTC1})\times e^{\left(\frac{T}{K}\right)}\right]}\right)\right| \quad (1)$$

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