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An Inkjet Printed CO2 Gas Sensor

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Abstract

In this paper a low cost CO2 sensor realized on a plastic substrate is presented. The sensor is realized by the deposition of a double layer of PEDOT/PSS (CLEVIOS™ PHCV4, by H.C.Starck) and Graphene on InterDigiTed electrodes printed onto a PET (PolyEthylene Terephthalate) substrate. The InterDigiTed electrodes have been realized by inkjet printing a conductive pattern of a silver nano-particle solution (Metalon® JS-B15P by Novacentrix), through a commercial EPSON® inkjet printer. The sensing principle of the sensor exploits the change in electrical conductivity of graphene due to gas molecules adsorbtion. A device responsivity, at 30°C, of 45µOhm/ppm and a sensitivity of 100 ppm have been obtained respectively. Compared to solutions proposed in the literature, the inkjet printed device here presented has advantages related to its low cost, flexibility and low demanding fabrication. The device flexibility is crucial for application requiring the device shaping to irregular surfaces, such as dresses or food packaging.

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Keywords: Inkjet printing; Gas sensor, PEDOT/PSS; Graphene; Interdigited electrodes; PET;

1. Introduction

The development of low cost sensors for Carbon dioxide (CO2) is becoming mandatory for applications in several fields from greenhouse and agricultural to exhalations monitoring.

Recently, conductive polymers and graphene have attracted attention of scientists and engineers due to their properties. In particular, poly(3,4-ethylenedioxythiophene)poly(styrenesulfonate) (PEDOT/PSS) is one of the most

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promising conductive polymers because it has water-dispersibility, good conductivity and excellent processability, while graphene, due to its two dimensional sp2-bonded structure, shows exceptional thermal, mechanical and electrical properties [1, 2].

The study of CO2 gas sensing properties of SnO2/PPy multilayer sensor, prepared by screen-printing method on Al2O3 layer followed by glass substrate is proposed in [3].

The features of a CO2 gas sensor fabricated from a graphene sheet by mechanical cleavage are discussed in [4].

Reduced graphene oxide (rGO) has a lot of potential as a platform for many applications such as gas sensing, transparent conducting electrodes, ultracapacitors and thin film transistors. The development of a carbon dioxide gas sensor from the room-temperature reduction of graphene oxide via hydrogen plasma is presented in [5].

In the last years the scientific community focused on the development of low-cost electronics and sensors by the use of graphic industry processes which exploit innovative materials and flexible substrates. Compared to traditional silicon electronics, printed devices are really cheap and can addresses a wide set of applications requiring low cost and disposable devices [6]. Main techniques for the realization of printed sensors are screen printing and inkjet printing. Screen Printing is based on deposition of thick film of material by the use of a mask based process. Main drawbacks of screen printing are related to the use of masks and waste of materials. Conversely, inkjet printing is a contactless technique which allows for the real rapid prototyping of electronic component with particular regards to sensors. Interesting advantages of inkjet technologies reside in the direct printing feature, high spatial resolution and compatibility with many substrates. Among materials compatible with inkjet printing technology polymers like PEDOT-PSS (3, 4-ethylen dioxythiophene) and PANI (Polyaniline) and conductive silver nanoparticles are widely used. Commercial printers for inkjet process are typically based on piezoelectric heads which allow for the deposition of functional and structural materials with resolutions in the order of the tens of micrometers [7, 8]. Example of devices developed by expensive professional inkjet printers are passive microstructures [9], biosensors for glucose on carbon electrodes [10], RFID tag and antennas [11-13], resistive humidity sensor on paper [14]. The combination of conducting and functional polymers has been proposed as a convenient solution to realize inkjet printed sensors [15]. Metal inks in combination with low cost printers have been successfully used for the rapid prototyping of sensors and conductive patterns [8, 16, 17, 18]. Hybrid solutions, where screen printing and inkjet technologies are used to realize electrodes and functional layers, respectively, are available in literature [19-21].

This paper focuses on the development and the characterization of a printed CO2 sensor, which exploits the synergistic effect of two polymeric layers, PEDOT/PSS and graphene, deposited on inkjet printed electrodes.

The main outcome of the proposed solution is related to its low cost, conferred by the adopted technology to realize both the electrodes and the functional layer. Actually, the inkjet printing technology adopted for the realization of the sensor complies with the disposable features required by many application contexts. Moreover, it must be taken into account that such technology allows for the rapid prototyping of cheap devices on flexible substrates which can be properly designed with different shapes.

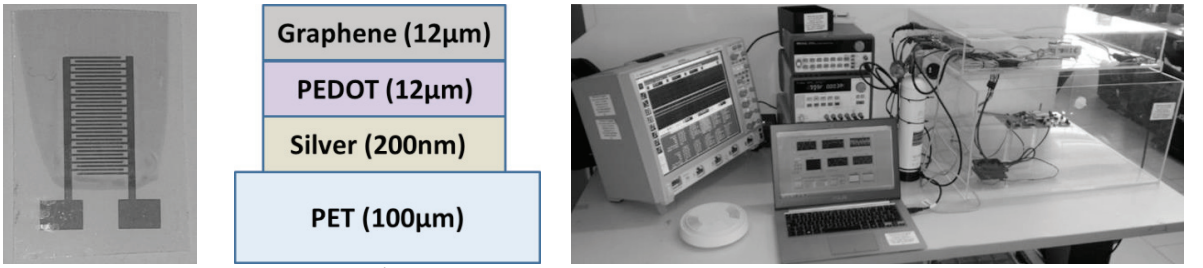
2. The developed sensor

The device consists of a PET substrate, where a IDT structure has been realized by a low cost inkjet printer and a silver nanoparticle based ink (Metalon® JS-015 by NovaCentrix). An ink of PEDOT/PSS (commercially available as an aqueous dispersion, CLEVIOS™ PHCV4, by H.C.Starck), prepared diluting the starting solution with distilled water (1:1, v/v), has been deposited, by a calibrated spreader (12μm), onto a silver electrode and heated at 80°C for 50 minutes. Successively, another layer (12μm) of a solution obtained dispersing graphene in water (by the use of sonication followed by centrifugation) has been deposited, over the PEDOT/PSS layer. Finally a new heating process at 80°C has been performed.

The working principle of the sensor exploits the changes on the electrical conductance of the graphene layer due to the adsorption of gas molecules on its surface detection. These molecules act as donors or acceptors thus leading to a conductance variation. The resistive output of the sensor is then conditioned by a traditional bridge configuration.

Since the sensor operation requires consecutive heating cycles, a heater was placed under the substrate, while a Pt100 sensor was used to measure the substrate temperature.

A real view of the sensor developed is shown in Fig. 1a, while the stack structure of the device is given in Fig. 1b.



a b c

Fig. 1. a) The real view of the sensor. Device dimensions: 1.8 cm by 1 cm with a thickness of about 140 µm. IDT fingers: width (200 µm), length (6 mm), thickness (200 nm), track spacing (350 µm); b) Schematization of the sensor structure; c) The experimental setup for the device characterization.

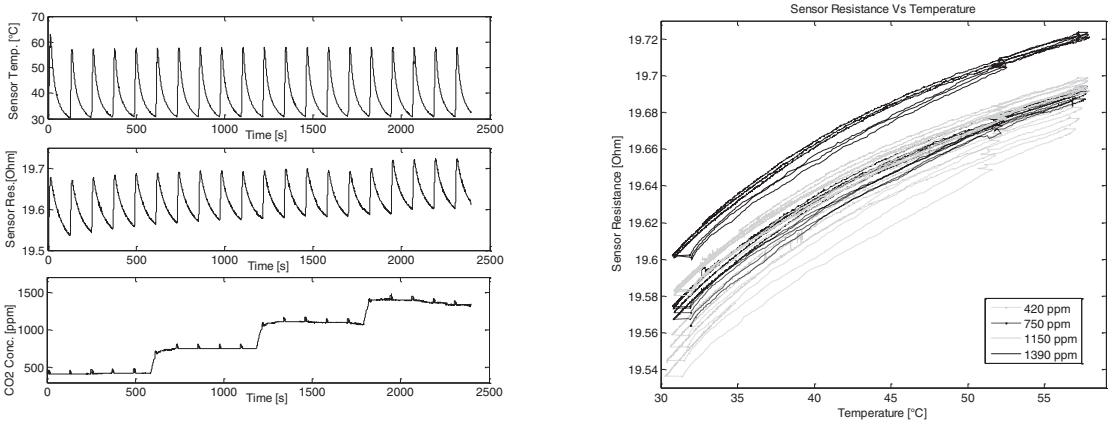
The experimental set-up adopted for the sake of the device characterization is shown in Fig. 1c. The system consists of a insulated chamber where a flow of CO2 can be injected. The gas injection system is equipped with flowmeters and electrically controlled valves, managed by a dedicated tool developed in LabVIEW. The reference sensor CDM4161A, a compact and low-power consumption device (300 mW) with an operating range of (400 - 4000) ppm, was used to perform an independent measurement of the CO2 concentration inside the chamber. Moreover, a data acquisition system is used to acquire signals provided by the reference sensors and the printed sensor under test.

3. Experimental results and conclusions

Before each experiment, the chamber was flushed with clean air to reduce the CO2 concentration to typical environmental values (400 ppm). After five heating cycles at room gas concentration, controlled quantities of CO2 have been forced inside the chamber up to 1390 ppm. Five heating cycles have been performed after each gas injection.

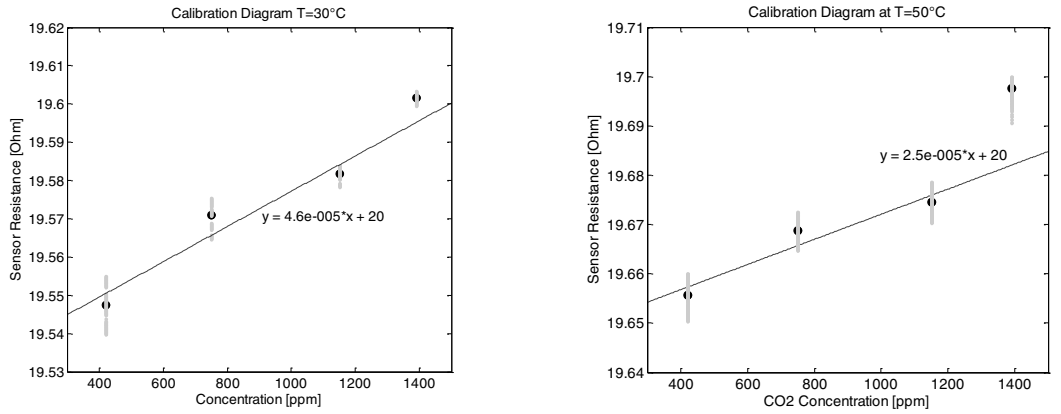
Fig. 2a shows the time domain response of the sensor while Fig. 2b shows the sensor behavior as a function of the heating temperature for increasing values of the gas concentration inside the chamber. The sensor response, for the two operating temperatures of 30°C and 50°C, are shown in Fig. 3a and Fig. 3b respectively.

The experimental results obtained demonstrate the functionality of the proposed sensor and encourage the development of CO2 sensors exploiting the suggested sensing strategy. Future efforts will be dedicated to the device modeling and the development of further investigations.



(a) (b)

Fig. 2. (a) The time domain response of the inkjet printed sensor, the operating temperature and the reference sensors. (b) The sensor behaviour as a function of the heating temperatures for different concentration of CO2.



(a) (b)

Fig. 3. The sensor response for two operating temperatures: (a) 30 °C and (b) 50 °C

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