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Low temperature gas sensing applications using copier grade transparency sheets as substrates

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ABSTRACT

Transparency sheets, coated with copper on both sides by means of thermal evaporation in vacuum, are patterned by direct chemical etching to realize sensing platforms having copper heaters on the backside, and resistances having calibrated temperature coefficient on the topside. The mechanical and thermal stability of these structures was demonstrated up to 70 °C. Bending tests also show that the metallic patterns do maintain unaltered performances after more than 10^4 bending cycles. Resistance measurements show that the resistance on the patterned copper structures linearly increases with the temperature in the range between room temperature and 70 °C, while above this temperature an irreversible damage occurs. Experimental investigations demonstrate that the heaters on the backside of the sensing platforms allow to obtain a quite uniform temperature distribution on the top side over an area larger than 1 cm^2.

Coating the flexible sensing platform by doped polyaniline and carbon nanotubes embedded in a polymer host, a chemoresistive system operating at low temperature is developed, which allows to perform tests at constant temperature, with the temperature being set and monitored by using the heater and the patterned resistance, respectively. The sensing performances of the films are evaluated by means of electrical measurements performed while exposing the samples to different relative humidity levels, and to calibrate ammonia pulses.

1. Introduction

During the last few years the rapid expansion experienced by flexible electronics and the unprecedented progresses in materials science have stimulated an increasing research activity focused on the development of novel electronic devices that, compared to the conventional ones, have simplified design, environmentally friendly processing, and inexpensive manufacturing [1,2]. The sensor field has taken advantage of the emerging technologies and materials, as it is evidenced by the advances in applications going from wearable healthcare devices [3] to flexible tactile sensors to be used as artificial skin in robotics [4].

Among the possible benefits of flexible electronics, conventional chemoresistive gas sensors, usually consisting of metal oxide layers deposited on alumina or silicon rigid substrates, can be replaced by lighter and cheaper flexible sensors. Recently, compact, lightweight and low power consumption sensing platforms have been developed by integrating miniaturised capacitive sensors and metal oxides gas sensors on polyimide flexible substrates, equipped with platinum heaters and temperature sensors [5–7]. The processing technologies used to develop the polyimide sensing platforms require a number of steps including the deposition of layers to promote the adhesion of metal coatings to the plastic substrates, and a number of electron beam metallization followed by lift off. Embedded metallic heaters are developed by spin-coating a layer of soluble polyimide precursor on the top of platinum patterns applied onto the polyimide substrate. The integrated heaters allow the plastic platforms to reach the working temperature of metal oxides, typically higher than 300 °C. However, it is worth mentioning that a number of sensing materials including nanostructured metal oxides [8], conjugated polymers [9], hybrid nanocomposites [10], carbon nanotubes grafted with metal nanoparticles [11], and metal nanoparticles [12], have been found to be able to detect a variety of gases at room temperature. On the other hand, even in the case of sensing materials able to work at low temperatures, substrate temperature control and stabilization are fundamental issues, because the sensing mechanism in itself, the properties of the sensing layers, the sensitivity towards the analyte, and the response/recovery times, are affected by the working temperature.

Within such a framework, this paper explores the possibility of developing platforms for low temperature sensing applications by means of simple, environmentally friendly and inexpensive

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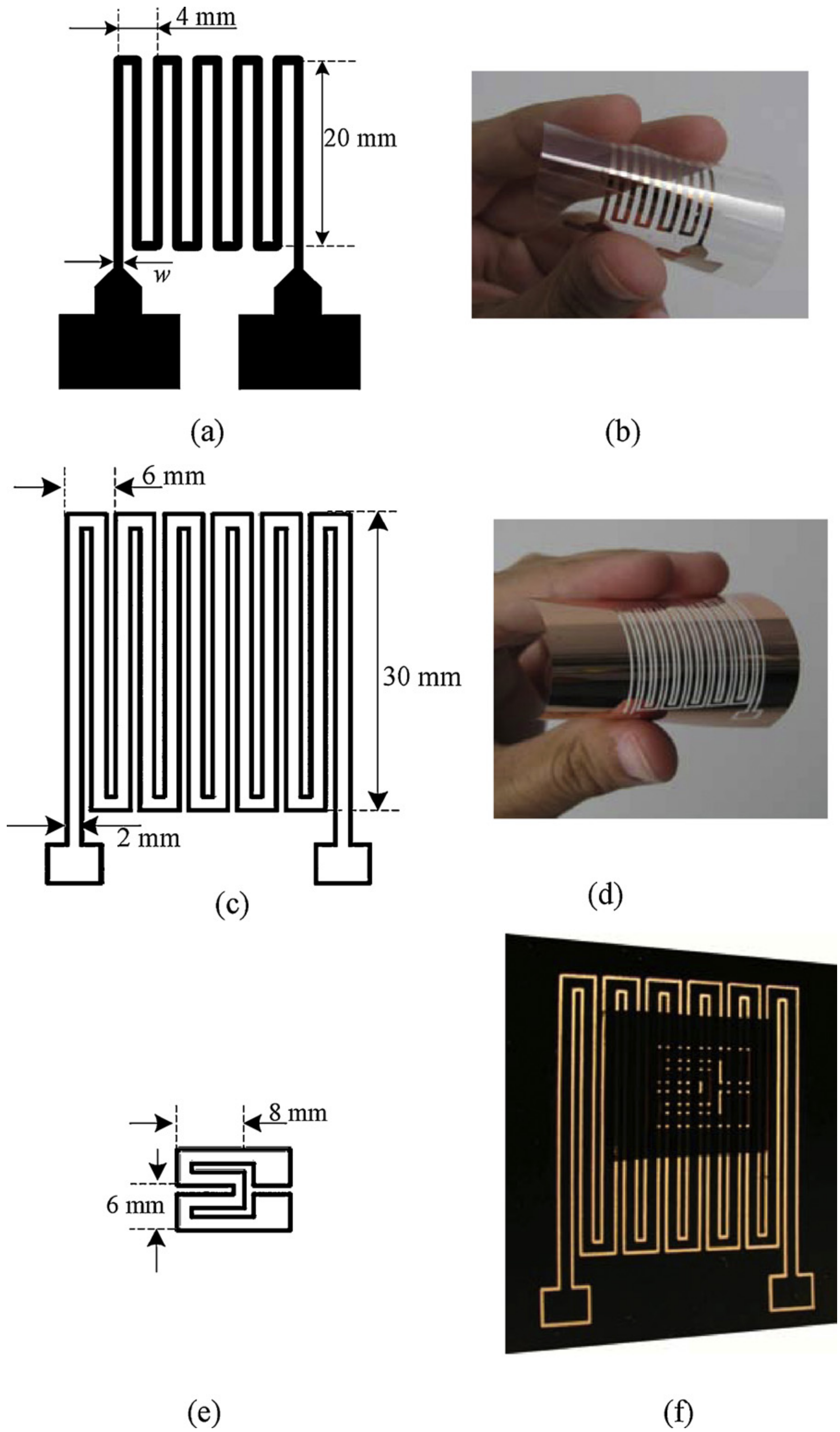

Fig. 1. Conventional lithography mask (a) and resulting patterned copper on the flexible substrate (b); direct etching pattern layouts (c and e) for obtaining the heather and a temperature sensing element on the top and bottom sides of the plastic substrate through local application of a fibre pen filled with $FeCl_3$ aqueous solution. The resulting patterned system is shown in (d), with the top copper layer completely removed, and in (f), where both layers are present and the sample is illuminated from the bottom (the top copper layer is partially removed in order to allow to distinguish both patterns).

processing, using transparency sheets coated with metallic films as substrates. The platforms are required to support an integrated heater, that has the function to settle the substrate temperature slightly above the ambient temperature, and a temperature sensor for temperature monitoring/control. To meet these requirements, transparency sheets, coated on both sides with copper by means of thermal vacuum evaporation, are patterned on the top and on the bottom sides. The thermal and mechanical stability of the evaporated copper films are investigated by means of resistance measurements vs. temperature, and by monitoring the electrical resistance of samples subjected to bending cycles at constant temperature. The structural modifications suffered by the samples when heated are investigated by means of scanning electron microscope (SEM) and X-ray Photoelectron Spectroscopy (XPS).