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Multilayer inkjet printed dew point hygrometer

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ABSTRACT

This paper describes the dew point temperature hygrometer as a complex microsystem manufactured using inkjet printing directly on the surface of a Peltier couple heat pump. The principle of the structure's fabrication is similar to that of other sensors printed directly on textiles, paper or thin foils, but is much more difficult to perform. Both the principle of specific detector construction as well as some technological aspects are discussed in the paper. All three elements of the detector i.e. thermoresistor, heater and impedance dew detector are widely characterized to ascertain the performance of each. Final tests of the whole dew point hygrometer operation parameters are carefully reported and discussed in the conclusions.

1. Introduction

Printed electronics is the manufacturing of electronic device technology using typical printing techniques such as flexography, gravure, offset lithography, as well as screen and inkjet printing [1,2]. Traditionally, printed electronics are produced on cheap and flexible materials such as thin plastic films, ceramics or even paper or textiles, which makes them an extremely cost-effective method in large volume production. In fact, printed electronics can be adapted to any type of substrate which enables new applications [3]. One of the main advantages of printed electronics is the elimination of manufacturing masks for photolithography and undergoing high temperature processes which makes standard semiconductor technology problematic and costly [4]. In printed electronic technology, devices are built up layer by layer on a substrate by imprinting special functional inks [5,6]. Using printing techniques, many kinds of electronic circuits/devices can be made. Currently, printing techniques are used to make organic/polymer light emitting diodes [7,8], RFID antennae [9,10], switches [11,12], photovoltaic cells [13,14], sensors [15–21], displays [22,23] and even processors [24,25]. The inkjet printing technique is convenient to use for the development stage of some electronic devices and especially for sensors. Moreover printing techniques are the ideal solution in mass production of disposable sensors and tags for product packaging [26].

Many types of sensors have been fabricated using printing technology but great attention was paid to moisture sorption sensors [27–32]. However, in the wide range of applications of these humidity measurements, the dew point temperature hygrometers are most optimal due to their high accuracy and faste response. Dew point hygrometers are inherently capable of covering the entire humidity range from almost 0–100% RH. The inkjet-printed integrated detector for dew point hygrometer is the subject of this report.

One of the first dew point detectors presented by Jachowicz et al. [33] was built in silicon technology. Due to the complexity and cost, it has been proposed to use printing technology as a cheaper alternative to silicon technology for the production of dew point hygrometers. Successful results have been achieved for inkjet-printed dew point detectors on Kapton foils [34,35]. One of the problems of hygrometer operation with such a detector structure was to ensure appropriate heat transfer between the heat pump (Peltier cell) and the dew point detector. Dynamic operation of these detectors was considerably faster than the printed moisture sorption sensor but still slower in comparison to the detectors made using semiconductor technology. The hygrometer time constant is crucial in medical applications such as measurement of humidity changes in the nasal cavities during breathing or in the measurement of transepidermal water loss factor [36]. Based on the investigation of earlier inkjet dew point hygrometer construction, a multi-layered structure of the dew point hygrometer printed directly on a Peltier cell has been proposed. Below, the paper discusses construction of the new hygrometer structure for dynamic parameters improvement.

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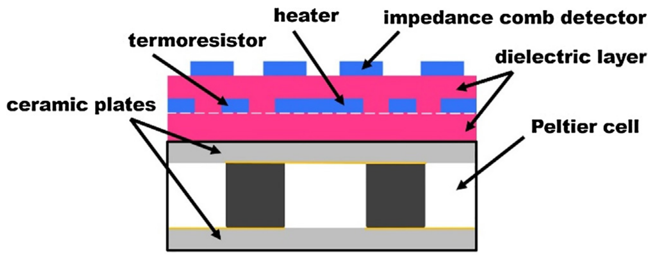

Fig. 1. Cross section of the dew point hygrometer structure in principle (not to scale).

2. Design and working principles

The structure of the dew point hygrometer consists of four elements: a dew point detector, a heater, a thermometer and a heat pump. Hebei TEC1-12706 Peltier cell was used as a heat pump. Typical construction of a Peltier heat pump has a series of p – and n-type semi conductive pillars arranged in a special order and located between two ceramic plates. The plates are electrical insulators and good heat conductors. A detector, a heater and a thermometer were printed directly on the ceramic plate of the Peltier cell. The designed dew point hygrometer has four layers: two conductive and two dielectric ones. All layers were applied one on top of the other, so we called it "Multilayer dew point hygrometer". The cross section of the dew point hygrometer structure (not to scale) is presented in Fig. 1.

The ceramic surface of the Peltier cells is rugged, hygroscopic and non-uniform at the microscopic scale, which results in bleeds and uncontrolled behavior of printed inks. To prevent these effects, the entire Peltier surface was smoothed by printing a dielectric ink overtop. This layer made for a homogeneous base for all subsequent layers. Such solution also brings additional advantages with better heat distribution from the heater. Next, two conductive layers separated by a dielectric layer were printed. The first (bottom) conductive layer forms the heater and thermistor and the second (top) conductive layer forms the impedance dew detector. Fig. 2 presents layouts of the conductive layers. During the fabrication process of the dew point hygrometer structures, two types of inks were used, and each layer was made on a substrate of different properties. Thus, for each layer it was necessary to select the appropriate process parameters. For the dielectric ink we used the Gersteltec GM 1040 SU-8 formula and for the conductive ink we used the Sicrys I30EG-1 ink with silver nanoparticles.

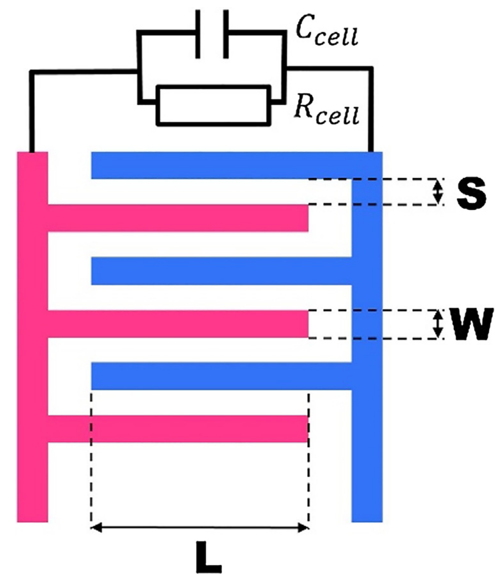

Fig. 3. The geometry of a planar interdigital sensor with equivalent RC parallel twoport.

The heater and the thermoresistor were designed as a meandering path which covers a square with dimensions 8 by 8 mm. The impedance comb detector was designed as interdigital electrodes (IDE) which are the most commonly used periodic electrode structures [37,38]. The active area of the detector has dimensions 4 by 6 mm and contains 33 electrodes (N). The geometry of typical planar interdigital electrodes is shown in Fig. 3, where L is the length of an electrodes, W is the width of an electrodes and S is the space between two adjacent electrodes.

Operation of the dew point detector is based on the measurement of admittance between the IDE. Such system of electrodes creates a planar structure which reacts to water condensing on its surface by changing the admittance. Since admittance Y_{cell} of the IDE strongly depends on properties of material between electrodes and it can be modeled as a parallel connection of a unit capacitor of capacitance C_{cell} and a unit resistor of resistance R_{cell}. In the IDE sensor structure, electric field lines pass through the material on the surface of sensor, therefore, the capacitance and resistance

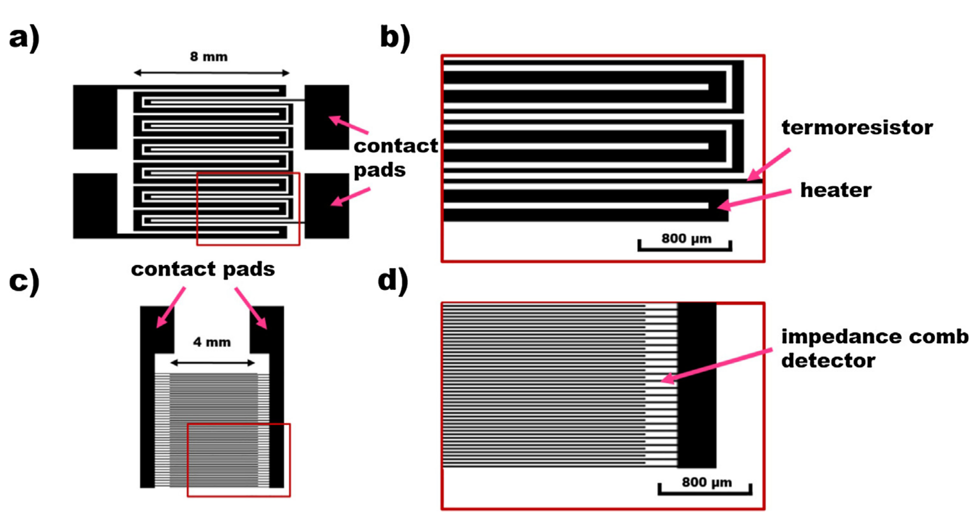

Fig. 2. The layout of first conductive layer – the heater and the thermoresistor (a) and magnification of their fraction (b). The layout of second conductive layer – the impedance comb detector (c) and magnification of their fraction (d).