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Economical fabrication of graphite/paper-based humidity sensor

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ABSTRACT

Paper is regarded as a promising alternative for low-cost and biodegradable substrate. Paper can be a very good humidity detecting substrate due to its capability to absorb water vapour, thanks to its porous surface. This work explores the feasibility of developing a paper-based humidity sensor using simple and low cost fabrication process. Two type of electrode structures, namely interdigitated and parallel electrode, were formed by using two different pencil grade. The pencil grades used were 2B and 6B. The current-voltage (I-V) characteristics of the fabricated device were measured under different relative humidity and its humidity sensing operation was analyzed. It was observed that the sensor with the 6B and parallel electrode configuration was the most responsive to humidity changes while the 6B interdigitated sensor was the second best. The sensors fabricated with the 6B electrodes are better at sensing humidity changes compared to the sensors fabricated using 2B electrodes

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1. INTRODUCTION

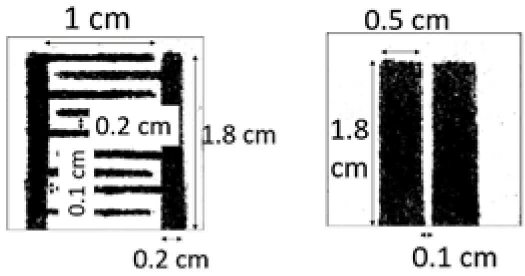
Humidity sensor is a device that is used to sense and detect the concentration of water vapour in various substances or in the air. Humidity sensors have been employed in various industries such as the food industry and the medical industry [1-3]. However, the issue with current humidity sensors [4-6] is that their methods of fabrication are way too complex, costs too much and there arises a whole lot of issues when disposing the sensor. For example, glazed ceramic used in the sensor releases harmful gases during the decomposition.

This is where paper-based sensors [6-18]comes in as an alternative technique of making a humidity sensor that is easy to fabricate, low-cost, portable as well as being easily disposable [11, 18-20]. Moreover, paper has unique properties which allows passive liquid transport and is compatible with biochemical [18]. Nevertheless, fabrication of paper-based humidity sensing device is still largely unexplored [9, 15, 21, 22]. This study focuses on developing a cost-effective humidity sensor that can be used by everyone for a short-term and easily disposable. In addition to being cost-effective, the developed prototype is also easily applied to monitor significant changes in humidity. The level of humidity can be seen as the changes in current at specific voltage applied. Different types of graphite were used as the electrode and humidity detecting substrate in developing the prototype sensor [17]. The paper chosen in this study was filter paper. The reason for using filter paper is because it is chemically inert compared to other papers. Graphite chosen was varied according to variation of the amount of clay and graphite composition which was represented by the pencil grade 2B and 6B respectively [23]. The sensing region for both the sensors were approximately the same which is around 1 cm^2.

The significance of this study is that it looks into the possibility of producing a low-cost humidity sensor with views into much easier and economical fabrication methods. The sensor is also meant to be small hence saving space in materials it is to be implemented. It should be noted that the sensor is environmentally friendly as the materials used are bio-degradable and will not cause foreseeable damage to the environment.

2. RESEARCH METHOD

The experimental work was designed and performed in order to address these two aims: (i) to evaluate the suitability of the graphite type used to fabricate the prototype sensor, and (ii) to identify the best working sensor design. Two different sensor designs were fabricated as shown in Figure 1. The first design was called interdigitated electrode (IDE) while the second design was denoted as parallel electrode (PE). The process was done by drawing the design traces manually by hand with two different pencil grades that acted as the source of graphite which were 2B and 6B. Generally, 6B pencil has higher amount of graphite compare to 2B [23]. 6B pencil consists of 84 % graphite and 10 % clay, while 2B pencil consists of 74 % graphite and 20 % clay. The variations of sensor device are shown in Table 1.



(a) (b)

Figure 1. Device design of a) interdigitated electrode (IDE), and b) parallel electrode (PE)

Table 1.Types of sensor design and pencil type used

Sample name	Electrode design	Pencil type
IDE-2B	IDE	2B
IDE-6B	IDE	6B
PE-2B	PE	2B
PE-6B	PE	6B

Figure 2 summarizes the overall flow of the processes involved in this expeperimental study. Initially, the filter paper was cut into a dimension of 2 cm × 2 cm and then the sensing region was traced on the filter paper according to the designed dimension. Verification of the graphite sensor is done through measurement of current-voltage (I-V) curve. A working fabricated device should exhibit consistent I-V characteristic which showed current increase at higher voltage.

To characterize the humidity sensing operation, the I-V characteristics of each samples were measured at different relative humidity (rH) level. The I-V measurement was done using the Keithley 2000 Multimeter at voltage range of -10 V to 10 V. Different rH levels was obtained by using different saturated salt solution. The measurement setup is shown in Figure 3. The sample was placed inside a container with saturated salt solution. The saturated salt regulates the rH level inside the container. Different saturated salt solution is known to give different rH levels. A hygrometer was used to measure the humidity inside the container. Summary pf the salt solution used in this study and their rH levels measured at room temperature were given in Table 2 [24].

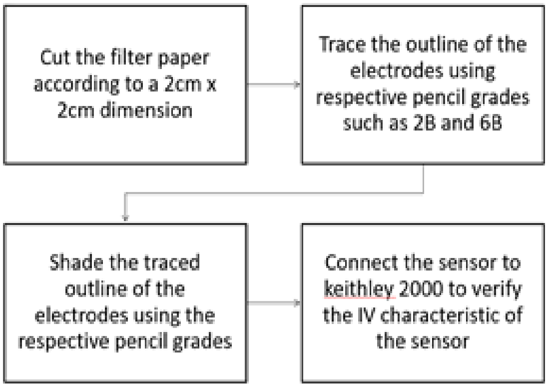


Figure 2.The process flow of the development of the sensor

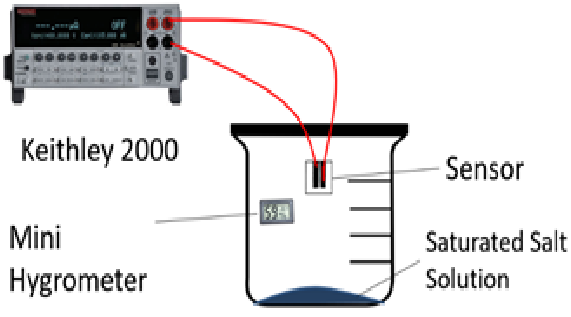


Figure 3. The experimental setup used to obtain I-V characteristics at different humidity levels

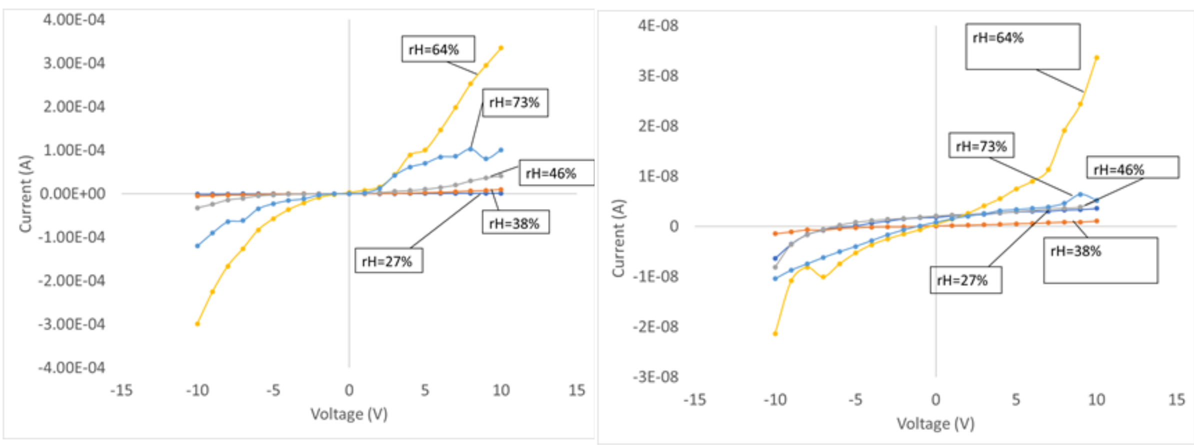
Table 2. Salt solution and their humidity levels

Salt Solution	rH (%)
Lithium Chloride	11.31
Magnesium Chloride	33.07
Magnesium Nitrate	54.38
Potassium Chloride	85.11

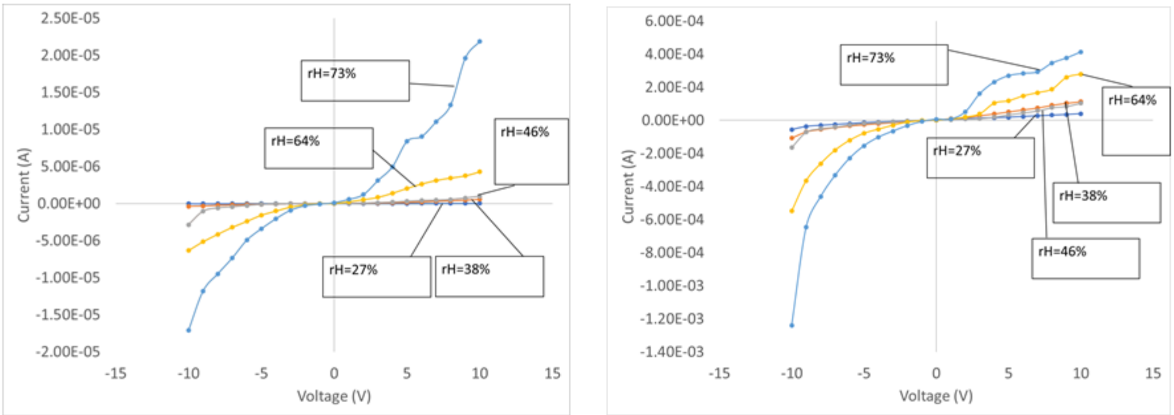
3. RESULTS AND ANALYSIS

Figure 4 shows the measured I-V characteristics of all the device variation. All the sensors did respond to humidity changes. Sensor current increased at higher RH level. Sample made from 6B pencil gave higher current value compared to sample made from 2B pencil. It is observed that the higher percentage of graphite leads to higher conductivity.

In order to analyze the sensor response toward rH changes, graph of current versus rH was plotted. The current value was taken at 10 V applied voltage. Figure 5 shows the plot for 4 different sensor types. The sensors fabricated with a 6B electrode had the most linear change with humidity as expected while the sensors with 2B electrodes had slight fluctuating currents repsonse. This happened due to graphite composition of the 6B pencil which is relatively higher hence shows better response in terms of current changes trend with respect to humidity level. Therefore, sensors fabricated with the 6B pencil was found to be more suitable for detecting humidity. Altogether, the 6B parallel sensor has given the most acceptable result in terms of the current changes according to humidity level. The inaccuracies could be due to the sensors being fabricated by human hand-pressure instead of the controlled auto-mechanized systems. The possibility of the pencil traces being worn out throughout the experiment could also be a causal factor.



(a) PE-2B (b) IDE-2B



(c) PE-6B parallel (d) IDE-6B

Figure 4. I-V characteristic of each prototype sensor

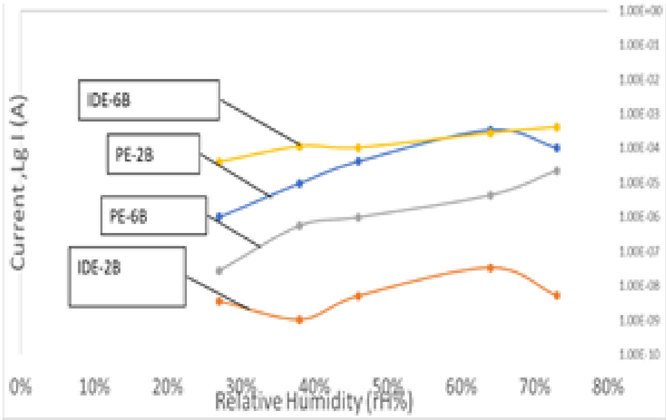
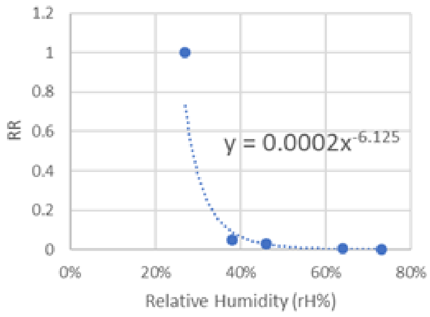


Figure 5. Current changes at 10V for different humidity levels of each respective sensor

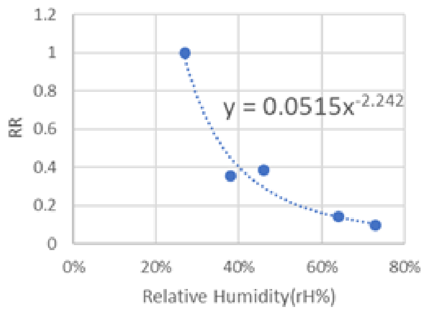
The experiment indicated that the sensors fabricated using the 6B pencil has better response to humidity changes. However, out of the two sensor design, it is seen that the 6B parallel sensor gave the most successful result. While the 6B interdigitated sensor had a more robust current response, the 6B parallel sensor gave the most acceptable I-V characteristic pattern that satisfies the hypotheses which is current increases when humidity levels increases. It was evidenced that relative resistance (RR) can be used to predict the humidity [12, 25]. The relative resistance (RR) is defined as follow:

$$RR = \frac{Resistance\ at\ corresponding\ humidity, R}{Resistance\ at\ lowest\ humidity\ recorded, R'} \quad (1)$$

From the obtained I-V characteristics of 6B samples, the RR values were extracted and then, the graph of RR against rH was plotted as shown in Figure 6. As shown in Figure 6, a trendline was obtained for both the sensors. This trendline shows the relationship of the RR and rH. Substituting relative resistance into y of the equation obtained from the trendline would allow the humidity to be calculated. However, this trendline would not be identical for every sensor that could be fabricated from methods shown in this study. This is because the sensor is fabricated by human hand-pressure and can therefore be defective as the margin for error is huge. However, the measurement technique demonstrated could be used as a suitable method to calculate humidity based on the current changes exhibited by the sensor.



(a)



(b)

Figure 6. RR against rH of 6B sample with electrode design of a) PE, and b) IDE

4. CONCLUSION

In this study, the fabrication of a simple and low-cost humidity sensing device was demonstrated. It has advantage in terms of being environmental friendly as well as cost-effective. Based on the experiment, the sensor that was fabricated using 6B pencil with a parallel electrode configuration gave the best response to humidity. Though the repeatability of the experimental results is a question mark, it is however a good start to note that sensors made as easy as tracing a pencil on paper can be used to measure humidity. Hence, more research needs to be done to develop a sensor that can consistently give results and then be implemented in the industry namely, the food packaging industry where such a sensor can prove to be very crucial. It is expected that the sensor developed in this study can be further optimized to measure humidity levels even more accurately.

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