

Characterization of moisture sensor based on printed Carbon-Zinc energy cell

Hans-Erik Nilsson¹, Johan Sidén¹, Tomas Unander², Torbjörn Olsson^{1,3}, Peter Jonsson¹, Andrei Koptioug⁴, Mikael Gulliksson⁴

1. Mid-Sweden University, Electronics Design Division, 851 70, Sundsvall, Sweden

2. AddMarkable Technologies, 583 30 Linköping, Sweden

3. Bofors Defence AB, 69180 Karlskoga, Sweden

4. Sensible Solutions Sweden AB, Universitetsallén 32, 851 71, Sundsvall, Sweden

Abstract

In this work we present a simple printed moisture sensor fabricated using electronic inks on a multilayer paper structure. The sensor is based on a Carbon-Zinc type energy cell and provides power to a readout electronic circuit when activated by moisture. The sensors are based on a number of our filed patents according to which the sensor is used for both event detection and as a power source for the processing electronics. Typical applications are moisture and leakage detection in buildings, water pipe lines, smart packages and health care systems such as smart incontinence sensors. As the detector is triggered, it powers up an electronic circuit (polymer based or silicon based) that starts communication with the alarm server. In the simplest systems a sound or a light alarm is started to alert the user. In this work we present a characterization of some critical parameters of the sensor such as power driving capability, linearity, internal memory effects and saturation. In addition, we examine a specific application, when sensor is used as defrosting alarm for surveillance of frozen articles during transport.

Keywords

RFID, Printed sensors, Moisture detection

I. Introduction

The current trend in transportation and distribution logistics is to target systems that provide higher visibility in the supply chain. Automatic ID control provides much better control of the logistic chain optimization, improves service and availability of products for the customer. The increasing problems with falsifications of popular brands call for better identification and authentication solutions. The current technology is driving for silicon based RFID systems using a standardized Electronic Product Code (EPC) [1] protocol. New technologies such as the Fluidic Self Assembly (FSA) [2] by Alien Technology promises to provide silicon based tag solutions in the 5 US cent range. This type of systems is starting to reach the market and in some years large number of systems is expected to be in active service. Printed sensor revolution connected to this new infrastructure is well in line with forecasts by business analysts [3].

One area of interest for industry is the surveillance of moisture and temperature- related problems for example in transportation, storage, insurance etc. The total losses due to moisture and water leakage damage according to the insurance business are well above 500 MEuros in Sweden alone. In spite of rather large economical impact

due to expected savings, the sensor solution needs to be extremely low cost. In most mentioned cases the alarm type surveillance is (i.e. the alarm is triggered if moisture level exceeds a certain threshold level) will be adequate. In such applications the Action Activated Tag (AAT) concept [4] is very efficient, since action is only taken when needed. However, there are applications where both AAT functionality and the possibility to monitor humidity by passive RFID readout are of significant interest. In such cases the printed moisture sensor will be very advantageous. The sensor structures studied in this work have such character. IPR and development are controlled by Sensible Solutions Sweden AB.

II. Sensor technology

The sensor structure studied is presented in Fig. 1. It consists of different “active” ink layers printed on the paper substrates. The sensor is in some configurations similar to a water activated battery. Printed battery technology is available both in academic research [5] and by commercial players [6]. However, in our case the target is sensor functionality and the chemistry and design has been developed explicitly for this purpose.



Figure 1. Sensor element consisting of two layers of “newspaper grade” paper with zinc based ink (top layer) and carbon based ink (bottom layer). Absorbing layer (doped with electrolyte and dried) is placed in between the active layers.

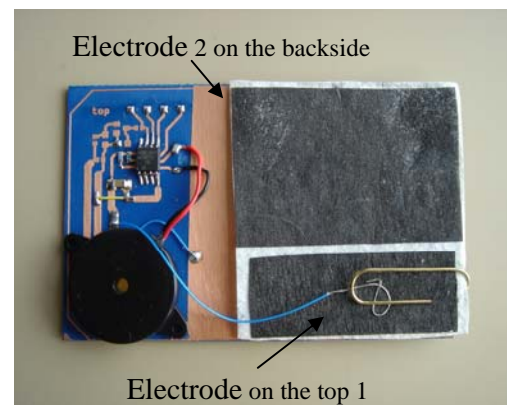


Figure 2. Example on student laboratory setup of simple serial sensor configuration.

The moisture sensor cell can be organized in a serial configuration which provides higher sensor signal levels. Typical configurations are two and three sensors in serial. The geometrical arrangement is very important in order to get full signal levels and efficient sensor function. In Fig. 2 a picture of a 3.4 V sensor designed for minimum self-leakage is presented. The sensor provides energy to the microprocessor and crystal beeper.

The design of the absorption layer provides control over the trigger level in the sensor. For example different moisture absorbing substances can be used to tune the sensitivity to air humidity. In Table I the designs used for the sensors evaluated in this work are presented. In the case of a smart diaper application the turn on of the sensor should be very close to 100% humidity. Sample 3 and 4 provides such functionality and can be stored a very long time in high humidity without losing its functionality.

TABLE I
DESCRIPTION OF THE SENSORS EVALUATED IN THIS WORK

Sample	Description (single energy cell)
S1	Paper substrate with mix of synthetic fibers, the porous electrolyte layer is made out of cellulose with soaked in moisture absorbing substance
S2	News-paper substrate, the porous electrolyte layer is made out of cellulose with top layer of moisture absorbing substance
S3	Paper substrate with mix of synthetic fibers, the electrolyte layer is made out of porous plastic.
S4	Paper substrate with mix of synthetic fibers, the porous electrolyte layer is made out of cellulose fibers

III. Experimental results

The signal produced by the sensor has been studied as a function of external air humidity in order to investigate the possible use for humidity logging. A typical sensor signal as a function of humidity is presented in Fig. 3. The sensor signal dependence on the air humidity and has a pronounced threshold followed by a linear region. The linearity depends on the sensor design and the size of the resistive load attached to the sensor.

The sensor signal after long time exposure in a climate room with 90% RH is presented in Fig. 4. The synthetic foam as porous electrolytic layer (S3) provides a sensor that only responds in direct contact with water (humidity levels near 100%). In Fig. 5 the sensor signal as a function of humidity is studied for a full humidity cycle, from 50% RH to 90% RH and back to 50% RH. The first observation that can be done is that different type of porous layers as electrolytic layer changes the trigger (or on-set) level by the sensors. Here there is a lot of freedom to design sensors with a desired threshold level. Thus, samples 1 and 2 can be used to trigger actions when the humidity reaches a certain level, for example the 70% level, and sample 3 and 4 can be used

for triggering at the 100% humidity level (water detection).

In addition the sensors show some memory effect resulting in hysteresis in the sensor signal. In Fig. 5 the hysteresis of sample 1 and 2 are presented. The origin for this memory effect is actually a thermodynamic process in the moisture absorption in the cellulose fibers [7] used. Thus, the strength of the memory effect can be adjusted by selecting different materials in the porous electrolytic layer. In an AAT configuration the hysteresis effect is desired, since it allows time for the registration and action to take place when the sensor is triggered by a peak in the humidity. It can be regarded as a latch function that ensures stable operation. Another way to look at it is that the hysteresis provides a memory effect that gives energy for data processing during longer times than actually provided by the event itself.

The dynamic behavior of the sensor is presented in Fig. 6. The time constant is in the range of 1 h for all the sensors in the study. However, using plastic porous electrolytic layer slightly reduces the time constant but the most important contribution of the time constant is related to the electronic inks used.

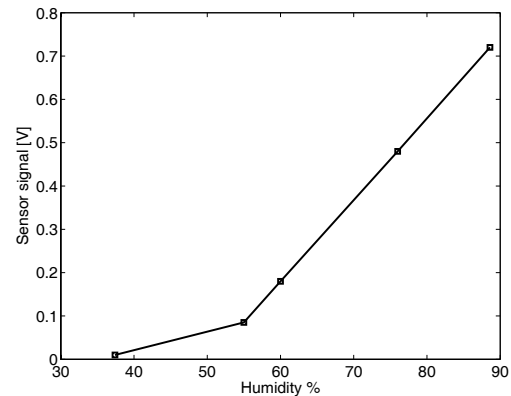


Figure 3. Typical sensor signal as a function of humidity. Note the slope of the signal can be tuned by an external resistive load attached to the sensor.

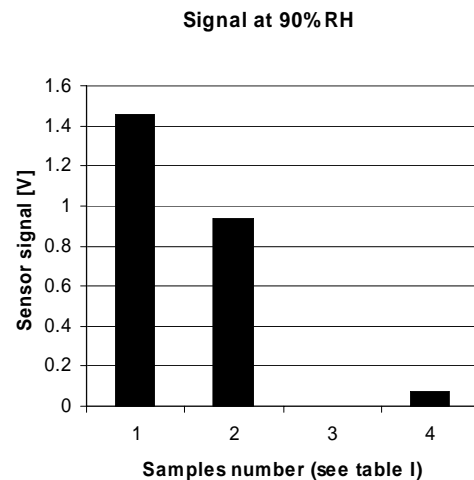


Figure 4. Signals at 90 % RH for the different sensor samples (see Table I) studied in this work.

The sensor will always be connected to some type of readout technology with a resistive load. In Fig. 6 the effect of the resistive load can be seen in the saturation region as a slight negative slope. In this case the load resistance was 500k Ω . The time constant for the leakage process with such load is in the order of weeks and months and can be improved by optimization of the sensor for power driving capability (sensor volume).

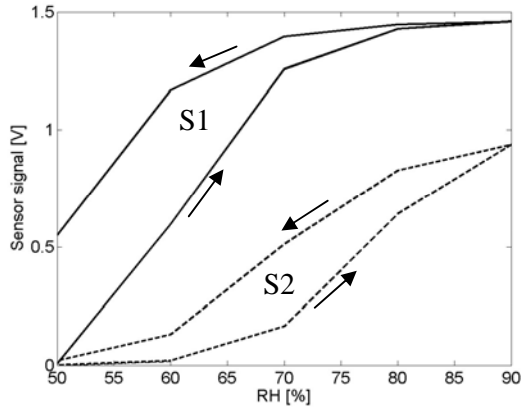


Figure 5. Signal response as a function of humidity for sensor sample 1 and 2 (see table I).

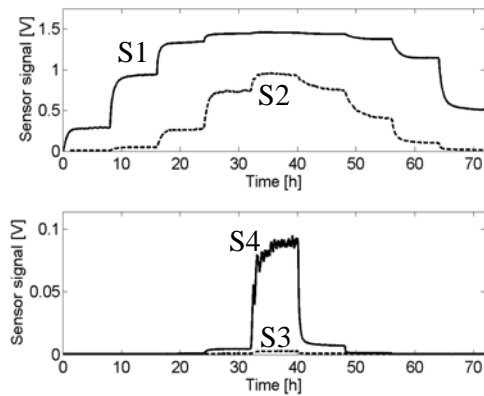


Figure 6. Plot of the dynamic response of different sensor samples. Humidity loop 50%, 60%, 70%, 80%, 90%, 80%, 70%, 60%, 50%. Each humidity step was scheduled for 8 hours.

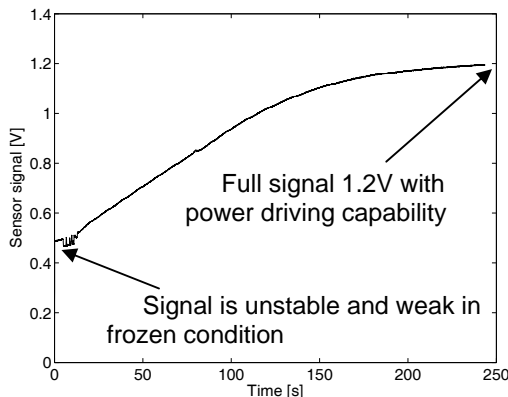


Figure 7. Sensor signal from frozen sensor as a function of time after exposed to room temperature.

The power driving capability depends on the volume of the sensor. A typical sensor has a driving power of a few mA and provides between 1.1V to 1.5V as a single cell. The difference in voltage level depends on the design of the sensor (chemistry and layout). Different applications demand different sensor designs.

The sensor linearity also depends strongly on the design and layout. A common feature of all the sensors is the S-shaped characteristics (see Fig. 5) and the true linear region is limited to approximately 15% RH. However, electronic signal processing can be used to reach full control over the targeted humidity interval in spite of non-linearity at low and high humidity levels.

The spread in sensor performance depends on the quality of the ink and the print technology used. Today's print technology can provide good control over the sensor characteristics. This type of sensor is also very stable and we have produced sensor batches with less than 10% variations in signal for the same humidity level using simple manual printing techniques. This value can of course be improved by using better printing techniques.

The sensor can be configured in such way that it provides substantial levels of electric power. For example a thin sensor in the size of square decimeter can provide as much as 0.5 W in power during several minutes. This opens up a low cost solution for AAT solutions communicating over long distances.

The presented sensor can also be effectively used as a "defrosting" alarm, for example in frozen article monitoring systems. In this case the sensor is preloaded by water and frozen together with the item to be monitored. When the article is removed from the freezer (or temperature control fails) the inner electrode releases moisture and the sensor is triggered. Triggering delay is about a minute or less after the sensor temperature raises above zero centigrade. Even when the sensor is frozen some signal (voltage) can be registered but the driving capability (current) is extremely low. As the sensor is held at room temperature the signal increases and sensor turns in to a power generating element (see Fig. 7 right). For this application the sensor has been optimized for minimum current leakage when frozen, which is the reason for the low maximum signal level of 1.2 V (see Fig. 7).

The system performance for the "defrosting" alarm can be described as

- The sensor powers up the electronics each time the product is in the wrong environment
- The electronics adds time counts to a timer in a non-volatile memory as long as the power is on.
- An external reader is used to readout the accumulated timer value through an active radio configuration, RFID passive/semi-active readout or as an optical signal in a simple display.

IV. Conclusions

A printable moisture sensor has been presented and characterized. The sensor could be produced at a very low cost and is disposable. The functionality provided is compatible with the growing need of low cost technology for disposable intelligent sensor nodes in logistics, security and health care. Five different sensor designs have been evaluated and characterized in terms of dynamic and static moisture response. In addition a frozen sensor concept has been presented where the moisture sensor can be used in surveillance of frozen goods in for example a supply chain.

We have shown that the sensors could be designed to trigger at various humidity levels, which allows for optimization towards specific functionality in various applications. The sensor can utilize the hysteresis process in the moisture absorption in organic materials, such as for example cellulose fibers, in order to provide stable triggering in a system configuration.

Acknowledgments

Financial support from the forest industrial research program FSCN at the Mid-Sweden University, the Knowledge Foundation and our industrial partners is gratefully acknowledged.

References

1. EPCglobal, <http://www.epcglobalinc.org/>
2. Alien Technology, <http://www.aliantechnology.com>
3. Active RFID becomes big business, IDTechEx, August 17, 2005, <http://www.idtechex.com>
4. J. Sidén, A. Koptioug, M. Gulliksson, The "Smart" Diaper Moisture Detection System, Microwave Symposium Digest, 2004 IEEE MTT-S International, Vol. 2, 6-11 June 2004 pp. 659 – 662.
5. G. A. Ghiurcan, Liu Chung-Chiun, A. Webber, F.H. Feddrix, Development and characterization of a thick-film printed zinc-alkaline battery, Journal of the Electrochemical Society, Vol. 150, no. 7, July 2003, p. A922-7
6. Powerpaper, <http://www.powerpaper.com>
7. Brecht, W., (1958) "Beating and hygro-stability of paper", in Fundamentals of papermaking fibres, Vol. 1, F. Bolam ed., Tech. Sect. British Paper and Board Makers' Assoc., 1958, London, p. 241