Student's Card

Printed Meteorological Station - printed sensors on paper

Module 1

Objective: Preparation of printed temperature, humidity, and UV sensors

Introduction

This activity aims to demonstrate that abundant and sustainable materials may be used to fabricate electronic devices using low-complexity processing techniques, fully aligned with the United Nations sustainable development goals. The students will acquired basic concepts about the transduction principle behind printed temperature, relative humidity, and UV sensors. The sensors where prepared using conventional printing technologies on flexible substrates as paper and Kapton foil, including the preparation of functional inks. Conductive silver patterns working as printed resistors are used to create a temperature sensor. Humidity sensitive printed layers were created using an ink containing cellulose as binding agent of chopped carbon fibers. These layers respond to relative humidity variations by swelling and promoting/cancelling percolation paths between the carbon fibers that modify its electrical resistance. Finally, an ultraviolet (UV) light sensitive nanoparticle-based ink was formulated using cellulose as a binding agent of zinc oxide (ZnO) nanoparticles. The electrical resistance of these printed layers decreases when exposed to UV light because of a surface phenomenon of photogeneration of electron-holes pairs.

Necessities

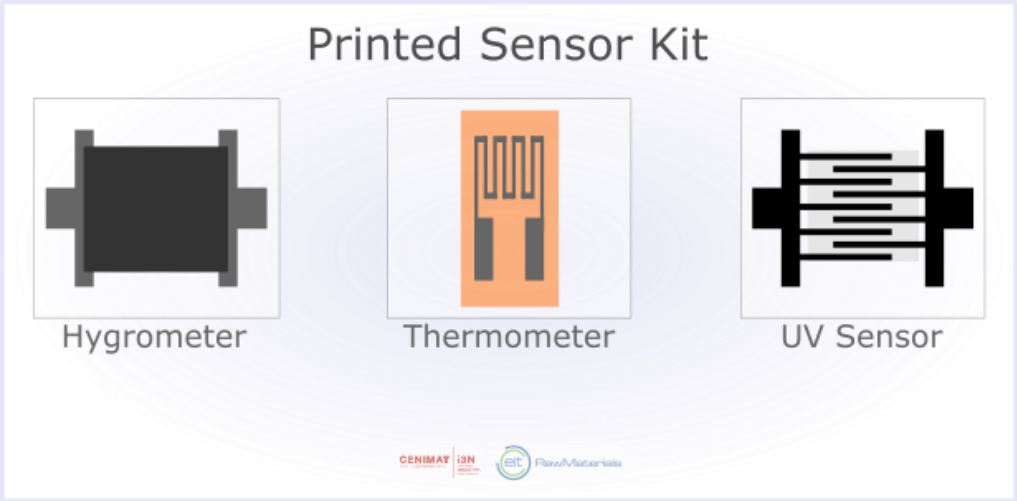

Figure 1 - Sensor kit. The sensors can be individualized form the kit.

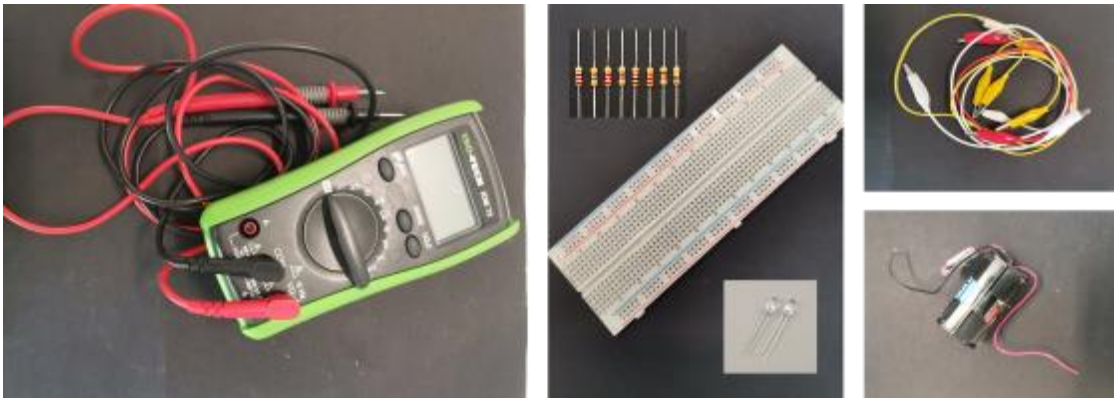

Figure 2 – Example of the materials necessary for the experiment. From left to right: Multimeter, board, resistors and UV LEDs, cables and 6V battery pack.

List of materials/tools

Temperature Sensor / Thermometer

- Temperature sensor from sensor kit
- Commercial or laboratory thermometer for reference
- Multimeter with universal terminal probes
- Metallic container
- Tap water
- Electric kettle (or some other source to heat the water)
- Ice cubes

Humidity Sensor / Hygrometer

- Humidity sensor from sensor kit
- Multimeter with crocodile terminal probes
- Piece of glass/ glass kettle (or an old credit card, for instance, for a better handling of the sensor during the experiment)
- Electric kettle (or some other source of steamy water)

UV Sensor

- UV sensor from sensor kit
- Multimeter with crocodile/flat terminal probes
- Piece of glass/rigid cardboard (or an old credit card, for instance, for a better handling of the sensor during the experiment)
- Controllable UV light source, or a set made of UV LED, 6V battery pack and different resistances.

Lab Procedure

Temperature Sensor

Student's Card

To observe the sensor response to temperature variations, begin by identifying the correct multimeter terminals and the sensor electrodes, by observing Figure 3 *and* Figure 4*. It is irrelevant whether you connect the red or black probes in the order indicated in* Figure 4*.*

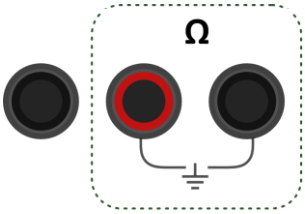

Figure 3

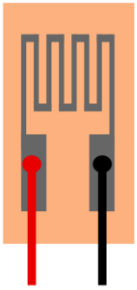

Figure 4

- *Start by connecting the multimeter probes in the sensor terminals for resistance measuring mode.*
- *Measure and register the resistance value in the printed temperature sensor. Use the commercial/laboratory thermometer to register the ambient temperature.*
- *Put the printed temperature sensor on the outer side wall of the metallic container. You can use scotch-tape to fix it leaving the printing layers facing you.*
- *Read and register the resistance on the temperature sensor using the multimeter. Use the commercial thermometer to measure the temperature on the surface of the sensor. (Be careful to not damage the printed layer)*
- *Use the electric kettle to boil enough water to fill the container. Make sure you have enough water to reach a level that allow to heat the side walls.*
- *Wait a couple of minutes to allow the temperature in the side wall of the contained to stabilize.*
- *Read and register the resistance on the temperature sensor using the multimeter. Use the commercial thermometer to measure the temperature on the surface of the sensor. (Be careful to not damage the printed layer)*
- *Discard the warm water and now use the ice cubes and enough water for the temperature of the ice bath being as close to zero degrees Celsius as possible.*
- *As before, wait some minutes for stabilizations of temperature before reading and registering the resistance at the temperature sensor.*

Humidity sensor

In this activity, switch the previously used probes in the multimeter to crocodile terminals. The sensors are inside zip bags to keep the initial humidity close to zero so make sure to only open the bags when you are ready to measure and register its initial resistance. Alternatively, place the sensors in a room where there is a low humidity level for at least some hours before performing this experiment.

- *Using scotch-tape, fixe the humidity sensor to the piece of glass, or the credit card (any rigid and thin small object will do) like shown in* Figure 5*. This will help when handling the sensor with the crocodile terminals attached.*
- *Place the crocodile terminals in the sensor and make sure there is a good electrical connection.*
- *Measure and register the resistance right away, as the sensor will readily absorb any humidity in the room and shift resistance values accordingly.*

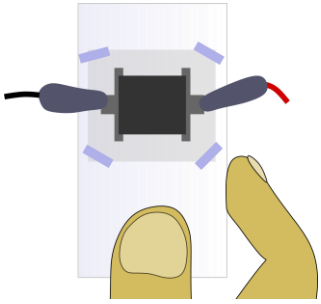

Figure 5

- *Prepare some steamy boiling water using the kettle and place the sensor facing the steam some minutes, while monitoring and registering the resistance value in the multimeter.*
- *You can either register the variation of the electrical resistance for a regular period of time (5 sec interval, for instance) of just wait some minutes until it eventually stabilizes.*

UV Sensor

To observe the sensor response to different UV variations/intensities, begin by again identifying the correct multimeter terminals and the sensor electrodes, by observing Figure 3 *and* Figure 4*.*

- *Using scotch-tape, attach the humidity sensor to the piece of glass, cardboard or credit card (any rigid and thin small object will do) like it is shown in* Figure 6*. This will help when handling the sensor with the crocodile terminals attached.*
- *Place the crocodile terminals in the sensor and make sure there is a good electrical connection.*
- *Measure and register the resistance values with the UV light OFF and then ON. Repeat it for some OFF/ON cycles (between 3 to 5), with a fixed time step of about 20/30 seconds if possible, registering the measured resistance values.*

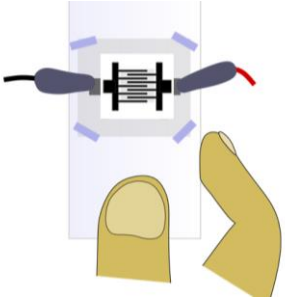

Figure 6

- *Use a glass slide or a plastic ruler to reduce the distance between the UV sensor and the UV light source and measure the same way, decreasing each time the distance between the sensor and the UV light source*.*

**- the UV light may be either a controllable one or a small circuit made of the 6V battery pack in series with the resistors and the UV LED. Please assure that you connect the UV LED with the right polarity. By changing the resistors will you change the current in the circuits, thus, the light intensity. In this case you do not need to change the distance to the source.*

Additional Safety Notes

- *Be careful when handling hot water and ice cubes to prevent any severe burn.*
- *Use UV filtering protection goggles.*
- *Ensure you make the electrical connections in the right way.*

Calculations

Printed temperature sensor

- *Calculate the temperature coefficient (α) using the following expression (ΔR – resistance variation, R_0- initial resistance, ΔT – temperature variation):*

$$\alpha = \frac{\Delta R / R_0}{\Delta T}$$

Printed UV sensor

- *Calculate the sensor photosensitivity (p_s) using the following expression (I_{ON} – current under UV irradiation, I_{OFF} current with in the dark):*

$$p_s = \frac{I_{ON}}{I_{OFF}}$$

Questions/Quiz