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Design and Evaluation of Impedance Based Sensors for Micro-condensation Measurement under Field and Climate Chamber Conditions

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Abstract: Condensation associated with the risk of electrochemical and chemical migration plays an increasing significance in the field of reliability of electronic components. The trends towards challenging electronic assembly technologies such as minimization of conductive track widths and spacing, and higher density in electric elements are increasingly faced with the negative influences of micro-condensation. The condensation occurs as a result of the thermodynamic conditions in the environment of the electronic board. The condensed water is in equilibrium of condensation and evaporation, not in a static state. Due to this fact, there is a demand for sensors to record the real state permanently. Due to its miniaturized packaging, a new generation of micro-condensation sensors allows placement on different parts of electronic devices. Results of field tests in different automobiles and in climate chambers are presented. *Copyright © 2012 IFSA.*

Keywords: Condensation, Humidity, Migration, Corrosion.

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1. Introduction

In recent years, humidity sensors have found an extended range of application. Increasing demand for improvements of quality, reliability and energy control of technical and non-technical processes lead to new relative and absolute measurement humidity sensors. The common type of sensors, the polymer sensors, is fabricated from a hygroscopic material. The electrical properties change as it absorbs water molecules. For measurement of absolute humidity dew point hygrometers are offered. The gas is cooling down until condensation appears on a small mirror. The temperature at which this happens is measured and is defined as the dew point temperature. The onset of condensation is sensed optically. Regarding the described demand for sensors to record the microclimate condition in field applications

and to prove the existence of condensation in environmental climate chambers on top of the electronic boards, these sensors have some problems. Polymer sensors have the potential of miniaturization including signal processing. But condensed water drops on top of the sensor area generate a 100 % relative humidity signal, typically. A further cross sensitivity exists with the hydrophoby of the surface and the dynamic of evaporation. The application of mirror condensation sensors is limited regarding the miniaturization of the temperature sensor, mirror, and radiator (light emitting diode) and receiver (photo diode) elements. Moreover, LED elements close to the mirror impact directly on evaporation and condensation.

Failures of electronic components due to corrosion as a result of condensation can be studied only to a limited extent with the above mentioned instruments. For monitoring by measurements of condensation processes in field tests or laboratory conditions, new measuring systems are required.

The presented microcondensation sensors measure the condensation directly. The basic principle consists of a stray field capacitor where the electric flux lines intersect the condensed water drops.

The miniaturization of the stray field interdigital capacitor in combination with a signal preprocessing close to this transducer, allows the measurement of water mass in the range up to 25 µg/mm². Depending on the comb pattern of specifically designed stray field capacity in combination with a water drops sensitive detection system, a change of the capacity with increasing water mass is fact. By varying the comb pattern, the sensitivity to the measured water mass can be adjusted (water drops in the range of 5 - 15 or 5 - 25 µg/mm²).

2. Influence of Condensation on Corrosion

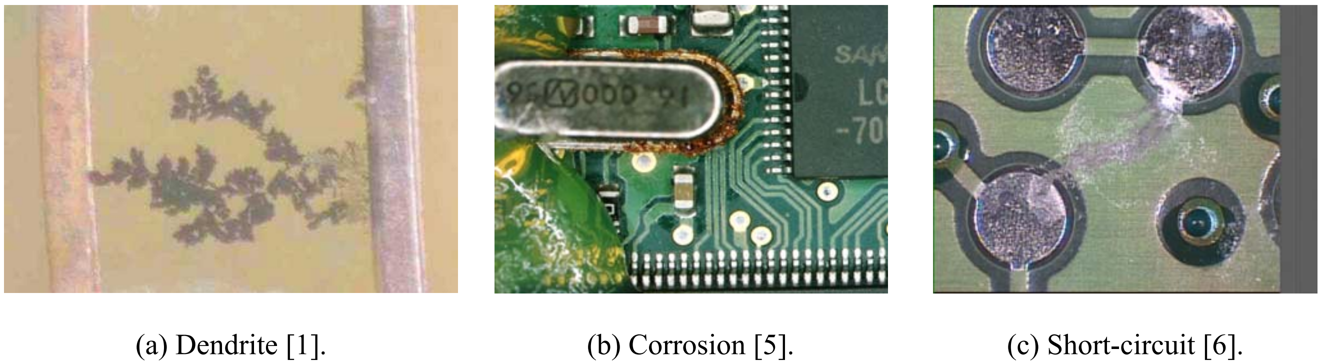
High ambient temperatures and humidity, water vapor or water and ionic contaminations entering from outside are all factors causing and accelerating the corrosion process.

It was found that the well known speeding up humidity tests (THB, HAST) do not always show the weak points in the system. Dewing tests of the unit under working (electric) conditions give important additional information regarding the reliability behavior of the system.

Electronic components and systems should be tested under the condition of permanent and reproducible condensation.

In the last years, an increasing number of papers were published dealing with any kind of corrosion of printed circuit electronic boards [1, 2]. Most of these are related to failures concerning the electronic reliability. Some authors reduce the failure to electrochemical or chemical corrosion [3-5]. Adding the growth of dendrites, the problem is becoming worse. Fig. 1 presents a selection of typical failures.

What do all these examples of corrosion have in common? An essential role for the initiation of corrosion plays the presence of moisture. The presence of moisture causes electrolysis processes. These cause uncontrolled currents (leakage). The corrosion occurs by dissolution of the metal due to anodic oxidation. Electrolysis processes are already initiated significantly at relative humidity below dewing. Very thin films of water are formed already at 40 % relative humidity. At relative humidity of 60 %, water films are formed with a thickness up to 4 molecular layers. This water film can already interact with hygroscopic impurities on the board. At relative humidity of 80 %, water films are formed with a thickness up to 10 molecular layers [6]. These act similar to "normal water". Solution processes of salts on the surface can start and ionic processes run subsequently. In combination with higher temperatures these corrosion and migration processes are accelerated.



(a) Dendrite [1]. (b) Corrosion [5]. (c) Short-circuit [6].

Fig. 1. Different kinds of failure.

Electronic boards are more exposed to changing climatic conditions. There is a growing risk of condensation of water vapor on the materials and components of electronic devices and consequently the risk of corrosion.

The processes could not only be described by the real climatic conditions. Rather, knowledge of the processes near the surface is required. Quantitative data of surface temperature, of humidity in the boundary layer, and, in particular, of the real condensation are necessary. Using microcondensation sensors, these data can be obtained.

3. Microsystem

Based on the increasing interest in direct condensation testing, different principles exist (e.g. optical [7], optoelectronical [8], and capacity [9] transducers).

We introduce an impedimetric principle and prefer such a solution for reasons of better miniaturization, better integration of condensation and temperature sensor, and to create smart systems with lower power consumption.

Because the customer is mainly interested in a calibrated sensor signal, the complete microsensor system must be integrated. Starting with the detection system (condensation), transducer (interdigital electrode) and signal pre-processing (capacity-frequency converter), the system has to be completed by the signal processing I (linearization, error compensation) the signal processing II (calibration, programming) and interface (see Fig. 2).

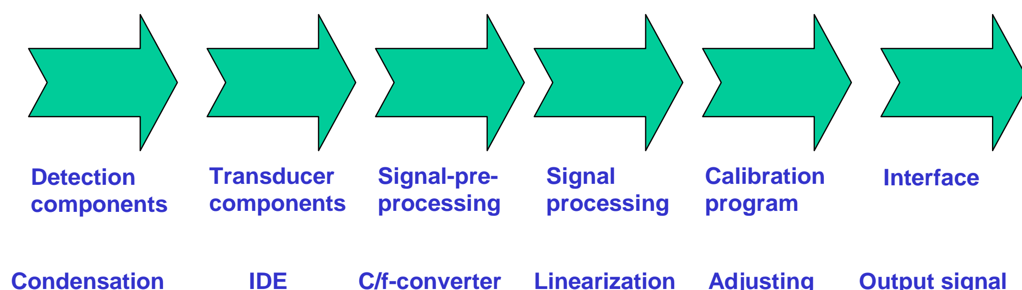


Fig. 2. Microsystem of micro condensation sensor.

3.1. Detection System

The detection system reflects the thermodynamical conditions in the immediate area of the surface. The detection system consists of a PE CVD Si_3N_4 layer, typically approximately 500 nm in thickness. This system has to guarantee a high and long term stability and reproducibility (see Fig. 3) of condensation. For signal generation, the size, shape and degree of coverage of the condensed water droplets on the sensor surface and the speed of their formation are relevant.

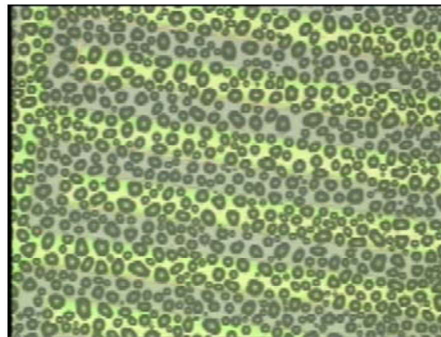


Fig. 3. Condensation on sensor surface.

A further task of this layer is the protection of the metal layer underneath against corrosion. The condensation surface is characterized in terms of pinhole generation, mechanical stability and chemical resistance to acids, alkalis and solvents.

3.2. Transducer

Two transducers are necessary, one for the measurement of temperature of the condensate and one for measurement of the water amount. The temperature transducer has been realized with a typical monolithic pn - junction. The water mass transducer has been designed as stray field capacitance with comb structures (Fig. 4). With a gap/line ratio of 25/33 (Fig. 5), water mass measurements are possible between 5 and 25 µg/mm².

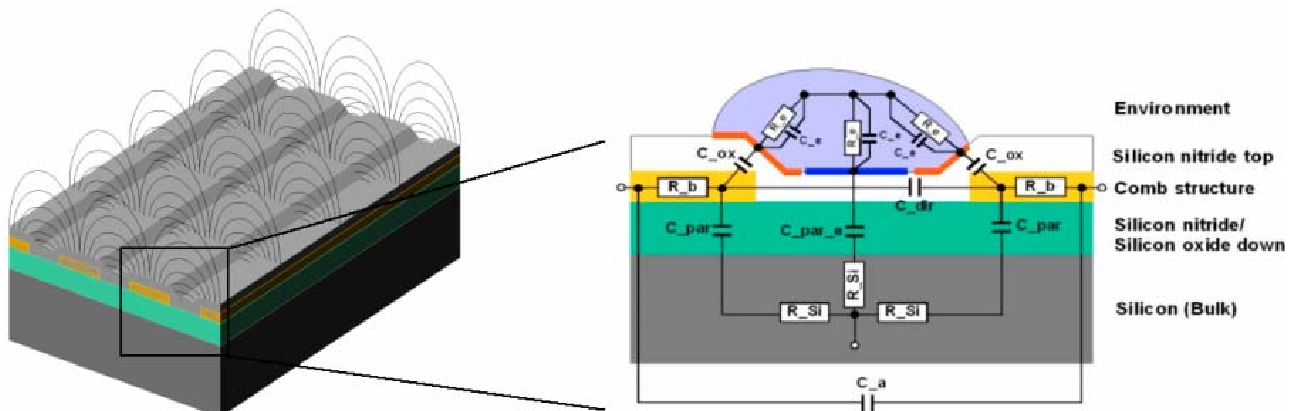


Fig. 4. Model of stray field capacitance – principle and diagram of the spice-model.

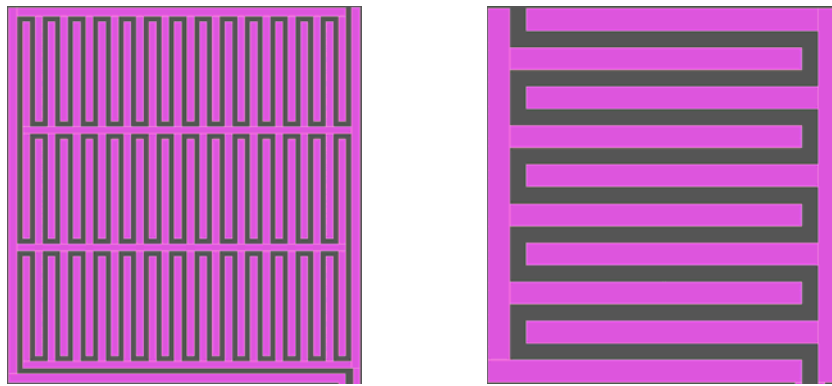


Fig. 5. Design of interdigital electrodes (25 and 75 µm Gap).

A SPICE-model of the stray-field capacitance as a module of the transducer exists. It allows the characterization of the stray-field capacitance by geometrical and technological parameters. Fig. 4 presents the model of the stray-field capacitance as R-C-network including technological layers.

The behavior of the sensor depends on geometrical and technological parameters of different layers. It is modeled by SPICE-Parameters. The parameters R_e and C_e describe the influence of the environment and determine the coupling of the oxide-capacitances C_ox. The initial capacitance at dry environment is determined by parasitic and direct capacitances C_par and C_dir.

Sensors with different layouts (Fig. 5) have different initial capacitances and different sensitivities for the ambient (the smaller the gap, the larger the initial capacitance).

The capacitance increases with the water amount. Increasing water amount means increasing coverage with water drops by combined increasing number and diameter of water drops. Fig. 6 illustrates the gap-dependent sensitivity for different drop diameters. The linear band of the red (3 µm Gap) and green (25 µm Gap) curves indicates increasing drop diameters of more than 3 respective 25 µm. The nonlinear band of the green (25 µm Gap) and blue (75 µm Gap) curves indicates increasing drop diameters of less than 25 respective 75 µm.

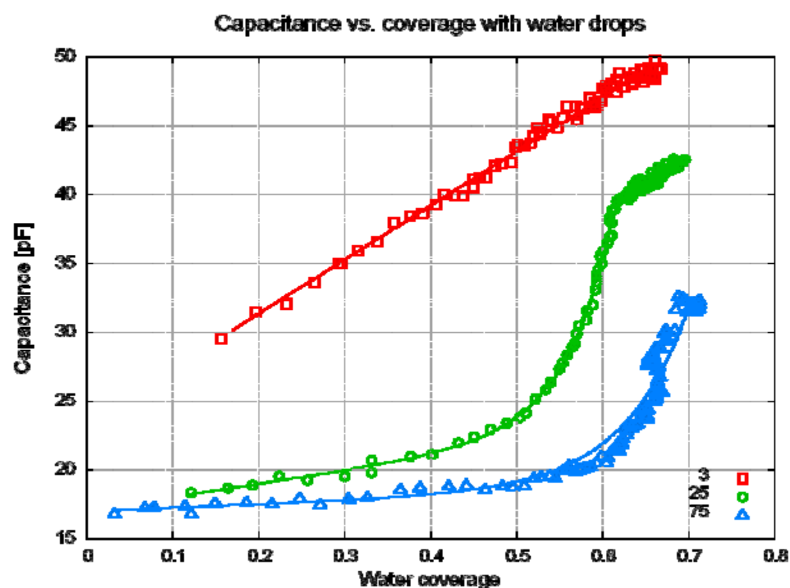


Fig. 6. Capacitance versus coverage with water drops (at 1 kHz, with 3, 25 and 75 µm Gap).

Fig. 7 illustrates the conductivity influence on capacitances with varying gaps. Sensors with small gaps have a lower capacitance ratio between lower and higher conductive ambient. The sensitivity is also influenced by the gap (the lower the gap, the lower the measurement range) and the measurement frequency (the lower the frequency, the lower the sensitivity). If there are varying ambient conditions, sensors with different gaps could be used to avoid interferences.

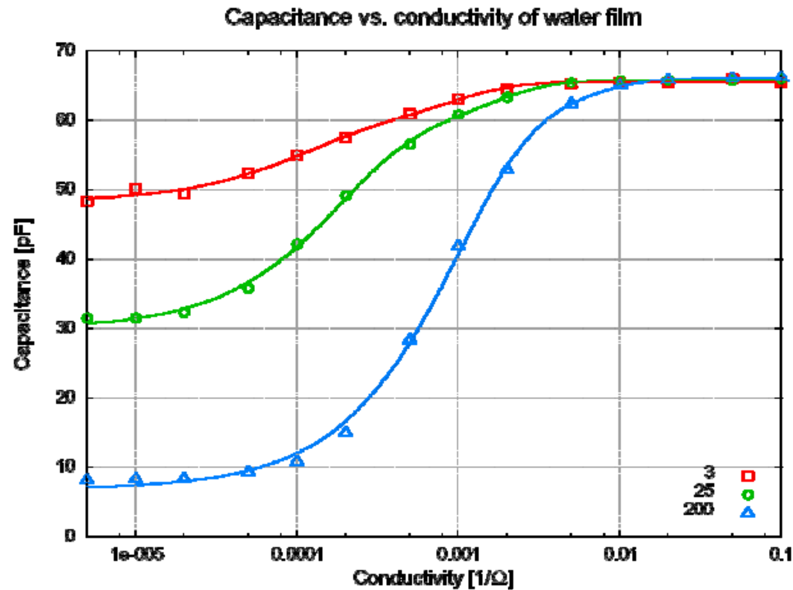


Fig. 7. Capacitance versus conductivity of water film (at 150 kHz, with 3, 25 and 200 µm Gap).

3.3. Signal Pre-processing

With the above mentioned demand regarding microsystem, the signal pre-processing has been reduced to a capacity-frequency converter. This converter allows a distance from the sensor element to the signal processing of about 1 - 2 meter. The temperature sensor does not need signal pre-processing. The change of temperature related flow voltage (2 mV/K) can be prepared for the electronic via the same signal line.

The detection system, transducer and signal pre-processing are hybrid integrated components (Fig. 8).

CoB (Chip on Board) technology with 33 µm bonding wire (material AlSi1) is applied for the interconnection of transducer die and board. The die is mounted in a cavity to minimize the length of wires and to manage the thermal coupling of the detection system to the measuring object. Furthermore, thermal vias in the printed circuit board help to match this goal.

SMT (Surface Mounted Technology) processing including flip chip soldering is used as a cost-efficient method for the mounting of devices with minimal length of signal paths. Vapor phase technology ensures low thermal loads during the soldering process.

The combination of different encapsulation materials and underfiller helps to improve the thermo mechanical behavior, stability and tightness of the package. For instance, materials with adapted CTE (Coefficient of thermal Expansion) were chosen for embedding of bonding wires and surface mounted device to minimize mechanical loads during temperature cycling. An additional coating improves the impermeability of the encapsulation.

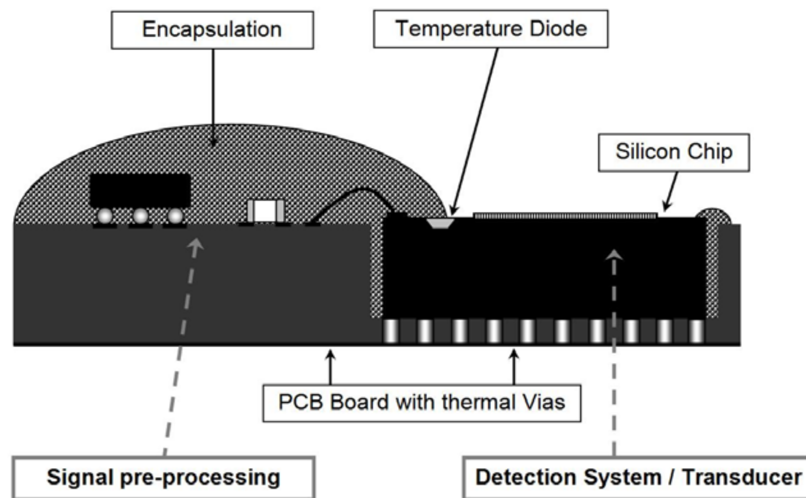


Fig. 8. Draft of a cross section of a sensor element (detection system, transducer, signal pre-processing).

3.4. Signal Processing / Interface

To obtain calibrated output signals for temperature and water mass, the primary signals from the sensor element have to be reworked. Therefore, the electronic part contains the appropriate parameters for linearization, temperature compensation, and programming. Tests for radio interference emission and immunity to electromagnetic fields were carried out and the results confirm that the sensor system (Fig. 9) meets the requirements of the automobile industry.

Fig. 9. Complete sensor system.

4. Results

4.1. Calibrated Output Signal

The sensor system provides calibrated analog or digital output signals for temperature and water mass.

The calibration process of the sensor is accomplished in a special climatic chamber under defined conditions. The dewing is traceable on the measurement of the dew point temperature and the

temperature, under the condition of a reproducible surface. The calibration of the water mass is realized by taking pictures of the sensor surface at different stages of dewing and simultaneous measurement of the output signal of the sensor. By means of image processing, knowing the contact angle of water at the sensor surface, and mathematical models, a correlation between the determined water mass and the output signal was fixed. An external processor processes the signals to an analog (0-1 V) or digital (I²C) output signal (Fig. 10).

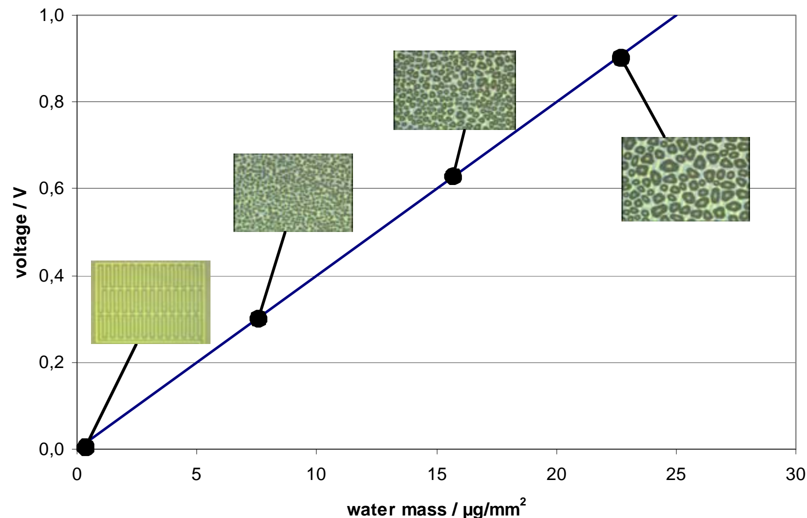


Fig. 10. Calibration curve.

The calibration of temperature is realized by comparison with resistance thermometer as reference in thermostat bath in dipping process.

4.2. Test Results in Automobiles

Different automobile suppliers have measured the condensation on different printed circuit boards at several places in an automobile and under different climatic conditions by means of the condensation sensor. The cars were tested under different climatic conditions such as time of day, entrance of several passengers, in the car wash, on the parking deck.

A variety of data in the boundary layer of the substrates and components as well as within electronic assemblies could be evaluated. One of the last tests was carried out at BMW, for example [10]. Mounting places chosen were the battery in the right-side tray, the transmission tunnel on the airbag sensor, the fuse box on the passenger side, the vehicle battery, the data acquisition, and the HIFI control unit in the rear trunk. Sensor modules are used to measure condensation and temperature as well as relative humidity and temperature. Fig. 11 shows the sensor modules placed on the HIFI control unit.

4.3. Tests in Climate Chambers

Based on the results in the automobile, comparable conditions were simulated in climate test chambers. With the standard ISO/DIS 16750-4 a temperature and humidity profile was defined to generate a dewing effect such as in an automobile environment (Fig. 12) [11].

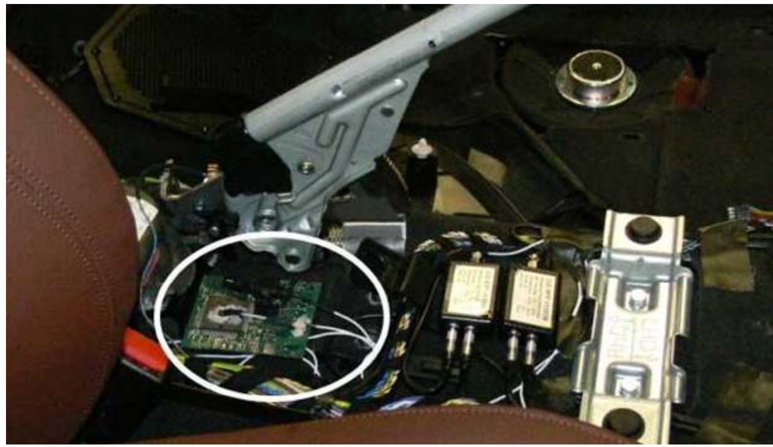


Fig. 11. Sensor module on HIFI control unit.

End of temperature rise
Start of temperature fall
100
95
Relative humidity % RH
100
90
80
70
60
50
½ h
½ h
½ h
Condensation
Drying
Time
+82
*78
½ h
½ h
+28
+25
+22
3/4
2
3/4
1 ½
3/4
5 h
1 cycle

Fig. 12. Dewing test cycle according to ISO/DIS 16750-4.

With the condensation sensor mounted on the surface to be detected, statements can be taken about the real micro climate at the boundary layer during the test cycle (Fig. 12).

The measured values in Fig. 13 confirm that during the cycle time of 3 h the surface temperature has increased from 25 °C up to 80 °C and a condensate of 15 µg/mm² has formed on the board.

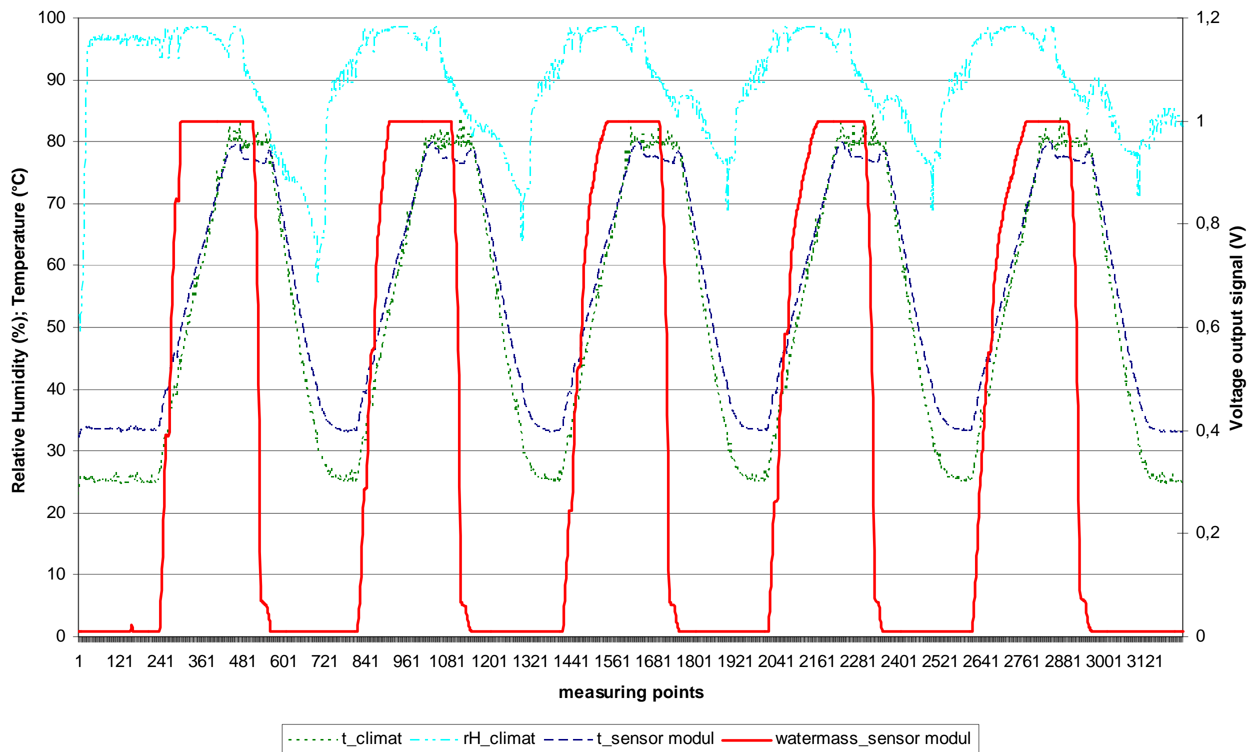


Fig. 13. Measurement of condensation during the dewing test cycle.

5. Conclusion

In the paper a miniaturized sensor system has been described. The sensor system allows first time quantitative measurement of condensate mass and temperature with calibrated output signals. The system is suitable for field measurement. Tests in climate chambers and in automobiles are presented.

This sensor system is a tool for reliability tests and to support R&D and production of highly integrated printed circuit boards.

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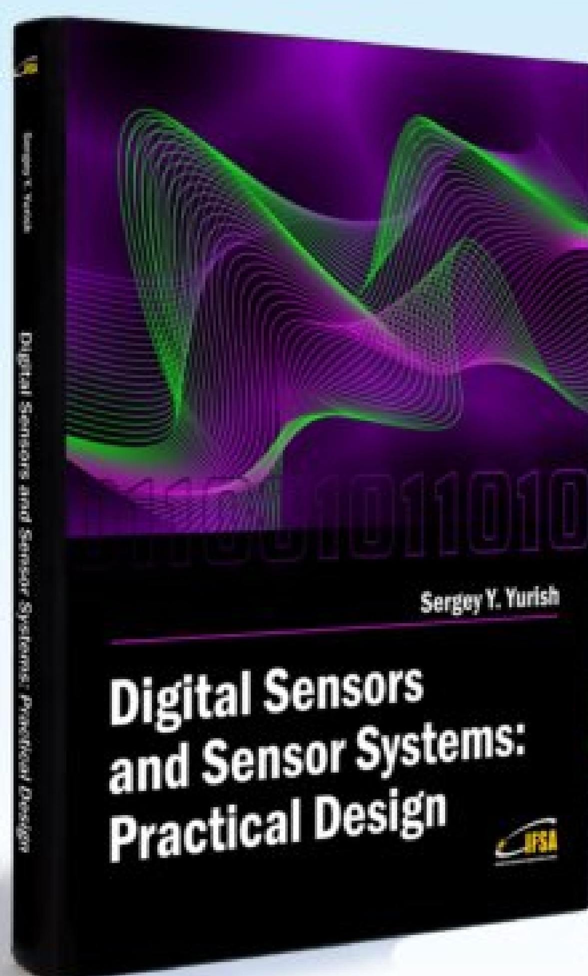

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