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MULTILAYERED SENSOR STRUCTURES FOR INTELLIGENT CONLROL SYSTEMS

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Abstract: A multifunctional sensor system using multilayered thick-film sensor structures based on spinel-type $NiMn_2O_4$-$CuMn_2O_4$-$MnCo_2O_4$ manganites and magnesium aluminate $MgAl_2O_4$ has been developed. The technological peculiarities of making nanostructured sensors have been represented. The circuit diagram of the monitoring system using nanostructured sensors and a microprocessor for signal processing has been proposed. This system can be successfully applied for intelligent monitoring and controlling environment.

Key words: sensor structure, environment, thick film, microprocessor system.

1. Introduction

Nowadays, the environment and bio-medical sensor electronics is an integral attribute of the modern human society. The sphere of sensor applications is still expanding [1, 2], even in the fields where human beings has managed to perceive some external environmental parameters using only the perception of senses. The sphere of sensor applications has been stretching from year to year, including such important branches as consumer electronics (air conditioners, audio amplifiers, cellular telephones, clothes dryers, computer power supplies, dishwashers, electric blanket controls, electric water heaters, electronic thermometers, fire detectors, home weather stations, oven temperature controls, rechargeable battery packs, refrigerator and freezer temperature controls, small appliance controls, solar collector controls, thermostats, toasters, washing machines, etc.); automotive (audio amplifiers, automatic climate controls, coolant sensors, electric coolant fan temperature controls, emission controls, engine block temperature sensors, engine oil temperature sensors, intake air temperature sensors, oil level sensors, outside air temperature sensors, transmission oil temperature sensors, water level sensors, etc.); medical electronics (blood analysis equipment, blood dialysis equipment, blood oxygenator equipment, clinical fever thermometers, esophageal tubes, infant incubators, internal body temperature monitors, internal temperature sensors, intravenous injection temperature regulators, myocardial probes, respiration rate measurement equipment, skin temperature monitors, thermodilution catheter probes, etc.); industrial, military and aerospace electronics and instrumentation (amplifier over temperature sensing, cellular telephones, copper coil winding temperature compensation, oscillator temperature compensation, rechargeable battery packs, transistor gain stabilization, transistor temperature compensation, etc.) and computer (power supplies with starting current limiting, uninterrupted power supplies, etc.).

Temperature and humidity sensors occupy a special place in this list [3], since monitoring and controlling these environmental parameters is a very essential economical task, and the importance of its resolving can hardly be exaggerated. These sensors are widely applied in humidity control and temperature-regulation automatic systems in food and light industries, agriculture (granaries, hothouses, greenhouses, incubators etc.), oil and gas pipelines. They are practically indispensable to medicine (for example, in the systems of breathing control, thermostats, operating rooms and pharmaceutics), the life-support systems in mineral resource industry, etc.

The aim of this work is the development of an intelligent multifunctional microprocessor system by using innovative nanostructured temperature / humidity sensitive thick-film sensors for measuring and controlling environmental parametres.

2. Development of sensor structures

Bulk thermosensitive ceramics have been prepared by the use of a conventional ceramic-making process with such reagents as grade copper carbonate hydroxide and nickel (cobalt, manganese) carbonate hydroxide hydrates [4, 5]. $Cu_{0.1}Ni_{0.1}Co_{1.6}Mn_{1.2}O_4$ ceramics have been sintered at temperature 1040 °C for 4 hours, $Cu_{0.1}Ni_{0.8}Co_{0.2}Mn_{1.9}O_4$ ceramics have been sintered at 920 °C for 8 hours, then for 1 hour at 1200 °C and at 920 °C for 24 hours.

Bulk $MgAl_2O_4$ ceramics have been prepared via a conventional sintering process as it was described in more details in [6, 7]. The pellets have been sintered according to a special mode of production at maximal sintering temperature 1300 °C for 5 h.

Temperature- and humidity-sensitive pastes for obtaining desired sensor systems have been prepared by mixing powder of basic nanostructured ceramics with ecological glass powder, Bi_2O_3 and an organic vehicle. The prepared pastes have been printed on cleaned alumina substrates with Ag electrodes using a manual screen-printing device. Then thick films have been baked in furnace PEO-601-084 at 850 °C [8]. This temperature-time firing mode is similar to one being applied for the metallization of dick-type thermistors.

The structure composed of a temperature-sensitive layer with p+-type of electrical conductivity based on $Cu_{0.1}Ni_{0.1}Co_{1.6}Mn_{1.2}O_4$ ceramics, a temperature-sensitive layer with p-type of electrical conductivity based on $Cu_{0.1}Ni_{0.8}Co_{0.2}Mn_{1.9}O_4$ ceramics, and a humidity-sensitive layer based on $MgAl_2O_4$ (i-type) is shown in the topological scheme (Figure 1).

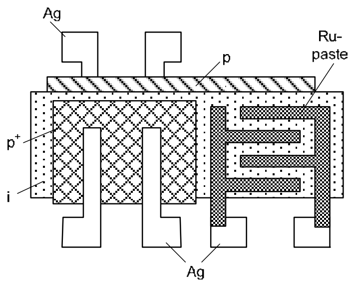

Fig. 1. Topological scheme of temperature/humidity sensitive thick-film structures

The temperature sensitive p^+ and p-conductive thick films based on spinel-type $NiMn_2O_4$-$CuMn_2O_4$-$MnCo_2O_4$ ceramics have good linear electrophysical characteristics in the temperature range from 298 to 358 K in a semi-logarithmic scale (Figure 2). The values of a temperature constant B are 3589 and 3630 K for p-, p^+-conductive thick films, respectively.

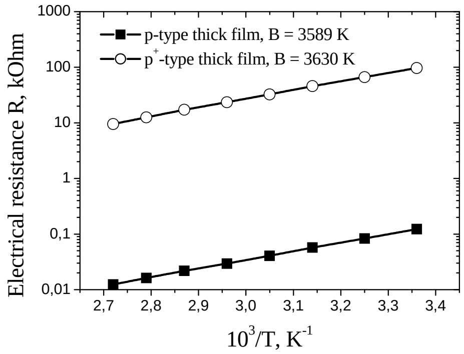

Fig. 2. R/T characteristics for temperature- sensitive p- and p^+-conductivity thick films

The insulating i-type humidity-sensitive thick film based on $MgAl_2O_4$ ceramics has a good linear dependence of electrical resistance on relative humidity without a hysteresis in the range of the relative humidity from 40 till 99 %, so it can be used for humidity sensors (see Figure 3). Since all the components (p-, p^+- and d-type thick films) are of the same chemical type (spinel) and possess high temperature/humidity sensitivity, they can be used not only for wider functionality (simultaneous temperature-humidity sensing), but also for providing unique functional reliability and stability.

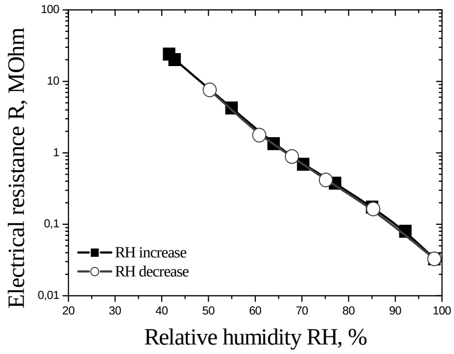

Fig. 3. Dependence of electrical resistance on relative humidity for humidity-sensitive thick- film structure

Owing to the results obtained, these nanostructured sensors can be successfully used in the design of measuring systems.

3. Microprocessor sensor system development

The system providing a specialized complex of temperature or / and humidity control has been realized on a modern element base with module organization, which is to work in the real mode of time. The control of the whole system and all its component units is performed by a microcontroller CY8C29466-24PVXI (Cypress Semiconductor), which is a crystal reprogrammable unit, containing all necessary modules.

There are some basic requirements to this system on the stage of its development, namely: modularity of the structure allowing the possibility of linking up new sensors in the future; functioning in the fully automatic mode; data acquisition and preprocessing; transferring data to a personal computer (PC) on demand in the automatic mode; receiving and performing the PC instructions (measurements, synchronization and calibration of sensors); the creation and support of local databasea containing the values of parameters measured over a long period of time with automatic accumulation of new information; openness of the structure and the software of the system to further developments and changes, including the introduction of new control algorithms.

The functional diagram of the soft- and hardware complex contains analog and digital parts (Figure 4). An analog part consists of nanostructured thick-film multilayered temperature and humidity sensors prepared by the authors, as well as units intended for adjusting the levels of their signals.

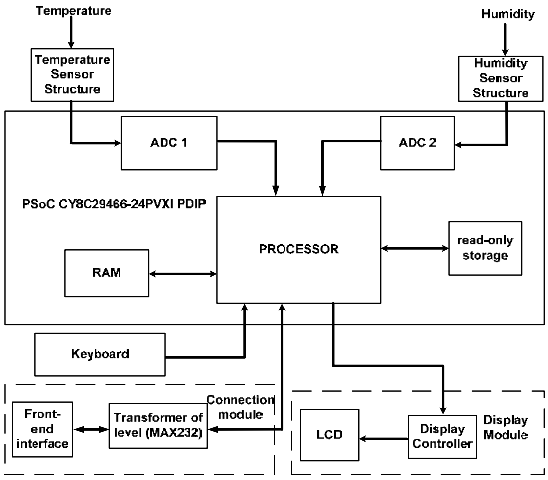

Fig. 4. Functional scheme of the proposed system

For making the results more accurate and linear, as well as providing nominal parameters (voltage/current) the additional adjusting schemes including active elements have been introduced (Figure 5). For such adjustments the resistors with values R1=220 kOhm, R2=220 kOhm, R3=680 kOhm have been used (as it is shown in schemes A and B). The resulting resistance of the activated temperature sensor (scheme A) is:

$$R_{\Sigma A} = R1 + Rt \,, \qquad (1)$$

where *Rt* is the resistance of the temperature sensor at the measured environmental temperature. The resulting resistance of the activated humidity sensor (scheme B) is:

$$R_{\Sigma B} = R2 + \frac{R3 \cdot Rp}{R3 + Rp} \,, \qquad (2)$$

where *Rp* is the resistance of the humidity sensor.

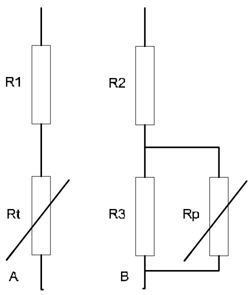

Fig. 5. Schemes of connection of active elements

The developed microprocessor system is a three-level structure. On the first level the temperature and humidity sensors are placed (if necessary, the use of other sensors is possible), whose reaction on certain environmental parameters is transformed into an electric signal which after the certain transformation (using a sample circuit) is given on the input of an ADC. The sample circuit provides the adjustment of levels of initial signals from the sensors according to the range of transformation of the ADC.

The electric circuit referring to the proposed system is shown in Figure 6.

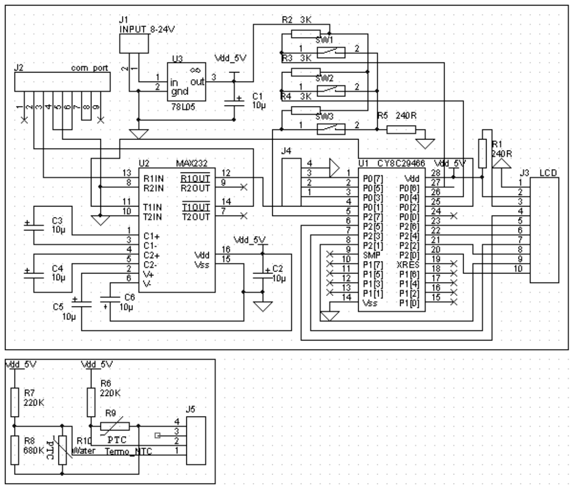

Fig. 6. Electrical circuit schematic of the proposed system

The microcontroller CY8C29466-24PVXI is intended for measuring and processing the information. Data transfer is performed through a COM-port with the help of a level transformer MAX-232. A liquid-crystal display (LCD) can also be used for providing the output of the measured values. Power supply of the system is arranged using voltage source from 8 to 24 V, and a load current of more than 100 mA. Receiving the information from sensors is performed from the ports P0 [3] and P0 [5] and is digitised with a built-in ADC. Microkeys have been provided for realizing possible changes of performance parameters, as well as for displaying information on the LCD.

The software, intended for managing the work of the system, has been developed for the microcontroller CY8C29466-24PVXI; the development has been executed using PSoC Designer 5.0 and the programming language C.

When the system is used with the sensors located in different places (complex monitoring), the measuring units will be able to independently and automatically accumulate, partly process and store the information received from the sensors, as well as to support the data exchange with the central terminal intended for the centralized processing and accumulating information from all complexes. The central terminal and the monitoring system as a whole can be served by one operator [8].

System software offers an operator the possibility of interactive communication, that allows the remote set of all measuring parameters; the change of intervals between measurings and getting information about the each sensor's performance in a user-friendly form.

In the ordinary mode each of the complexes is able to read data from the sensors several times a day. The obtained information proceeds to the central terminal during non personal operation. In this case the complex itself must compare the information from every sensor with the thresholds set beforehand and output the report to the central terminal.

The proposed automatic measuring system enables the possibility of varying the number of sensors, which means its multifunctionality.

For storage and processing the results obtained a database has been created. A basic class named Environmental Monitoring.java provides linking between the saoftware and the hardware of the monitoring system and its proper performing. The main window of the program allows to begin a new work cycle of the system and to create a new database, the time and date of its creation being fixed. The information from the RS-232 gets renewed each 5 minutes. It is stored in the database on a server. If the amount of information exceeds the capacity of the database set, the system executes the intermediate breaking and warns the user about the fact of exceeding of possible information amount.

System can work in a few following modes: temperature monitoring, relative-humidity monitoring and simultaneous temperature and humidity monitoring.

4. Conclusion

It has been shown that innovative temperature-sensitive thick-film structures possess sensitivity in the temperature range from 298 to 358 K and humidity-sensitive thick films are sensitive to the humidity from 40 to 98 %. The obtained thick-film structures have been successfully applied in temperature-humidity sensors.

The proposed intelligent microprocessor system containing the above mentioned sensor units can be used for the simultaneous temperature and humidity control in different environments.

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МУЛЬТИШАРОВІ СЕНСОРНІ СТРУКТУРИ ДЛЯ ІНТЕЛЕКТУАЛЬНИХ СИСТЕМ КОНТРОЛЮ

Г. Клим, Ю. Костів

Одержано мультишарові сенсорні товстоплівкові структури на основі шпінельної кераміки. Розглянуто технологічні особливості одержання наноструктурованих сенсорів. Показано можливість успішного використання одержаних сенсорних структур в інтелектуальних системах моніторингу та контролю.

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