Development of Porous Silicon Based Humidity Sensor and Organic Vapor Sensor Array with Integrated Signal Processing Systems

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Porous silicon (PS) has the potential of an excellent sensor material for developing CMOS compatible varieties of sensors like humidity, gas, organic vapors, pressure etc. in different applications such as environment monitoring, detection of toxic and explosive gases, food processing and biomedical. Extensive research work has been carried on to utilize this material for measuring relative humidity of the atmosphere. However, a practical PS humidity sensor has limitations for its commercial usefulness due to the nonidealities of the sensor response with humidity like nonlinearity, hysteresis, short-term drift due to ambient temperature and long-term drift due to aging. In this work, the limitations of the PS humidity sensor are addressed and ANN based softcomputing techniques have been developed to compensate all these errors. The range of humidity sensing has also been extended from percentage relative humidity (1 - 98 %) to the trace moisture in dry gas in the range of 6 to 200 ppm volume. With suitable formation parameters the morphology of the PS layers has been optimized as far as possible and it was observed that 55 % porosity p type sample gives sensing parameters like sensitivity, response and recovery time, reproducibility that are comparable to the parameters of the commercial porous alumina based trace level moisture sensor.

To measure the capacitive impedance of the PS sensor precisely at all humidity range suitable instrumentation systems based on either signal amplitude measuring active bridge (equivalent form of transformer ratio arm bridge) technique or the phase detection technique have been developed. Efforts are made to minimize the effect of parasitic earth capacitance and offset voltage of the sensor output. The detection electronics has been utilized to characterize the PS humidity sensor to determine the sensitivity, response and recovery time and the errors.

Studies have been made experimentally with both freshly prepared and post oxidized samples in different oxidizing medium to determine the nonlinearity, hysteresis, and variation of sensor output with temperature and time dependent aging of the PS layer. Suitable signal processing schemes based on ANN based softcomputing techniques have been developed for compensating these errors.
Experimental results show that adaptive linear neural network (ADALINE) based ANN technique can compensate the nonlinearity to 2.5% from its initial value of 13% while the hysteresis to 3% from its initial value of 16%. To compensate these errors to ±1% value multi layer perceptron based ANN network with tansigmoidal activation in the hidden layers have been utilized. Further ADALINE based network with suitable training parameters was also used to compensate the time dependent long-term drift of 13.5% to ±1% value.

Efforts are also made to hardware implement the error compensating ADALINE based ANN models of the sensor using either analog IC or Microcontroller (μC). Also an integrated signal processing unit based multilayer perceptron based neural network was developed to obtain the drifts (short-term and long-term) compensated linearized output with an accuracy of ±1%. Then the signal-processing unit was hardware realized using field programmable gate array (FPGA) chip.

Finally the morphological dependence on the sensitivity, selectivity, response and recovery time of the PS sensor has been extended to develop an organic vapor sensor array having different porosity and pore morphology for e-nose application. The different PS layers were utilized to determine the sensitivity and selectivity of the organic vapors; like ethanol, methanol and isopropyl alcohol. Response of the sensing layers to the organic vapors both individually and in mixture form is a unique fingerprint, which was analyzed by adopting (i) Matrix diagonalization based statistical technique and (ii) Multilayer perceptron (MLP) based pattern recognition with principal component analysis (PCA) technique. To improve the accuracy of recognition and to reduce the number of sensing layers required for correct representation of the fingerprint and subsequently to estimate the vapor concentration of the identified vapor in the mixture, an MLP based multiparametric approach with non-supervised PCA was found to be more suitable. The multiparametric approach allows correct representation of the fingerprint by collecting other features of the sensor like response and recovery time in addition to the sensitivity without the need of more sensing unit. PCA helps to reduce the complexity of the data matrix by extracting the more informative
features of the data. At last, a PS vapor sensor array with four sensing units having different porosity on the same silicon substrate was fabricated.

Enclosure: List of publications in journals


**Book:**