Topic: 3

Novel Gas Sensors Based on Thin Film Bulk Acoustic Resonators

W.Reichl*, J.Runck*, M. Schreiter+, E. Green# and R. Gabl+

*E+E Elektronik GesmbH., 4209 Engerwitzdorf, Austria, wolfgang.reichl@epluse.at

+Siemens AG, Corporate technology, 81739 Munich, Germany

#Bath University, Bath, United Kingdom

Summary

This paper describes the application of thin film bulk acoustic resonators (TFBAR) with an operating frequency around 2 GHz as gas sensors. The sensor consists of a solidly mounted thin film ZnO resonator fabricated on a silicon substrate covered with a gas sensitive polymer receptor. The sensitivity of the device for vapors and gases like humidity or carbon dioxide has been measured. The TFBAR sensitivity is up to two orders of magnitude higher compared to conventional quartz microbalance sensors. The sensitivity for a given target gas depends in a nonlinear way on the receptor thickness. Furthermore, the characteristics of the sensitivity versus receptor-thickness curve depends significantly on the target gas and allows a discrimination between gases. The TFBAR-gas sensor performance and the novel observation of a thickness dependent selectivity of a receptor material are discussed.

Motivation

While mass sensitive acoustic sensors like quartz crystal microbalance (QCM) and surface acoustic wave sensors (SAW) have been widely used as transducers in chemical sensors, TFBAR's (see Fig.1) have not yet been explored in chemical sensing. Due to their high operating frequency TFBAR should exhibit considerably higher sensitivities and in addition they hold a potential for miniaturization and integration.

Results

ZnO based TFBAR transducers have been fabricated[1] and coated with a polyimide based receptor layer to explore the gas sensing capability. The resonance frequency shifts as a function of target gas (e.g. humidity) concentration have been measured (see Fig. 2). Table 1 highlights the 100-fold increased sensitivity of the TFABR. Fig.3 shows the sensitivity as a function of receptor layer thickness for humidity and carbon dioxide. For both gases the sensitivity changes its sign and is enhanced when the receptor thickness increases. This behavior indicates the transition from a pure gravimetric response - caused by gas absorption in the acoustically thin receptor layer - to a response that is determined by the change of the acoustic properties of the in relation to the wavelength "thick" receptor layer upon gas absorption in the polymer. In table 2 the selectivities of the receptor material determined with a QCM transducer and with the novel TFBAR transducer are compared. The selectivity of the TFBAR sensor can be controlled and tuned by varying the receptor thickness.

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[1] R. Gabl, et al., "Novel Integrated FBAR Sensors: a Universal Technology Platform for Bio- and Gas-Detection", Proceedings IEEE Sensors 2003, p. 1184-8 (2003)

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Figures

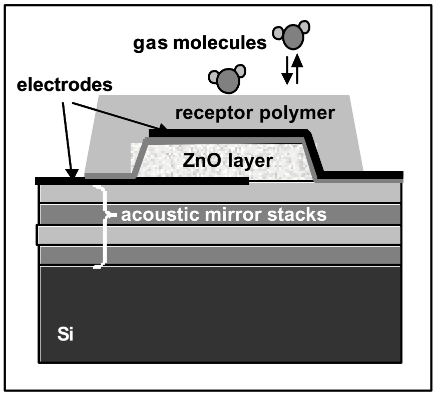

Fig. 1: Scheme of the solidly mounted TFBAR transducers covered with a polymer receptor.

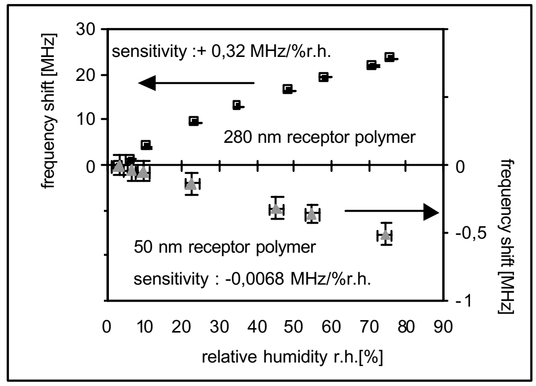

Fig. 2: Resonance frequency shift as function of relative humidity for two polymer layer thicknesses.

Table 1: Sensitivity for humidity measured with a TFBAR and with a QCM each device covered with poly mer receptor. Thickness of the receptor as indicated.

TFBAR (2 GHz) receptor thickness [nm]	frequency normalised sensitivity (humidity) [ppm /%]
50	-6,8
280	+160

QCM (10 MHz) receptor thickness [nm]	frequency normalised sensitivity (humidity) [ppm /%]
200	-0,57
930	-1,3

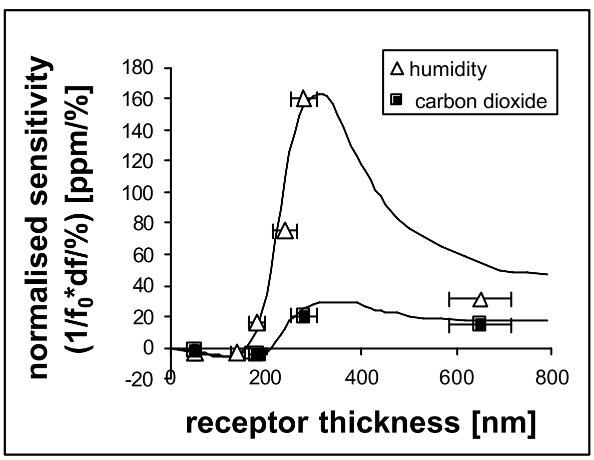

Fig. 3: Sensitivity of TFBAR-device versus thickness of the polymer coating for humidity and carbon dioxide. Measurement (points) is compared with simulation (line).

Negative frequency shifts due to mass attachment to the receptor are observed at small receptor thickness. A positive and strongly enhanced sensitivity is observed at intermediate receptor thicknesses, where the response is governed by changes in the acoustic properties of the receptor layer.

Table 2: Selectivity (defined as the sensitivity for H_2O divided by sensitivity for CO_2) of the polymer receptor measured with a TFBAR and with a QCM device. The selectivity determined with the QCM transducer is independent of the receptor thickness, whereas that determined with the TFBAR varies with receptor thickness.

TFBAR (2 GHz) receptor thickness [nm]	selectivity (H_2O vs. CO_2)
50	1,7
180	-3,9
280	7,8

QCM (10 MHz) receptor thickness [nm]	selectivity (H_2O vs. CO_2)
140	1,8
930	1,9
2300	1,8