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Planar Microstrip Ring Resonator Structure for Gas Sensing and Humidity Sensing Purposes †

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Abstract: A planar microstrip ring resonator structure on alumina was developed. It was covered with a zeolite film. The device was successfully operated at around 8.5 GHz at room temperature as a humidity sensor. In the next step, an additional planar heater will be included on the reverse side of the resonator structure to allow for testing of gas sensitive materials under sensor conditions.

Keywords: radio frequency gas sensing (RF); microwave sensors; zeolite in operando spectroscopy

1. Introduction

In typical chemiresistors, gas sensitive functional films [1,2], especially of zeolite films, are applied on interdigital electrodes and their resistances or their complex impedances are determined [3–8]. Mostly, sensors are operated in the range of room temperature to 400 °C. High ohmic electrode-film interfaces and/or very high resistivities of the sensitive materials may prevent promising sensor materials from technical application.

However, as an alternative approach, microwave transducers have also been suggested. They have been attracting research interest in recent years [9–12]. They are even applied in automotive exhausts to monitor directly the status of zeolite-based SCR catalysts [13,14].

Microwaves are usually used for sensor purposes in a guided form with hollow or planar waveguides. The favored interest of these phenomena is the interaction with the permittivity of the material and thus the dependence on the wave-transmitting medium. Considering the trends and interests in gas sensors, attention has been directed towards the sensing and material characterization purposes of the planar waveguides due to their miniaturized, inexpensive and sensitive characteristics.

Another important issue and general requirement for gas detection with microwaves are gas adsorbing sensitive materials. Zeolites are a favored material for this, since many gas adsorbing zeolites are also used for catalytic purposes and thus from great interest [15]. Usually, beneath the need of a gas sensitive layer, a general preferred and challenging criterion is a miniaturized and integrated device structure.

Therefore, we suggest gas sensors using planar microstrip ring resonator structures with integrated heaters that are covered with the sensitive films to determine the complex material permittivity that depends from the ambient gas concentrations. As an initial step, design studies were conducted and first sensors were manufactured and characterized at room temperature.

2. Experimental

For that purpose, as a first step, a planar ring resonator structure has been designed (COMSOL Multiphysics) and characterized. In contrast to Zarifi et al. [9], who recently suggested a similar idea, no active feedback loop could be used, since it is intended to heat the sensor to several hundred °C. The resonator was initially designed for transmission and reflection measurement (Figure 1).

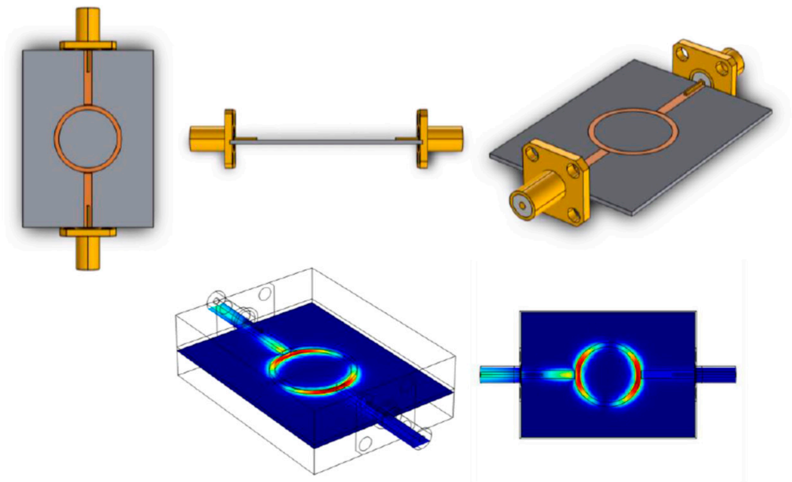

Figure 1. Typical setup (**top**) and modeled field distribution by COMSOL Multiphysics (**bottom**). Later, the ring area was covered by the sensitive functional material (zeolite).

It consists of an alumina substrate, covered with laser-patterned gold microstrip lines. The ring resonator itself is covered with the functional material. An SMA plug connects the sensor to a network analyzer.

3. Results

For the first tests at room temperature, an iron-exchanged zeolite film was applied and fired at 600 °C. The response towards water was measured in the reflection mode. Figure 2 shows the final device.

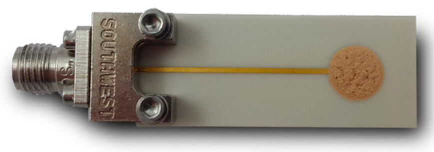

Figure 2. Final sensor device for measuring the reflection parameter S_{11}.

The sensor was placed in a gas test rig and was exposed to pure nitrogen. Typical resonance spectra are shown in Figure 3. The blue curve denotes a spectrum of a sensor after storage in air. The black and the red curve were recorded after purging with nitrogen. One can clearly see that both the resonant frequency (f_{res}) and the modulus of the reflection coefficient at resonance ($|S_{11}|$) are affected due to the incorporation of water into the zeolite during storage at ambient air, since water changes the zeolite's permittivity. Later, defined water contents were admixed. After water exposure, the test chamber was again purged with nitrogen. Figure 4 is a time-dependent plot of f_{res} and $|S_{11}|$ for 1 vol. % and 2 vol. % water admixed to nitrogen. One can clearly see that the device responds to water. Adsorbed water can be desorbed in water-free nitrogen even at room temperature, but the process requires a longer time.

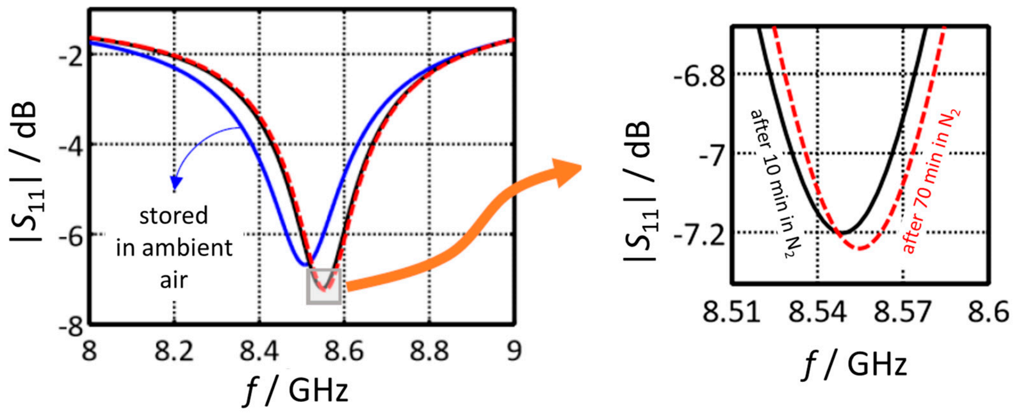

Figure 3. Typical resonance spectra of the device shown in Figure 2. The blue curve denotes a spectrum of a sensor after storage in air. The black and the red curve were recorded after purging with nitrogen.

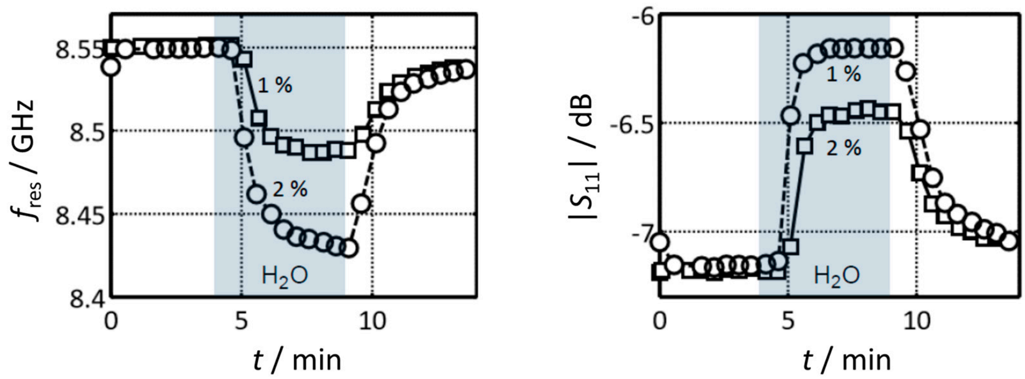

Figure 4. Resonant frequency (**left**) and reflection parameter at resonant frequency (**right**) when exposed to nitrogen and water (1 vol. % and 2 vol. %) in nitrogen.

4. Conclusions and Outlook

Therefore, we intend to extend this setup with an additional heater on the reverse side of the resonator structure. Then, a material testing system could come in sight that allows for testing of gas sensitive materials under sensor conditions. With an inexpensive evaluation circuitry, also a direct sensor operation should be possible.

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Conflicts of Interest: The authors declare no conflict of interest.

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