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Telemetric surface acoustic wave sensor for humidity

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Abstract. Surface acoustic wave sensors consist of a piezoelectric substrate with metal interdigital transducers (IDT) on top. The acoustic waves are generated on the surface of the substrate by a radio wave, as it is well known in band pass filters. The devices can be used as wireless telemetric sensors for temperature and humidity, transmitting the sensed signal as a shift of the sensor's resonance frequency.

1 Introduction

The insulation capability of the oil in high voltage power transformers strongly depends on its humidity content. As known from literature, the maximum electrical field before spark discharge occurs descents dramatically, if the water content of the transformer oil rises to about 50 ppm. It is the aim of the power plants owners to get information about the current oil condition continuously. Due to the extreme environment inside the transformer it is not possible to use sensors with wires for power supply and data transfer.

The approach of this work is to use surface acoustic wave (SAW) sensors to measure the humidity content of the oil by telemetric data acquisition. The sensor consists of an interdigital transducer (IDT) on top of a piezoelectric quartzite chip, which converts an electrical input signal of a radio wave into an acoustical wave propagating at the surface of the sensor material. The surface wave is transformed back into an electromagnetic wave by another IDT located on the SAW sensor (delay line), or by the same IDT in case of a resonator structure (Fig. 1). In both cases the transmitted frequency can be detected by high sensitive receivers.

The velocity of the acoustic wave respective its frequency depends on the density of the surface material of the sensor. The captured humidity reduces the density, so the transmitted frequency received by the detector drops. The paper describes the principles of the SAW sensor for applications in liquids, its integration technology, and the first measurement results.

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2 Acoustic waves

There are different modes of SAWs, which can be selected by the set up of the sensor structure. Most common in SAW band pass filters are Rayleigh waves (Fig. 2). These waves consist of oscillations partly perpendicular to the sensor surface, partly in the propagation direction. The first part of the wave results in an energy transfer out of the wave into the ambient, so it is suitable for gases only. In case of liquids the propagation loss is very high, so this kind of wave is not suitable for sensors operating in oil.

More useful seems to be a transversal acoustic wave, which is called a “Love”-wave. This kind of wave consists of oscillations parallel to the sensor surface, but perpendicular to the propagation direction (Fig. 3). Because there is no amplitude of the wave perpendicular to the surface plane, the propagation loss for this kind of wave is very low even in liquids like oil.

The wavelength of the stimulated acoustic wave corresponds with the periodicity of the IDT finger structure. Only those waves with a wave length of two times the pitch of the IDT will cause a surface acoustic wave with the well defined frequency of the resonance mode. This means the resonance frequency can be defined by the layout of the IDT structure.

Due to the humidity dependence of the resonance frequency, the transmitted signal from the sensor is a measure for the ambient humidity.

3 Sensor integration

As it is necessary to convert the electric signal into a surface wave, piezoelectric substrates like quartzite or Lithiumniobate are suitable for SAW sensor applications. Quartzite seems to be the adequate material due to its compatibility to standard silicon technology, which is used to integrate the

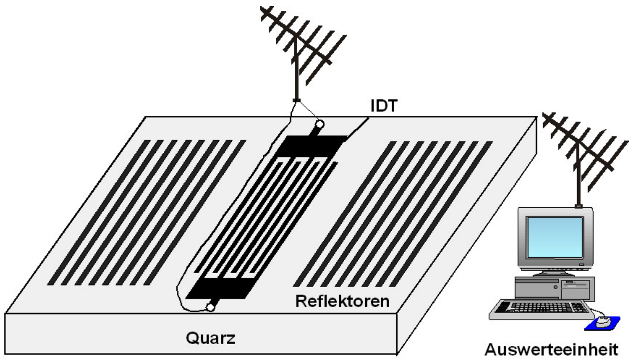

Fig. 1. SAW sensor system consisting of an SAW sensor, antennas and a receiver unit.

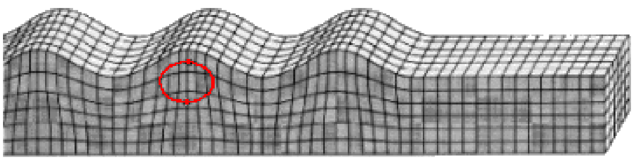

Fig. 2. Sketch of a Rayleigh wave propagating at the surface of a solid.

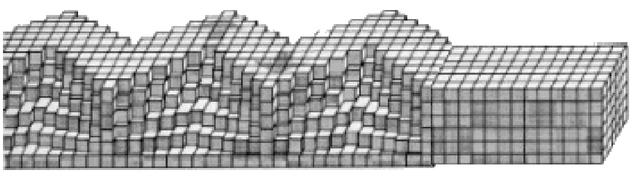

Fig. 3. Sketch of a love-type surface wave propagating at the surface of a solid.

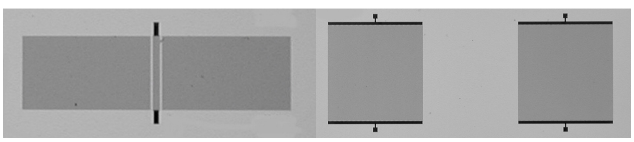

Fig. 4. Photograph of the SAW sensors, left a resonator, right a delay line device.

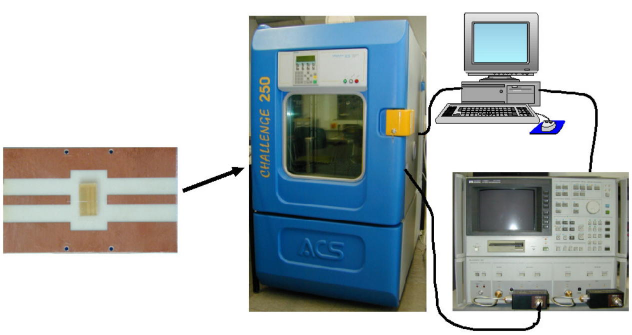

Fig. 5. Test device mounted on a circuit board for a test in the climatic chamber.

sensor device of this paper. The process starts with the deposition of aluminium on top of the cleaned quartzite wafer (100 mm in diameter) either by e-beam evaporation or by magnetron sputtering. Next a photo lithography step using vacuum contact and UV exposure defines the metal structures on the surface. Typical structure sizes are in the range of 1 μm. The aluminium layer is etched by chlorine chemistry applying reactive ion etching. Then the resist is removed in oxygen plasma, so the IDT structures are completely finished (Fig. 4).

The stimulation of a love wave in the sensor device requires a top layer on the substrate surface, where the velocity of the acoustic wave is lower than in the quartzite itself. On the other side, the humidity sensor needs a humidity sensitive layer on top. Silicon oxide can meet both requirements in case of a PECVD oxide. Due to its porous character it is able to adsorb humidity. Nevertheless, it is not known if an oxide layer is suitable in oil ambient.

4 Measurement set-up

First tests of the sensor have been performed in ambient atmosphere at well defined temperature and humidity. The test equipment consists of a network analyser and a climatic chamber, which are controlled by a computer (Fig. 5).

The network analyser sweeps the frequency from 1 kHz up to 500 MHz and transmits the electromagnetic signal to the sensor device. In case of resonance with the IDT structure, only little energy is reflected. So the scattering parameter S_{11} strongly drops in case of the resonance frequency at the input.

The device under test is mounted on a 50Ω circuit board while the electric connections consist of ultrasonic bonds. Up to now no broadcast transmitting/receiving has been realized.

5 Results

The temperature dependence of the sensor's resonance frequency is depicted in Fig. 6. Due to the raising temperature the velocity of the acoustic surface wave in the sensor drops continuously, so the resonance frequency descents with increasing temperature.

The regression line of the frequency-temperature diagram results in −47 kHz/K. This high sensitivity allows a resolution in the mK range.

The dependence of the resonance frequency on the relative humidity is shown in Fig. 7. An increase in the humidity concentration results in a reduced density of the sensing material, so the acoustic wave velocity drops again. The sensitivity is about −74 kHz/%.

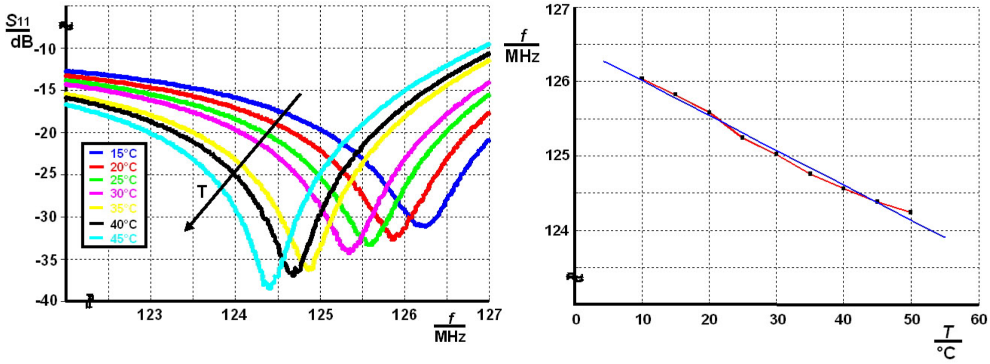

Fig. 6. Temperature dependence of the scatter parameter S_{11}, reflecting the resonance frequency of the sensor.

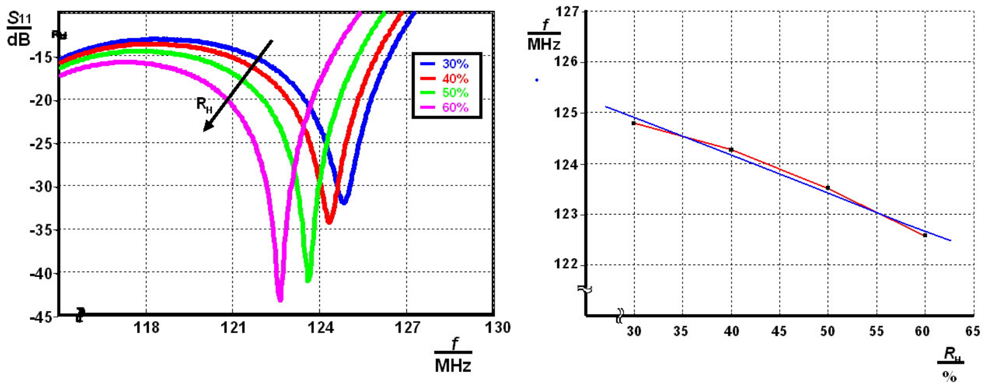

Fig. 7. The S_{11} parameter reflecting the resonance frequency of the SAW sensor versus the input frequency with the relative humidity as the parameter.

6 Conclusion

SAW sensors strongly react on humidity and temperature changes in the ambient atmosphere. Sensitivities of about −47 kHz/K for temperature and −74 kHz/% for humidity were achieved with an resonator type SAW sensor consisting of 20 IDT fingers and 500 reflectors. Although these results are satisfactory, it is not sure to reach the aim of detecting 50 ppm of humidity in transformer oil.

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