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A Wireless, Passive ID Tag and Temperature Sensor for a Wide Range of Operation

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Abstract

Surface acoustic wave (SAW) devices are since long known for their wireless sensing capabilities in harsh environment. While the mainstream of the investigations was so far dedicated to room temperature or high temperature applications, we have demonstrated the employment of SAW based sensors at temperatures down to -200°C. We constructed SAW sensors for cryogenic temperatures that are based on reflective delay lines and feature a unique identification number. We tested them in a dedicated setup during cooling, both wired and wireless. As results figures for the reading range, the temperature resolution and reproducibility were derived. The devices show a good and reliable performance in an operating range from -200°C to 200°C.

Keywords: SAW, Surface acoustic wave; low temperature; sensor, wide operation, ID Tag

1. Introduction

The described wireless devices are based on reflective SAW (Surface Acoustic Wave) delay lines [1]. They work as temperature sensors and ID tags in a wide temperature range. The completely passive functionality allows to operate these devices at very low temperatures, where battery powered devices come to their active limit. Hence, the SAW based sensors/tags provide an alternative to wired temperature sensing or identification e.g. in climate monitoring or stock control. In medical applications it might be important that the devices provide accuracy of temperature measurements at a distance of a few meters with the power radiated by the reader antenna which is 20 times lower than the power radiated by mobile phones.

2. Experimental

The sensors are built on 128° rotated Y-cut of Lithium Niobate and operate in the 2.45 GHz ISM band. The bandwidth of about 80 MHz provides a good time resolution of the signal. Fig.1 (a) shows the time response of a typical delay line sensor. Eight peaks can clearly be identified. Three peaks are used to determine the sensor temperature from the change of the round trip delay time, while the other 5 peaks are used for a pulse position encoding, with a code volume of 2^{20} [2,3]. The dies are packaged in a metallic housing using a dedicated assembly technology. A metallic slot antenna was used for the wireless investigations, Fig.6 (b).

After the design has been verified by wafer level measurements, the identification capability was checked by operating the devices wirelessly on a hot plate. These high temperature measurements are a challenge as the propagation losses of SAW increase with temperature, see Fig.1 (a). The ID was read out by an FSCW reader operating in the ISM band while the devices were heated from room temperature to more than 200°C.

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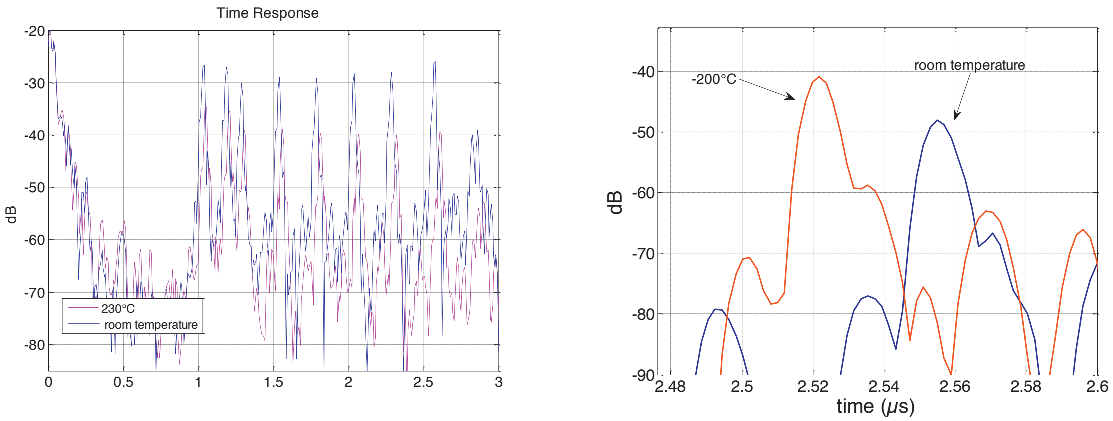


Fig.1 Time response of wireless measurement of an ID tag and temperature sensor for room temperature and at 230°C (a). Change of delay time and amplitude during cooling. The amplitude increases of about 6.6dB for a peak at 2.55µs (b)

As expected from our experiences with high temperature SAW sensors [4, 5], all IDs were correctly identified in this temperature region. Further investigations were hence focused on low temperature.

We constructed our own measurement setup that allows assessing the devices during cooling. Two temperature sensors were installed next to the SAW sensors to ensure good temperature reference. Fig. 2 shows the cooling equipment and the sample holder. The setup uses a Peltier cooler in a cylindrical, vacuum tight housing. The test jig allows the installation of up to 4 packaged SAW sensors in direct thermal contact with the cooling head. In addition to the thermal isolation provided by the vacuum of 5.10^{-7} mbar, several temperature shielding foils were used to minimize the thermal heat flow from the surroundings. With this setup the S-parameters were collected down to temperatures of -200°C and analysed in time domain. This data was used to check the ID and to derive the calibration parameters of the SAW sensors. The signal to noise ratio is better at -200°C than at room temperature. Fig.1 (b) demonstrates the change of delay time and the decreased losses at low temperatures for one signal peak at about 2.5µs. Using the relative signal change of the first and last peak we observed a change of about -1.14 dB/°C µs. In Fig.1 (b) the total the signal increases by about 6.6dB which results in a better reading range and higher accuracy of the temperature measurements.

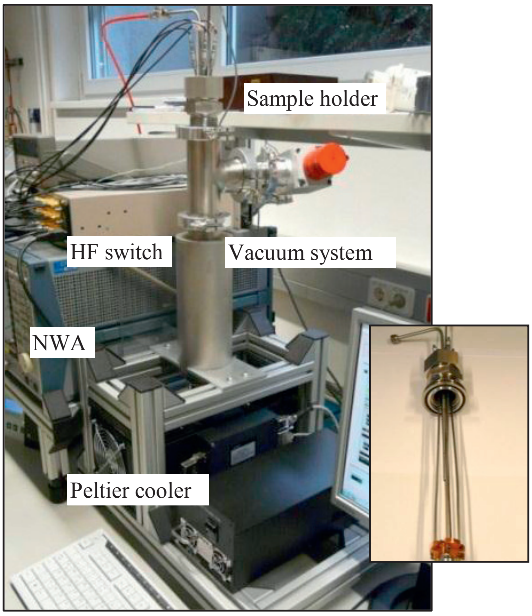


Fig. 2 Setup for wired cryogenic measurements including Peltier cooler, vacuum system (turbo vacuum pump 10^{-7} mbar), network analyser (NWA), and HF switch. The inlet shows the sample jig for 4 packaged SAW devices including a reference temperature sensor.

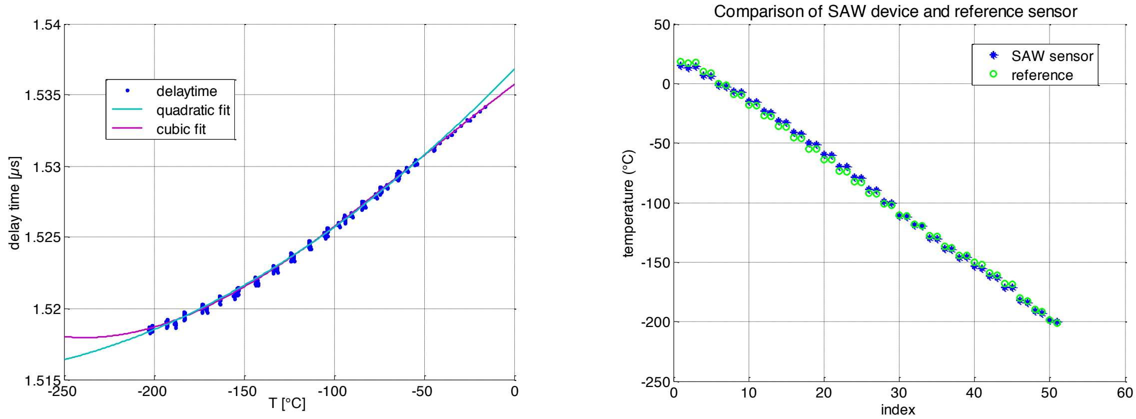


Fig.3 (a) Calibration curve obtained from 10 cooling cycles, measured wired with a network analyser. (b) Comparison of a wireless measurement with the FSCW reader using the derived calibration parameters, with a reference sensor.

Fig. 3(a) shows the correlation between delay time and temperature from room temperature down to -200°C. The figure contains the data of ten cooling cycles of one device. The calibration parameters were obtained by correlating the delay time as derived from the network analyser measurements with the temperature of a Pt 100 reference sensor, installed in the same metallic housing as the SAW devices. Down to about -130°C we observed a quadratic behaviour with a linear coefficient of 77ppm/°C and a small quadratic term of 98 ppb/°C. These values are in reasonable agreement with the published TCD of 75ppm/°C of the 128° rotated cut of Lithium Niobate [6], if one considers that the measurements weren't done on a free surface, but with reflective delay lines and glued inside a package. At lower temperatures the change is described better by a cubic function. This could indicate that the TCD (Temperature Coefficient of Delay) goes towards zero near absolute zero, as it demands the basic physics, but may also be caused by the glue or a bias of the reference sensor due to thermal heat flow. As a starting point we have used the calibration parameters obtained from the mean value of the quadratic fit of ten devices with different IDs as calibration parameters in the FSCW reader. Fig.3 (b) shows the comparison of the temperature derived by a wireless measurement with the calibrated FSCW reader and the reference sensor installed in the cooling head. The agreement for this calibration using average parameters is ±1.5 °C.

The cyclic cooling was also used to check the stability of the devices. 12 devices were cooled and heated 10 times and the investigations, which took 30h per device, confirmed that the delay time (e.g. Fig.3 (a)) and the amplitude are reproducible. As we observed no malfunction or degradation, we can state state a lifetime for at least 10 cooling cycles.

Besides the low temperature assessments we accomplished performance tests at room temperature. As the signal amplitude increases with cooling, the obtained values provide worst case benchmarks for the sensor performance in cryogenic applications.

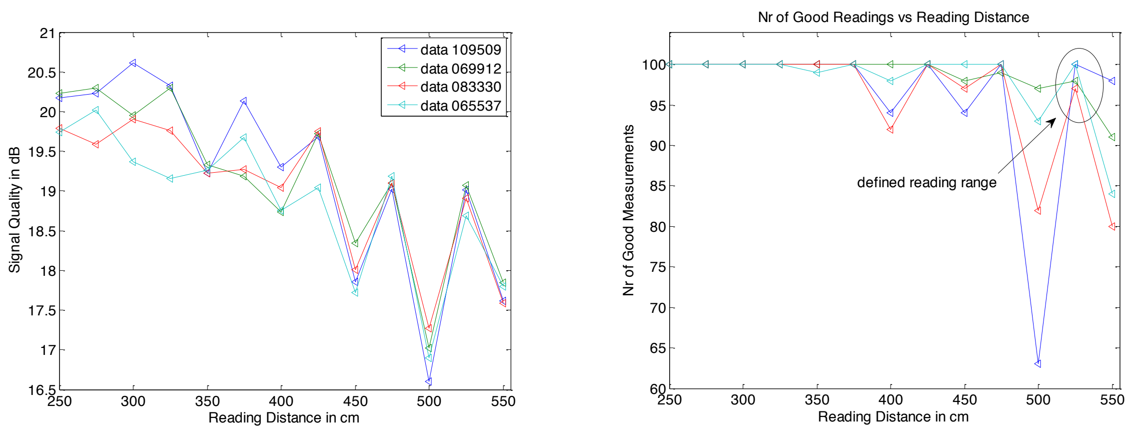
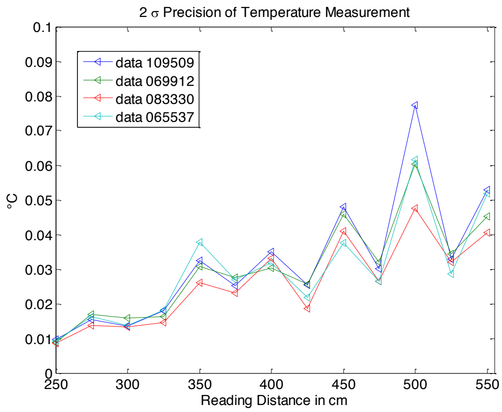


Fig. 4 Signal quality and number of valid ID and temperature measurements versus reading range



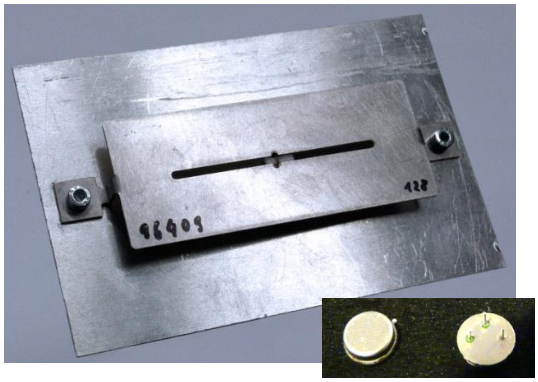


Fig.5 Resolution of temperature measurement versus reading range (a) and picture of an ID sensor connected to a slot antenna (b)

The reading range was measured with a 7dBi sensor antenna and 25mW emitted power. We used the number of correct readings and the signal strength as parameters for the reading range. For all readings below 2.5m the yield of valid measurements was 100%. As wireless measurements are always effected by alignment of receiving and emitting antennas and electromagnetic interferences, the number of true measurements is hardly ever 100% at larger reading distances. We have chosen a limit of 95% correct temperature and ID readings. This definition results in a reading range of more than 5.25 m. The results of the range assessments of four ID tags can be seen in Fig. 4. The good values correspond to a signal to noise ratio > 18.5 dB as can be seen in Fig. 4(a). The signal quality is used as a threshold in the reader software to indicate reliable data.

As the resolution of the temperature measurement depends on the signal to noise ratio it deteriorates with the reading distance. Fig. 6 (a) shows the resolution, defined as two times the variance (2σ) versus reading distance for four sensors. For a reading distance ≤ 2.5m the precision is better than 0.01°C, while for 5.5m the results are still excellent with a 2σ variance of about 0.05°C. (The inferior values of the 5m measurements can be ascribed to imperfect adjustment of the antennas).

3. Conclusion and outlook

This work demonstrates that SAW reflective delay lines can be operated as reliable temperature sensors and ID tags in a wide temperature range, from -200°C to 200°C. They provide a resolution in temperature of 0.05°C and a reading range of more than 5m. Such sensors with ID number, demanding no battery and no technical support can find application in severe conditions, such as permafrost, monitoring of disaster situations, blood banks etc. Low radiation of RF power by readers is an advantage for applications in medicine and in all other cases where human or animal exposure to EM radiation can be considered as unwanted.

We are currently working on further assessments of the reference sensors to ameliorate the absolute calibration of the devices.

Acknowledgement

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