SAW Resonators at High Temperatures

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SAW Resonators are suitable for sensor applications in sensor systems with the capability of wireless remote sensing. It has been proved that quartz substrates can be used for temperatures up to 300°C. In this way a large temperature range is covered which is important for many industrial applications. But lots of measurements have to be done under extreme conditions. So the interesting temperature range is seated above 300°C. From the point of view of SAW technique this concerns the substrate material and the metalization layer as well. For the piezoelectric substrate Galliumorthophosphate (GaPO₄) and Langasite (La₃Ga₅SiO₁₄) were chosen. These crystals both offer a promising piezoelectric behavior at temperatures up to 900°C. For the high temperature application it is necessary to use a noble metalization layer instead of the commonly used Al. This is necessary to protect from oxidation processes at these temperatures. Therefore Pt was chosen for both crystals. After a short description of the resonator design structure and the production procedure of both types of resonators, the electrical behavior under high temperature conditions (up to 600°C) is considered. The experiments show that the electrical characteristics (e.g. quality factor) suffer not only from the substrate but also from the physical properties of the metalization. Furthermore changes in the stability of the devices occur under the influence of high temperature. The results of the calculations and the measurements will be presented, compared and discussed.

High - Temperature Stability of LiNbO₃ and Quartz Based SAW Devices

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The high temperature stability of SAW devices based on LiNbO₃ and Quartz is investigated in this paper for high temperature applications up to 400° C. Driven by the need for high temperature applications based on sophisticated
SAW technology, e.g. temperature measurement and identification, Quartz and LiNbO₃ have been examined, regarding low cost solutions and mass production. Using a high temperature oven and a network analyser the acoustic attenuation loss and the aging of the devices have been observed. The aging and demoli-
tion of substrates and metalizations have been investigated in detail to make an estimation of the economic life-time. The test series gives information about the temperature limit for short time stability, the long time behaviour and the mechanisms of damage on the surface of the devices. An estimation of the eco-
nomic life-time to lower temperatures according to an Arhenius equation follows. Considering Quartz and LiNbO₃ as a standard substrate for SAW applications this paper shows the capability of those devices for temporary usage.

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TOWARDS AN UNDERSTANDING OF THE ANOMALOUS ELECTROMECHANICAL BEHAVIOUR OF LGS AND RELATED COMPOUNDS AT HIGH TEMPERATURES

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Due to their promising electromechanical properties and the suspected absence of phase transitions between room temperature an their melting points, most members of the Ca₃Ga₂Ge₄O₁₄ family are candidates for high temperature piezo-
electric applications such as SAW devices. However, most of these crystal species suffer from strong ultrasonic attenuation effects evolving at higher temperatures. The origin of the dissipation is not yet fully understood.

With the aid of resonance ultrasound spectroscopy, impedance spectroscopy, an inductive gauge dilatometer and X-Ray diffraction techniques, we determined the elastic, piezoelectric and dielectric constants including their temperature coefficients, the specific conductivity and the coefficients of thermal expansion of La₃Ga₅SiO₁₄ (LGS) and La₃Ta₀.₅Ga₅.₅O₁₄ (LGT) between 150K and 1000K. Further, we derived from ultrasonic resonance spectra coefficients of internal friction associated with individual elastic constants.

The most remarkable feature of the high temperature behaviour of LGS and LGT is a rapidly evolving ultrasonic dissipation. In both compounds the coefficients of internal friction increase between 450K and 850K by more than three orders in magnitude and become nearly isotropic. The attenuation is accom-
panied by a softening of all elastic stiffnesses. The electric conductivity, which increases at higher temperatures according to an Arrhenius law, cannot account for the observed effects. It is more likely that structural defects mainly contribute to the ultrasound absorption. This picture is supported by the observation that depending on thermal treatment the high temperature state can be frozen so that attenuation effects already occur at room temperature.
RELIABLE CURIE TEMPERATURE MEASUREMENTS
FOR CHEMICAL COMPOSITIONS OF LiTaO$_3$
CRYSTALS FOR SAW DEVICES

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The demand for surface acoustic wave (SAW) devices has been rapidly increasing in association with the recent proliferation of mobile communications systems. Growing homogeneous crystals in a chemical composition ratio is important for realizing high-performance SAW devices. The Curie temperature, $T_C$, is closely related to the chemical composition ratio and has been widely used as an indicator for evaluating the chemical composition ratio of LiTaO$_3$ single crystals. We have been studying accurate material evaluation techniques using the line-focus-beam ultrasonic material characterization (LFB-UMC) system. Evaluation is made by measuring the velocity of leaky surface acoustic waves (LSAWs), $V_{LSAW}$, excited on the water-loaded specimen surface. We presented a guideline for the standardized evaluation using the interrelationships among the $V_{LSAW}$, chemical composition ratio, and $T_C$ for LiTaO$_3$ single crystals. We then suggested that $T_C$ values measured by different crystal manufacturers possibly differed depending upon the measurement conditions of each manufacturer. This is a serious problem for establishment of the standardized specifications of piezoelectric single-crystal SAW wafers.

In this study, we first investigate dependences of measurement condition parameters (particle diameter and weight of sample, heating rate, room temperature $T_R$, and so on) on $T_C$ measured by differential scanning calorimetry (DSC). In particular, it is clarified that the temperature environment is also a very important factor and the $T_R$ should be controlled within $\pm 2^\circ$C to reduce the $T_R$ dependence to less than $\pm 0.3^\circ$C in the $T_C$ measurements. A method of calibrating $T_C$ using $V_{LSAW}$ is also proposed. Next, we measure $V_{LSAW}$ and $T_C$(standardized) under the same measurement conditions (particularly within $\pm 2^\circ$C in $T_R$) for 36°YX-LiTaO$_3$ wafers produced by several manufacturers, and compare the results with the $T_C$(individual) measured by the individual manufacturers. The calibration line showing the relationship between $T_C$ and $V_{LSAW}$ was obtained to be with deviations of $\pm 2.6^\circ$C for $T_C$(individual) and with deviations of $\pm 0.4^\circ$C for $T_C$(standardized). The standardized measurement conditions enable improving the reliability of $T_C$ measurements.
PREDICTION OF THE THERMAL SENSITIVITY OF SURFACE ACOUSTIC WAVES EXCITED UNDER A PERIODIC GRATING OF ELECTRODES

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In order to design efficient electroacoustic devices, excitation and propagation of acoustic waves need to be accurately characterized. This allows designers to simulate and identify structures meeting customer’s specifications. During this simulation stage, initial templates have to be modified to take into account technological and thermal dispersion. The former is easily deduced from the manufacturing dispersion. On the other hand, there is only few theoretical works to predict thermal sensitivity of the devices and most of them are restricted to homogeneous boundary conditions (propagation on homogenous surfaces) [1]. A more recent work includes grating contribution in the thermal dispersion law, but is limited to propagation of Rayleigh waves on quartz substrates [2]. In this work, a general approach is proposed to take into account electrode contribution to the frequency-temperature law. It is based on periodic FEM/BEM simulation, where both Green’s function and harmonic admittance are computed as a function of the temperature. The device thermal sensitivity is then predicted in terms of CTF and turnover point, for different grating geometry (period, metallization height and ratio#). With this approach, thermal behavior of every kind of waves can be simulated, even the ones, like longitudinal leaky waves, which require the grating to be guided close to the surface. The computed frequency-temperature laws are compared to experiments for different kind of substrates and waves (Rayleigh, shear, longitudinal, leaky waves or plate modes). This technique allows to recover original phenomena in agreement with experience: leaky waves show different thermal sensitivities for resonance and anti-resonance frequencies. In addition, this work focuses on temperature-compensated devices whose turnover point are known to be very sensitive to mass loading effect.


MATERIAL PARAMETERS OF RF MAGNETRON SPUTTERED SIO₂ THIN FILMS FOR TEMPERATURE STABLE SIO₂/LINBO₃ SAW DEVICES

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LiNbO$_3$ based surface acoustic wave (SAW) devices lack temperature stability and possess a high positive temperature coefficient of delay (TCD). Introduction of SiO$_2$ over layer of appropriate thickness is known to reduce the TCD of LiNbO$_3$ based devices to zero. SiO$_2$/LiNbO$_3$ structures have been widely studied, however, a deviation in the theoretically calculated and experimentally determined SAW phase velocity and TCD values has been observed and is attributed to the variation in the material parameters of deposited SiO$_2$ layers. Evaluation of the SiO$_2$ thin film material parameters (density, dielectric constant, elastic constants and their temperature coefficients) is becoming important for determining the desired SiO$_2$ film thickness required for temperature compensation.

In the present work SiO$_2$ films deposited by rf magnetron sputtering have been investigated. Film density, dielectric constant and temperature coefficient of dielectric constant were determined. SAW phase velocity and TCD of the SiO$_2$/LiNbO$_3$ structure was measured experimentally with varying thickness of SiO$_2$ over layer and were tend to differ from the theoretically calculated values.

The density (2185 kg/m$^3$) and dielectric constant (3.53) values of the as-deposited SiO$_2$ thin films were found to be close to the bulk values of SiO$_2$. The deviation in the experimentally determined and theoretically calculated SAW velocity and TCD was found to depend on the variation in the elastic constant and their temperature coefficients. The elastic constants (C$_{11}$ and C$_{44}$) and their temperature coefficients, [TC(C$_{11}$) and TC(C$_{44}$)] were determined by fitting the obtained experimental data of phase velocity and TCD to the theoretically calculated values as a function of SiO$_2$ over layer thickness. The estimated values of the elastic constants (C$_{11}$ = 0.75 x 10$^{11}$ N/m$^2$ and C$_{44}$ = 0.225 x 10$^{11}$ N/m$^2$) are found to be lower and the respective temperature coefficients (5.0 x 10$^{-4}$/°C and 2.0 x 10$^{-4}$/°C) are high in comparison to the bulk values.