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LITHIUM TETRABORATE SINGLE CRYSTALS AS A SUBSTRATE FOR SAW DEVICES

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Single crystals of lithium tetraborate ($Li_2B_4O_7$) as a potential substrate for SAW devices have been investigated. Single crystals of lithium tetraborate have been grown according to the Czochralski technique. They combine a high electromechanical coupling coefficient for SAW with a small temperature coefficient of SAW velocity.

1. Introduction

New piezoelectric materials have been investigated to find one which could combine the properties of two materials commonly used in surface acoustic wave (SAW) devices: $LiNbO_3$ with a high electromechanical coupling coefficient and $\alpha-SiO_2$ with zero temperature coefficients of time delay for some cuts. Recently lithium tetraborate $Li_2B_4O_7$ has attracted much attention as a promising SAW material [1]. The material is tetragonal and belongs to the 4 mm point group. It melts congruently at 917°C what allows for its crystals growth from the melt. The crystals of $Li_2B_4O_7$ are colourless, optically uniaxial negative and nonferroelectric. Low density ($\rho=2451$ kg/m³) is combined with quite high hardness (6 in the Mosh scale) [1].

2. Crystal growth

$Li_2B_4O_7$ single crystals were grown from the melt using the Czochralski method [2]. A platinum crucible was used. The starting material was prepared by melting boric acid H_3BO_3 and lithium carbonate Li_2CO_3 until water and carbon dioxide were completely removed from the melt which became totally transparent. Chemical analysis showed that during the growth process evaporation of the compound enriched in B_2O_3 occurred. To reduce the formation of cores in the central parts of the crystals due to changes in the stoichiometry of the melt, 1 mol% excess of B_2O_3 was used. First, small crystalline samples of $Li_2B_4O_7$ were obtained on a platinum were, then [001] seeds were cut from the samples. The seeds were mounted in a platinum holder to avoid reaction with the alund tube. The resistance furnace giving sharp temperature gradients was used to make $Li_2B_4O_7$ crystallizaton possible. Molten lithium tetraborate has a very high viscosity and shows a tendency to solidify as a glass in conditions of small temperature gradients. Only high temperature gradients in the vicinity of the surface of the melt (≅100 K/cm) allowed to obtain $Li_2B_4O_7$ single crystals of good quality. The seed was rotated with 5 rpm and was pulled up with a speed of 0.5 mm/h. Transparent single crystals 5 cm long and 1.5 cm in diameter were grown. Only the central parts of the crystals were slightly defected by thin cores. The quality of the crystals was investigated by means of the chemical etching method in a mixture of water and glycerine (1 : 1) at 25°C for 24 hours. The density of dislocations revealed in a (001) plane, using this method, was 6×10^3 cm^{-2}. The method was also used to eliminate crystals partially defected by twinning.

A plate 30 mm long in a [001] direction, 10 mm wide in a (110) plane and 3 mm thick was cut from a $Li_2B_4O_7$ single crystal. To evaluate the usefulness of the material as a substrate for SAW devices, the following parameters were investigated:

1. The velocity of the surface wave — υ;
2. Electromechanical coupling coefficient — k^2;
3. Dielectric constant (resultant) — ε;
4. Temperature coefficient of delay $\Delta\tau/\Delta T$;
5. Attenuation of the surface wave in the material;
6. The quantity of bulk waves generated in the material;

To determine the above parameters, two co-working, simple periodic interdigital transducers with 20 pairs of electrodes and with an aperture of 2910 μm were made on the $Li_2B_4O_7$ substrate. The distance between their geometrical centres was 16.81 mm, when the distance between successive electrodes d was 28 μm. The electrodes were made from aliminium and had a 2000 Å thickness.

This kind of transducer generates surface acoustic waves with a fundamental frequency described by the following formula:

$$f=\frac{\upsilon}{2d}, \tag{1}$$

and also on its fifth harmonic.

The velocity of the surface wave υ was determined from the slope of the phase characteristic of the transducers in function of the frequency ω as 3.5 mm/μs.

Using the measurements of the statical capacity of the transducer in the Wayne–Kerr bridge, the dielectric constant was found as $\varepsilon=8.5$. It is twice as big as for (Y,X) quartz and five times smaller than for (Y,Z) lithium niobate. A high electromechanical coupling coefficient k^2 connected with a small dielectric constant is useful when high frequencies and long transducers are used, because the resistance effect is minimalized.

The transducers conductance measured by the Wayne–Kerr bridge near the fundamental frequency gave the value of the electromechanical coupling coefficient $k^2=1.7\%$. The coefficient is ten times bigger than for (Y,X) quartz and three times smaller than for (Y,Z) lithium niobate.

The simplest way to obtain information about bulk waves generated in the transducer is the measurement of the conductance of the tranducer σ. Measurements in the wide band of frequency are very difficult and time-consuming, hence measurements were performed of the reflection coefficient of the wave from the transducer with respect to 50 Ω. Its value is proportional to $|\sigma + j\omega c|$, so it includes the same information as the conductance σ. The measurements were made using the Wiltron measuring set. The shape of the coefficient versus the frequency curve is shown in Fig. 1. The surface wave is generated at 62.5 and

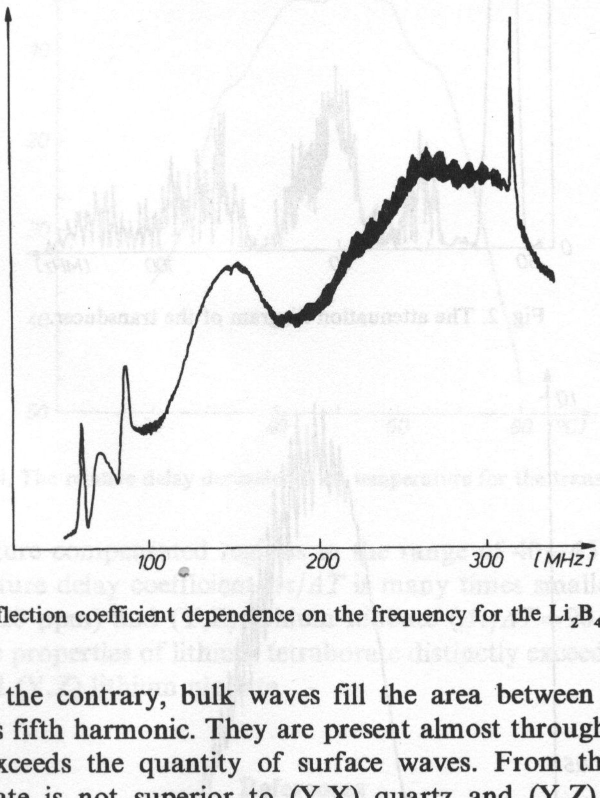

Fig. 1. The reflection coefficient dependence on the frequency for the $Li_2B_4O_7$ transducer.

312.5 MHz. On the contrary, bulk waves fill the area between the fundamental frequency and its fifth harmonic. They are present almost throughout the area and their quantity exceeds the quantity of surface waves. From this point of view lithium tetraborate is not superior to (Y,X) quartz and (Y,Z) lithium niobate. These effects restrict the possibilities of constructing SAW transducers to cases in which their bands are below their structural frequency because the attenuation of transducers above their structural frequency is influenced by such large bulk waves. The influence is shown in Fig. 2. Figure 3 shows a characteristic of the transducer in its working band. The characteristic is independent of bulk waves. Its shape and irregularities (caused by the wave reflections from the transducers) are totally compatible with the theoretical curve. Filter losses are equal to 16 dB on the structural frequency and 36 dB on the fifth harmonic. The quantities are compatible with the theory and give the evidence that the material attenuation of the wave in this range of frequencies is negligible.

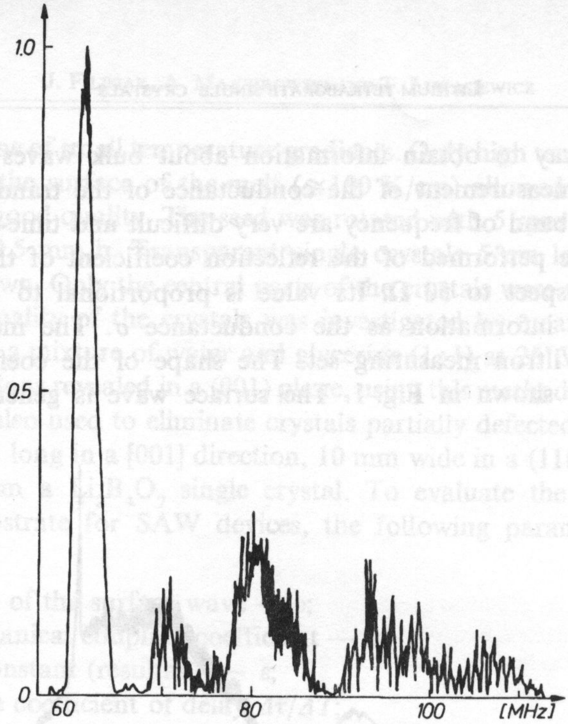

Fig. 2. The attenuation diagram of the transducer.

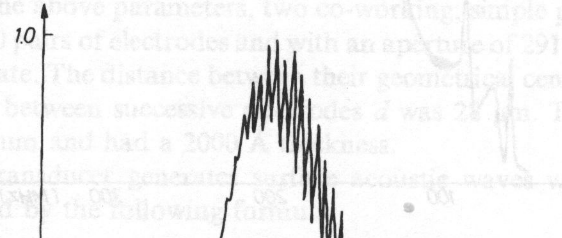

Fig. 3. The transducer characteristics in its working band.

The coefficient of temperature delay $\Delta\tau/\Delta T$ was measured in the generator set in which the SAW unit worked as a delay line in the loop of the amplifier feedback. The generator was set at 62.5 MHz. Measurements of the working frequency of the generator versus temperature in the range of 20–80°C were made. The relationship has a parabolic form (Fig. 4) and the vertex of the parabola is at 50°C. Besides

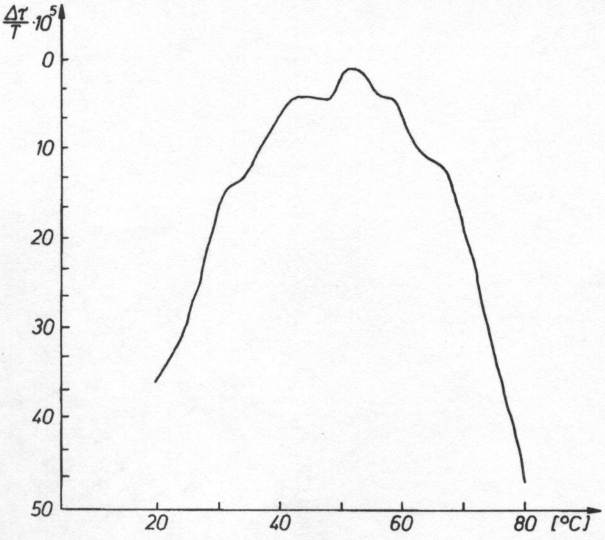

Fig. 4. The relative delay dependence on temperature for the transducer

existing temperature compensated regions in the range of 40–45°C and 50°C, the $Li_2B_4O_7$ temperature delay coefficient $\Delta\tau/\Delta T$ is many times smaller than for (Y,X) quartz ($\Delta\tau/\Delta T=20$ ppm) and (Y,Z) lithium niobate ($\Delta\tau/\Delta T=90$ ppm). From this point of view, the properties of lithium tetraborate distinctly exceed the properties of (Y,X) quartz and (Y,Z) lithium niobate.

References

[1] A. BALLATO, J. KOSIŃSKI and T. ŁUKASZEK, IEEE 1989 Ultrasonics Symposium, p. 441.

[2] T. ŁUKASIEWICZ and A. MAJCHROWSKI, Materials Letters, 11, 8, 9, 281–283, 1991.