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The influence of the metal film, placed close to the free side of the piezoelectric lateral electric field excited resonator, on its characteristics

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ABSTRACT

The influence of the width of the gap between the free side of the piezoelectric lateral electric field excited resonator and the metal film placed on the dielectric plate on the frequencies of the parallel and series resonances was experimentally and theoretically studied. The measurements were carried out in the temperature range of 14–45 °C. It has been shown that the change of the gap width from 0 up to 3.5 mm leads to the change of the parallel resonant frequency on 1.3% at the constant temperature. At the same conditions the change of the series resonant frequency does not exceed 0.07%. Theoretical analysis quantitatively confirmed the experimental dependencies of the aforementioned frequencies on the gap width at the room temperature. At that the maximum difference between the theoretical and experimental values of the parallel and series resonant frequencies in all cases does not exceed 1.2%. The obtained results may be used as the basis for the development of the sensors for the measurement of the displacement in the interval of 0.2–2 mm in the temperature range of 15–45 °C.

1. Introduction

At present a great interest of the researchers is attracted by the piezoelectric lateral electric field excited resonators [1–12]. This interest is connected with the fact that the acoustic sensors based on such resonators have some advantages compared to the resonators with the longitudinal electric field. The electrodes of the resonators with the lateral electric field are placed on the one side of the piezoelectric plate and the electric field significantly penetrates in the contacting vacuum. It is obvious that the electric field of such a resonator will penetrate into the contacting medium, for example, into the liquid. In this case, the parameters of the resonator will depend not only on the mechanical properties of the liquid, but also on its electrical ones. This property allowed to develop the multitude of the sensors for measuring the viscosity, conductivity, and dielectric constants of the liquids [1–5,7,11], the sensors for measuring the dielectric constant of the gasoline and its octane number [12], and the biological sensors for the detection and identification of the bacterial cells [13] and bacteriophages [14] directly in the liquid phase. The piezoelectric resonator with a longitudinal electric field has the electrodes on both sides of the piezoelectric plate and the electric field localized between the electrodes does not penetrate into the surrounding medium. Therefore, the parameters of such a resonator depend only on the mechanical mass loading. So the change in the electrical boundary conditions near the free side of the resonator with the lateral electric field must have an influence on the resonator parameters. In the present paper we carried out the investigation of the influence of the width of the gap between the metal film, placed on the dielectric plate, and the free surface of the resonator on its parallel and series resonant frequencies at the different values of the temperature. The resonator was based on the plate of lithium niobate of the X – cut.

2. The description of the resonator and experimental setup

The resonator based on the plate of lithium niobate of the X – cut with the thickness of 0.5 mm was fabricated (Fig. 1). Two rectangular aluminum electrodes with the shear dimensions of 10 × 5 mm^2 and width between them of 2 mm were deposited on the piezoelectric plate in the vacuum. For the suppression of the parasitic Lamb waves the region around the electrodes and partially electrodes were covered by the damping coating [15,16]. The resonator was connected with the LCR meter 4285A (Agilent) and the frequency dependencies of the real and imaginary parts of the electrical impedance and admittance were measured. Fig. 2 shows the frequency dependencies of the real R (a) and imaginary

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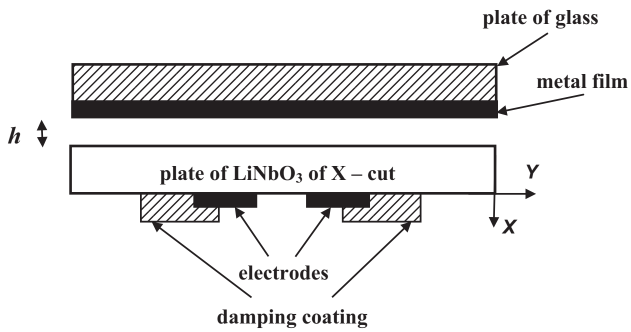

Fig. 1. Device under study.

X (b) parts of the electrical impedance of the resonator at the absence of the metal film. The resonance maximum on the frequency dependence of R determines the parallel resonant frequency f_{par} [16] and the corresponding value of the Q – factor. These values turned out to be f_{par} = 6.5733 MHz and Q_{par} = 1825. The frequency dependencies of the real G (a) and imaginary B (b) parts of the electrical admittance of the resonator at the absence of the metal film are presented in Fig. 3. The resonance maximum on the frequency dependence of G in one's turn determines the series resonant frequency f_{ser} [16] and the value of the Q – factor. These values are equal to f_{ser} = 6.48 MHz and Q_{ser} = 12960. The values of the resonant frequencies allowed us to estimate the electromechanical coupling coefficient [16], as $(f_{par} - f_{ser})/f_{par} = K^2$. It was equal to 1.44%. From Figs. 2 and 3 one can also see the total absence of the parasitic oscillations near the frequencies of the parallel and series resonances.

For the experimental investigation of the influence of the width of the gap between the free side of the resonator and the glass plate with the aluminum film the special micrometer mechanism was used [17]. This mechanism consisted of the clock indicator of the movements with the scale division value of 0.01 mm and the full stock displacement of 10 mm and the micrometer screw (1 mm/revolution). It allowed ensuring the gap width *h* with the accuracy of 0.01 mm. By means of the pointed LCR meter the frequency dependencies of the real and imaginary parts of the electrical impedance and admittance were measured at the different values of *h* and temperature. For keeping the given temperature the entire device was placed inside the special thermostat, which allowed changing and keeping the temperature in the range of 10–50 °C. This thermostat was made in the laboratory conditions on the basis of the conventional household refrigerator. The aforementioned micrometer mechanism with the resonator and plate with the metal film was placed inside the refrigerator. The resonator was connected to the test fixture 16047D (Agilent), which in one's turn was contacted with the LCR meter through 4 cables with the known length. The given temperature was maintained manually by using the cooling device of the refrigerator and the resistor heater placed inside the refrigerator with the accuracy of ±1 °C. The temperature of the resonator was measured with the chromel – alumel thermocouple, the first thermojunction of which was glued to the edge of the piezoelectric plate of the resonator, and the second one was placed in the Dewar vessel with the melting ice. The total measurement at the given temperature for the different values of the width of the gap between the resonator and the metal film (11 points) took about 3 h and this duration prevented the appearance of the temperature gradients.

3. The discussion of the obtained experimental results

Fig. 4 shows the measured dependencies of the parallel resonant frequency on the gap width at the values of the temperature: 14, 26, 34, and 45 °C. One can see that at the fixed temperature of the device the frequency of the parallel resonance monotonically increases with the increase in *h* and achieves the saturation. At the fixed value of the gap width the parallel resonant frequency decreases with the increase in the temperature. The fractional change in the parallel resonant frequency at any temperature is equal to ~1.3% due to the change of *h* from 0 up to 3.5 mm. This value (1.3%) turned out to be very close to the electromechanical coupling coefficient (1.44%), which is the maximum achievable value of the change in the parallel resonant frequency due to the approaching of the conductive layer to the free side of the resonator. Fig. 5 shows the temperature dependencies of the parallel resonant frequency for the values of the gap width of 0.1, 0.5, 1, and 2 mm. The decrease of the parallel resonant frequency with increasing the temperature at any value of the gap width may be explained by the fact that with increasing the temperature the thickness of the piezoelectric plate increases and the velocity of the acoustic wave decreases [18].

The measured dependencies of the series resonant frequencies on the gap width at the pointed above values of the temperature are shown in Fig. 6. One can see that at the fixed value of the temperature the series resonant frequency has the insignificant splash in the range of *h* = 0–0.2 mm and at the further increase of the gap width does not practically change. In a whole the increase of *h* from 0.2 up to 3.5 mm leads to the fractional change in the series resonant frequency less than 0.03% for the fixed temperature in the studied temperature interval. So with the pointed accuracy one can consider that the series resonant frequency does not change with the change of the width of the gap between the resonator and metal film. Fig. 7 shows the temperature dependence of the series resonant frequency at the gap width of 0.2 mm. This dependence was obtained by using the graphs in Fig. 6 for the gap width of 0.2 mm, from which the series resonant frequency at the fixed temperature practically ceases to depend on the gap width. Fig. 7 shows that with increasing the temperature the series resonant frequency decreases, since at that as it was said

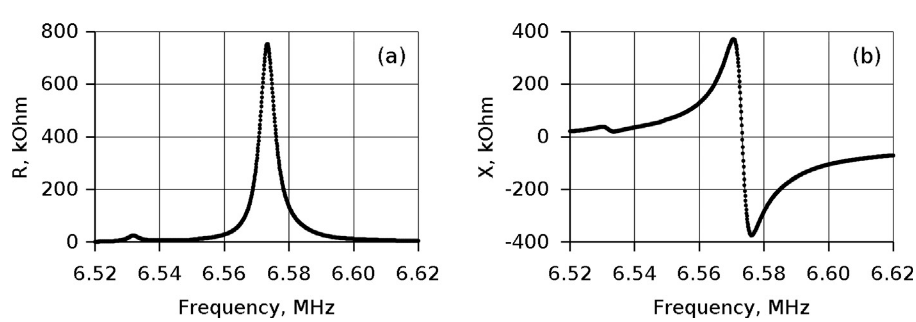

Fig. 2. The frequency dependencies of the real R (a) and imaginary X (b) parts of the electrical impedance of the resonator without the dielectric plate with the metal film.