The Influence of Electrode's Stratified Structures on SAW Devices Microwave Characteristics

Sergey Suchkov
Physical Department,
Saratov State University,
Saratov, Russia
suchkov.s.g@mail.ru

Dmitry Suchkov
Physical Department,
Saratov State University,
Saratov, Russia
suchkovds@yandex.ru

Dmitry Chaikovskiy
Physical Department,
Saratov State University,
Saratov, Russia
technopark@sgu.ru

***Abstract* — The thickness and elastic properties of electrodes' aluminum film as well as behavior nanometer adhesion sublayer influence on characteristics of SAW devices in microwave band. Influence adhesion sublayer thickness to thermostability resonance frequency of IDT on ST-cuts quartz at the 2 GHz and also reflection coefficient SAW from electrodes' edges IDT is investigated. Determine value layer thickness of aluminum and also values adhesion sublayer thickness of chrome and vanadium into two-layer electrodes at which the reflection coefficient is equal to the zero. In paper is shown substantial influence adhesion sublayer on frequency description amplitude-frequency characteristic of SAW filter. Into the there are some crystallography directions in the crystal $LiNbO_3$ found strong frequency dependence angle between group and phase velocities. Some crystallography crystal cuts and directions in the crystal $LiNbO_3$ with layer structure «metal film - piezocrystal» on the surface are found at which exists strong frequency dependence of angle between group and phase velocities.**

I. Introduction

In the SAW devices, operating on frequencies no more than 100 MHz, electrodes thickness infinitely small and not influencing on elastic properties surface of crystal is consider. At the higher frequencies the difference of the crystal elastic properties and IDT electrodes leads to SAW reflection from electrode's edges [1] and also to thermostability worsening [2] and SAW frequency characteristics changes. Therefore, for example, it is necessary to apply the IDT with "split fingers" for elimination of SAW reflections [1] and to change a little the cut's angle for recovery of IDT's thermostability properties.

At the frequencies above 1 GHz the influence of the elastic properties of electrode's aluminium film and also nanometer adhesive sublayer (usually, chrome, vanadium or titan), which are deposited on the crystal surface before aluminum evaporation become significant

II. Influence on Thermostability

In the paper [2] the influence of IDT homogeneous aluminium electrode's thickness and elastic properties on the thermostability was investigated. Thermostability is determined by deviation of IDT resonance frequency at the temperature changes in the wide temperature interval (more than 100 ^{0}C). For this purpose the parameter D_f is used, so-called the frequency temperature deviation (FTD), and determined by

$$D_f(T)=\frac{f_0(T)-f_0(T_0)}{f_0(T_0)} \qquad (1)$$

where the IDT centre frequency $f_0(T)$ taking into consideration the temperature dependence of SAW velocity on the free surface $V_f(T)$, SAW velocity on the metallized surface $V_m(T)$ and changes of linear sizes of electrodes width b and gap g between them is calculated by formula

$$f_0(T)=\frac{1}{2}\left(\frac{b}{V_m(T)}+\frac{g}{V_f(T)}\right)^{-1}(1+\alpha_{11}(T-T_0))^{-1}$$

where T_0 is operating temperature of IDT, α_{11} is linear expansion coefficient.

The values modulus of elasticity and density of aluminum film have been calculated [3] by experimental dependences of SAW velocity on the metallized surface ST-quartz from the angle of direction in the cut's flat, shown in [4]. The results are presented in the table.

TABLE I
MODULUS OF ELASTICY AND DENSITY FOR BULK AND FILM ALUMINUM

Thickness, nм	$C_{11}\cdot10^{-10}$, N/m^2	$C_{12}\cdot10^{-10}$, N/m^2	$C_{44}\cdot10^{-10}$, N/m^2	ρ, kg/m^3	Anisotropy parameter, *A*
∞ *isotropic* Al	11.13	5.91	2.61	2700	1
∞ *crystal* Al	10.73	6.08	2.83	2702	1.22
150, *pure* Al	11.148	6.78	0.212	2607	0.1
150, Al+Cu	13.673	6.626	2.605	2697.6	0.739

In this paper, by analogy [2], the influence of elastic properties of two-layer metal on the SAW velocity at the microwave band up to 3 GHz is numerically investigated based of rigorous solution of boundary problem for equations of piezomedium motion with electric and mechanical boundary conditions at all interfaces in the structure "two-layer metallic film-crystal" (Fig. 1).

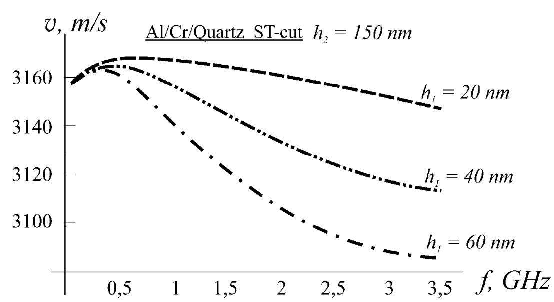

Fig. 1. Influence adhesive sublayer metal on SAW velocity.

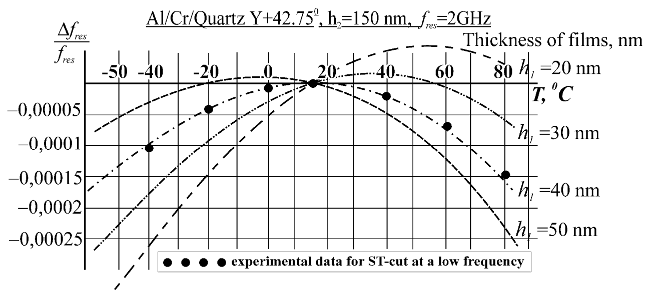

Fig. 2. TFD for IDT on ST-cut quartz for resonance frequency 2 GHz by different values of adhesion sublayer thickness.

Using these calculations, TFD are computed by formula (1). TFD calculations have been carried out for chrome adhesive sublayer thickness h_1 from 20 nm to 50 nm and for aluminium film thickness h_2=150 nm. The Fig. 2 presents the results of calculation TFD for ST-cut quartz and the IDT resonance frequency 2 GHz. Under change of chrome adhesive layer thickness from h_1=20 nm to h_2=50 nm TFD changes considerable and for h_1=40 nm it becomes symmetrical and near to TFD at low frequencies (50 MHz) (experimental values are shown as dots).

The calculations have show that using vanadium instead of chrome the qualitative pattern of TFD changes remains the same, but quantitative changes become less. This phenomenon is explained greater stiffness of chrome film as compared to vanadium film.

Possibility restores of thermostability SAW devices at the frequency band above 1 GHz using cut's angle changes is practically important result. This is shown in Fig.3, where TFD at the 2.4 GHz for IDT on ST-quartz with electrodes Al (150 nm)/Cr (10 nm) is shown by dashed line, and TFD for Y+48^0 cut with the same electrodes is shown by solid line.

Thus, during of SAW devices designing in microwave band it is necessary to take into consideration not only the influence of adhesive sublayer on TFD, but to use such influence for thermostability increase.

III. Influence on the Fingers' Reflectivity

It is known that SAW reflection from finger worsens the SAW devices characteristic. For suppression of the reflected waves into IDT the "split electrodes" is used. However,

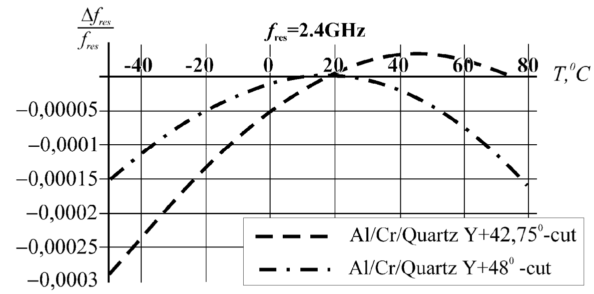

Fig. 3. Comparison TFD for IDT with resonance frequency 2,4 GHz on ST-cut and Y+48°-cut quartz.

using "split electrodes" twice decrease maximum operating frequency of IDT SAW in consequence of the double diminishing electrodes' width. Necessity of finger's split disappears when reflections are eliminated. Therefore, in this paper, the dependence of SAW reflectivity from edges of IDT two-layer electrodes has been investigated.

The reflection coefficient calculates by approximation formula [1]:

$$R\left(\frac{h}{\lambda}\right)=\frac{V_m-V_f}{V_m+V_f}+C\frac{h}{\lambda} \qquad (2)$$

where V_f and V_m are SAW velocity on free and on metallized surfaces of crystal, $h=h_1+h_2$ is a thickness of electrode, and C is a coefficient, determined experimentally for every combination of materials (for the quartz ST-cut and aluminum of C=0.27).

The adhesion sublayer leads to the layer metal film stiffness increasing, and, as a consequence, to the increasing of SAW velocity at the metallized areas of the crystal surface. Therefore, choosing parameters of layers it is possible to attain such increase velocity under an electrode at which it will be equal SAW velocity on the free surface and reflection coefficient vanishes.

In the Fig. 4 the frequency dependencies of the reflection coefficient R for the different chrome and vanadium sublayer thicknesses are shown. The calculations were performed at fixed aluminum film thickness of h_2=150 nm.

IV. Influence on the Amplitude-Frequency Response of SAW Filter

Based on the method and programs for calculation characteristics SAW in multi-layered structure and on the quasi-field model of IDT [5] the influence of adhesion sublayer to IDT amplitude-frequency response on frequencies above 2 GHz was investigated. In Fig. 5 results of amplitude-frequency response calculations for apodized IDT with aluminum electrodes are shown. Curve 1 shown to calculation without taking adhesion sublayer. Curve 2 is calculated for the sublayer of chrome (h_1= 20 nm), and curve 3 is calculated for the sublayer of vanadium (h_1= 20 nm).

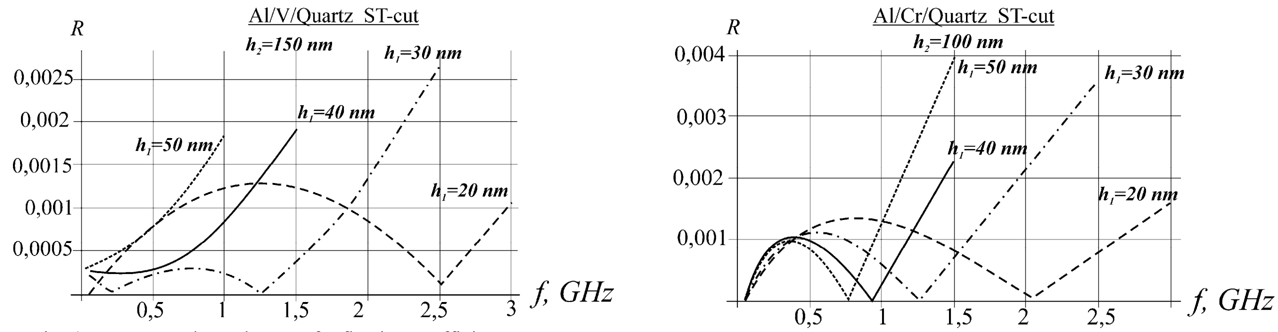

Fig. 4. Frequency dependences of reflection coefficient *R*.

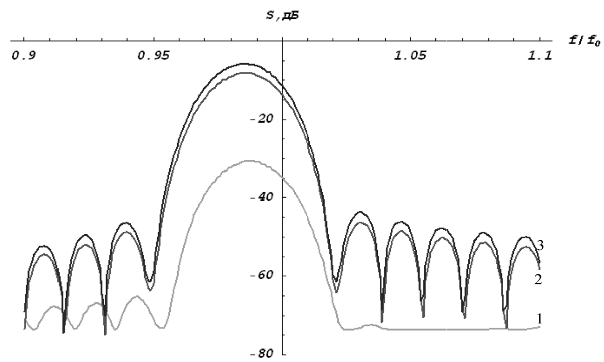

Fig. 5. Influence adhesion sublayer to amplitude-frequency response for an apodized IDT in microwave band.

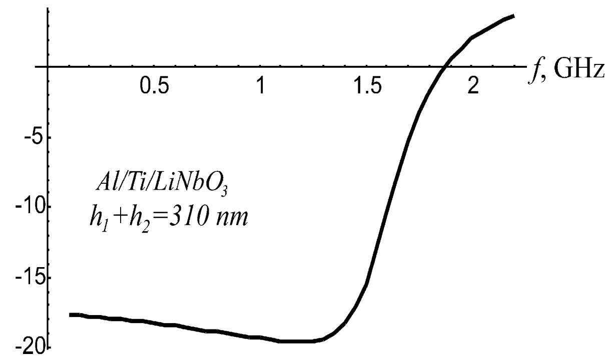

Fig. 6. The frequency dependence angle between group and phase velocities for layered structure Al/Ti/ $LiNbO_3$.

SAW structure, which consists in elastic displacements amplitude decrease in metal film and in electric potentials in piezocrystal increase.

V. Influence on the Angle Between Group and Phase Velocity of SAW

The existence of another material film on the crystal surface leads to the not only SAW velocity dispersion, but also the angle between group and phase velocity of SAW dispersion. This dispersion is small for a most of investigated directions in different cuts crystal $LiNbO_3$ and its value is no more than 3 degrees. However, there are directions, in which it reaches 10-20 degrees at the frequency band up to 500 MHz. Fig. 6 shows the frequency dependence of the angle between group and phase velocities for layer structure Al/Ti/$LiNbO_3$.

VI. Conclusions

The investigations showed that it is possible increase thermostability of SAW devices in microwaves band by change thicknesses of sublayer and basic layer of IDT electrodes. It's shown, there are some parameters of layers with it is possible to remove reflection into IDT.

Also it's shown, using adhesion sublayer it is possible to improve frequency response of SAW filters in microwave band. Found out, there is strong frequency dependence angle between group and phase velocities of SAW in some cuts and directions of crystal $LiNbO_3$ in the structure «two-layer metal film - piezocrystal».

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