# PHYSICS

© I. G. SIMAKOV, CH. ZH. GULGENOV
*simakov-bsc@rambler.ru*
*gchj@rambler.ru*

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## *DETERMINATION OF HUMIDITY BASED ON REGISTRATION OF ZERO TEMPERATURE COEFFICIENT OF DELAY OF SURFACE ACOUSTIC WAVES*

*ABSTRACT. The article shows that in a humid gas medium the temperature coefficient of delay of surface acoustic waves in the 'lithium niobate-adsorbed water' system has a zero figure at a certain temperature. In the studied system there is a correlation between zero temperature of the temperature coefficient of delay with a dew point. It is proposed to use the dependence of zero temperature of the temperature coefficient of delay on the vapor pressure to determine the relative humidity. The advantages of this method are considered.*

*KEY WORDS. Determination of humidity, surface acoustic waves, dew point, the coefficient of delay.*

In a humid gas medium a layer of adsorbed water is formed on the solid surface, the parameters of which depend on the temperature, state of the solid surface, the temperature of gas medium, and the degree of humidity of this medium. If surface acoustic waves (SAWs) are propagated in a solid, then an adsorption layer perturbs the conditions of their distribution. Investigating the influence of an adsorption layer on SAW parameters, it is possible to determine the relative humidity of a gas medium.

It is more convenient to excite SAWs in piezoelectric substrates. Typically, a substrate in a form of a plane plate is made of a piezoelectric crystal and has a particular alignment. To excite and receive SAWs, it is possible to accommodate two interdigital transducers (IDTs) on the polished surface of the substrate [1]. Such a device forms a delay line. The main reasons for destabilizing the work of the delay line are the impact of the temperature and humidity of the medium. The influence of the adsorption layer on the surface elastic wave parameters is reduced to the change of the amplitude and velocity of SAWs [2].

As a result of temperature exposure (without considering the influence of humidity), the distance between the SAW-transducers and the speed of surface waves change, which leads to a change in the delay time of the acoustic signal $\tau$. Complex influence of temperature and humidity leads to a change in the amplitude and phase of the delayed signal, the delay time changes accordingly.

For acoustoelectronic devices, an important characteristic of SAWs is the temperature coefficient of delay (TCD) $\zeta = \tau^{-1}\partial\tau/\partial T$. A solid or a liquid layer on the substrate surface can significantly increase or decrease the TCD. Excluding the impact of the adsorption layer, TCD includes the temperature coefficient of velocity change of elastic surface waves $V_s^{-1}\partial V_s/\partial T$ and the temperature coefficient of linear dilatation of the substrate $\alpha = L^{-1}\partial L/\partial T$ [3]. (T—temperature, L—distance between SAW-transducers).

$$\zeta = \frac{1}{\tau}\frac{\partial \tau}{\partial T} = \frac{1}{L}\frac{\partial L}{\partial T} - \frac{1}{V_s}\frac{\partial V_s}{\partial T} = \alpha - \frac{1}{V_s}\frac{\partial V_s}{\partial T} \quad (1)$$

The humidity of gas medium is determined by the relative vapor pressure $p/p_s$. In general, humidity depends on the temperature and humidity content of the gas medium. As it was mentioned above, a water layer is adsorbed in a humid gas medium on the surface of a solid substrate. The humidity of gas medium and the state of the solid surface determine the conditions of the adsorption layer formation. Thus, there is a link between the humidity of gas medium and the parameters of the adsorption layer. Consequently, there is a relation between the humidity of the medium and the parameters of elastic surface waves propagating in the layered system—'piezoelectric substrate–adsorption water layer'.

In order to identify the possibility of determining the humidity of the gas medium by the signal parameters in the acoustic path, it was necessary to investigate the variation of the delay time depending on the humidity of the medium. For this purpose a measurement cell was developed (Fig. 1a). The design of the measurement cell provides the opportunity to set necessary vapor pressure in the adsorption zone, to control temperature of the substrate, and to conduct acoustic measurements. The required vapor pressure in the adsorption zone may be obtained in two ways. Firstly, it is possible to maintain a desired substrate temperature $T_2$ and to change the liquid temperature $T_1$, above which the substrate is located. Secondly, the substrate temperature $T_2$ can be varied keeping constant the liquid temperature $T_1$. Relative vapor pressure in the adsorption zone is linked with the temperatures $T_1$ and $T_2$ by Clapeyron-Clausius equation:

$$ln\frac{p}{p_s} = -\frac{Q}{R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right), \quad (2)$$

where Q and R—steam heat (condensation) and gas constant of water.

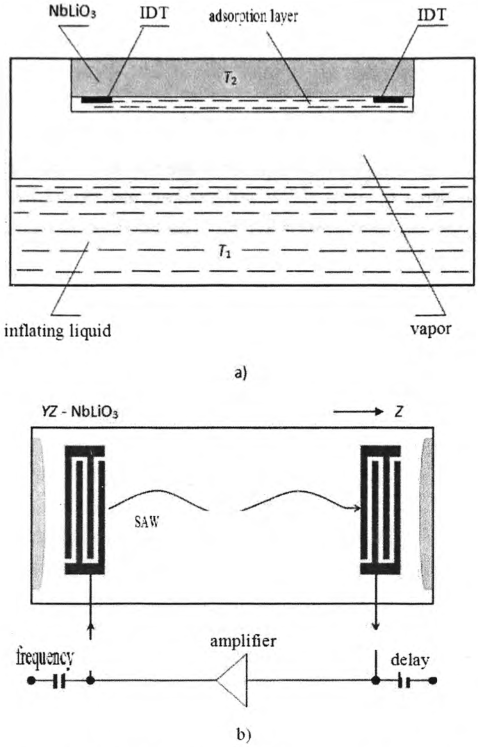

*Fig. 1.* a) The diagram of the measurement cell;
b) Flow diagram of the measurement unit

Lithium niobate crystal with an optically polished work surface of YZ-cut was pre-cleaned in a glow discharge and placed above the surface of double-distilled water in a constant-temperature oven. The required vapor pressure according to the equation (2) was set and controlled with an accuracy of 0.1 % through distilled water temperature change $T_1$ and the substrate temperature $T_2$. The adsorption of water molecules was carried out on the work surface of the crystal between the emitting and receiving SAW-transducers. SAW frequency was ~128 MHz. To eliminate the effects of the signals reflected from the ends of the substrate, absorbing coatings were used.

The change of the time delay of SAWs was the main measured acoustic value. In the experiment, the method of determining the change of the time delay $\Delta\tau$ was used. It is based on the registration of frequency change of SAW-oscillator $\Delta f$, formed by introducing a delay line based on surface acoustic waves in the high-frequency feedback loop amplifier (Fig. 1b).

Self-excitation conditions of the SAW-oscillator are satisfied if full insertion loss in the feedback loop of the generator is less than the gain of the amplifier and the full phase shift in the loop generator $\psi_\Sigma$ is multiple of $2\pi$:

$$\psi_\Sigma = \psi = \psi_E = 2\pi \cdot n,$$

where n = 1, 2, 3... —an integer that specifies the mode of oscillation, $\psi_E$—the total phase shift in the amplifier circuits, SAW-transducers and matching circuits, $\psi = \omega\tau$— the phase advance in the propagation of SAWs. The generation frequency is defined as

$$f = \frac{n - \psi_E / 2\pi}{\tau}. \tag{3}$$

Mode of oscillation *n* is determined by the frequency characteristics of the amplifier, input and output IDT. Since the phase slope in the SAW delay line $d\psi/d\omega$ is significantly greater than the slope of phase $d\psi_E/d\omega$ for other components and the phase advance in the delay line is the predominant, frequency and stability of the SAW-oscillator depends on the conditions of the wave's propagation in the acoustic path [1, 4].

Any change in the surface and surficial region of the substrate may lead to perturbation conditions of SAW propagation. As a result of adsorption onto the surface of the acoustic transmission line, the speed and amplitude of SAWs are changing, thus the frequency of SAW-oscillator is changing as well. Its new value is recorded by a frequency counter. As it follows from (3), the change of the time delay is associated with the change of oscillation frequency by the formula $\Delta\tau / \tau = - \Delta f / f$. Signal attenuation is determined from the change in the amplitude of the signal at the amplifier input.

The actual diagram of SAW-oscillator includes a device for the input and output impedances matching of the SAW-structure with load, attenuator for receiving a desired power level in the loop and a decoupler to eliminate the influence of the recording apparatus (not listed in Fig. 1b).

In the experiment, the humidity in the adsorption zone was set by changing the substrate temperature. The temperature of distilled water was maintained at 20°C. The substrate was heated to thermodynamic equilibrium. With decreasing substrate temperature of 30°C, humidity in the adsorption zone increased, therefore thickness of the adsorbed layer increased. With a certain thickness of the adsorption layer, the change of time delay due to a linear change in the size of the substrate and the surface wave velocity depending on the temperature decreasing rate is compensated by the velocity loss of SAWs as a result of the layer impact. Hence, the temperature coefficient of the delay time becomes equal to zero [5]. Temperature $t_m$ is the temperature of TCD zero value. With further decreasing temperature the system reaches the dew point, i.e. the temperature of intensive humidity condensation on the substrate surface.

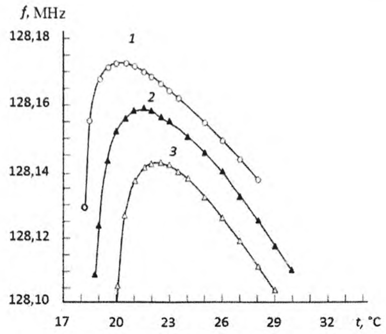

*Fig. 2*. Temperature dependence on interference minimum frequency.

1–$p/p_s = 0{,}9$; 2–$p/p_s = 0{,}96$; 3–$p/p_s = 1$; $t = 20$ °C.

Changing the humidity of the gas medium leads to a change in the dew point and the corresponding change in the temperature of TCD zero value. When reducing the relative humidity of the gas medium, the temperature of TCD zero value $t_m$ should decrease. Figure 2 shows the dependence of the change of SAW-oscillator frequency on the temperature for different values of the vapor pressure of water in the measurement cell. The figure shows that the nature of the curves *1–3* $(p1 < p2 < p3)$ virtually unchanged. The temperature of TCD zero value decreases with decreasing vapor pressure in the cell in accordance with a decrease of the dew point temperature. At the same time, the frequencies of extreme values $f_m$ of curves *f(t)* increase.

The dew point depends on the humidity: with decrease in the relative vapor pressure, the dew point is also decreased. Its dependence on the relative vapor pressure is used in dew point hygrometers. From the analysis of the experimental and calculated data it follows that the dependence of the temperature of TCD zero value and the dew point on the relative humidity is well correlated with each other (Fig. 3).

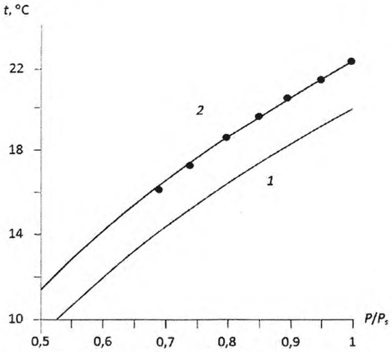

*Fig. 3*. The dependence of the dew point (1) and the temperature of TCD zero value (2) on the relative vapor pressure

Dew point determination of humidity is reduced to the following. The dew point is determined. The temperature of the hygrometer working surface is decreased to the temperature of intensive condensation. This is the dew point $t_d$. Relative humidity $p/p_s$ at temperature $t$ can be calculated using the empirical equation:

$$lg\frac{p}{p_s}=\frac{a(t_d-t)}{(1+bt_d)(1+bt)}, \tag{4}$$

where $a = 3{,}156\cdot10^{-2}$; $b = 4{,}19\cdot10^{-3}$. The error in determining the relative humidity by using the empirical equation (4) does not exceed 0.1%.

It should be noted, that after repeated cycle of condensation and evaporation of moisture there are traces of soluble substances on the working surface of the dew point hygrometers. Soluble contaminants may occur as a result of chemical reaction between the insoluble particles and active gases impurities in the air. A major source of pollution is the deposition of nuclei condensation in the air. Practically any surface of the solid condensate is deposited at a temperature higher than the dew point. As a result of the accumulation of soluble contaminants on the hygrometer working surface, the dew point registration accuracy decreases significantly.

The temperature of TCD zero value is higher than the condensation temperature of humidity (in the experiment with ~2.3°C). Consequently, when the temperature reaches TCD zero value, there is no condensation and pollution is not formed. Therefore, it is possible to use the dependence of the temperature of TCD zero value on vapor pressure to determine the relative humidity of the gas medium.

It is necessary to determine the dew point temperature of the curve maximum $f(t)$, corresponding to the temperature of TCD zero value out of the condition that the temperature difference $\Delta t = t_m - t_d$ remains constant. Further, the relative humidity of the gas at temperature $t$ is determined from the equation (4). The procedure is similar to the definition described above.

Thus, it has been demonstrated that the integrated effect of temperature and humidity of the temperature coefficient of delay of SAWs varies from a positive value to a negative one. At some intermediate value of humidity, TCD becomes of zero value. With the correlation of the dew point temperature and the temperature of TCD zero value it is shown that one can determine the relative humidity of the gas without lowering the temperature of the substrate to the dew point, i.e. to a temperature of condensation. Therefore, the working surface contamination and the subsequent degradation of the SAW-hygrometer are eliminated.

## REFERENCES

1. Koleshko, V.M., Meshkov, Ju.V. Microelectronic Information Transducers on Surfactant. *Zarubezhnaja jelektronnaja tehnika — Foreign Electronic Engineering*. 1985. № 9. (in Russian).

2. Morgan, D. *Ustrojstva obrabotki signalov na poverhnostnyh akusticheskih volnah* [Devices of signal's processing on superficial acoustic waves]. M.: Radio i svjaz', 1990. 416 p. (in Russian).

3. V'jun V.A., Rzhanov A.V., Jakovkin I.B. *Akustojelektronnye metody issledovanija poverhnosti poluprovodnikov* [Acoustoelectronic methods of research of semiconductors surface] / Pod red. S.V. Bogdanova. Novosibirsk: IFP SO AN SSSR, 1987. 126 p. (in Russian).

4. Bagdasarjan, A.S. Surface Acoustic Wave Device in Systems and Means of Communication. *CHIP NEWS*. 2002. № 8, Pp. 33-39. (in Russian).

5. Simakov, I.G., Gulgenov, Ch.Zh. The Effect of Humid Gaseous Medium on Temperature Coefficient of Time Delay in Acoustoelectric Device. *Vestnik Tjumenskogo gosudarstvennogo universiteta — Tyumen State University Herald*. 2011. № 7. Pp. 94–98. (in Russian).

6. Dorzhin, G.B., Simakov, I.G. Acoustic Investigation of Adsorbed Layers of Fluids. *Akusticheskij zhurn — Acoustic Journal*. 2002. Vol. 48. № 4. Pp. 499–503. (in Russian).

7. Simakov, I.G., Gulgenov, Ch.Zh. Vlijanie polimolekuljarnoj adsorbcii vody na parametry akustojelektronnyh ustrojstv. *Vestnik Burjatskogo gosudarstvennogo universiteta — Buryatia State University Herald*. 2009. № 3. Pp. 171–175. (in Russian).

8. Slobodnik, A. ml. Material and its Effect on Behaviour of Device // *Poverhnostnye akusticheskie volny* [Acoustic Surface Waves] / Edit. by A. Oliner. M.: Mir, 1981. Pp. 270–358. (in Russian).

9. Oliner, A. Volnovody dlja poverhnostnyh akusticheskih voln // *Poverhnostnye akusticheskie volny* [Acoustic Surface Waves] / Edit. by A. Oliner. M.: Mir, 1981. Pp. 226–269. (in Russian).

10. Simakov, I.G., Gulgenov, Ch.Zh. Registracija izmenenija amplitudy i skorosti rjeleevskih voln na poverhnosti p'ezojelektrika. *Vestnik Burjatskogo gosudarstvennogo universiteta — Buryatia State University Herald*. 2011. №. 3. Pp. 216–220. (in Russian).