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MEASUREMENT OF AIR HUMUDITY WITH APPLY MEMBRANE SILICON ULTRASONIC DEVICES

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Abstract: The devices to the measurements of relative air humidity with the membrane silicon ultrasonic sensors were presented. The temperature measurements and the determination so called dew point are especially important in the determination of relative air humidity by dew point technique. The accuracy of the dew point determination appoints the accuracy of the method. The optical and photoelectric devices are used very often to the dew point determination in the different applications of this technique. The possibility of the membrane silicon sensor with ultrasonic plate waves application to the determination of the appearance of condensed water vapour is presented in this paper. The device with the ultrasonic plate waves is shown and described. The advantages of the constructed sensor in the practical determinations of air relative humidity by dew point technique are discussed. The results of experimental date are presented.

Keywords: air humidity, membranes.

1. THE SENSOR CONSTRUCTION AND THE CONDITIONS OF ULTRASONIC WAVES PROPAGATION

The sensor membrane with the ultrasonic wave consists of several layers which have different thickness. For the membrane that is made in silicon wafer, the basic layer (which determines the elasticity properties of the whole membrane) is monocrystalline silicon layer or the silicon nitride or silicon dioxide layers (Fig.1, 3, 4). The other layers are the isolation and metallic layers. In the metallic layer the electrodes of the electromagnetic transducers are made. The view of the transducers that are placed on the membrane surface and the contact fields is presented in Fig.3. When a static , in-plane magnetic field is applied perpendicular to the current direction, a surface-normal Lorentz is generated. The membrane vibration excited by forcing an alternating current in a input transducer produces motion that generates a voltage on a output transducer. The principle of the sensor work consists in generation of the ultrasonic wave in the plane membrane by means of two electromagnetic transducers (EMT). One of them works as a transmitter and the other works as a receiver. The velocity of wave propagation depends on the wave frequency and the membrane thickness [1,2]. For the symmetric wave it is possible to obtain lower phase velocities and lower wave frequency in the respectively thin membrane. In order to obtain the high sensitivities in the membrane sensor application as the mass detectors, the thin membranes should be used [2,4]. That is why for the membrane the following conditions should be fulfilled: the maximum wave amplitude is smaller than the thickness d, the wavelength λ is significantly higher than the membrane thickness ($\lambda >> d$), the membrane width a and length b are significantly higher than the thickness ($a >> d$, $b >> d$). The technologies of the thin, elastic layers production for the membranes of the sensors are presented below.

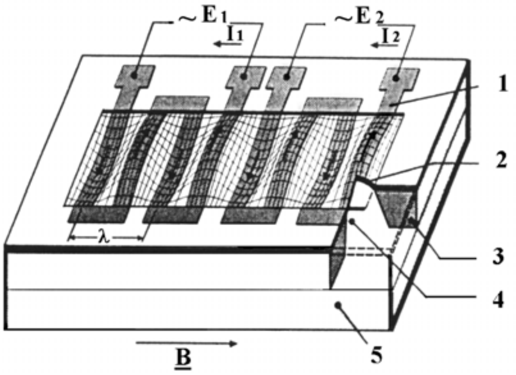

Fig.1 Schematic of the silicon membrane sensor with two electromagnetic transducers [3,8]
1- metallic pad, 2- thin membrane, 3- monocrystalline silicon, 4- air cavity, 5- Peltier device, B- magnetic flux density

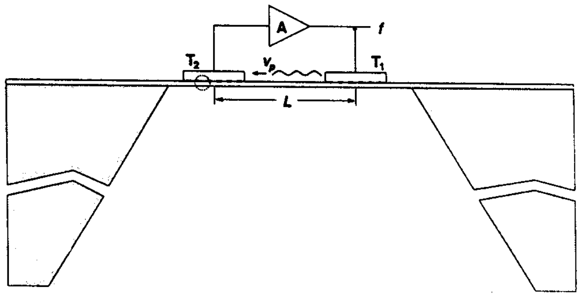

Fig.2 The generation membrane sensor with ultrasonic wave T_1, T_2 - transducers, A - amplifier.

The microsensors with ultrasonic wave often work in the generation systems where the sensor is the delaying line system placed in the feedback loop (Fig.2) [4]. The generation and detection of the ultrasonic wave need the application of two transducers denoted in Fig.2 as T_1 and T_2. The wave which phase velocity in the membrane undergoes the influence of the external factors that can change its attenuation as well as the velocity of propagation.

The analysis of the propagation of the plane wave in the homogeneous, isotropic plate, under the assumption that the wave length λ is considerably higher than the plane thickness d leads to the following equation, expressing the phase wave velocity V_p for the asymmetric mode [1,6,8]:

$$V_P = \sqrt{\frac{1}{m}[T + \left(\frac{2\pi n}{P}\right)^2 \frac{E \cdot d^3}{12(1-\nu^2)}]} \qquad (1)$$

where :m - the mass per unit area,
T - the component of tension in the x-direction,
P - the transducers' period ($P=n\lambda_n$),
E - Young's modulus, ν - Poisson's ratio, n - 1, 3, 5,
$D=Ed^3/12(1-\nu^2)$ – bending moment

The phase velocity depends on the tensions T, the effective bending stiffness of the plate, the transducers period P and the mass m per unit area. As a result the change of the delaying time causes the change of the generator input frequency f [8]:

$$f = \frac{\varphi_s V_P}{2\pi L} = \frac{2\pi k - \varphi_e}{2\pi} \frac{V_P}{L} \qquad (2)$$

where : φ_s - the phase shift of the sensor
φ_e - the phase shift of the electric circuit
L - the distance between T_1 and T_2 transducers
k- the whole number

The application of the suitable kind of the wave in the sensor depends on the type of the environment as well as on the measured value [1,5]. By means of the microsensors with ultrasonic waves, it is possible to measure the physical parameters such as: air humidity, force, pressure, acceleration, the viscosity of liquids as well as the biochemical values such as: the concentrations of the different gases, the contents of proteins and bacteria in solutions .

2. FABRICATION OF THE THIN SILICON MEMBRANES

The silicon membranes were obtained as a result of anisotropic etching of the silicon. The wafers with the diameter of 3" made of the monocrystalline silicon, one-side polished with the orientation of <100> , and the donor conductivity, phosphorus doped with resistivity of 1-2Ωcm were the basic materials. The thickness of wafers was equal to 380μm. The upper surface of the wafers was protected against etching in the potassium hydroxide (KOH) by the silicon nitride. This layer was made by LPCVD (Low Pressure Chemical Vapour Deposition) method in the reaction of dichlorosilane (SiH_2Cl_2) with ammonia (NH_3) at the temperature of 800^0C and the ratio of SiH_2Cl_2 to NH_3 was equal 4:1. The thickness of the silicon nitride layer (Si_3N_4) was equal to 20nm. The membrane shape on the bottom side of the silicon wafer was defined by photolitographic process. From the membrane area the silicon nitride layer was etched off in the plasma process and then the photoresist was removed. At the end, wafer was etched in the water solution of KOH. As a result of the anisotropic silicon etching the membranes with the sizes of 2∗2.5mm and the thickness of 2-10μm were obtained [7]. The top view and bottom view of the silicon membrane with two electromagnetic transducers are shown in Fig.2 and Fig.3.

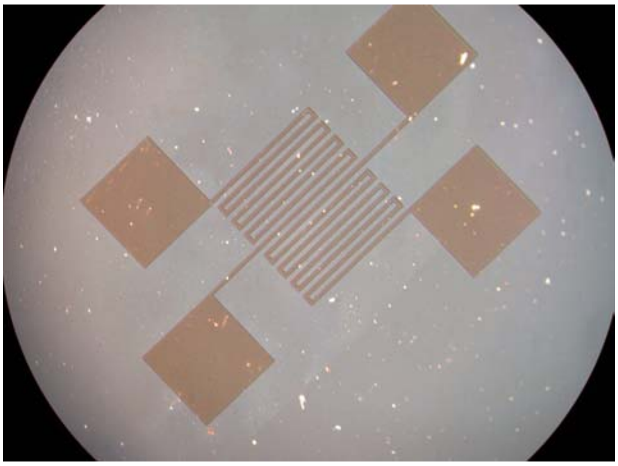

Fig.3 The top view of silicon membrane

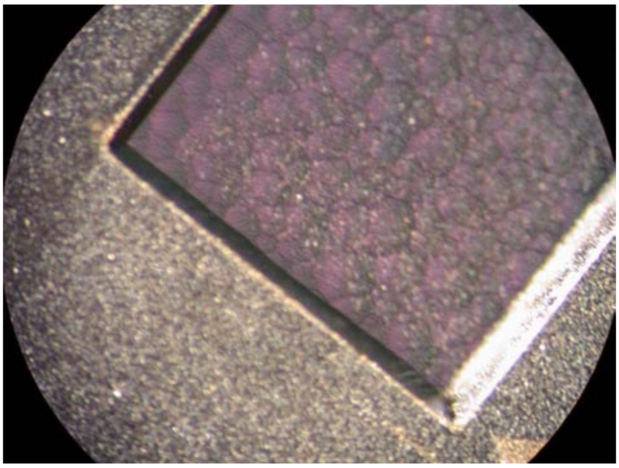

Fig.4 The bottom view of silicon mebrane

3. MICROSYSTEMS WITH THE ULTRASONIC WAVES TO THE DETERMINATION OF DEW POINT TEMPERATURE

The relative humidity of gas can be determined by the designation of dew point. The condensation of the gas takes place on the clean, polished and uniformly cooled surface at the temperature that is called "dew point temperature". The designation of this temperature and the simultaneous measurement of the temperature of surrounding gases allow to determine the relative gas humidity. It is known that the ultrasonic plate wave is markedly suppressed in the zone between two transducers it disperses when the condensed gas drops appear on the basement. The behaviour is the essential of the method. The basement is cooled down by means of Peltier's device that is placed on the other basement side to reach dew point. The schematic arrangement of the system to the measuring of air relative humidity by the designation of dew points is show Fig.5. The temperature of the basement the membrane sensor with the ultrasonic plate wave is located on is decreased by means of the regulating system with Peltier device (4) to temperature that the appropriate suppressing of wave is observed (3). The signal coming from generator (1) produces the ultrasonic plate wave in the transmitter transducer T_1 (2). The plate wave is propagation in silicon membrane and generates the signal in the receiving transducer T_2 (3). The signal is amplified (5) and detected (6) and then it is delivered to the compared input (7). The signal coming from the generator is detected (8) and supplied to the second input of the comparator.

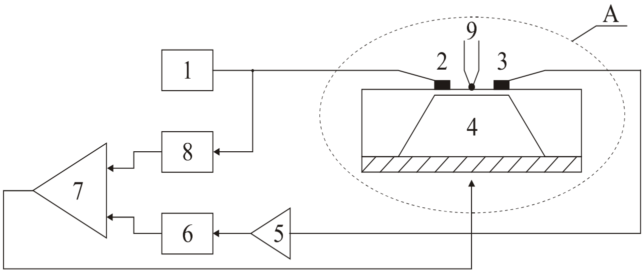

Fig.5 The system to the determination of the dew point temperature (A- silicon sensor with thermocouple 9 and Peltier device 4)

The input voltage of the generator is compared with the amplified input voltage of receiver. The condensation of the water vapour on basement is reflected in the evident wave suppressing, and it influences the comparator state. The change of the comparator state is a symptom that the surface reaches the temperature of dew point. At the moment the process of basement cooling is stopped. The temperature of the surface membrane is controlled by means of the thermocouple (9). The decrease of the influence of surface impurities can be acquired by appropriate selection of the amplification factor. The membrane sensor with ultrasonic plate wave makes here the delaying line that works in the feedback loop.

The equation (2) indicates that the generator frequency depends on the distance L and the wave velocity V_p. The more evident wave suppressing that is observed when the surface is covered with the water drops (at the dew point temperature) is reflected in the breaking of the oscillations in the generator circuit. The mentioned above amplitude condition isn't fulfilled. There are a few ways to obtain the desirable dependence of the frequency on the basement temperature: the choice of appropriates basement material, the regulation of the suppressing device, the regulation of the amplifier (5) in Fig.5.

The temperature properties of the basement are characterised by the coefficient of wave suppressing and the coefficient of delay time $T\tau$ or the coefficient of rate change Tv. The generator frequency can be a measure of the basement temperature. The frequency of the oscillations just before a moment they are broken indicates the dew point temperature. There are some advantages of the described system. There is no need to use the thermoelectric sensor to the temperature measurement. The equipment to the temperature control works alternatively: the cooling is stopped at the moment of breaking of generator oscillations and subsequently the heating is continued. The suppressing device minimises the influence of surface impurities and it protects the system against the random breaking of the oscillations.

$$T\tau = \alpha_l - \frac{1}{2c}\frac{\partial c}{\partial T_t} + \frac{1}{2\rho}\frac{\partial \rho}{\partial T_t} \tag{3}$$

$$Tv = \frac{1}{2c}\frac{\partial c}{\partial T_t} - \frac{1}{2\rho}\frac{\partial \rho}{\partial T_t} \tag{4}$$

where : T_t – temperature background surface
c – constant stiffness
ρ - density
α_l- coefficient temperature extension

4. EXPERIMENTAL DATA

The measuring system that is presented in Fig.5 was tested experimentally. The electromagnetic transducers were symmetrical (Fig.3) on the parameters : a=2.5 mm, b=2mm, d=0.002 mm, E=2.76*10^{11} N/m^2 , P=0.160 mm, D=0.19*10^{-6} Nm, T=122 N/m, ρ_0=2.95*10^3 kg/m^3, m_0=11.1*10^{-3} kg/m^3. The period P of the electrodes was 160 μm and the distance between them was 160 μm. The middle generator frequency was equal to 1210.77 kHz. The microwave united MUDAMPs MSA type systems made by Avantek were used as the multiplying devices. The multipliers were stabilised thermally where they were working. The thermoelectric CP 08-127-06L type Melcor module was used as a temperature regulator. The frequency was measured by means of PFL-22 type frequency meter that was previously stabilised. The independent temperature measurement was made by means of NiCr-NiAl thermocouple that was equipped with the device to the compensation of the free terminal temperature. The electromotive force was measured by means of MIT 380 T type digital voltmeter. The temperature of dew point (measured by means of thermocouple) was compared with the generator frequency just before the moment the oscillation breaking. The optical microscope was applied in order to take notice the appearance of moisture drops. The measurements were carried out at the conditioned chamber at 20^0 C. There was a possibility to regulate the humidity of air at the chamber.

The results of the measurements that were carried out are presented in Table1.

TABLE 1: The dew point temperature-induced frequency change

relative humidity	generator frequency	dew point temperature	temperature-induced frequency change
%	kHz	^{o} C	Hz/^{o} C
32	1206.94	3.9	242
37	1207.40	5.8	243
43	1207.96	8.1	243
50	1208.47	10.2	252
58	1209.05	12.5	253

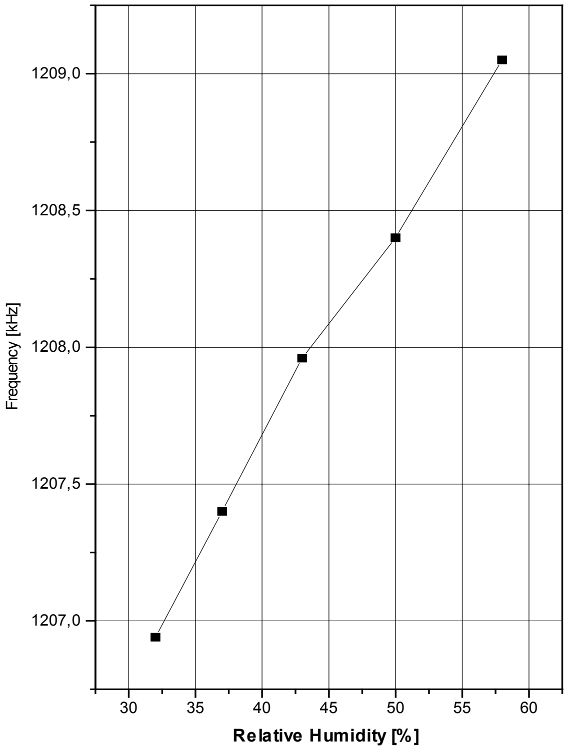

Fig.6 Fractional change in oscillator frequency as functions of change relative humidity air

5. CONCLUSIONS

The results of the measurements that were carried out lead to the conclusion that the membrane ultrasonic sensor can be applied to the dew point designation. There is a possibility to regulate the sensitivity of the system. It can be achieved through the appropriate selection of frequency range as well as through the selection of the sizes of basement the water vapour condensation takes place. It was stated that the cooling rate, the properties of the material the basement is made of as well as the generator stability influence the method accuracy [5,9,10]. The application of monocrystalline silicon as a basement material seems to be a quite good solution because of its mechanical characteristics, and its electro-mechanical coupling and the temperature induced delay time coefficients. The additional improvement of the sensitivity is possible through the application of ultrasonic flexural plate waves (FPW, Lamb waves).

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