ISSN 1392 – 1215 ELECTRONICS AND ELECTRICAL ENGINEERING 2009. No. 4(92)
ELEKTRONIKA IR ELEKTROTECHNIKA

T190 ELECTRICAL ENGINEERING
ELEKTROS INŽINERIJA

Research of the Method Opportunities of Growing Films Conductance Measurement

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Introduction

The island stage, mono-atomic layers or other nano-derivatives are derivable at the initial stages of the condensation of the metal vapor. There are many different physical models for the estimation of the growing film conductance subject to its thickness [1–4]. The conductance of the growing film depends on the condensate state, the size of the grain, temperature [5], the condensation rate [6], impurities and the other conditions, therefore all these methods give us only approximated results. The special probes [1, 7] and the measurement schemes [8] are used for measurement of the growing films conductance. The analysis shows, that sometimes the conductance is on the pendulous increase during the growing of metal films [9]. The charges flow into the surface of the film and create the space charge above it during the condensation process. The measurement results of the conductance are under the influence of this space charge.

The made-up mathematical model of the measurement method of the growing film uses the space charge above the film instead the outer supply [10]. The research of the opportunities of this measurement method, using the conductance measurement probe with two contact areas, is given in this paper.

The mathematical model of the measurement of the condensate conductance

The probe of the condensate conductance measurement (Fig.1) consists of the dielectric substrate *1*, having width *b*, with two metallized areas *2* and *3*. The distance between contact areas is *L*. The molecules of the evaporating material flow into *XY* plane of the probe along the *Z* axes. The ionized atoms and the emitted electrons flow there too. The distance between *XY* plane and the evaporator are long; therefore the density of charges and atoms flow to the condensate *4* is even between the contact areas *A* and *B*.

It is assumed in the mathematical model that the condensate *4,* having the resistance r_p, is growing at the same rate along the all area between contact areas *A* and *B* [10]. The condensate is in island stage and there is no solid layer at the initial stages of condensation, therefore the *h* is the equivalent thickness of the condensate. For the creating of the model, the condensate zone is divided into the parts of the length *dx*, width *b* and with the thickness *h*. The equivalent resistance of the charges flow i_E is marked as r_E. It is assumed r_E is a constant. The comprehensive mathematical model of the conductance measurement is given in the paper [10].

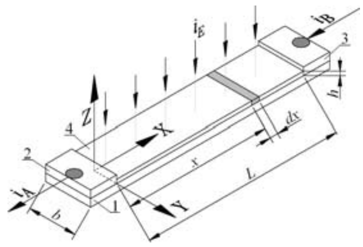

Fig. 1. The probe of the condensate conductance measurement: 1 – the dielectric substrate; 2 – contact area *A*; 3 contact area *B*; 4 – film of the condensate

The potential u_x of the part *dx* as a function of the distance *x* to the contact area *A* is as follows:

$$\frac{d^2u_x}{dx^2} - \frac{r_p}{r_E L^2} u_x = -\frac{r_p}{r_E L^2} E . \tag{1}$$

The characteristic equation roots of the differential equation (1) are as follows:

$$\lambda_{1,2} = \pm \frac{1}{L}\sqrt{\frac{r_p}{r_E}} = \pm \frac{\beta}{L} . \tag{2}$$

Than the general solution of the equation (1) is:

$$u_x = C_1 e^{x\frac{\beta}{L}} + C_2 e^{-x\frac{\beta}{L}} + E . \tag{3}$$

The coefficients C_1 and C_2 depend on the inner condition of the contact areas *A* and *B*, id est on the probe connection to the measurement scheme. The probe *A* was connected to the earth and the potential u_B of the probe B, which is equal to the voltage drop on the resistance r_m, was measured during the experiments (Fig.2).

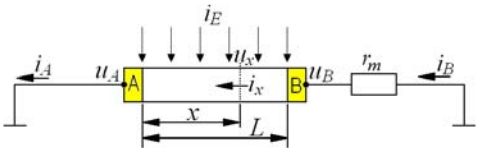

Fig. 2. The connection scheme of probe of condensate conductance measurement

The notation is as follows:

$$A = \frac{r_m}{r_p}\beta, \quad D_E = \frac{e^{\beta} - e^{-\beta} + A\left(e^{\beta} + e^{-\beta}\right)}{-E}. \tag{4}$$

Taking into account the expressions of the coefficients C_1, C_2 [10] and the notation (4), the potential of the condensate u_x as a function of the distance x is as follows:

$$u_x = \frac{e^{x\frac{\beta}{L}} - e^{-x\frac{\beta}{L}} + e^{\frac{\beta}{L}(L-x)} - e^{-\frac{\beta}{L}(L-x)}}{D_E} + A\frac{e^{\frac{\beta}{L}(L-x)} + e^{-\frac{\beta}{L}(L-x)}}{D_E} + E. \tag{5}$$

Replacing the distance x by the distance L between contact areas A and B in the equation (5), the potential u_B of the contact area B as a function of β and the resistance r_p becomes as follows:

$$u_B = -E\frac{e^{\beta} - e^{-\beta} + 2A}{e^{\beta} - e^{-\beta} + A\left(e^{\beta} + e^{-\beta}\right)} + E. \tag{6}$$

The equation of the potential u_B as a function of the condensate resistance r_p was expressed using the equivalent model of two resistances for the measurement of the condensate conductance [11]:

$$u_B = \frac{-2Er_p r_m}{r_p^2 + 2r_p\left(2r_E + r_m\right) + 4r_E r_m}. \tag{7}$$

The potentials u_B were calculated using the equations (6) and (7) (Fig.3). The revised physical model, using the equation (6), gives major values of the potential u_B at the high ohmic resistances. Decreasing the condensate resistance r_p from the extreme value of the potential u_B, the values of the potential u_B, calculated using the equations (6) and (7), are approximating to each other until they are becoming equal.

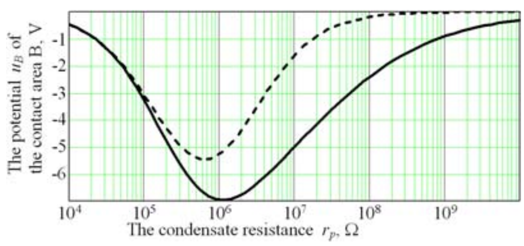

Fig. 3. The potential u_B of the contact area B as a function of the condensate resistance r_p

However the value of the condensate resistance r_p between the contact areas is determined by several factors: a – the thickness of the condensate h; b – the geometrical proportion of the condensate area between the contact areas; c – the quality of the condensate structure.

Resistivity as a function of the thickness of the condensate

The condensate resistance r_p between the contact areas A and B, when the equivalent thickness of the film h is even all-over and the conductivity of the solid is σ_0, is calculated as follows:

$$r_p(h) = \frac{1}{k_\sigma(h)\sigma_0}\frac{L}{bh}. \tag{8}$$

The conductivity of the thin films is not the constant value; it depends on the thickness of the thin film h. This dependence can be write as a function $k_\sigma(h)$. There are several physical models of the function $k_\sigma(h)$. The Fuchs-Sondheimer (F-S) model is used in this research work [2, 3], taking into account the diffuse dispersion of the electrons crashed into the surface of thin film. The function $k_\sigma(h)$ is expressed as follows in the F-S model:

$$k_\sigma(h) = 1 - \frac{3\lambda}{2h}\int_0^{\frac{\pi}{2}} \sin^3\Theta\cos\Theta\left(1 - e^{\frac{-h}{\lambda\cdot\cos\Theta}}\right)d\Theta, \tag{9}$$

where λ – the mean free path of the electrons. This approximated expression is used [1], when the film is relatively thick, $h >> \lambda$:

$$k_\sigma(h) = \frac{\sigma(h)}{\sigma_0} = \frac{1}{1 + \frac{3\lambda}{8h}(1-p)}, \quad \frac{h}{\lambda} >> 1, \tag{10}$$

where p – the dispersion parameter of the Fuch's electrons crashed into the inner surface of the film: p=1 – dispersive scatter, p=0 – mirror-image. Being the film relative thin, $h << \lambda$, such approximated expression is used [2]:

$$k_\sigma(h) = \frac{\sigma(h)}{\sigma_0} = \frac{3h}{4\lambda}\left(\ln\frac{\lambda}{h} + 0{,}4228\right)\frac{1+p}{1-p}. \tag{11}$$

The function $k_\sigma(h)$ was calculated using the equations (9) and (10) (Fig.4.). The approximated equations (10) and (11) don't give the right results in that case, when $h \approx \lambda$. Therefore the numerical solution of the equation (9) is used in this work.

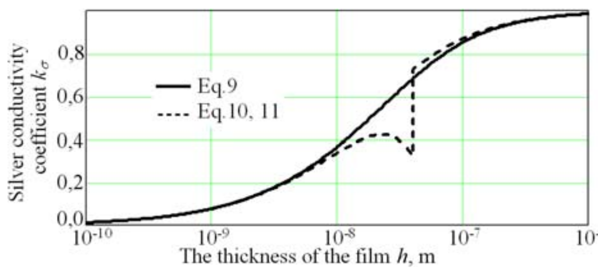

Fig. 4. Silver conductivity coefficient $k_\sigma(h)$ as a function of the thickness of the film h

The evaluation of the influence of the substrate measurements

The electrons flow emitted from the hot evaporator is used instead of the outer supply in this method of the condensate conductance measurement [10]. The inner resistance of the charges flow flowing into the substrate is r_E. It was decided to use the substrates of the different measurements, but with the same areas between the contact areas *A* and *B*, reducing the influence of the resistance r_E. For example, the area is 40mm^2. Then the measurements *L*×*b* of the several typical substrates will be such as: 40×1mm, 20×2mm, 10×4mm, 5×8mm (Fig.5). The resistances of the silver condensate r_p as the functions of the thickness of the film *h*, when the measurements of the substrates are different, are shown in Fig.6.

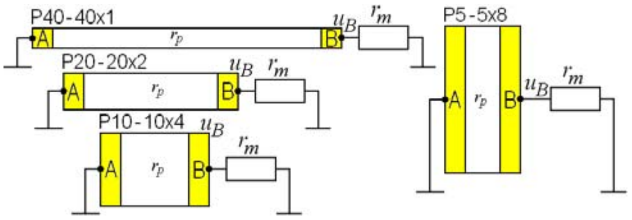

Fig. 5. The typical substrates with the same areas for the condensate between contact areas

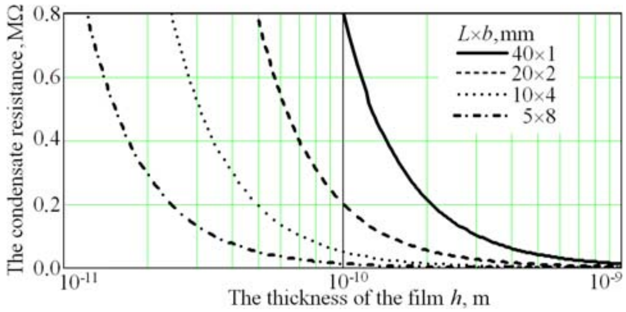

Fig. 6. The condensate resistance r_p as a function of the fil thickness *h*, when the measurements of the substrate *L*×*b* are different

The change of the condensate resistance r_p from 100kΩ to 1MΩ, calculated using the equations (9) and (10), is equivalent to the change of the film thickness *h* from 10 Å to 0.1 Å. The silver film of such thickness can be in island stage or it can be of one or several mono-layers.

The potential of the substrate as a function of the condensate thickness and the measurements of the substrate

The potential alternation u_B of the contact area *B*, when the film thickness and the measurements of the substrate *L*×*b* are different, is shown on Fig. 7. The marked change of the potential u_B is discernible when the thickness *h* is from 0,1Å to 1Å. The extreme value of the potential u_B is the same in the same conditions. Consequently, the measurements of the substrate can be chosen in such a way that in the due resistance r_p and the thickness of the condensate the values of potential u_B would be extreme.

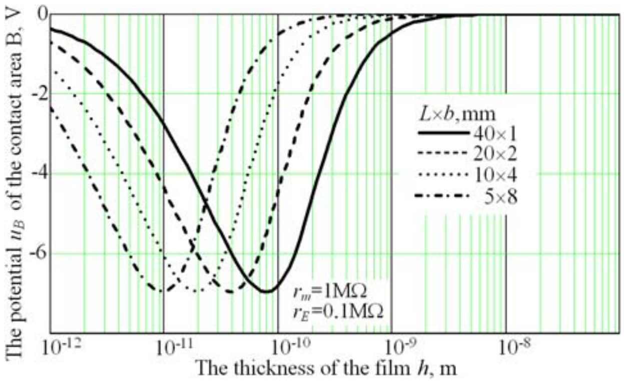

Fig. 7. The alternation of the potential u_B of the contact area *B* growing the thickness of the film *h*, when the substrates of the different measurements are used

The potential of the substrate as a function of the resistance r_m

The selection of the measurement resistance r_m, contacted to the contact area B (Fig.2) has a great influence on the place and he form of the potential u_B extreme. There are two measurement modes: r_m>100kΩ – measurement of the probe potential u_B (Fig.8), r_m<100Ω – measurement of the probe current (Fig.9). When the extreme of the potential u_B is reached, the condensate film is ten times thicken, using the low ohmic measurement resistance. Therefore, it is possible to research the condensate state with the same probe in the wide diapason of the film thicknesses commutating the resistance r_m.

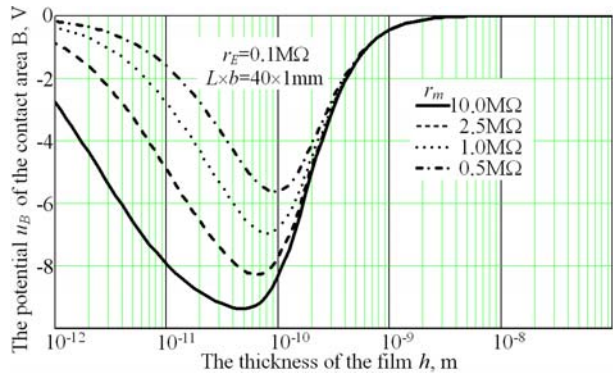

Fig. 8. The potential u_B of the contact area B as a function of the film thickness *h*, when the high ohmic measurement resistance r_m is used

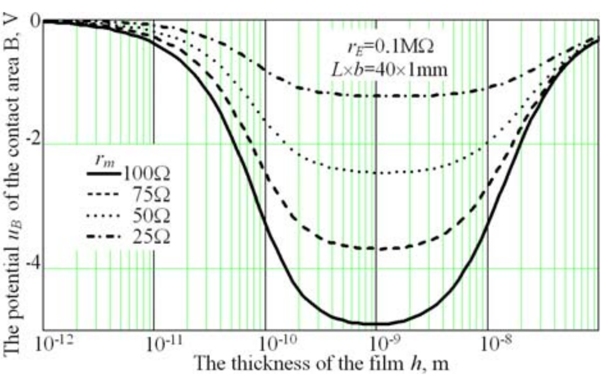

Fig. 9. The potential u_B of the contact area B as a function of the film thickness *h*, when the low ohmic measurement resistance r_m is used

The potential of the substrate as a function of the configuration

The equivalent resistance of the charges r_E depends on the evaporator as on the supply of the electrons, also on the area of the surface, the orientation in the space, the distance to the probe and the configuration of the surrounding metallized parts connected to earth. The potential u_B as the functions of the thickness h and the resistance r_E are shown on Fig.10. The resistance r_E can't be changed during the evaporation process. Thought the probe can be flood with the extra electrons using the electron optical system.

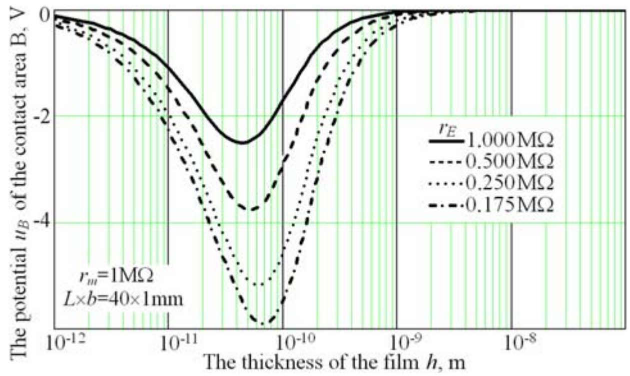

Fig. 10. The potential u_B of the contact area B as a function of the film thickness h, when the different charges flow resistances r_E are used

Conclusions

1. It was determined, that the probe of the condensate conductance measurement with two contact areas, growing the condensate film, always gives the extreme of the signal.
2. The signal of the extreme, choosing the geometrical measurements of the probe and the measurement resistance, can be noticed, when the thin film is in the island stage or it is composed of several mono-atomic layers.

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Received 2009 02 14

V. Sinkevičius. Research of the Method Opportunities of Growing Films Conductance Measurement // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 4(92). – P. 71–74.

The methods of the non-invasive conductance measurement of the growing thin films were analyzed using the measurement probe with two contact areas. It was determined, that it is possible to reach the extreme of the signal for the layers from the island stage to the continuous layers, choosing the measurements of the substrate, measurement resistance or configuration. Ill. 10, bibl. 11 (in English; summaries in English, Russian and Lithuanian).

В. Синкявичюс. Исследование возможностей метода измерения проводимости растущих пленок // Электроника и электротехника. – Каунас: Технология, 2009. – № 4(92). – С. 71–74.

Исследованы основные способы применения измерительного зонда с двумя контактными площадками для безинвазного измерения проводимости конденсата, растущего в вакууме. Определено, что при подборе размеров подложки зонда, величины измерительного сопротивления или конфигурации измерительной системы можно получить экстремум сигнала зонда для толщин конденсатов в широком диапазоне – от островковых до сплошных плёнок. Ил. 10, библ. 11 (на английском языке; рефераты на английском, русском и литовском яз.).

V. Sinkevičius. Augančių plėvelių laidžio matavimo metodo tyrimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 4(92). – P. 71–74.

Išanalizuoti pagrindiniai vakuume augančio kondensato laidžio neinvazinio matavimo metodo taikymo būdai. Naudojamas matavimo zondas su dviem kontakto aikštelėmis. Nustatyta, kad, pasirenkant padėklo matmenis, matavimo varžą ar konfigūraciją, galima gauti zondo signalo ekstremumą saleliniuose ir ištisiniuose sluoksniuose. Il. 10, bibl. 11 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).