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BIOSENSORS

UDC 53.082:612.017.1

OPTICAL PHASOMETRY OF INFORMATION SIGNALS IN SPR-SENSORS

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Abstract. There were considered the specificities of the optical phasometry of information signals in sensors employing the surface plasmon resonance (SPR-sensors). The applied principle is the interference between the polarized light beams reflected from a sentitive receptor under the conditions of resonance. The efficiency of the SPR phasometry is related to the benefitial application of the wedge-shaped light beam and the optimal angle positioning of the polarizer and the analyzer relative to the plane of the light incidence onto the receptor. The method has been proposed to determine the phase shift and resonance that employs the sequences of rectangular calibration impulses to construct information signals and their correlation processing. The angular resolution capacity of the SPR phasometry is restrained with the conditions of the registry of the above signals and is described by the value $(\Delta\theta)_{\min} \sim 0{,}001^0 \div 0{,}0001^0$, that corresponds to the change in refraction index $(\Delta n)_{\min} \sim 10^{-7} \div 10^{-8}$.

Keywords: surface plasmon resonance, SPR-sensor, optical phasometry, interference, polarization, correlation method, resolution capacity

ОПТИЧНА ФАЗОМЕТРІЯ ІНФОРМАЦІЙНИХ СИГНАЛІВ У ППР-СЕНСОРАХ

І. Д. Войтович, І. О. Яворський

Анотація. Розглянуто особливості оптичної фазометрії інформаційних сигналів у сенсорах на основі поверхневого плазмонного резонансу (ППР-сенсорах). Використана інтерференція між поляризованими світловими променями, відбитими від чутливого рецептора в умовах резонансу. Ефективність ППР-фазометрії пов'язується із доцільністю застосування клиноподібного світлового променя та оптимальним кутовим розміщенням поляризатора і аналізатора відносно площини падіння світла на рецептор. Запропонована методика визначення фазового зсуву і резонансу, яка використовує послідовності прямокутних еталонних імпульсів для побудови інформаційних сигналів і їх кореляційну обробку. Кутова роздільна здатність ППР-фазометрії обмежується умовами реєстрації зазначених сигналів і оцінюється величиною $(\Delta\theta)_{\min} \sim 0,001^0 \div 0,0001^0$, що відповідає зміні показника заломлення $(\Delta n)_{\min} \sim 10^{-7} \div 10^{-8}$.

Ключові слова: поверхневий плазмонний резонанс, ППР-сенсор, оптична фазометрія, інтерференція, поляризація, кореляційний метод, роздільна здатність

ОПТИЧЕСКАЯ ФАЗОМЕТРИЯ ИНФОРМАЦИОННЫХ СИГНАЛОВ В ППР-СЕНСОРАХ

И. Д. Войтович, И. А. Яворский

Аннотация. Рассмотрены особенности оптической фазометрии информационных сигналов в сенсорах на основе поверхностного плазмонного резонанса (ППР-сенсорах). Использована интерференция между поляризованными световыми лучами, отраженными от чувствительного рецептора в условиях резонанса. Эффективность ППР-фазометрии увязывается с целесообразностью использования клиноподобного светового луча и оптимальным угловым размещением поляризатора и анализатора относительно плоскости падения света на рецептор. Предложена методика определения фазового сдвига и резонанса, использующая последовательности прямоугольных эталонных импульсов для построения информационных сигналов и их корелляционную обработку. Угловое разрешение ППР-фазометрии ограничивается условиями регистрации указанных сигналов и оценивается величиной $(\Delta\theta)_{\min} \sim 0,001^0 \div 0,0001^0$, что соответствует изменению показателя преломления $(\Delta n)_{\min} \sim 10^{-7} \div 10^{-8}$.

Ключевые слова: поверхностный плазмонный резонанс, ППР-сенсор, оптическая фазометрия, интерференция, поляризация, корелляционный метод, разрешающая способность

1. Introdudction

The traditional application of resonance parameters in SPR-sensors becomes insufficient if high levels of analysis precision are at stake. In these cases, to increase the resolution capacity of a sensor and to obtain additional information as to the matter under examination, the light phasal shifts can be considered that normally accompany the surface plasmon resonance [1-3].

The existing up to now SPR phasometry sensors employ the interference of polarized light waves that allow reveal the above-mentioned phase shifts. Typically, such sensors are construed according to the classic interferometric circuit with separate reference and signal paths [2,4,5], or, alternatively, with the circuit where those paths are mutually integrated at the optical level [6,7,8]. The above integration means that within a certain special interval the interferating light waves of different polarization reflected from the sensitive receptor are combined inside a common light path and are distributed along a single direction (common-path interferometry [7]). Yet, in all the instances under discussion, SPR-sensors were upgraded technically to a significant measure, such as complemented with precision mirrors, optical beam separators and attenuators, electrical optical modulators, phaseregulating modules, etc. Furthermore, the methods of heterodyne interferometry, that are applied most often, require rather bulky feedback circuits and control system of high voltage (thousands of Volts) [5,8]. In fact, this kind of sensors rather represent themselves examination laboratory stations that makes the analysis procedure rather costly.

The purpose of the current work is to develop much simpler approaches to determine the above phase shifts, to provide for their noise filtration and convert into signals that could be registered by SPR, the work further intends to design inexpensive portable sensors of high resolution ability.

2. The Circuit and the Operation Method of the phasometrical SPR-sensor

Herewith the typical circuit of light transmission in a SPR-sensor is considered complemented with the components intended for the phasometrical analysis of the optic signal (Fig.1). The basis is the circuit with the integrated beam path. The above circuit comprises the emitter 1, polarizer 2, rectangular aperture diaphragm 3, cylindrical lense 4, total internal reflection prism 5, sensitive receptor 6, analyzer 7, objective lens 8 and optical receiver 9. The emitter is a narrow-band laser and the optical receiver is a CCD gage. The objective lens is used to shape at the optical receiver of the interference signal that is generated inside the passing beam.

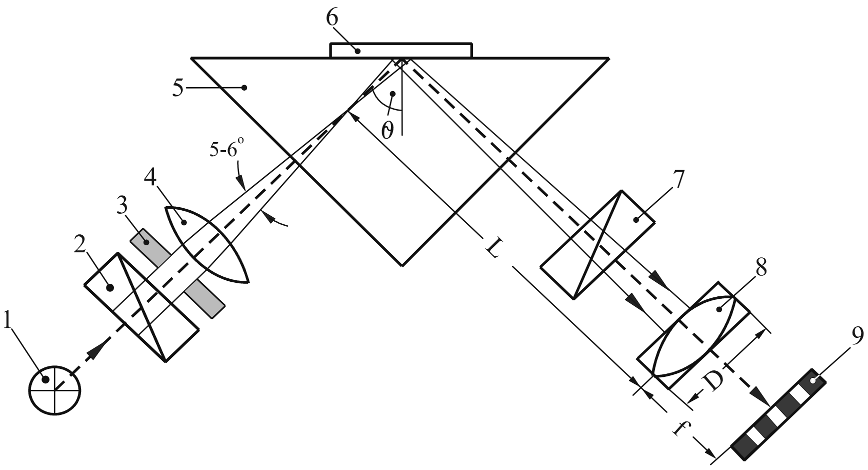

Fig. 1. The diagram of light transmission in SPR-sensor with optical phasometry: 1 — radiation source, 2 — polarizer, 3 — rectangular aperture diaphragm, 4 — cylindrical lens, 5 –total internal reflection prism, 6 — sensitive receptor, 7 — analyzer, 8 — objective lens, 9 — optical receiver

Let us assume that into the prism and the sensitive receptor, that have an immersion contact between them, from the side of the prism at angle θ (the axial angle), close to resonance θ_0 there falls a polarized light beam with the oscillation amplitude of electric vector E_0. By use of rectangular diaphragm 3 and cylindrical lens 4 the beam has the wedge shape of a constant breadth (the breadth is determined by the diaphragm and is estimated perpendicular relative to the light incidence plane). The beam breadth ($\sim 5-6^0$) is necessary for the angular scan along the receptor while in the search of resonance. The beam is being focused directly before the receptor or after it. The means to shape that kind of beams are well known and are not to be considered in any extra detail herein. To describe the processes occurring within the above type of circuit let us apply the vector method [9].

In case of traditional SPR method of measuring that makes use of resonance parameters, the polarizer is typically positioned in a way to make the polarizing plane parallel to the plane of the light incidence onto the receptor. Whereas for the phasometry method related to interference there is a need in composite emissions both with parallel and perpendicular (vs. the incidence plane) polarization. For these purposes, polarization plane P is positioned at angle φ relative to the light incidence plane R (Fig.2). This makes the parallel component $E_{//} = E_0 \cos\varphi$, and the perpendicular one — $E_{\perp} = E_0 \sin\varphi$. The above components are coherent and have the same phase. Yet, only the component $E_{//}$ participates in the plasmonic resonance excitation and is absorbed by the receptor. Reflected from the receptor is only part of this component $\sqrt{r}\, E_{//}$ (r - reflection rate).

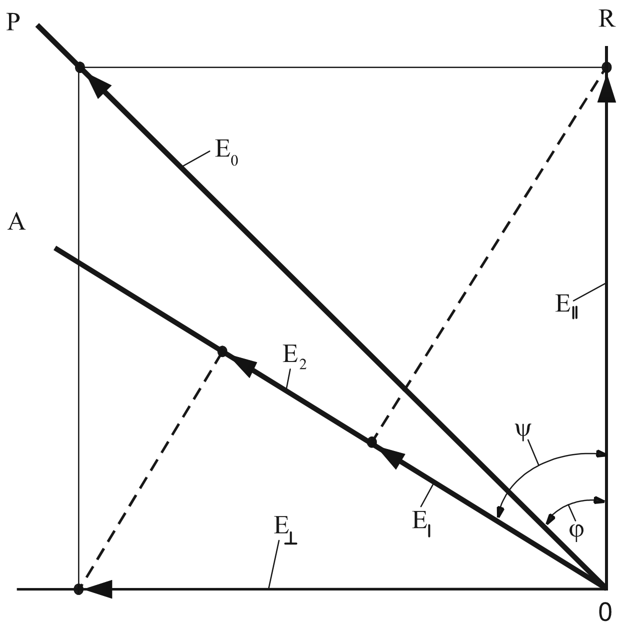

Fig.2. Vector diagram of calculating the phasometric process

Hence, after the reflection, the parallel component $E_{//}$ decreases by amplitude to $\sqrt{r}\, E_0 \cos\varphi$. By this it also changes its phase. As for the perpendicular component $E_{\perp}$, it changes its phase only without changing the amplitude [1-3,9]. As the result, between components $\sqrt{r}\,E_0\cos\varphi$ and $E_0\sin\varphi$, that are directed towards the analyzer, there occurs a certain phase difference δ. The specificity of the phase shift between these components in case of SPR and its drastic difference in case of an ordinary total internal reflection (such as, for instance, in case of the surface 'glass — air') are stipulated by the presence of free electrons inside the thin metal film of the sensitive receptor and the corresponding composite refraction index of the film. The abrupt step δ is the criterion that signifies that given a certain angle $\theta=\theta_0$ there is an occurrence of a plasmon resonance. To determine the resonance the interference between the above components is to be considered.

Assuming the transmission area A of analyzer 7 is at angle ψ to light incidence plane R, then after the beam passess the analyzer new components are formed E_1 and E_2:

$$\begin{aligned} E_1 &= \sqrt{r}\,E_0\cos\varphi\cos\psi, \\ E_2 &= E_0\sin\varphi\sin\psi. \end{aligned} \tag{1}$$

The above components remain coherent and due to the analyzer function they are also parallel. Between them the phase shift is preserved that is characteristic of the shift between $E_{//}$ and $E_{\perp}$ after reflection from the receptor, hence, there is interference. Applying the rule of adding vectors, at the analyzer output, taking into consideration the decrease of component $E_{//}$ in case of resonance, the obtained light has intensity

$$\begin{aligned} I = E_0^2\Big[& r\cos^2\varphi\cos^2\psi+\sin^2\varphi\sin^2\psi+ \\ & +2\sqrt{r}\,\cos\varphi\cos\psi\sin\varphi\sin\psi\cos\delta\Big]. \end{aligned} \tag{2}$$

The phase shift and interference are characteristic by some measure of any i - discrete components of the wedge-shaped light beam that the latter beam can be conventionally decomposed into, including the beam reflected at the angle $\theta_i\neq\theta_0$. Each of such beams has its own components polarized in parallel and perpendicular with the characteristic phase shift δ_i. After passing the analyzer each i beam forms along the direction of its distribution a spacial ('localized at the infinity' [9]) interference image. Each beam at its own angle is incident onto the objective lens and is directed by the latter to a singular point of its focal plane. Towards the very same point the lens gathers the rest of the beams parallel to the above discrete beam. All the beams are reflected from the receptor at identical angles and, correspondingly, convey identical information on the phase shift, and their number is proportional to the breadth of the light wedge. All the above helps localize the interference image within the plane of positioning of the photosensitive CCD gage and also increase its intensity, which is the necessary condition for the registry of the interference signal.

There is a possibility to use in the place of a regular (spheric) objective lens 8 a cylindrical lens under the condition that such an objective and the cylindrical lens are 'criss-crossed' (are orthogonal), and the central (axial) plane of the beam scattering passes via the focal line of the objective. By this, the interference is localized along the above focal line, yet its intensity is lower due to the absence in the cylindrical lens of the light refraction along the direction coinciding with the direction of the focal line.

Let us consider the correlations that determine the optimum interference signal. For the effective interference of reflected light waves it is necessary for their amplitudes to be equal and of possible maximum value. The equality of amplitudes with the account of the change $E_{//}$ under resonance is given by condition

$$E_0\sin\varphi\sin\psi=\sqrt{r}\,E_0\cos\varphi\cos\psi\,. \tag{3}$$

With (3) the expression can be found for the amplitudes of each of the waves that contribute to the interference:

$$U(y)=\pm E_0\sqrt{\frac{y^2-y^4}{1+\mu y^2}}\,, \tag{4}$$

where $y=\sin\psi$, $\mu=\dfrac{1-r}{r}$. In correspondence to the well-known in mathematical analysis 'mean value theorems', function $U(y)$ at the interval $0\le|y|\le 1$ has its extremum. Under condition $\dfrac{d}{dy}U(y)=0$ the obtained equation is

$$\mu y^4+2y^2-1=0 \tag{5}$$

that determines the optmum values y_{opt}, for which amplitude $U(y)$ reaches its maximum. Solving the equation (5) gives

$$y_{opt}=\sin\psi_{opt}=\pm\sqrt{\frac{\sqrt{r}-r}{1-r}}\,. \tag{6}$$

Hence, from (3) it follows that $\sin\varphi_{opt}=\sin\psi_{opt}$.

It is evident that $\varphi_{opt}=\psi_{opt}$. Hence, to obtain maximum interference the polarization plane P of the polarizer and transmission plane A of the analyzer are to be parallel, which can be achieved by means of turning the polarizer and the analyzer. By this, the optimum angle positioning $\varphi_{opt} = \psi_{opt} = \phi_{opt}$ of the above planes versus the light incidence plane R onto the sensitive receptor is a function from reflection rate r :

$$\phi_{opt} = arctg\ r^{1/4}. \tag{7}$$

The corresponding dependency is shown in Fig. 3. To calculate the interference intensity, instead of (2), the expression to use is:

$$I = 2E_0^2 \sin^4 \phi_{opt}\ (1+\cos\delta), \tag{8}$$

that is the basis to obtain the phase shift δ.

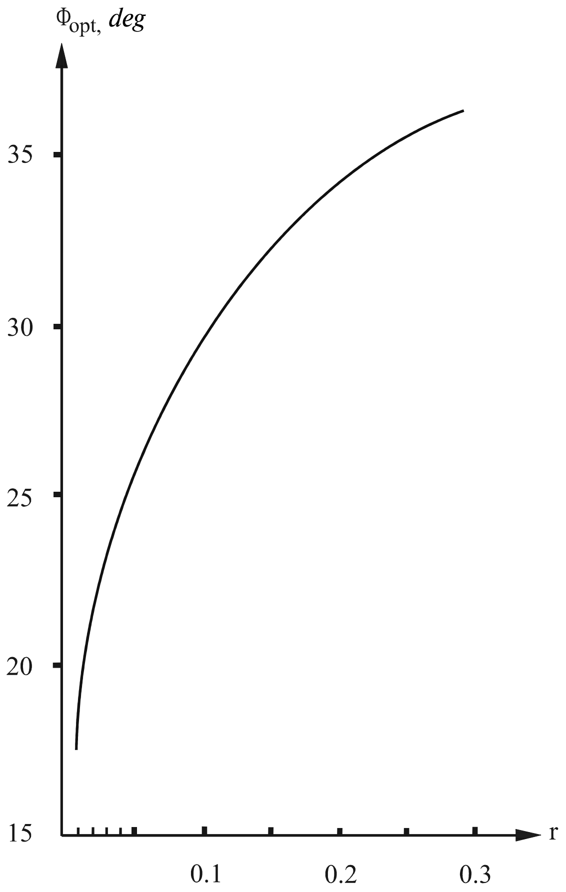

Fig.3. Correlation between ϕ_{opt} and the light reflection rate r in the resonance minimum

In general, (8) describes the interference intensity both under the condition of total internal reflection ($r=1$), and under surface plasmonic resonance ($0 \le r < 1$). Under the former condition in correspondence to (7) $\phi_{opt} = \frac{\pi}{4}$, hence

$$I = 0,5E_0^2\ (1+\cos\delta). \tag{9}$$

Under SPR the interference is determined by the changes in reflection rate. For instance, under $r=0$ angle $\phi_{opt} = 0$, $I=0$ and interference does not occur whatsoever, as the component $E_{//}$ is absent in the reflected light. Whereas $r=0,1$ and corresponding $\phi_{opt} = 29,35^0$ result in

$$I = 0,115E_0^2\ (1+\cos\delta). \tag{10}$$

Comparing expressions (9) and (10), the first impression is that in case of regular total internal reflection the interference is considerably more effective than that under SPR. The explanation is the decrease of the intensity component $E_{//}$ in the resonance zone. Yet, it is instrumental to consider, that within the resonance minimum there take place rather abrupt phase changes $E_{//}$ (dramatic change) [4], that could serve a physical basis in the resonance search. The objective is to develop the registry methods of the above changes and the means of shaping at their basis of information signals compatible with the requirements of SPR phasometry.

3. Processing of Information Signals

In presence of noise and interference determining experimentally the phase shift and the resonance based on expression (8) becomes insufficiently precise. Besides, the additional deviation takes place related to the possible uncontrolled changes in the value of reflection rate r within the resonance minimum and the corresponding imprecision in determining angle ϕ_{opt}. This deviation results in the relative change in the interference intensity

$$\frac{\Delta I}{I} = \frac{\Delta r}{\left(1+\sqrt{r}\right)r}, \tag{11}$$

that, for instance, under $r=0,1$ and $\Delta r = 0,01$ amounts to $\sim 7,6\,\%$. That is why for each separate measurement (at least, for each series of uniform measurements at the common receptor) rate r is to be declared and the corresponding corrections are to be introduced as for the angular positioning of the polarizer and analyzer.

To process the SPR sensor signals the approach proposed is the correlation method [10]. As was mentioned earlier, the essence of the above method is the comparison (using large-scale databases) of information signal with the reference signals by applying the integration operation. As the result, the noise and side interference are eliminated and the outsome signal conveys the filtered useful information only characterized by the high level of averaging. Fig.4 shows functional graph of the correlation method applicable for determining both rate r, and phase shift δ.

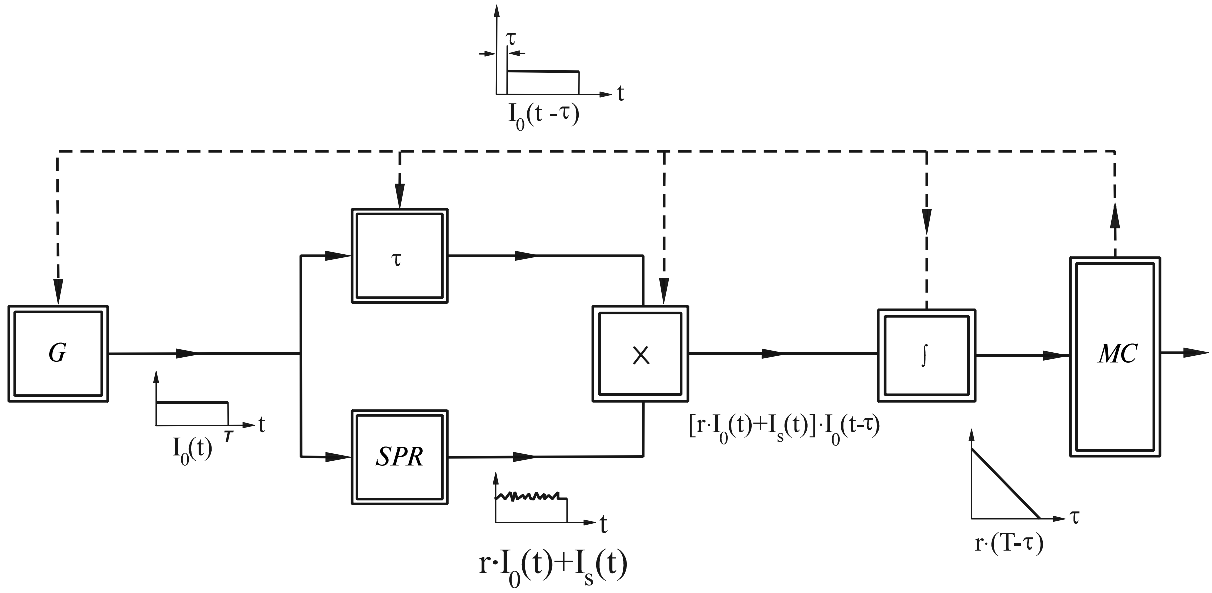

Fig.4. The functional diagram of correlation method of information processing: "G" — the generator of calibrating impulses, "*SPR*" — optical electronic pass of SPR-sensor, "τ" - the module of time delay of calibrating impulses, " × " — multiplication module, " ∫ " — integrator, "*MC*" — microcomputer

As long as r is determined, the polarizer and the analyzer are positioned at angles $\varphi = \psi = 0$ relative to the plane of light incidence onto the receptor and the basic expression for the further calculations becomes (2), hence

$$I(t) = r\, I_0(t)\,, \tag{12}$$

where $I_0(t) = E_0^2$. Driving generator " Γ " generates uni-polar rectangular reference impulses of singular amplitude $I_0(t)$ of duration T. The impulses are transferred to the input of the optoelectronic pass of '*SPR*' sensor to modulate the light source and to the module "τ" regulated with the step $\Delta\tau$ in time delay of impulses. From the '*SPR*' output the noised information signal is registered $r\, I_0(t) + I_s(t)$ (where $I_s(t)$ — is the noise), and from the output of the module " τ " the signal registered is that with the time delay $I_0(t-\tau)$. Both signals are further transmitted to the multiplication module "×", that in turn outputs the signal

$$\tilde{I}(t) = \left[r\, I_0(t) + I_s(t)\right] \cdot I_0(t-\tau)\,. \tag{13}$$

Signal $\tilde{I}(t)$ is transmitted to the integrator " ∫ ". Under the condition that for the interval $0 \le t \le T$ $I_0(t) = 1$, the integrator outputs the correlation signal

$$J_r = \int_{0+\tau}^{T} \tilde{I}(t)\,dt = r \int_{0+\tau}^{T} I_0(t)\, I_0(t-\tau)\,dt +$$
$$+ \int_{0+\tau}^{T} I_0(t-\tau)\, I_s(t)\,dt = r \int_{0+\tau}^{T} dt + 0 = r(T-\tau)\,, \tag{14}$$

that is free from the noise and conveys (for rate r) the useful information. Signal J_r can be calculated by numerical procedure.

Typically, to obtain r it is sufficient to know value J_r with $\tau = 0$ (that is, at a single point). Yet, there is a chance of influences from irregularities coming from, for instance, accidental changes in amplitude or 'zero drift' of the correlation signal. Hence, the averaged value of r is instrumental to determine as

$$r = \frac{\sum_{j=0}^{N} \frac{(\Delta J_r)_j}{\Delta\tau}}{N}\,, \tag{15}$$

where: $(\Delta J_r)_j$ is the increment of the correlation signal related to the change at $\Delta\tau$ with time lag τ; N is the number of steps of time delay ($N = \frac{T}{\Delta\tau} \approx 1000$). From each of the pixels of the photo-sensitive CCD gage the corresponding value of r is received. With these values by means of computer 'questioning' of pixels the minimum value is identified that is necessary to calculate angle Φ_{opt}.

For determining phase shift δ the polarizer and the analyzer are positioned (in correspondence to the obtained r) at angle Φ_{opt} vs the plane of light incidence onto the receptor and the basis for further calculations becomes expression (8), hence

$$I = k\, I_0(t)\,, \tag{16}$$

where $k = 2\sin^4 \Phi_{opt}\,(1+\cos\delta)$. In similitude to the above procedures, the series of rectangular unipolar impulses of singular amplitude are used. As the path of signal transmission and the algorithm of their processing is preserved, the outcoming correlation signal is

$$J_\delta = k(T-\tau)\,, \tag{17}$$

that with coiefficient k conveys the information on the phase shift δ. For further purposes, this is the signal needed.

Determining the CCD gage pixel of minimum r is equivalent to the traditional identification of SPR-resonance with the minimum of the resonance curve. Essentially, here the traditional method meets phasometry, which allows to a certain measure reserve the results received.

Amplitude of the reference impulses $I_0(t)$, their duration T and steps of delay $\Delta\tau$ have to be strictly stabilized, and the time interval between the impulses is to be sufficient for calculating the correlation signal. All the operations related to shaping impulse sequences, to correlation processing, etc. can be performed by microcomputer "MC" inbedded into SPR-sensor.

4. Phasometry Parameters

The correlation signal (17) is described as $J_\delta = J_\delta(k, T, \tau)$, and its increment with the change k under the condition $\tau = 0$ is $\Delta J_{\delta 0} = \left(\frac{\partial J_\delta}{\partial k}\right)_{\tau=0} \Delta k = T\,\Delta k$. As $\Delta k = \frac{\partial k}{\partial r}\Delta r + \frac{\partial k}{\partial \delta}\Delta\delta$, and at the resonance minimum $\Delta r = \frac{dr}{d\theta}\Delta\theta = 0$ and $\Delta\delta = \frac{d\delta}{d\theta}\Delta\theta$, then increment $\Delta J_{\delta 0}$, related to phase change δ with the angle change θ, is as follows:

$$\Delta J_{\delta 0} = T\frac{\partial k}{\partial \delta}\frac{d\delta}{d\theta}\Delta\theta\,. \tag{18}$$

In the resonance zone function $\delta(\theta)$ is characterized by step (or close to step) form [4,8], that is approximated by the expression

$$\delta(\theta) = \left\{-\frac{1}{\pi}\,arctg\, m(\theta-\theta_0) + \frac{1}{2}\right\}\eta\pi + const\,, \tag{19}$$

where: $m = 1, 2, 3, \ldots.., \infty$ (the higher m is, the closer the form of $\delta(\theta)$ to step function) [11], η is the rate of phase shift ($0 \le \eta \le 1$). Expression (19) is true for the periphery of the resonance angle θ_0. It is evident, that under the conditions of high values of m and with $const = 0$

$$\delta(\theta) = \begin{cases} \eta\pi & at\ \ \theta < \theta_0; \\ \frac{1}{2}\eta\pi & at\ \ \theta = \theta_0; \\ 0 & at\ \ \theta > \theta_0. \end{cases} \tag{20}$$

Due to the above pattern of $\delta(\theta)$ the resonance becomes characterized by an abrupt burst

$$\left|\frac{d\delta}{d\theta}\right| = \frac{\eta m}{1+m^2(\theta-\theta_0)^2} \approx \eta m\,. \tag{21}$$

The above burst increases with proximity of $\delta(\theta)$ to a step function. The higher is the burst, the higher is the value $\Delta J_{\delta 0}$. For the corresponding calibrated correlation signals $\bar{J}_{\delta 0}(\theta) = \frac{J_{\delta 0}(\theta)}{T}$ the following is true:

$$\bar{J}_{\delta 0}(\theta) = \begin{cases} 2\sin^4 \phi_{opt}\,(1+\cos\eta\pi) & at\ \ \theta < \theta_0; \\ 2\sin^4 \phi_{opt}\,(1+\cos\frac{\eta\pi}{2}) & at\ \ \theta = \theta_0; \\ 4\sin^4 \phi_{opt} & at\ \ \theta > \theta_0. \end{cases} \tag{22}$$

Fig.5 shows correlations $\delta(\theta)$ i $\bar{J}_{\delta 0}(\theta)$. It is apparent that in resonance the correlation signal drastically changes and its increment can be rather significant and completely sufficient for the resonance registry.

The angular separating power of such registry is described by the expression

$$(\Delta\theta)_{\min} = \frac{1+\cos\delta(\theta_0)}{\sin\delta(\theta_0)} \frac{\left|\frac{\Delta\bar{J}_{\delta 0}}{\bar{J}_{\delta 0}}\right|_{\min}}{\left|\frac{d\delta}{d\theta}\right|}\,. \tag{23}$$

For instance, under $\delta(\theta_0) = \frac{1}{2}\eta\pi$, $\eta = 1$, $\left|\frac{\Delta\bar{J}_{\delta 0}}{\bar{J}_{\delta 0}}\right|_{\min} \approx 0{,}001$, $\left|\frac{d\delta}{d\theta}\right| = m = 1000$ value $(\Delta\theta)_{\min} \approx 0{,}00006^0$. For the interferometry measurements with the wave length $\lambda = 6500\cdot 10^{-8} cm$ and the sample breadth $d = 1cm$ that corresponds to the phase change $(\Delta\delta)_{\min} \approx 1\cdot 10^{-3}$ and refraction rate $(\Delta n)_{\min} = \frac{\lambda}{2\pi d}(\Delta\delta)_{\min} \approx 1\cdot 10^{-8}$ [2].

The resonance is determined by software-algorithm calculations of the pixel number of the CCD gage, for which an abrupt correlation signal step has been registered, the angle shift of the resonance is determined by the change in the above numbers. The steps for the phase and the corresponding signals occur only for the angle θ_0, that is for a rather narrow angle area (Fig.5). In the rest of the instances, as the resonance is absent, the change of the phase δ with the change of the angle θ proceeds rather smoothly. In this connection there arise a complex task to photo-register remarkably small angle changes $\Delta\theta$.

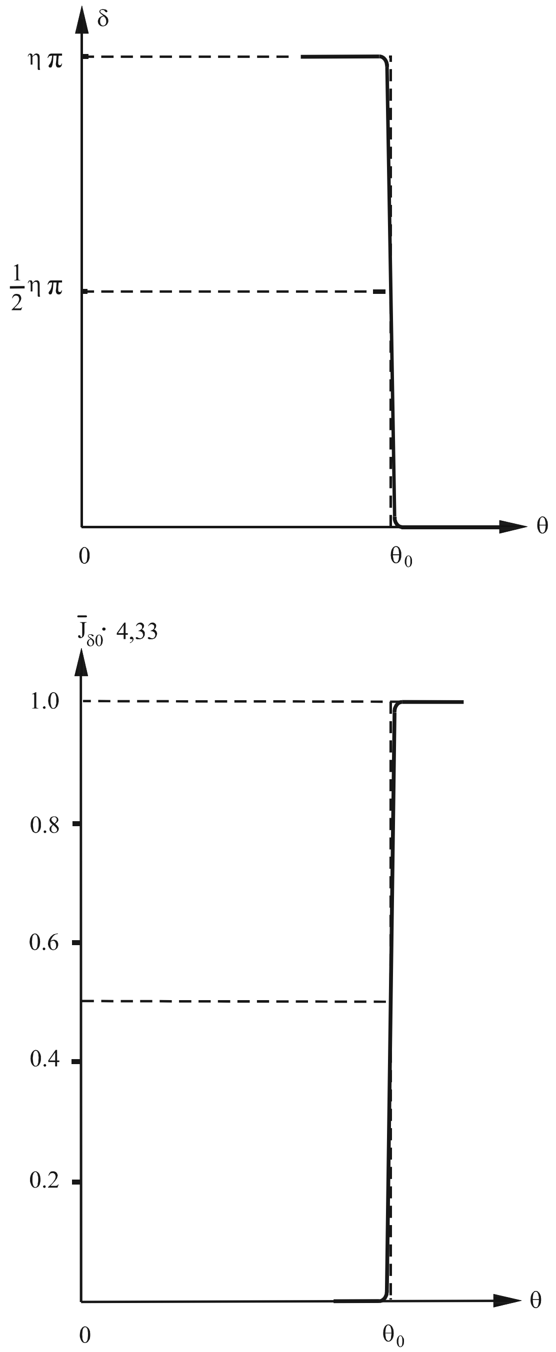

Fig.5. The dependency between phase shift δ and correlation signal $\bar{J}_{\delta 0}$ from angle of light incidence θ onto sensitive receptor ($\eta = 1$, $r = 0{,}1$, $\phi_{opt} = 29{,}35^0$)

The angular resolution capacity of the objective lens of the photometric SPR-sensor is limited with the light diffraction, and with $L >> D$ (L - distance from the receptor to the objective, D — aperture of the objective) it is defined with the expression $(\Delta\theta)_{obj} = \frac{\lambda}{D}$ [12]. For instance, to meet the condition $(\Delta\theta)_{obj} = (\Delta\theta)_{\min} \sim 0{,}0001^0$ with $\lambda = 6500 \cdot 10^{-8}\,cm$ there is a need in objective with the aperture $D \approx 37\,cm$, which does not meet the requirements to the sensor dimensions. Moreover, the objective lenses of high aperture are characterized by significant optical aberrations. They are quite complicated in design and production and are rather costly. Hence, it is instrumental to use small-scale objective lenses with linear resolution capacity $\Delta S = f \cdot (\Delta\theta)_{obj} = \frac{\lambda f}{D}$ (f - focal distance) [13], that are to have resolution capacity of photo registering CCD structures (that equals several μm [14,15]). The above characteristic are ensured through the selection of the optimum correlation between f focus and D aperture with the account taken of the diffraction affect, aberration and the design factors. Such as, compatible would be an objective lens with $\frac{f}{D} \sim 2 \div 3$ and $D \sim 5 \div 7\,cm$, although its angular resolution capacity $(\Delta\theta)_{obj} \sim 0{,}0006^0$, as it may be, does not completely meet the requirements of phasometry.

Along with the above factors, values $(\Delta\theta)_{\min}$ and $(\Delta n)_{\min}$ are limited by the quality of the materials (glass, metal and biochemical films) used for the sensor, as well as by the monochrome character of the emission, stability of the light source, of the optical receiver and the temperature ambiance of the measurements, operating thresholds of the registry devices, digit capacity of the latter DA and AD converters, and also by the essential physical limits of the phasometry method itself (related, for instance, to the abrupt quality of the phase changes in resonance). Altogether, this might lead to the decrease (vs. the ideal instances) in the resolution capacity of SPR-phasometry, although even that way it will be considerably higher than in the instances of applying resonance curves.

5. Conclusion

1. The well-known principle of designing phasometry SPR-sensors with integrated light passes that are characterized, compared to usual sensors,

by much higher resolution capacity, can be further optimized by means of using wedge-shaped light beam and the selection of the optimum positioning angle of the polarizer and analyzer vs the plane of the light incidence onto the sensitive receptor $\phi_{opt} = arctg\ r^{1/4}$ (r - reflection rate in the resonance minimum).

2. The use of sequences of rectangular calibrating impulses to shape the information signals from the sensor and their correlation processing allow avoid the affect from the noise and side interference and obtain registration signal from the phase step necessary to determine the resonance.

3. The angular resolution capacity of SPR phasometry is limited by the conditions of the signal registry, inclusive of the resolution capacity of the objective lens and optical receiver, and is defined by value $(\Delta\theta)_{\min} \sim 0{,}001^0 \div 0{,}0001^0$, that corresponds to the change of the refraction rate $(\Delta n)_{\min} \sim 10^{-7} \div 10^{-8}$.

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