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DEVELOPMENT AND APPLICATION OF DEVICES BASED ON SURFACE PLASMON RESONANCE

The purpose of the SPR sensor is to quickly and accurately determine the refractive index of the environment with the ability to diagnose the presence of a specific substance. SPR devices and biosensor diagnostic methods for laboratory diagnostics in medicine, veterinary medicine, determination of environmental pollution, for food quality control are being developed. The work is devoted to the development of devices based on the surface plasmon resonance of the "Plasmontest" series, which can be used for refractometric and biosensor applications. Comparison of optical circuits of SPR devices, their capabilities and operational characteristics during biochemical and physical experiment are carried out Features of the design of devices "Plasmontest" with discrete and aperture optical circuits are presented. The method of approximation of the resonant SPR curve is proposed to accurately find the value of the resonance minimum. Procedures for normalizing and calibration of devices have been developed to improve measurement accuracy. The use of "Plasmontest" devices for refractometry, for the development of thin-film technological processes and for the creation of methods of immunosensory detection of a number of bacteria and toxins is described. Work on the creation of "Plasmontest" series devices has shown the possibility of creating portable SPR devices for refractometric studies, thin film studies and biosensor studies.

Keywords: *surface plasmon resonance, sensor, refractometer, biosensor.*

Introduction. In recent years, the number of papers devoted to the effect of surface plasmon resonance (SPR) and development of sensors based on it has been steadily growing. This suggests that studies based on the SPR method are of great interest both from a physical point of view and for various practical applications. The purpose of the SPR sensors is to quickly and accurately determine the refractive index of the medium and/or diagnose the presence of a particular substance by changing the optical characteristics of a thin layer adjacent to the surface of the SPR sensor. In comparison with the classical methods, the SPR method provides possibility to observe kinetics of the biochemical reactions *in-situ*. A little cost of equipment, short time of analysis using the SPR method (less than a hour), the small number of reactants, makes SPR economically attractive for a clinical analysis. SPR devices and biochemical diagnostic methods have been developed for laboratory diagnostics in medicine, veterinary medicine, determination of environmental pollution, and food quality control [1–6]. Technologies are being developed to create portable SPR sensors to meet the growing demands for the identification of dangerous toxins and the detection of pathogenic microorganisms in regions that have not access to expensive laboratory equipment.

Currently developed as sophisticated analytical SPR sensors), middle-class sensors - SPR sensors of "Plasmon" series and portable small size sensors similar to "Spreeta" family of sensors, first developed and manufactured by Texas Instruments, USA.

This work is devoted to the development of SPR devices of the "Plazmontest" series, which can be used both for laboratory applications and as portable devices for outdoor research. Features of it design, development of procedures for normalizing and calibrating instruments with an aperture optical scheme and some features of software development are presented.

1. Background of SPR method

The implementation of the SPR sensor requires the presence of a *p*-polarized light source, a light recording or light distribution device, a plasma-supporting metal film, typically gold, tens of nanometers thick, and the ability to manipulate by the wavelength of light or the angle of incidence light on the metal film.

At SPR studies on monochrome light, the light reflection dependence (SPR curve) from the SPR substrate is measured under conditions of complete internal reflection. The presence of SPR reveals as the minimum reflection at some resonant angle of incidence light φ_{SPR}, included in the equation

$$\sqrt{\varepsilon_d \sin\varphi_{SPR}} \approx \sqrt{\frac{\varepsilon'(\omega)\varepsilon_c}{\varepsilon_c + \varepsilon'(\omega)}} \qquad (1)$$

where ε' – is the real part of the complex dielectric constant $\varepsilon(W) = \varepsilon'(\omega) + i\varepsilon''(\omega)$ of metal film, ε_d – is the dielectric constant of the material underlying the deposited metal, ε_c – dielectric constant of the medium above the metal surface.

The shape and angle minimum of the SPR curve depends on: 1) polarization, wavelength, and angle of incidence of excited light; 2) thickness of the thin layer of metal and its complex dielectric constant and dispersion; 3) dielectric constant of the layers adjacent to the metal; 4) dielectric constant of the environment. At the SPR studies, any changes that affect SPR can be detected. Therefore, the range of tasks that can be solved by SPR sensors are very wide – the study of thin metal and dielectric films, refractometry of liquids and gases, diagnostics of a specific substance-analyte joining to the surface of receptor layer on sensor substrate, *in-situ* studying of kinetics of biochemical reactions.

A large number of different SPR devices already created. SPR refractometers are precise instruments for measuring refractive indices of liquids and gases, ensuring accuracy of measurements up to the 5th – 6th decimal point. The method has a record sensitivity for detecting changes in layers adjacent to a metal film, exactly where the receptor-molecules interact with the analyte molecules. Typically, an SPR biosensor has a detection limit on the order of 10 pg/mL.

At the angular studies of SPR, the dependence of the reflection coefficient from the angle of incident light near the minimum of SPR is experimentally determined. The view of the SPR curve is shown in fig. 1 on the left – it shows SPR curves taken at different times during the adsorption of the analyte. The chart is rotated 90 degrees anticlockwise so the axis of the angles is vertical. To study bimolecular interactions, builds the dependence of the resonance angle on time – a sensorgram, which is shown in fig. 1, on the right.

The main tasks at the creation of SPR devices are the design of optical and electronic parts, the development of possibilities to increase the sensitivity and resolution of SPR sensors, the development of mathematical and software methods for accurate determination of the angle of SPR.

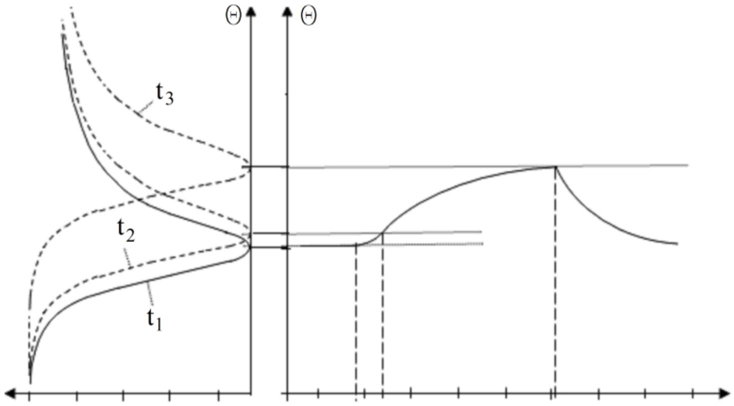


FIG. 1. The principle of sensorgram obtaining

2. Designing devices of the “Plazmontest” series

The team of authors has developed and manufactured a series of devices under the general name "Plasmontest", which are used in refractometric and biochemical studies, as well as in the development of thin-film technology of sensor substrates for SPR sensors and metal clad waveguide (MCWG) sensors based on layers of metals and oxides [7–16].

2.1. "Plasmontest – Lab" device.

The first was designed and manufactured a computerized device "Plasmontest-Lab" for laboratory studies on the basis of a stationary semi-cylindrical prism and a semiconductor laser with a wavelength of 635 nm with a collinear beam (fig. 2). Changing the angle of incidence of light on the substrate and the reflected light on the radiation detector is achieved by rotating of the laser and the photodiode located on the opposite shoulders around the longitudinal axis of the prism using a stepper motor. The range of angles is 40° – 70°, the minimum step is 0,03 degrees. The software of the device allows to set down 10 series on 10 SPR curves, to define positions of a SPR minimum at approximation by a polynomial of the 3rd order, to construct a sensorgram of the SPR angle from time. The device has a convenient dialog box with a graphical representation of SPR curves and sensograms.

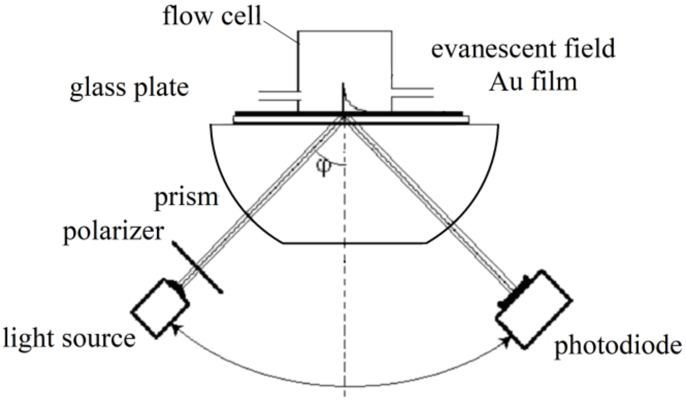
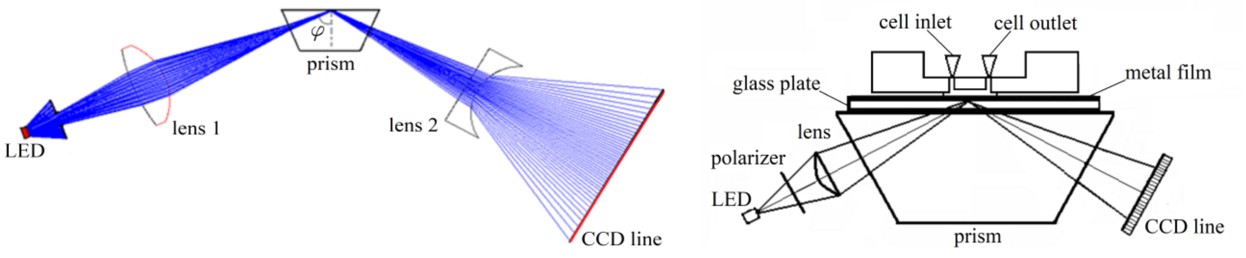


FIG. 2. Operation scheme of a computerized device "Plasmontest-Lab".

Due to the wide range of angles, the “Plasmontest-Lab” can be used for both gas and liquid media. Since there are no optical factors leading to distortion of the obtained reflection curves, the ”Plasmontest-Lab” can be used to quantify the parameters of the formed layers, for example, by the fitting method in the Winspall program. It is used by us in development of the thin-film the technology and testing the manufactured substrates, as well as a refractometer with an accuracy of determining the refractive index of 10^{-3}. The scan time of the full range of angles at a step of 0,03 degrees is 8 minutes, that does not allow the use of "Plasmontest-Lab" for the study of fast processes. This led to the necessity to develop SPR devices with an aperture of the radiation beam.

2.2. Single-channel device “Plasmontest”.

The single-channel aperture-optic SPR device “Plasmontest “ was designed to be portable, taking into account the need for field studies in veterinary or screening studies in remote areas. On this basis, the size, weight and cost of the device were imposed. It was also decided to use a typical optical scheme with a converging laser diode beam, which, after reflection by the surface of the SRR sensor substrate, is registered by a one-dimensional CCD line. The optical scheme of the device has been preliminary calculated in program Zemax (fig. 3).



a b

FIG. 3, a – optical scheme of “Plasmontest” device calculated in program Zemax, b – scheme of “Plasmontest” device with measuring cell

CCD line ILX551A has 2048 pixels. Microprocessor unit controls a light source, captures data from a CCD line, processes measurement data, displays results and exchanges data with a computer.

CCD lines have a number of parameters restricting sensitivity threshold and other technical characteristics. It is the dark current in the first place and its dependence on the sensor’s temperature, and the fixed pattern noise. It is possible to get rid of such drawbacks by processing the black pixels data and reading out CCD lines while there is no useful signal, and by further subtracting a “mask” to eliminate parasite signals from a frame. Microprocessor’s software is specifically intended for such purposes. Each measurement implies multiple readouts of a CCD line with 100 Hz frequency with on/off sequence of an irradiator. Apart from the informative 2048 pixels, CCD line has service (including black and blank) pixels. In addition, a CCD line can accumulate parasite charge in cell pixels within the time frames between measurement cycles and cannot remove it completely with one readout cycle. Therefore an informative cycle is preceded by a number of blank readout cycles of CCD line. Algorithm of a measurement cycle implies 20 blank readout signals of CCD line, 15 readout cycles of black pixels without turning on an irradiator and 32 informative readout cycles of CCD line with on/off sequence of an irradiator. Resulting data array of CCD line is thus formed by averaging the difference between data for an irradiator in ON and OFF position and subtracting an average value of a black pixel signal. Amount of the exposure is determined by a period of time of an irradiator in ON position and can be established by an operator, or its optimum amount can be established during the automatic launch procedure of the device.

Unequal distribution of the radiation across angles of irradiator’s beam is compensated by generating and storing in device’s memory a reference data array of CCD line without SPR signal with further adjustment of current measurement data arrays to the reference array.

CCD line data array remains to be rather noise- polluted even after preliminary processing is done.

Biochemical research techniques require thermal stabilization of a measurement cell because the shift of the SPR resonance angle caused by the temperature dependence of the optical parameters on the measurement environment can be compared with the anticipated result of biochemical reactions. On the other hand, it is known that heating a CCD line by more 9 °C brings about two-times increase of its dark current. Therefore, thermal stabilization of a measurement cell and CCD line is needed. Peltier elements are used for this purpose. Thermal sensors measure the temperatures of measurement cell and CCD line while microcontroller system closes a feedback sustaining the temperature. Precisions are – 0,1°C and 1°C for a measurement cell and for CCD line accordingly.

Major characteristics of “Plasmontest”:

- Length of radiation wave: 660 – 680 nm,
- Range of measurement angles: 60 degrees – 70 degrees,
- Variation of convergence angles: ± 4 degrees,

- Resolution: 0,005 degrees/pixel,
- Time of exposure: 5,5 ms – 8 ms,
- Minimum time span between measurements: 1 s,
- Weight of the device: 0,5 kg.

User interface software, apart from the ability to record SPR curves and a sensogram by the minimum of a resonance curve, can also work in the mode of the constant angle which differs from the mode of the resonance angle by the way the data are processed. Therefore, these modes can be changed or used simultaneously both in the process of measurement and for the data being recorded.

It should be noted that the "Plasmontest" device has received the State certification as a refractometer in the range of refractive indexes with accuracy $1 \cdot 10^{-3}$ of refractive index unit [7–8].

2.3. "Plasmontest-2L" device.

Thus, SPR studies are sensitive to the temperature drift of the signal. This problem can be solved by either a thermostabilizing cell (as described above for the "Plasmontest" device) or by using a parallel reference channel as described below for "Plasmontest-2L" device.

The construction of a dual-channel SPR device involves splitting the light beam to 2 parts, each of which passes through its segment of the measuring cell and separately detecting by 2 lines of photodiodes. The simplest technical solution for the construction of the detector part is using of two-dimensional photodiode matrix. Such matrixes are offered by the Hamamatsu group. But widespread use of two-dimensional matrixes is limited due to it expensiveness. Thus, one-dimensional photodiode lines were used. The ILX551 photodiode line has a size of 41.6 x 10 mm, so placing two lines nearby using translucent mirrors requires a sophisticated optical system. This problem was solved in another way, illustrated in fig. 4.

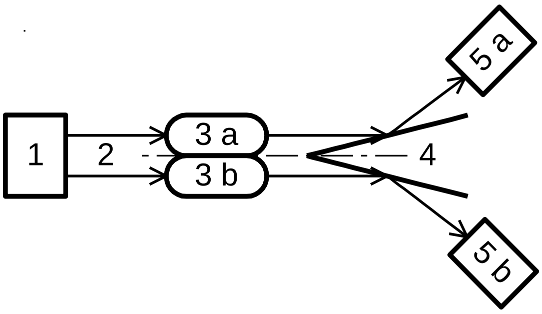


FIG. 4. Schematic representation of splitting of light beam to 2 photodiode lines: 1 – LED; 2 – light beam; 3a, 3b –measuring cells; 4 – system of mirrors; 5a, 5b – photodiode lines

A wide light beam is formed from the light source, passing through 2 separate measuring cells simultaneously. Further, the light beam falls on two sides of a triangular prism, which are placed at the angle to the optical axis of the light beam. Each of the halves of the light beam is reflected in its direction and gets on its photodiode line, which are spatially spaced.

Advanced software tools allow to read and process signals from two CCD lines. Both CCD lines have clock and control pulses in parallel, ensuring simultaneous readout. ADC conversions are also started synchronously and their data is read by the microcontroller in series. Both CCD sensors are connected to a single line of single-wire interface of temperature sensors.

Like the single-channel "Plazmontest" instrument, the electric circuit includes modules for stabilizing the radiation power of an LED with a reference channel and a module for thermal stabilization of CCD arrays and measuring cell.

The SPR methodology of investigations by the "Plasmontest-2L" instrument involves the preliminary recording of the reflection curves of each of the two CCD lines without liquid in the measuring cell, the storage of the data in the device memory, and further normalization of the measurement results using these reference curves.

At the recording both the reference and measuring SPR curves, the same algorithm for reading both CCD lines is used. A spurious charge accumulates between the measurement cycles in the pixels of the CCD lines. To remove it, at the beginning of each measurement cycle, the CCDs are readout 12 times without saving the data when the radiation is off. Thereafter, 32 reads are performed alternately, by switching the emitter on once. Depending on whether or not the light source was switched on at the previous reading, the current reading data is either added to previously accumulated or subtracting. This procedure minimizes the impact of illumination from exterior sources. The on time status determines the duration of the exposure. (Total exposure time is determined by the length of time the light source 's state is turned on). After dividing by 16, we have an average array of data for each CCD line with the maximum filtered signal that is transmitted for further analysis to the PC user interface.

3. Features of software development for “Plasmontest” series instruments

3.1. Development of a procedure for calculating the SPR minimum angle

For the realization of modern SPR sensors besides optical, electronical and technological problems it is necessary to solve the problems of information processing, in particular, the definition of the reflection curve minimum in the presence of the background noise.

The determining of the angle of reflected curve minimum using CCD-line was considered. Experiments show that data array obtained by CCD array is quite noisy even after pretreatment by averaging of 16 measurements. Therefore, for accurate determination angle of the minimum the mathematical approximation around reflective curve minimum is required.

In the first stage the minimum point region searching procedure is carrying out. Thus the 16 pixels with the lowest values of signal are determining. And then average meaning of the pixel number which is corresponding to center of a minimum could be calculated. The next stage is the construction of approximating polynomials, and deducting the exact minimum of SPR curve.

Polynomial approximation of 2nd order gives better results on the average deviation of minimum angle. But due to asymmetry of SPR-curve in the minimum region it inaccurately describes itself SPR-curve and therefore distorts the absolute value of the minimum angle. It was therefore chosen polynomial approximation of order 3 for 300 points, which takes into account asymmetry of SPR-curve and gives the best average deviation of angle minimum.

The next stage is the construction of approximating polynomials and deducting the exact minimum of SPR dependence. The problem reduces to finding the coefficients of third order polynomial for a sequence of N points, $n = 1, ..., N$, for fixed Δx and N. Since Δx_n and N are fixed, we can get a fixed sequence of points $\tilde{x}_n = 0, \Delta x ... (N-1)\Delta x$ in calculating of the value x_1 from the sequence of x_n .To find the approximating polynomial coefficients it is appropriate to use the Gaussian method of least squares, using which you can obtain the system of equations for the coefficients of the polynomial.

As a result we obtain the following algorithm for the minimum calculation for the microcontroller of SPR device:

Calculation of sums in one cycle:

$$S_1 = \sum_{n=1}^{N} y_n ,$$

$$S_2 = \sum_{n=1}^{N} \Delta x(n-1) y_n ,$$

$$S_3 = \sum_{n=1}^{N} (\Delta x(n-1))^2 y_n ,$$

$$S_4 = \sum_{n=1}^{N} (\Delta x(n-1))^3 y_n . \qquad (2)$$

Calculation of coefficients of the polynomial:

$$b = \tilde{a}_{10}N + \tilde{a}_{11}s_1 + \tilde{a}_{12}s_2 + \tilde{a}_{13}s_1;$$

$$c = \tilde{a}_{20}N + \tilde{a}_{21}s_1 + \tilde{a}_{22}s_2 + \tilde{a}_{23}s_1;$$

$$d = \tilde{a}_{30}N + \tilde{a}_{31}s_1 + \tilde{a}_{32}s_2 + \tilde{a}_{33}s_1. \qquad (3)$$

where $\tilde{a}_{ik}$ are the constants (previously calculated coefficients of A^{-1} matrix).

Calculation of the polynomial extrema by 1st derivative

$$\tilde{P}'(\tilde{x}) = b + 2c\tilde{x} + 3d\tilde{x}^2 . \qquad (4)$$

$$\tilde{x}_0 = \frac{-c \pm \sqrt{c^2 - 3db}}{3d}. \qquad (5)$$

Choice of the minimum from the condition that the 2nd derivative of the polynomial is greater than zero: $c + 3d\tilde{x}_{\min} > 0$.

Consideration of the initial minimum shift:

$$x_{\min} = \tilde{x}_{\min} + x_1. \qquad (6)$$

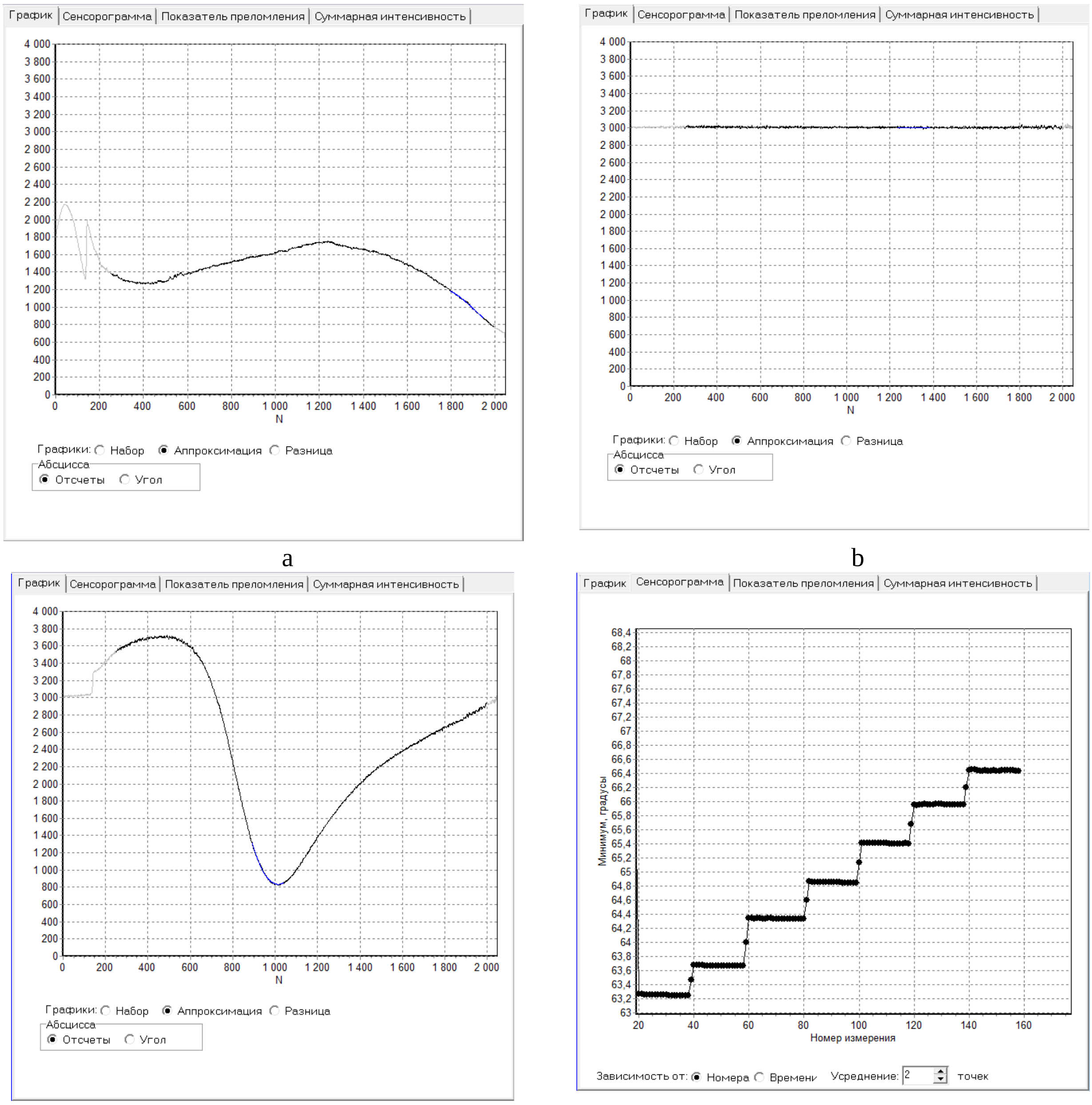
This algorithm uses $5N$ +14 additions, $3N$ +15 multiplications, 1 division and 1 square root extraction, and also requires 28 bytes of RAM (when using variables with floating point single-precision). Experimental studies have shown the effectiveness of the procedure of approximation – the absolute error of the angle decreases from 0,005 to 0,001 degrees.

3.2. Development of procedures for normalization and calibration of the device with aperture optical circuit.

One of the features of aperture devices is the presence of the initial inhomogeneity of the angular distribution of light incident on the CCD. This inhomogeneity is the angular distribution of the light source intensity, in our case, of laser Hamamatsu photonics™ light emitting diode *L*6108, which distorts the look of the SPR-curve and makes inconvenience in the measurement process (fig. 5, a). To counteract this factor, a normalization procedure was applied. The normalization criterion is to obtain a straight line on the angular distribution of intensity (fig. 5, b), whereby the SPR curve has a canonical shape, convenient for further processing (fig. 5, c).

As can be seen from fig. 3, a, the dependence of the pixel number on the angle of incidence for this device is non-linear. The analytical expression of the dependence has a complex appearance, involving trigonometric functions, both direct and inverse, and the parameters of the elements of the optical system. Therefore, the method of calibration of the device is a subject of research.

A common unit in biosensor SPR measurements is the angle of resonance minimum shift, and the calibration of these devices must be carried out in angular units. In general, such techniques are based on the finding of distribution function of angular units over the operating range of the device. Nonlinearity of such a distribution makes necessary to find base points using liquids with a known refractive index. Theoretical values of the SPR minimum angles for a set of such liquids are put in accordance with experimentally determined pixel numbers of the CCD line corresponding to the SPR minimum for each of the liquids.



Графики: ○ Набор ● Аппроксимация ○ Разница
Абсцисса ● Отсчеты ○ Угол

Зависимость от: ● Номера ○ Времени Усреднение: 2 точек

a b c d

FIG. 5. Procedures of normalization and calibration of "Plasmontest" device with aperture optic scheme

For this purpose, a set of certified refractive index measures based on ethylene glycol solutions was created. With the sequential introduction of these liquids into the measuring cell of the "Plasmontest" device, a stepwise shift of the resonance minimum is observed on the sensorgram, which corresponds to a change in the refractive index (fig. 5, d). The construction of the pixel/angle dependence is then performed and an approximating polynomial is selected according to the criterion of minimum error. This polynomial is introduced into the dialog program of the device and is further used by the software in the measurements, providing interpolation within the working range of the device.

4. Applications of "Plasmontest" devices

Instruments of "Plazmontest" series are used for a wide variety of studies.

So, the "Plazmontest-Lab" instrument, which has a wide range of working angles, is successfully used for testing thin-film structures during the development of thin-film technologies. Using it, we investigated the effect of gold film deposition and annealing on sensor substrates, the effects of adhesive and coating layers of multilayer thin-film sensor structures, the formation of anode oxides, both continuous and porous, for sensor substrates Al-Al_2O_3, Al-Nb_2O_5, Al- porous Al_2O_3, Nb-Au-Nb_2O_5. "Plazmontest-Lab" was also used in-situ in the manufacture and study of transparent conductive nanosets of aluminum.

To test the characteristics of nanostructured Al-porous Al_2O_3 coatings directly in the process of substrate manufacturing using the already proven technology, we used the device "Plasmontest", which has a high speed (recording time of reflection curve – 1 sec) and allows you to quickly stop the process when the specified parameters of the nanostructured layer are reached [9–11].

The "Plasmontest" device is being piloted at the National University of Life and Environmental Sciences of Ukraine. It is used to develop techniques for a range of biosensor assays that should serve as a basis for monitoring agricultural, food, environmental, and veterinary and medical disease diagnostics. The device was used to work out the detection methods for *Salmonella Typhimurium*. "Plasmontest" detection level was within 10^1–10^6 cells/ml but statistically sufficient difference of results of lays in ranges 10^2–10^6 cells/ml [12, 13].

Using the "Plasmontest" instrument, methods for detecting some mycotoxins were worked out. It is shown that when optimizing the algorithm of the analysis, the device allows determine *aflatoxin B1* in model solutions at a level less than 10 ng/ml, which even exceeds the sensitivity of the enzyme-linked immunoassay method. Immunobiosensory analysis of *aflatoxin B1* can be performed within 10 minutes if the transducer surface is pre-prepared, that is, the expressiveness of immunobiosensor SPR analysis with the "Plasmontest" instrument has significant advantages over the enzyme immunoassay [14].

With the help of the instrument "Plasmontest" researches on development of optimal variants of preparation of samples of blood and milk for the purpose of biosensory diagnostics of retroviral leukemia of cattle and estimation of origin of dairy products from sick or healthy animals. It has been shown that samples prepared as serum or milk should be used for verified pathogen detection. And screening can be performed with "Plasmontest" even with whole blood and milk samples [15].

Methods for analyzing *spermine* and *spermidine polyamines* as potential markers of cancer were also developed at the "Plasmontest" instrument [16].

Thus, the experimental operation of the device "Plasmontest" showed the prospect of its use for expanding the range of substances for diagnostics, the development of new methods of biosensor diagnostics, improving the accuracy and selectivity of biosensory studies.

5. Conclusions

We have developed a series of devices based on surface plasmon resonance. These devices were made taking into account the needs of rapid diagnostics in medicine and veterinary medicine, determination of environmental pollution, for food quality control. SPR devices with discrete and aperture optical circuits were produced, a comparison of the instrument designs and their operational characteristics during physical and biosensor studies was made. A method for approximating the resonance SPR curve to accurately find the value of the angle of the resonance minimum is proposed. To improve the accuracy of measurements, the standardization and calibration procedures have been developed for devices with an aperture optical design. Some features of the developed software for "Plazmontest" devices are presented. Successful applications of "Plazmontest" instruments for refractometry, development of thin-film processes and for the creation of immunosensory detection methods for a number of bacteria and toxins are described.

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РОЗРОБКА ТА ВИКОРИСТАННЯ ПРИЛАДІВ НА ОСНОВІ ПОВЕРХНЕВОГО РЕЗОНАНСУ

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Вступ. Призначенням ППР сенсорів є швидке і точне визначення показника заломлення середовища з можливістю діагностики наявності певної речовини. Розробляються ППР пристрою і біосенсорні методики діагностики для проведення лабораторної діагностики в медицині, ветеринарії, визначення забруднень у навколишньому середовищі, для контролю якості харчових продуктів. Робота присвячена розробці пристроїв на основі поверхневого плазмонного резонансу серії «Плазмонтест», які можна використовувати для рефрактометричних та біосенсорних застосувань.

Мета роботи. Показати розробку ППР-пристроїв серії «Плазмонтест», які можуть бути використані для лабораторних застосувань, і як портативні прилади для польових досліджень. Провести порівняння оптичних схем ППР-приладів, їх можливостей і експлуатаційних характеристик при біохімічному і фізичному експерименті.

Результати. Представлені особливості конструкції приладів «Плазмонтест» з дискретною і апертурними оптичними схемами. Запропоновано метод апроксимації резонансної ППР-кривої для точного знаходження значення резонансного мінімуму. Для підвищення точності вимірювань розроблені процедури нормування і градуювання приладів з апертурною оптичною схемою в одноканальному і двоканальному виконанні. Представлені деякі особливості розробленого програмного забезпечення для приладів серії «Плазмонтест». Описано застосування приладів «Плазмонтест» для рефрактометрії, при відпрацюванні тонкоплівкових технологічних процесів і для створення методик імуносенсорного детектування ряду бактерій і токсинів.

Висновки. Робота по створенню приладів серії «Плазмонтест» показала можливість створення портативних ППР-приладів для проведення рефрактометричних досліджень, досліджень тонких плівок та біосенсорних досліджень. Показано, що прилади з апертурною оптичною схемою є найбільш перспективними з урахуванням умов компактності, надійності та низької вартості.

Ключові слова: поверхневий плазмонний резонанс, сенсор, рефрактометр, біосенсор.

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РАЗРАБОТКА И ПРИМЕНЕНИЕ УСТРОЙСТВ НА ОСНОВЕ ПОВЕРХНОСТНОГО ПЛАЗМОННОГО РЕЗОНАНСА

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Введение. Назначением ППР сенсоров является быстрое и точное определение показателя преломления среды с возможностью диагностики наличия определенного вещества. Разрабатываются ППР устройства и биосенсорные методики диагностики для проведения лабораторной диагностики в медицине, ветеринарии, определения загрязнений в окружающей среде, для контроля качества пищевых продуктов. Работа посвящена разработке устройств на основе поверхностного плазмонного резонанса серии «Плазмонтест», которые можно использовать в рефрактометрии и биосенсорике.

Цель работы. Показать разработку ППР-устройств серии «Плазмонтест», которые могут быть использованы для лабораторных применений и в качестве портативных приборов для полевых исследований. Провести сравнение оптических схем ППР-приборов, их возможностей и эксплуатационных характеристик при биохимическом и физическом эксперименте.

Результаты. Представлены особенности конструкции приборов «Плазмонтест» с дискретной и апертурной оптической схемами. Предложен метод аппроксимации резонансной ППР-кривой для точного нахождения значения резонансного минимума. Для повышения точности измерений разработаны процедуры нормировки и градуировки приборов с апертурной оптической схемой в одноканальном и двухканальном исполнении. Представлены некоторые особенности разработанного программного обеспечения для приборов серии «Плазмонтест». Описаны применения приборов «Плазмонтест» для рефрактометрии, при отработке тонкопленочных технологических процессов и для создания методик иммуносенсорного детектирования ряда бактерий и токсинов.

Выводы. Работа по созданной приборов серии «Плазмонтест» показала возможность создания портативных ППР-приборов для проведения рефрактометричним исследований, исследований тонких пленок и биосенсорных исследований. Показано, что приборы с апертурной оптической схемой являются наиболее перспективными с учетом условий компактности, надежности и низкой стоимости.

Ключевые слова: поверхностный плазмонный резонанс, сенсор, рефрактометр, биосенсор.