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ZHARKOV, I. P.[1] (https://orcid.org/0000-0003-1626-5655),
SAFRONOV, V. V.[1] (https://orcid.org/0000-0002-2982-9627),
KHODUNOV, V. O.[1] (https://orcid.org/0000-0002-5881-5080),
KONOVAL, V. M.[1] (https://orcid.org/0000-0002-5240-1207),
PALAMARCHUK, I. P.[1] (https://orcid.org/0000-0003-4513-9850),
SELIVANOV, O. V.[1] (https://orcid.org/0000-0001-9579-885x),
SOLONETSKY, A. G.[1] (https://orcid.org/0000-0001-8837-4776),
MAMYKIN, S. V.[2] (https://orcid.org/0000-0002-9427-324X),
YASTRUBCHAK, O. B.[2] (https://orcid.org/0000-0001-6641-5768),
and ROMANYUK, V. R.[2] (https://orcid.org/0000-0002-0068-5973)
[1] Institute of Physics of the National Academy of Science of Ukraine,
46, Nauky Ave., Kyiv, 03028, Ukraine,
+380 44 525 1220, +380 44 525 1589, fizyka@iop.kiev.ua
[2] Lashkaryov Institute of Semiconductor Physics of the National Academy of Science of Ukraine,
41, Nauky Ave., Kyiv, 03028, Ukraine,
+380 44 525 4020, +380 44 525 2201, info@isp.kiev.ua

AUTONOMOUS VIBRATIONLESS TEMPERATURE-CONTROLLED CRYOSYSTEM FOR OPTICAL STUDIES WITH A SPECTROSCOPIC ELLIPSOMETER

Introduction. *Ellipsometry is a highly sensitive, non-destructive optical method used to study the optical and structural properties of materials and thin films.*

Problem Statement. *At the Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine, the first in Ukraine serial spectroscopic ellipsometer SE-2000 (manufactured by SEMILAB Ltd., Hungary) has been employed for research, but its measurement capabilities are currently limited to room temperature.*

Purpose. *This research aims to expand the functionality of the SE-2000 by creating a temperature-controlled cryosystem that operates within a temperature range from −195 °C to +80 °C (approximately 80—353 K).*

Materials and Methods. *An autonomous, precision, vibrationless, cryosystem has been designed and manufactured for low-temperature optical investigations in reflection mode, based on a gas-flow cryostat. The cryosystem includes a cryostat, a microprocessor temperature controller, and an adjustment table.*

Results. *The cryostat operates on a gas-flow principle. A laminar gas flow is generated by excess pressure achieved through the heating of cryogenic liquid by a heater-evaporator in the feeder tank. The flow intensity is regulated by adjusting the power supplied to the heating element, eliminating vibrations in the cryostat and sample.*

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The heat exchange chamber is positioned at the top of the nitrogen tank, with the test sample mounted in horizontal plane. Incident and reflected light beams interact with the sample from the upper hemisphere. Sample positioning is adjustable via translational motion along three Cartesian coordinates and by tilting the cryostat with the help of the adjustment table.

Conclusions. *This system is suitable for use in optical devices that operate in specular reflection mode, with access to the sample surface from the upper hemisphere.*

Keywords: temperature-controlled nitrogen cryosystem, spectroscopic ellipsometry, semiconductor structures, optical constants temperature dependencies.

Ellipsometry is a highly sensitive, contactless, and non-destructive optical method for investigating surfaces and thin films [1]. The sensitivity of this technique is attributed to the simultaneous measurement of changes in the polarization state (both amplitude and phase) of light reflected from a surface. This sensitivity is particularly enhanced when measurements are conducted at angles of incidence close to the Brewster angle.

With advancements in technology and the increased speed of optical signal detection, spectroscopic ellipsometry has emerged and evolved as a significant tool in this field [2]. Unlike traditional methods that measure parameters at a single wavelength, spectroscopic ellipsometry enables measurements across a broad wavelength range, such as from ultraviolet (~200 nm) to the near-infrared region (1700—2100 nm), or even within the infrared range (from 1.5 to 25 μm). These spectral regions are crucial for revealing electronic excitations, atomic vibrations within the crystal lattice, and other structural excitations (e.g., interference modes) in layered structures, providing detailed information about the structural parameters of multilayer systems [3].

The results from spectroscopic ellipsometric studies offer valuable insights into the electronic band structure, optical properties of materials (such as refractive index and absorption coefficient), and the thickness of thin films and layers in heterostructures. The inclusion of the infrared range, where the effect of surface roughness is diminished due to longer wavelengths, further allows for the determination of crystal lattice oscillation parameters and the concentration of free carriers in semiconductors.

Ellipsometry, including in-situ applications, has become an indispensable diagnostic method in the production of semiconductor materials and thin film structures. At the Institute of Semiconductor Physics of the National Academy of Sciences of Ukraine, the first commercially available spectroscopic ellipsometer in Ukraine, the SE-2000 (manufactured by SEMILAB Ltd., Hungary), is employed for scientific research within the wavelength range of λ = 245—2100 nm.

Ellipsometric measurements are predominantly carried out in reflectance mode that offers greater versatility as compared with light transmission mode. It is important to note that optical measurements in transmission mode are less sensitive to positioning errors caused by slight rotations or displacements of a homogeneous sample. In contrast, measurements in specular reflection mode require precise positioning of the sample surface at the intersection point of the optical axes of the polarizer and analyzer arms (aligned along the goniometer axis). Additionally, the condition of equal angles of incidence and reflection must be met accurately. Minor deviations from these conditions, including those induced by mechanical vibrations of the ellipsometer stage, can result in undesirable signal modulation in the registered optical signal due to the narrow aperture for the reflected beam.

Commercially available spectroscopic ellipsometers are designed with either vertical or horizontal optical goniometer axes, where the test sample is positioned either vertically (using a special holder) or horizontally (freestanding).

For solid-state physics and various practical applications of semiconductor materials and structures (e.g., photodetectors), it is crucial to measure optical properties and electronic structure parameters as a function of temperature. The aforementioned device, in its standard configuration, is suitable for laboratory research at room temperature.

Leading manufacturers of variable-temperature cryogenic equipment often prefer continuous-flow gas/liquid cryostats [4, 5]. These cryostats allow for the creation of a compact cooling chamber for the sample, which can be integrated into the limited space of the measuring device, while the cryoliquid tank and other auxiliary components are placed externally. Operating such a cryostat requires a cryogen source (e.g., Dewar vessel), a pump to circulate the cryogen, flexible transfer lines, and more. Although relatively simple and inexpensive, these cryostats have significant drawbacks, including high cryogen consumption and low temperature stability. A typical example is the cold finger cryostat [6, 7] or cryocoolers based on cryorefrigerators ("cold stage refrigerator") [8]. Due to the continuous flow of liquid and the extended length of the cold finger, it is challenging to eliminate noticeable vibrations of the chassis and the sample, which is unacceptable for rapid measurements.

Most standard solutions involve structures with vertical sample placement, which are unsuitable for specular light reflection measurements on ellipsometers with a horizontal goniometer axis. These measurements require access to the probing optical beam from the upper hemisphere to a horizontally fixed test sample and a vertical plane of light incidence. The positioning of the sample on a long cold finger rod does not ensure complete vibrationless stability during system operation and necessitates compensation for thermal expansion or contraction as the temperature changes.

In ellipsometers with a vertical goniometer axis and vertical sample fixation, vertical cold finger cryostats are typically used. For example, the Woollam V-VASE spectroscopic ellipsometer (J.A. Woollam, USA) with vertical sample fixation can be equipped with the ST-400 cryostat (Lakeshore Janis, USA), a continuous gas-flow system with a vertically oriented cold finger. This device, with variable components, can operate from 5 to 1000 K in the spectral range of 150—1700 nm [9]. However, this cryosystem's weak points include insufficient temperature stability due to the cold finger's length, high cryogen consumption, and the inability to fully eliminate sample vibrations. Additionally, achieving reliable thermal contact through vertical sample fixation poses extra challenges [9]. A similar approach, but with a horizontally oriented cold finger, is employed in the cryosystem for the SENresearch 4.0 ellipsometer (Sentech, Germany) that has a horizontal goniometer axis and horizontal sample fixation.

Linkam offers the THMS350V environmental cell as a temperature control vacuum stage for ellipsometry systems, covering a temperature range of –195 °C to +350 °C. This stage is compact, as it separates the cryoliquid tank and control system into external units connected by tubes through which cryogas is pumped.

Some cryodevice manufacturers design cryostats using the so-called Swenson method [10] that incorporates a built-in cryogenic liquid tank. Although this configuration is slightly larger, it eliminates the need for a long cold finger and external flexible transfer lines. Temperature is regulated by controlling the gas flow rate through a heat exchanger chamber, with the cryoagent supply valve and a heater mounted on the chamber's outer surface. This setup allows for more precise temperature regulation and stabilization, as the coolant gas is heated and delivered to the working chamber in a laminar flow.

As evident from the above, each unique device requires a tailored cryosystem solution. The purpose of this work was to expand the functionality of the SE-2000 (SEMILAB Ltd.) spectroscopic ellipsometer by developing an autonomous gas-flow temperature-controlled cryostat. This cryostat operates in the temperature range from liquid nitrogen (–195 °C) to +80 °C (80—353 K) for optical studies in specular reflection mode at light incidence angles around 70°. It is designed to be integrated into an ellipsometer with horizontal sample placement, allowing optical rays to access the sample from the upper hemisphere. The cryosystem based on this cryostat aims to achieve high operational parameters, ensuring a stable position of the sample in space with fine adjustments for height and tilt, as required for precise ellipsometric measurements.

CONFIGURATION OF TEMPERATURE-CONTROLLED CRYOSYSTEM FOR OPTICAL STUDIES

In the Laboratory of Cryogenic Technologies at the Institute of Physics of the National Academy of Sciences of Ukraine, a precision vibrationless temperature-controlled cryosystem was developed and manufactured. This system, based on a gas-flow type cryostat, has been specifically designed for low-temperature optical studies using spectroscopic ellipsometry to determine the parameters of semiconductor materials. The laboratory has extensive experience in creating cryosystems for physical research [11—14] and their accessories [15].

The cryosystem comprises the cryostat, temperature controller, and adjustment table, with the design details provided below.

The temperature-controlled cryostat system features a double-loop configuration (Fig. 1), consisting of:

a) **thermoregulation and temperature stabilization loop** that includes the cryostat, temperature sensor, temperature regulator, and an electric heater on the cryostat's heat exchange chamber.

b) **forced cryogenic vapor supply loop** that includes the cryostat, cryoliquid level meter (in the form of a thermodiode line connected to an external level indicator), constant pressure support valve, cryosystem overload protection circuit, heater-evaporator, and a protection sensor.

The cryostat (see Fig. 2) features a vertical configuration. The cryoagent feeder tank is positioned in the lower part of the cylindrical chassis. The sample under study is installed horizontally above this tank, allowing access for the probing optical beam from the upper hemisphere, typically at an angle determined by the placement of the input and output windows.

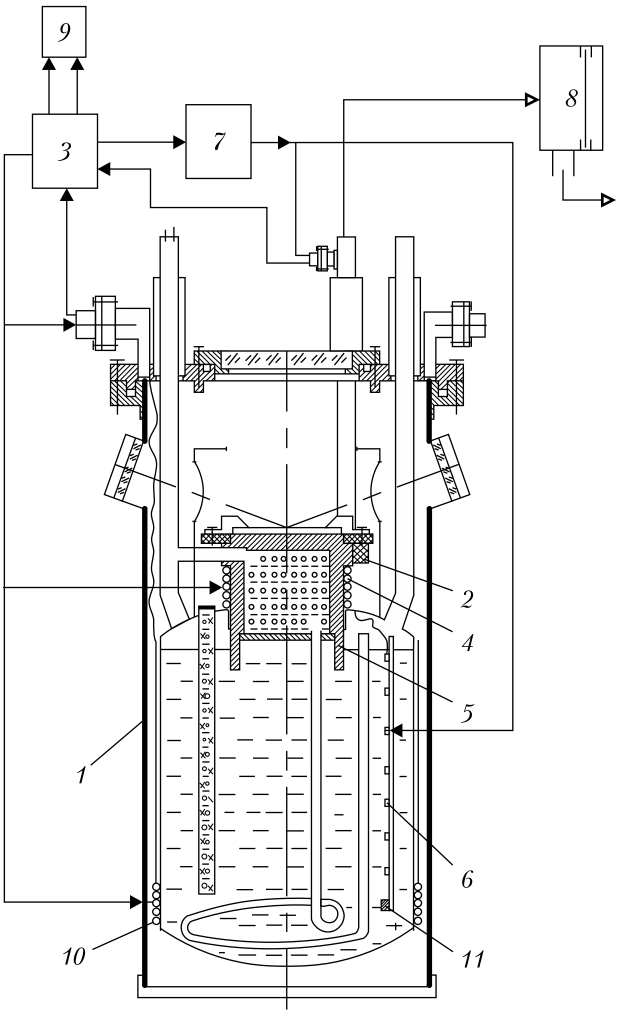

Fig. 1. Structural and functional scheme of the cryosystem
Thermoregulation and temperature stabilization loop: 1 — cryostat; *2* — temperature sensor; *3* — temperature regulator; *4* — electric heater on the heat exchange chamber *5* of cryostat. *Forced cryogenic vapor supply loop: 1* — cryostat; *6* — cryoliquid level gauge; *7* — external level indicator; *8* — gas flow regulator with constant pressure support valve and manostat; *9* — cryosystem protection circuit against overloads; *10* — heater-evaporator; *11* — protection sensor

The cryostat chassis (Fig. 2) consists of an outer casing-shell with an evacuated inner volume

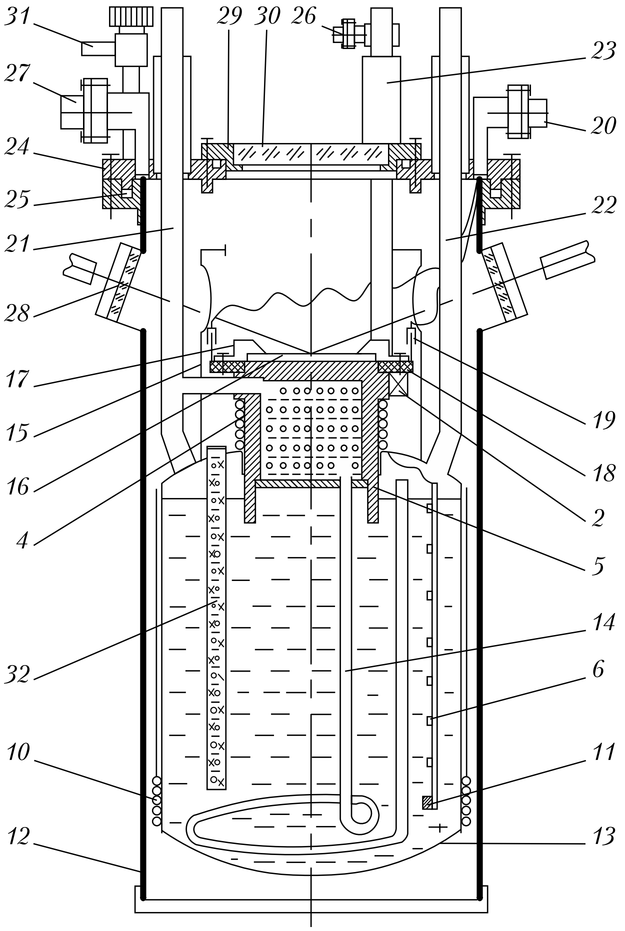

Fig. 2. Vertical section of the cryostat: *2* — temperature sensor; *4* — additional heater; *5* — heat exchange chamber densely packed with copper shavings; *6* — cryoliquid level gauge; *10* — heater-evaporator, *11* — protection sensor; *12* — outer casing shell; *13* — cryoliquid feeder tank; *14* — serpentine pipeline for supplying gaseous cryoagent; *15* — copper screen; *16* — sample; *17* — pressing movable contacts; *18* — board made of electrical insulating material; *19* — detachable contacts; *20* — 7-pin connector (with user contacts from measuring board *18*); *21* — hangers of the feeder tank, designed for the exit of used nitrogen from the heat exchange chamber; *22* — for pouring liquid nitrogen into the feeder tank; *23* — for installation of cryoliquid level gauge and protection sensor; *24* — cover; *25* — its vacuum sealing; *26* — 4-pin connector (with contacts from cryoliquid level gauge *6* and protection sensor *11*); *27* — 10-pin connector (with contacts from evaporator *10*; heater *4* and temperature sensor *2*); *28* — two symmetrical windows made of fused quartz; *29* — hatch cover with a window *30* for visual control of the measurement point on the sample; *31* — vacuum valve for pumping by a forevacuum pump; *32* — built-in cryopump of high vacuum

and a liquid nitrogen reservoir-feeder in the form of a nitrogen tank. A heater-evaporator is wound around the outer surface of the nitrogen tank. To minimize external heat inflows and infrared (IR) radiation, a radiation screen made of multi-layer Mylar foil covers both the heater-evaporator and the feed tank.

In the upper part of feeder tank *13*, copper heat exchange chamber *5* is mounted from above, surrounded by copper screen *15* and densely packed with copper shavings. The outer surface of the heat exchange chamber has an additional heater *4* and temperature sensor *2*. On the upper plane of the heat exchange chamber, sample *16* is horizontally mounted with the use of up to six movable pressing contacts *17*, fastened with screws on board *18* made of electrical insulating material attached to the heat exchange chamber. These contacts can be used to measure the electric potential from any part of the tested sample and can move along the contact pads of board *18*, to which removable contacts *19* are soldered. Wires from these contacts are connected to 7-pin connector *20*.

Pipeline *14* supplies the gaseous cryoagent to the heat exchange chamber, with the top of the pipeline positioned above the surface of the cryoliquid. The serpentine section passes through liquid nitrogen to minimize the temperature of the cryoliquid vapors, and the end enters the heat exchange chamber. This design allows for better heat transfer between the cryoagent and the heat exchange chamber.

The feeder tank is fixed on hangers *21*, *22*, and *23* to cover *24* that is mounted through vacuum seal *25* on the flange of outer chassis *12*. The hangers of the feeder tank are used for for the exit of used nitrogen from heat exchange chamber *5* (21); for pouring liquid nitrogen into the feeder tank (*22*); and for releasing nitrogen from the feeder tank, installing cryoliquid level meter *6*, and protection sensor *11* (23).

For the operation of the cryostat with liquid nitrogen, heater-evaporator *10* is mounted on the outside of the feeder tank. Inside the feeder tank, there is protection sensor *11* that serves as an indicator of the minimum level of cryogenic liquid and serves as one of the elements for protecting the cryosystem from overheating. This sensor functions as a switch for evaporator *10* when the level of liquid cryoagent drops below the acceptable limit. These sensors are connected to 4-pin connector *26*, installed on the upper part of tube *23*. Contacts from temperature sensor *2*, heater *4*, and heater-evaporator *10* are routed to 10-pin connector *27*.

To perform ellipsometric studies (optical measurements in the mode of specular reflection of light from the surface of a horizontally placed sample), two windows *28* are symmetrically installed in the cryostat chassis. These windows are inclined at an angle of 20° from the vertical so that the collimated beam of the ellipsometer, passing perpendicularly through the first window, reflects off sample *16* at an angle of 70° and enters the signal registration arm through the second window. The windows, made of fused quartz, are designed to accommodate the spectral range of the device (λ = 245—2100 nm). Window *30* on the upper flange of the cryostat serves for visual control of the measurement point on the sample and can also be used to illuminate the sample when measuring the light current-voltage characteristics of photoconverters at low temperatures. The vacuum chamber of the cryostat is evacuated by the forevacuum pump through vacuum valve *31*, and high vacuum is achieved by the built-in cryopump *32*.

The system operates as follows:

Installation or replacement of the test sample is performed after heating the cryostat to room temperature and allowing air to enter it. Hatch *29* with window *30* on the upper flange of the cryostat is then removed, the sample is changed, and fixed to the upper plane of heat exchange chamber *5*.

Once the test sample is installed and the cryostat is sealed, its internal volume is evacuated with a forevacuum pump to a residual pressure of 2×10^{-3} Hg mm. The feeder tank is then filled with the working cryogenic liquid that cools heat exchange chamber *5* and the sample to the desired temperature. The level of cryogenic liquid in the feeder tank is monitored visually using electronic level indicator *7*.

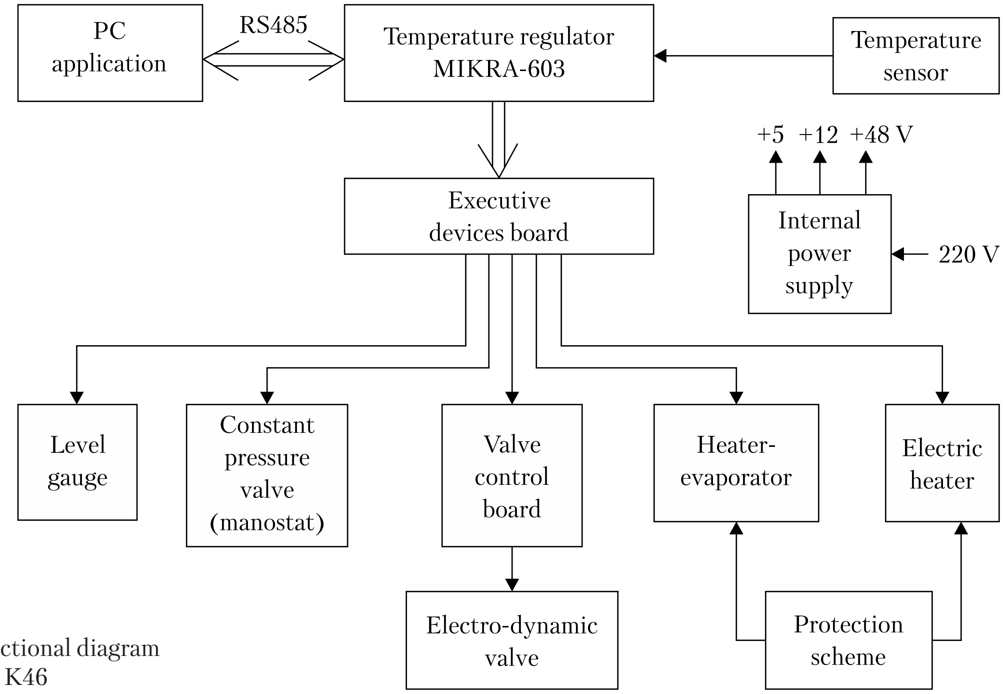

Fig. 3. Structural and functional diagram of temperature controller K46

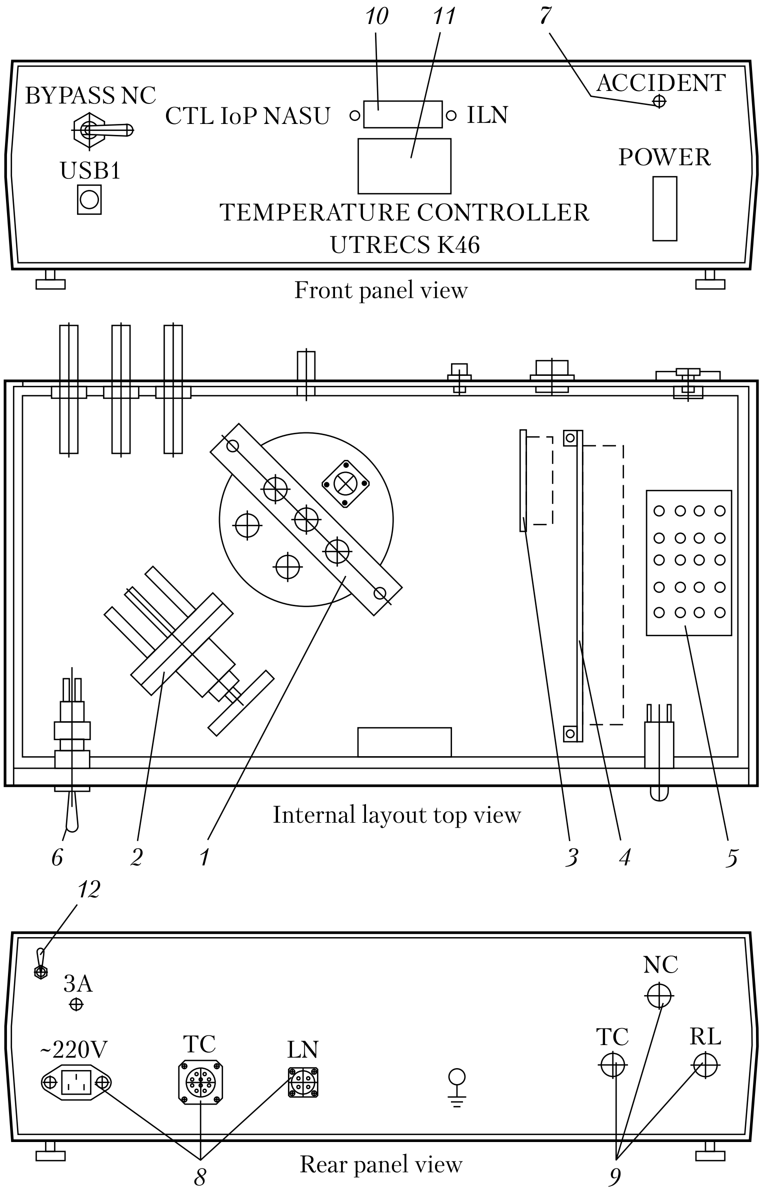

Fig. 4. K46 temperature controller: *1* — electrodynamic valve; *2* — manostat; *3* — valve control board; *4* — board of executive devices; *5* — power source; *6* — pneumatic switch; *7* — emergency situation indicator; *8* — connectors for connection: 220 V power supply; TS — temperature sensor and heaters; LG — cryofluid level gauge; *9* — fittings for connecting: NT — nitrogen tank, TC — thermostatic chamber, EX — nitrogen exhaust manifold; *10* — cryoliquid level gauge indicator; *11* — Mikra-603

Temperature regulation of the heat exchange chamber *5* is achieved by adjusting the flow intensity of the gaseous cryoagent through it and by heating it with electric heater *4*. Cryogenic liquid vapor is maintained under pressure in feeder tank *13*, controlled by a constant pressure valve (manostat) *8*, and are directed through serpentine tube *14* to heat exchange chamber *5*, with excess vapors removed through hanger *20*. The flow intensity is controlled by heater-evaporator *10* that serves as the executive mechanism for the thermoregulation and temperature stabilization circuit.

To regulate the temperature in the cryostat, a custom K46 temperature controller was developed based on the Mikra-603 serial regulator. The structural and functional diagram of this controller is shown in Fig. 3, and its structure and appearance are presented in Fig. 4. This intelligent device converts the measured voltage from the certified temperature sensor (thermoresistor) into a temperature value, compares it with the set point, and generates a control signal for the PID controller. This signal is then transmitted to the executive devices, including the gas flow regulator, constant pressure valve (manostat), and the windings of the electrical heater and heater-evaporator.

When a command to decrease the temperature in the heat exchange chamber is given, the temperature controller maximizes the heating of the evaporator. This increases the flow of gaseous cryogen through the heat exchange chamber, leading to a reduction and stabilization of pressure in the tank, which is essential for achieving the desired temperature. The simultaneous regulation of the gas flow rate through the heat exchange chamber and the control of the heater mounted on it ensures the necessary thermal balance within the cryostat's thermostatic chamber, providing high stability in maintaining the set temperature.

Table 1. **Technical Characteristics of UTRECS K46 Temperature Controller**

Temperature controller type	Digital microprocessor with built-in temperature regulator Mikra-603
Temperature control range, °C	–200 ... +100
Temperature display resolution, °C	0.1
Temperature controller information displaying	5-digits 7-seg LED indicator
Method of setting the temperature	Keyboard of Mikra-603 or PC
Temperature setting resolution, °C	1
Stability of the set temperature point, °C	±0.1
The principle of temperature regulation	proportional-integral-derivative (PID)
Type of control signal of executive devices	power-width modulated (PWM)
Number of output control signals of executive devices	2
PWM period setting range, sec.	0.5—99.0
Built-in interface type	USB-2.0
Data exchange protocol	Modbus RTU
Data transfer rate, Kbit/sec	4.8; 9.6; 14.4; 19.2; 28.8; 38.4
Temperature sensor used	Thermoresistor TSP-100
Number of measuring channels for the temperature sensors	1
Calibration curves	EEPROM
Sensor connection	3-wire
Power consumption, W, no more	150
Environmental conditions	
environment temperature, °C	20 ± 5
environment relative humidity, %	30—80
atmospheric pressure, Hg mm	750 ± 20
power supply frequency, Hz	50—60
power supply voltage, V	220 ± 10%
Overall dimensions, mm	300 × 230 × 100
Weight, kg	1.5

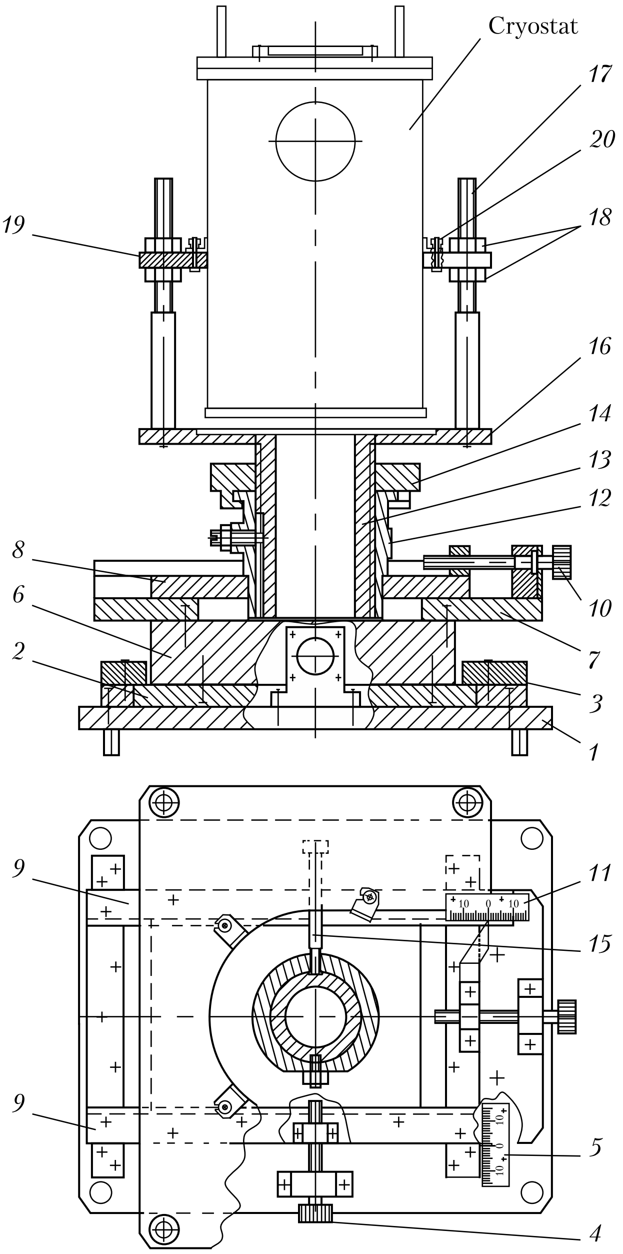

Fig. 5. The design of the adjustment table: *1* — base substrate; *2* — slider; *3* — guides; *4* — screw of translation along the horizontal axis *Y*; *5* — vernier of movement; *6* — stand to the base *7*; *8* — slider of movement along the *X* axis; *9* — guides; *10* — screw of movement along the *X* axis; *11* — Vernier; *12* — housing of the vertical movement guide; *13* — threaded rod; *14* — nut of translational movement along the vertical *Z* axis; *15* — position fixing screw; *16* — tilt base substrate; *17* — threaded racks (4 pcs.); *18* — nuts (4 pcs.) of tilting plate; *19* — tilting plate; *20* — nuts

The target temperature can be set either via the keyboard on the Mikra-603 controller or from an external computer through the built-in USB interface. For integration into an automated control system, the controller is equipped with an RS-485 network interface, with command and data exchanges managed through the Modbus RTU protocol. In this configuration, the controller operates in “slave” mode. The technical specifications of the developed controller are presented in Table 1.

In this system, designed for the Semilab SE-2000 ellipsometer, the sample is fixed horizontally on the upper plane of the heat exchange chamber. The cryostat, along with the sample, can be adjusted by moving it along three Cartesian coordinates (X, Y, Z) and by altering its tilt within ±3° relative to the vertical axis. These adjustments are made using the adjustment table, whose design is illustrated in Fig. 5.

The adjustment mechanism works as follows: Slider *2* is moved horizontally along the Y-axis using screw *4*, guided by guides *3*, with reference to vernier *5*. This movement takes place on substrate *1* of the table. Above slider *2*, stand *6* connects to base *7*, to which another slider *8* is attached. Slider *8* can be moved along the X-axis via screw *10*, with reference to vernier *11*, along guides *9*.

Vertical guide *12* is fixed to slider *8*, allowing threaded rod *13* to move along the vertical Z-axis using nut *14*. Screw *15* is used to lock the height position.

At the top of rod *13*, sloped substrate *16* is attached, onto which four threaded racks *17* are fixed. These racks allow plate *19* to tilt within ±3° from the horizontal plane using nuts *18*. The cryostat is securely attached to plate *19* with nuts *20*.

The technical specifications of the adjustment table are summarized in Table 2, while the overall technical specifications of the cryosystem are provided in Table 3.

Figure 6 shows the components of the created cryosystem; Fig. 7 features the cryosystem mounted in the SE-2000 spectroscopic ellipsometer.

The developed temperature-controlled cryostat system has several distinctive features:

Table 2. **Technical Characteristics of Adjustment Table**

Parameter	Specification
Horizontal movement (*X, Y*-axises), mm	±15
Vertical movement (*Z*-axis), mm	±5
Cryostat and sample tilt range, °	±3
Overall dimensions:	
height with mounting racks, mm	220
width, mm	170
length, mm	242
Weight, kg	2

Table 3. **Cryosystem Technical Parameters**

Parameter	Specification
The temperature on the substrate at the place of installation of the sample, K	80—353
Cryoliquid	Liquid nitrogen
Cryoliquid tank volume, cm^3	400
Initial cooldown time, min	no more than 10
Nominal crioagent consumption rate:	
a) for filling the cryostat, l	no more than 0.7
b) while maintaining a temperature of 80 °K, l/h	no more than 0.3
Time of continuous operation at 80 °K without additional liquid nitrogen, hr	no less than 4
Overall cryostat dimensions, mm	∅120 × 280
Weight of cryostat without cryoliquid, kg	1.6

Fig. 6. Image of the cryosystem

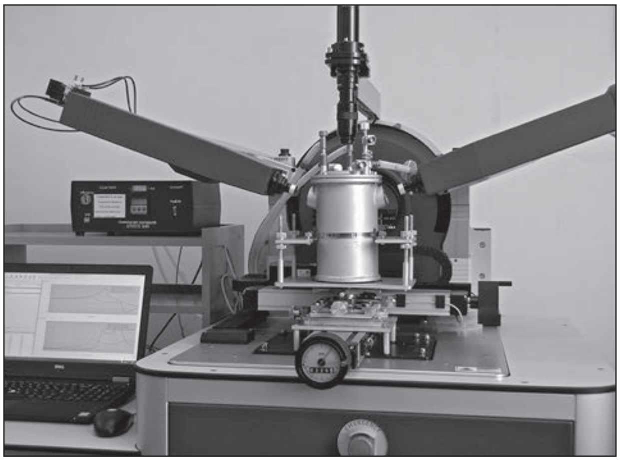

Fig. 7. Image of the cryosystem as part of the ellipsometer

- Bottom Tank-Feeder Design: The cryostat is equipped with a bottom tank-feeder for the cryoliquid. The heat exchange chamber that holds the sample, is mounted as the upper part of this tank. The chamber's bottom directly contacts the cryoliquid (liquid nitrogen), while its upper section, where the sample is fixed, is located within a vacuum cryostat chamber.
- Gas-Flow Cryostat Design: The cryostat operates on a gas-flow principle, where a laminar flow of gas is generated by the excess pressure within the feeder tank. The cryogenic liquid is heated by a heater-evaporator, and the intensity of the gas flow is regulated solely by adjusting the power supplied to the heating element. This design minimizes vibrations of the chassis and sample, and reduces cryoliquid consumption.
- Efficient Heat Exchange Chamber: The heat exchange chamber, positioned at the top of the nitrogen tank, is made from solid copper and is densely packed with copper shavings to ensure uniform heat distribution. An electric heater is placed on the side surface of the chamber, serving both to stabilize the temperature and

to heat the system from room temperature up to +80 °C.

- Precision Sample Positioning: The sample is mounted horizontally in the heat exchange chamber, positioned in the focal point of a sample visualization camera. The sample's position can be precisely adjusted through translational movement along three Cartesian coordinates and by tilting the cryostat as a whole, using an adjustment table.
- Optical Channel Design: The cryostat is equipped with one vertical and two lateral optical channels positioned at specific angles. This configuration enables optical measurements, including ellipsometry, by allowing the detection of the amplitude and phase of a beam specularly reflected from the sample's surface using a detector.

A precise, autonomous, vibrationless, temperature-regulated cryosystem has been developed. It is based on a gas-flow liquid nitrogen cryostat, where the sample under investigation is fixed in a vacuum on the flat surface of the heat exchange chamber, located at the top of the nitrogen tank. The system includes a built-in liquid nitrogen level gauge, an overheating protection mechanism, and a temperature controller utilizing the Mikra-603 serial regulator.

This cryosystem is specifically designed to investigate the optical properties of solid-state materials and thin film heterostructures within a wavelength range of 245—2100 nm, and at temperatures ranging from the boiling point of liquid nitrogen to +80 °C (approximately 80—353 K). It is compatible with optical instruments operating in the specular reflection mode, where the sample is accessed from the upper hemisphere, such as in the Semilab SE-2000 spectroscopic ellipsometer. The adjustment table allows precise positioning of the sample by enabling movement along three Cartesian coordinates and adjusting the angle of inclination, ensuring the accurate reflection of the light beam into the output device aperture.

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І.П. Жарков[1] (https://orcid.org/0000-0003-1626-5655),
В.В. Сафронов[1] (https://orcid.org/0000-0002-2982-9627),
В.О. Ходунов[1] (https://orcid.org/0000-0002-5881-5080),
В.М. Коновал[1] (https://orcid.org/0000-0002-5240-1207),
І.П. Паламарчук[1] (https://orcid.org/0000-0003-4513-9850),
О.В. Селіванов[1] (https://orcid.org/0000-0001-9579-885x),
А.Г. Солонецький[1] (https://orcid.org/0000-0001-8837-4776),
С.В. Мамикін[2] (https://orcid.org/0000-0002-9427-324X),
О.Б. Яструбчак[2] (https://orcid.org/0000-0001-6641-5768),
В.Р. Романюк[2] (https://orcid.org/0000-0002-0068-5973)

[1] Інститут фізики Національної академії наук України,
просп. Науки, 46, Київ, 03028, Україна,
+380 44 525 220, +380 44 525 1589, fizyka@iop.kiev.ua
[2] Інститут фізики напівпровідників ім. В.Є. Лашкарьова Національної академії наук України,
просп. Науки, 41, Київ, 03028, Україна,
+380 44 525 4020, +380 44 525 2201, info@isp.kiev.ua

АВТОНОМНА БЕЗВІБРАЦІЙНА ТЕРМОРЕГУЛЬОВАНА КРІОСИСТЕМА ДЛЯ ОПТИЧНИХ ДОСЛІДЖЕНЬ НА СПЕКТРАЛЬНОМУ ЕЛІПСОМЕТРІ

Вступ. Еліпсометрія є чутливим неруйнівним оптичним методом дослідження властивостей матеріалів і тонких плівок.

Проблематика. В Інституті фізики напівпровідників НАН України для наукових досліджень експлуатується перший в Україні серійний спектральний еліпсометр SE-2000 (*SEMILAB Ltd.,* Угорщина), але умови вимірювання обмежені лише кімнатною температурою.

Мета. Розширення функціональних можливостей спектрального еліпсометра SE-2000 завдяки створенню автономної терморегульованої кріосистеми в діапазоні температур –195 °С до +80 °С (~80—353 К).

Матеріали й методи. На базі кріостата газопротічного типу розроблено та виготовлено автономну прецизійну безвібраційну терморегульовану кріосистему для низькотемпературних оптичних досліджень методом спектральної еліпсометрії в режимі відбивання світла. Кріосистема складається з власне кріостата, контролера температури та юстувального столика.

Результати. Кріостат побудовано по газопротічному типу, ламінарний потік газу створюється надлишковим тиском газу в резервуварі-живильнику від нагрівання нагрівачем-випарником кріогенної рідини, а його інтенсивність регулюється, відповідно, зміною потужності, прикладеної до нагрівного елемента, завдяки чому відсутні наведені вібрації корпуса і зразка. Теплообмінну камеру вмонтовано у верх азотного бака, а досліджуваний зразок кріпиться до теплообмінної камери в горизонтальній площині, зондуючий та відбитий промені — у верхній півсфері відносно нього. Юстування положення зразка здійснюють поступальним переміщенням в трьох декартових координатах та зміною нахилу кріостата в цілому за допомогою юстувального столика.

Висновки. Ця система може бути використана у оптичних приладах, котрі використовують режим дзеркального відбивання світла від поверхні зразка з доступом до поверхні зразка з верхньої півсфери.

Ключові слова: терморегульована азотна кріосистема, спектральна еліпсометрія, напівпровідникові матеріали та структури, температурні залежності оптичних параметрів.