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CRYOAPPARATUS WITH EMBEDDED SUPERCONDUCTIVE SOLENOID FOR STUDYING THE MAGNETO- AND ELECTRO-PHYSICAL PROPERTIES

Complex cryogenic equipment based on temperature-controlled helium cryostat with a superconducting embedded solenoid for studying the galvanic and magnetic phenomena in 2D systems has been designed. It ensures the temperature control of studied sample within the ranges of 1.6—4.2; 4.2—80; and 80—300 K and the temperature stability in the magnetic field of up to 7.84 T with an accuracy of 0.1 K, at most.

Keywords: cryogenic system, helium, temperature control, temperature stability, and superconductive solenoid.

While designing and using various electronic and optoelectronic devices (UHF generators, IR receivers and emitters) based on quantum well (QW) structures, it is important to understand the physical parameters influencing the processes related to the charge carrier transport in these systems. The study of galvanic magnetic phenomena within wide range of temperature, electric and magnetic fields is among the methods for getting information on the properties of QW structures. The most important research is studying the temperature dependence of the Hall coefficient and specific resistance, as well as the magnetic resistance, the Shubnikov-de Haas (SdH) oscillations, and the Hall quantum effect at fixed temperature. The temperature at which the quantum-dimensional effects manifest themselves ranges under 20—70 K. In the majority of cases, the research is done within the range 4.2—1.2 K reached by pumping down vapors of helium fluid. The magnetic field for effective research of magnetic resistance and SdH oscillations is above 5 T.

To study the angular dependence of magnetic resistance (the angle between the magnetic field vector and electric current direction through the sample), a device for sample rotation around longitudinal axis during the measurement has been designed. The study of processes related to heating of electrons in QW applying electric field is important for the QW systems. To this end, the holder with lead wires has coaxial inputs for enabling research in pulsed lateral electric fields. To prevent the Joule overheating of samples, strong electric field is supplied to the sample in the pulse mode with pulse duration of about 1 μs. The optical inputs within the terahertz range can be realized through light guides as hollow polished tubes. For working with superconductive magnet, a controlled source able of smoothly scanning the whole range and stopping at the given point has been designed.

There are the cryostats with embedded superconductive solenoid [1—3]. Among their disadvantages, there is the lack of option of solenoid re-

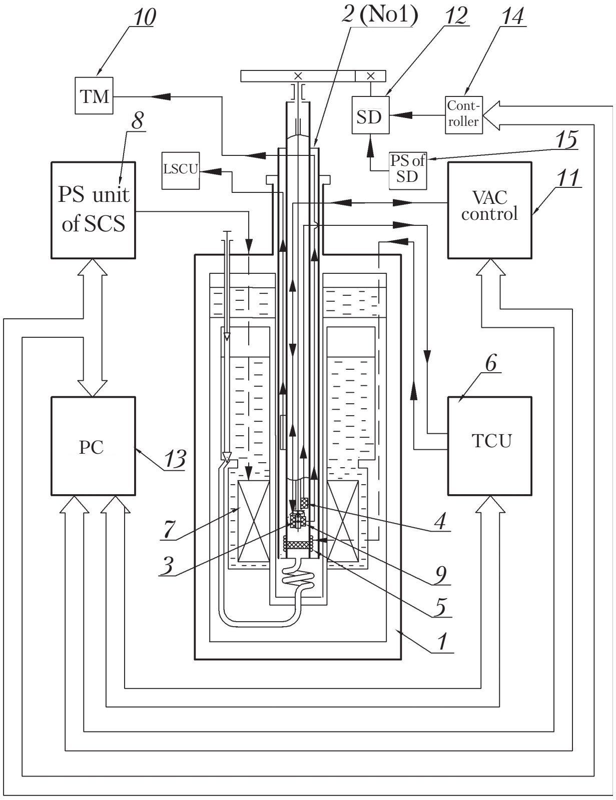

Fig. 1. Functional structure of the cryogenic complex

placement in some cryostats, as a result of which their functional operability is limited, since the sample can be influenced only by constant magnetic field (in terms of homogeneity, maximum intensity) or the homogeneity of magnetic field is not sufficient. Therefore, this research is aimed at designing such a configuration that enables improving the main characteristics of the system, in particular, keeping the homogeneity of magnetic field of superconductive solenoid, and carrying out comprehensive magneto- and electro-physical experiments.

To this end, the case of temperature-controlled helium cryostat is detachable. Inside, there are a feeding tube and a container for cryogenic fluid with embedded superconductive solenoid. This container is embraced by a radiation shield connected to the cooling reservoir. The container has inlet and outlet for cryogenic fluid. Inside the tube, in the center of superconductive solenoid, there is an insert with work chamber bearing the heat exchanger, the heater, and the temperature sensor, with sample holder placed in the center. The cryostat is additionally equipped with circuits for measuring the magneto- and electrophysical properties and with a step insert drive connected to the PC by electric and information grids for studying the angular dependences of these characteristics.

The work chamber of the cryostat with the heater and the temperature sensor being located in a draft and embracing the sample holder and the heat exchanger being placed in the feeding tube have allow the designers to reduce the number of soldered joints, insofar as the surface of the work chamber is independent on the heat exchanger. In this way, the magnetic field of superconductive solenoid becomes more homogeneous.

The solution is showed in Fig. 1 featuring the structure of cryogenic system used for studying the magneto- and electro-physical properties. Fig. 2 shows the configuration of the cryostat: *2* — vertical cross section of the cryostat with the insert, **A** — top view of the cryostat, **I** — enlarged vertical cross section of the bottom part of the insert, **B** — enlarged vertical cross section of the bottom part of the insert (side view).

The temperature-controlled cryogenic system consists of the following units: *a* — the temperature control and stabilization circuit with the cryostat *1*; insert *2* with the sample *3*; temperature sensor *4*; electric heater *5*; temperature control unit (TCU) *6*; and level sensor capasity unit (LSCU) for measuring the level of helium fluid in the cryostat shaft; *b* — the circuit for control and stabilization of magnetic field strength containing the cryostat *1* with embedded superconductive solenoid (SCS) *7*, SCS power supply module *8*, Hall sensor *9*, teslameter (multimeter) *10*; *c* — the set for measuring the VACs *11*; *d* — the unit for computerized control of the slope angle of the sample. It contains the insert *2* converting the yaw movement of the rod into the rotation of the holder together with the sample *3* about the horizontal axis; step drive (SD) *12* connected to the PC *13* via the controller *14* by the electric and information grid; and the power supply module of the step drive (SDPSM) *15*.

The configuration of cryostat with the insert *2* (the axial cross section) is given in Fig 2. Inside the separable case of cryostat *1*, there is the detachable reservoir having a capacity of 5.5 l for the cryogenic fluid (helium) *16* enveloped with the copper shield *17* cooled by cryogenic fluid (nitrogen) contained in the 2.8 l tank *18*. The reservoir *16* is fixed at the upper flange *19* suspended on the cover *20* by thin-walled tubes *21, 22, 23, 24* that are made of material having a low thermal conductivity. The tubes are multifunctional. The tube *21* is used for:

- fixing the needle valve *25* controlling the supply of helium fluid through the tube *26*, detachable tube *27,* and coil *28* to the thermostat chamber *29* of the cryostat using the handle *30* and for fixing the needle valve *31* controlling the supply of helium fluid to the thermostat chamber *29* with the help of handler *32*;
- The tube *22* is used for fixing the current feedthrough *33* to the SCS *34*;
- The tube *23* is used for filling the reservoir *16* with helium fluid;
- The tube *24* is used for holding the helium level indicator *35*.

The lower flange *37* is fixed to the upper flange *19* by pins *36*. The SCS *34* with the detachable tank for helium fluid *16* is pinned (by *38)* to the lower flange. The SCS is made as a frame with superconductive wire coiled. The current feedthrough *33* is made as bunch of copper wires. From the SCS the conductors are soldered to the board *39* and to the connector *40*. The potential conductors of SCS lead to the connector *41*. In the upper part, the hanger tubes of the flange *19* and the tank *16* are connected to each other with the collector *42* for withdrawing helium fluid evaporated into the main pipe via the fitting adapter *43*.

The hanger tubes of nitrogen container *44* and *45* are used for filling and withdrawing nitrogen vapors. The vacuum compartment of the cryostat is evacuated by backing pump through the vacuum valve *46*. High vacuum is ensured by the cryogenic pump *47*. In the center of the cryostat, the feeding tube 48 ended with thermostat chamber *29* is located. To the chamber *29* of the cryostat, helium fluid or gas is fed through the tubes *26* and *27* and the heat exchanger (coil) *28* to cool the sample *3* fixed in the holder *49* of the insert *2* (see *4* and *5*). For heating the chamber, the electric heater *5* established in the bottom part of the insert *2* is used. Outputs of the heater *5* are connected to the plug *50*.

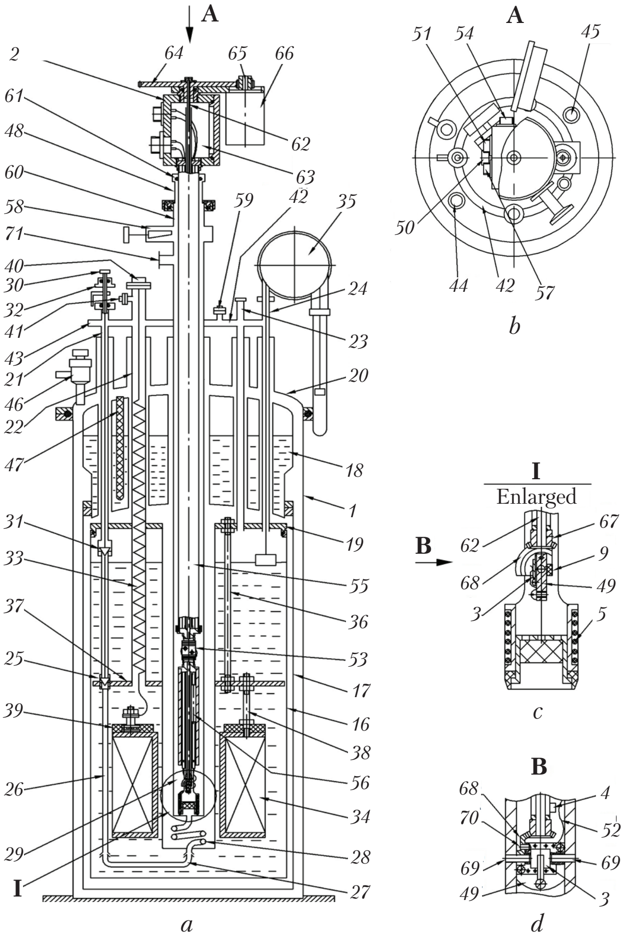

Fig. 2. Cryostat configuration

For controlling temperature the temperature sensor *4* is put in the chamber. In the sample holder *49,* there is the Hall sensor *9* for measuring the intensity of SCS magnetic field in the center of the solenoid. The outputs of the Hall sensor are connected to the plug *51*. The wires *52* are connected to the sample and to the plug *54* through the commuting board *53*. In the tube *55* of the insert, there is the helium level indicator *56* connected to *57*. At the top of the feeding tube, the gate valve *58* locks the pass of feeding tube while sluicing the samples for their replacement. This enables replacing the samples without warming the cryostat.

To prevent the damage of cryostat under high pressure, the safety valve *59* is placed on the cryostat case. On the upper nozzle *60* of the cryostat, there is fastened the insert *2* that can move up and down and jaw before its fixation with dynamic seal *61*. The rotatable rod *62* is placed in the central tube *55* of the insert. In the upper part, the rod is fastened on the junction box *63*. The gear *64* interlocked with the gear wheel *65* is stiffened in the rod. The gear wheel is rigidly fastened in the shaft of step drive *66*.

Table 1

Dependence of Cryogenic Agent Consumption Rate on SCS Current at 4.2 K

SCS current, A	Magnetic induction, T	Cryogenic agent consumption rate, cm^3/h
0	–	200
10	1.12	220
20	2.24	250
40	4.48	280
50	5.60	300
60	6.72	310
70	7.84	320

In the bottom part of the rod *62*, there is the rigidly fixed gear *67* that via a simple bevel gear is interlocked with the gear set *68* stiffened on the semi-axes *69* in the bottom part of the insert. The gear set *68* rotates on the axes about the horizontal axis and via the pin *70* revolves the sample holder *49*. In the initial position, the holder *49* with the sample *3* is oriented in parallel with SCS axis *34*, whereas in the full-shift position, the holder is tilted by 90° with respect to the initial position and is oriented normally to the SCS axis. The holder with sample can rotate by various angles ranging from 0 to 90°. The revolution angle is set by the PC through the step drive.

The cryostat with helium fluid operates as follows: the vacuum compartment of the cryostat is evacuated by backing pump through the vacuum valve *46*. The sample *3* is fixed in the holder *49* of the insert. When the gate valve *8* is open the insert *2* is put into the feeding tube *48* of the cryostat and fastened in the upper nozzle *60*. The insert is put as far as it can go to the bottom of the work chamber *29* and fastened with dynamic seal *61*.

After supplying nitrogen to the tank *18*, the suspended radiation shield *17* embracing the tank *16* with SCS and the work chamber *29* cools down, which leads to the cooling of all parts of the cryostat inside the shield. As the adsorption cryogenic pump *47* gets cool, the vacuum height-

Table 2

Temperature Dependence of Cryogenic Agent Consumption Rate at the Maximum Field

Preset temperature, $T_{з}$, K	Actual temperature, $T_{ф}$, K	Readjustment, $\Delta T_{пер.}$, K	Temperature stability, $\Delta T_{ст.}$, ±K	Gas pressure in the tank containing cryogenic agent, mm Hg	Cryogenic agent consumption rate, cm^3/h
4.2	4.19	–	0.01	200	320
6.0	6.00	<0.05	<0.05	200	280
12.0	12.00	<0.05	<0.05	200	260
20.0	20.00	<0.05	<0.05	200	220
40.0	40.00	<0.05	<0.05	200	190
80.0	80.00	<0.05	<0.05	200	170

ens. After the supply of nitrogen and cooling of the mentioned components of the cryostat, helium is fed to the tank *16* through the tube *23*. The level of helium in the tank *16* is controlled with the help of the level indicator. For feeding the helium gas to the work chamber *29*, the valve *25* is shut using the handle *30* and the valve *31* is opened via the handle *32*.

For supplying the helium fluid to the work chamber, the valve *31* is shut with the help of the handle *32*, while the valve *25* is opened using the handle *30*. Pressurized helium or its vapors come from the tank *16* via the tubes *26*, *27* and the heat exchanger (coil) *28* to the work chamber *29* and come out through the nozzle *71* to the main collecting the helium. Since the heat exchanger (coil) is placed in the feeding tube instead of the outer surface of the work chamber, it is not soldered to its surface for the whole of its length. In this way, the quantity of solder alloy reduces and so does the effect of its components on the homogeneity of the SCS magnetic field.

For the operation under 4.2 K, the work chamber *29* is filled with helium fluid with helium vapors withdrawn by the vacuum pump via nozzle *71*.

For studying the magneto- and electro-physical properties, the cryostat system showed in Fig.1 is used. The magnetic field is set and stabilized before the study. The magnetic field is controlled by the Hall sensor PHE602117A.

The required angle of sample orientation (by its revolution) with respect to the magnetic field vector is set by the PC *13* via the controller *14* operating the step drive *12*.

The research has showed that the cryogenic agent consumption rate (at 1.6 K), at the maximum field is at most 400 cm^3/h. The consumption rate at 4.2 K and within the range 4.2—80 K is given in Tables 1 and 2. As one can see from the date, one refill of cryostat is sufficient for the whole work day.

Fig. 3 shows the cryogenic complex having the following technical parameters:

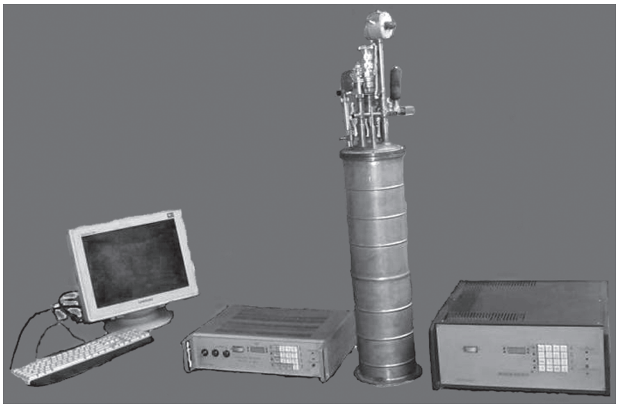

Fig. 3. Cryogenic complex external view

Temperature control range	1.6—4.2; 4.2—80; 80—300 K
Magnetic field control range	0—7.84 T
Temperature instability	less than 0.1 K
Magnetic field inhomogeneity in the center of cryostat work chamber, T	at least, $1 \cdot 10^{-3}$ for a length of 30 mm
The sample can be placed into liquid or gaseous environment	
Diameter of channel for the sample	20 mm
Rapid change of the sample	
Computerized reposition of the sample with respect to magnetic field vector	
Programmable change in temperature, field, and position of the sample	
Helium fluid consumption rate at the maximum field	at 1.6 K at most 400 cm^3/h
Helium fluid consumption rate within the range 4.2—80 K	at most 0.320 cm^3/h
Helium fluid consumption rate within the range 80—300 K	at most 0.320 cm^3/h

CONCLUSIONS

The designed cryogenic complex ensures the simultaneous programmable control of the sample temperature within the ranges 1.6—4.2; 4.2—80; and 80—300 K and its stabilization with an accuracy of ± 0.5° in the controlled magnetic field of up to 7.8 T and the computerized reorientation of the sample with respect to the magnetic field vector.

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КОМПЛЕКС КРІОАПАРАТУРИ З ВБУДОВАНИМ НАДПРОВІДНИМ СОЛЕНОЇДОМ ДЛЯ МАГНІТОФІЗИЧНИХ ТА ЕЛЕКТРОФІЗИЧНИХ ДОСЛІДЖЕНЬ

Створено комплекс кріогенної апаратури на базі терморегульованого гелієвого кріостата з вбудованим надпровідним соленоїдом для дослідження гальваномагнітних явищ у низькорозмірних системах. Комплекс забезпечує регулювання температури досліджуваного зразка в діапазонах 1,6—4,2; 4,2—80; 80—300 К та її стабілізацію з точністю не більше 0,1 К у магнітному полі до 7,84 Тл.

Ключові слова: кріосистема, гелій, терморегуляція, стабільність температури, надпровідний соленоїд.

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КОМПЛЕКС КРИОАППАРАТУРЫ СО ВСТРОЕННЫМ СВЕРХПРОВОДЯЩИМ СОЛЕНОИДОМ ДЛЯ МАГНИТОФИЗИЧЕСКИХ И ЭЛЕКТРОФИЗИЧЕСКИХ ИССЛЕДОВАНИЙ

Создан комплекс криогенной аппаратуры на базе терморегулируемого гелиевого криостата со встроенным сверхпроводящим соленоидом для исследования гальваномагнитных явлений в низкоразмерных системах. Комплекс обеспечивает регулирование температуры исследуемого образца в диапазонах 1,6—4,2; 4,2—80; 80—300 К и ее стабилизацию с точностью не более 0,1 К, в магнитном поле до 7,84 Тл.

Ключевые слова: криосистема, гелий, терморегулирование, стабильность температуры, сверхроводящий соленоид.

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