Appendix No. 2 to STC

Procedure mark: CEZAMAT/ZP15/2023

Description of the Subject of the Order

The subject of the order is the delivery of the tools described below, having the technical and functional parameters no worse than specified.

The subject of the order must come from a legal source and be intended to operate in Poland.

The subject of the order: **Delivery of an innovative platform for the synthesis of 2D materials and their heterostructures for new generation electronics**

General requirements:

No.	General requirements:
1.	The tool must be new and unused.
2.	At the moment of submitting the offer, all the offered elements, components, consumables etc. must be provided by the manufacturer.
3.	Devices and their components must be marked by manufacturers in such a way that both the product and the manufacturer can be identified (also applies to the device components).
4.	The devices must be delivered to the Ordering Authority in the original factory packaging of the manufacturer.
5.	A set of standard technical documentation for the user in paper or electronic form must be provided for each device.
6.	Devices must comply with European standards for CE marking.
7.	All devices must work with the European power grid.
8.	The company assembling and servicing the devices must have implemented the ISO 9001 quality system or an equivalent standard for the provision of maintenance services.

Requirements specifying the parameters of individual parts of the procedure

A platform for the synthesis of 2D materials and their heterostructures

The subject of the order is a platform for the production of two-dimensional (2D) materials and van der Waals heterostructures based on them using metal-organic chemical vapor deposition (MOCVD). This platform is designed to allow the growth of various high-quality 2D materials, including graphene, hBN, MoS_2, WS_2, $MoSe_2$, WSe_2, $MoTe_2$, WTe_2, and structures composed of these materials stacked vertically, i.e., van der Waals heterostructures. The platform should be equipped with a system to limit pre-process reactions, an advanced in-situ monitoring system for grown layers, and a gas distribution system that enables very

homogeneous two-dimensional layers on substrates up to 4 inches. This platform should be universal and adaptive, enabling changes in carrier gases, reaction gases, and organometallic sources used in the synthesis process. In addition, the construction of the reaction chamber should eliminate the problem of deposition of synthesized materials on the walls of the reactor.

The subject of the order is a system for deposition of 2D materials layers along with the following equipment: reactor; glovebox; process gas supply system; a real-time characterization system; vacuum system; cooling system; computer control system with a computer and control software; reactor heating system; post-reaction gas outlet system; security system in the event of a failure of the device or external infrastructure.

The entire system must fit within an area of 5.5×3.5 m^2 and not exceed a height of 2.5 m from the ground to the highest point of the assembly. The platform must be constructed in such a way that its largest component can be transported through a laboratory door 2.05 m high without interfering with the building structure. The Ordering Authority allows for an installation site visit.

The components of the platform must meet the minimum requirements in accordance with the following specification of individual system components, safety requirements, and expandability:

1. Reactor:
   - 1.1. Water-cooled reaction chamber made of 316L stainless steel or equivalent to grow two-dimensional materials such as graphene, hexagonal boron nitride, molybdenum disulfide, tungsten disulfide on substrates (interchangeable): 4 inch (100 mm), 3 inch (75 mm) and 2 inch (50 mm).
   - 1.2. A heating system capable of reaching a substrate temperature of at least 1400 ˚C with independent heating zones ensuring high thermal uniformity (temperature difference over 2-inch substrate to be not higher than 2 ˚C in typical growth conditions) of the graphite susceptor.
   - 1.3. Silicon carbide (SiC) coated graphite susceptor suitable for 2, 3, and 4 inch substrates.
   - 1.4. SiC uncoated graphite susceptor suitable for the 2, 3, and 4 inch substrates.
   - 1.5. Two independent systems for delivering process gases to the reaction chamber, allowing to reduce parasitic pre-reactions.

1.6. Small distance between the substrate and the injection point of the process gases (max. 20 mm) for high efficiency of the growth process.

1.7. Possibility to install a system that enables changing the gap between substrates and gas injection (an option that gives additional points in the tender).

1.8. Reaction chamber and gas injection system design ensuring laminar flow over the substrate.

1.9. Gas distribution system ensuring uniform supply of process gases over the entire surface of a 4-inch substrate to maintain the high uniformity of layer growth, measured as the guaranteed growth of a 2D structure over the whole substrate.

1.10. At least 5 optical ports to monitor the actual surface temperature of substrates and other parameters.

1.11. Substrate rotation system with a regulated speed of at least 100 rpm.

1.12. The design of the internal reaction chamber preventing deposition of materials on the chamber walls, allowing it to be easily removed for cleaning.

2. Glovebox:

2.1. With direct access to the reaction chamber.

2.2. Allowing to work in argon atmosphere.

2.3. With a regenerable deoxidation and gas drying column in the chamber with an integrated hydrogen leak detector.

2.4. A load lock equipped with a vacuum pumping system allowing loading the substrates and reactor parts from the ambient environment to the glovebox in high-purity conditions.

2.5. Oxygen and humidity sensors.

2.6. Vacuum tweezers and a vacuum cleaner for dusting the graphite susceptor and the glovebox.

3. Process gas supply system:

3.1. Gas pipework made of electropolished 316L stainless steel, orbitally welded with VCR/ Swagelok connections, with a purity required for ultra-high purity gases (UHP).

3.2. Integrated gas system allowing the use of at least 10 organometallic sources and at least 10 lines of other gases (an option that gives additional points in the tender).

3.3. Cooling/heating thermostats for organometallic sources.

3.4. Gas system allowing to install hydrogen and nitrogen purifiers inside the system.

3.5. Digital mass flow and pressure controllers with metal seals.

3.6. Possibility to maintain the constant total flow through the reactor despite the changes in reactant gas flows.

3.7. Gas system for safe replacement of organometallic bubblers and checking the tightness of connections.

3.8. Ability to measure the concentration of organometallic gases in the carrier gas with an automatic feedback loop connected to the gas flow control system.

3.9. Possibility to install line heating with maximum temperature 60-80 ˚C or higher on all organometallic lines to reduce pre-reactions.

3.10. Possibility to install an additional heater up to 120 ˚C on a selected organometallic line.

3.11. Gas lines to in-situ dilute the gas content in the carrier stream for gases and organometallic sources.

3.12. A system that guarantees the stability of gas flow in the reactor and protects against unfavourable pressure changes when switching on and off individual reactants. A gas system that guarantees a minimal gas inertia of the reactor, understood as a delay in relation to the opening of the gas flow valve to the reaction chamber.

3.13. Required active organometallic lines during device start-up:

3.13.1. $W(CO)_6$

3.13.2. $Mo(CO)_6$

3.13.3. $C_8H_{18}S$ (DTBS)

3.13.4. $C_6H_{14}Se$ (DIPSe)

3.13.5. $C_6H_{14}Te$ (DIPTe)

3.14. In-situ gas concentration dilution line required during start-up:

3.14.1. $B_3N_3H_6$

3.15. Reaction gas line required during start-up:

3.15.1. CH_4

3.16. Carrier gas lines required during start-up:

3.16.1. Ar

3.16.2. H_2

3.16.3. N_2

4. A real-time characterization system:

4.1. Real-time substrate temperature mapping system with automatic temperature control using thermal feedback.

4.2. An option to add a real-time substrate bow monitoring system.

4.3. An in-situ reflectance measurement system.

5. Vacuum system:

5.1. Dry vacuum pump with a butterfly valve and a pressure regulator that allows controlling the pressure in the reactor in the range of not less than 50-900 mbar under conditions of typical flow of process gases during the growth process.

6. Post-reaction gas outlet system equipped with:

6.1. Particle filter with pores not larger than 6 μm.

6.2. Differential pressure sensors informing about the degree of filter wear.

6.3. Check and relief valves protecting against excessive pressure increase in the reactor.

7. Computer control system with computer and control software:

7.1. Control by a PC computer with the Windows 7, 10 or 11 operating system and the control software, integrated as part of the system, enabling at least:

7.1.1. Monitoring and control of the vacuum system and pressure in the process chamber;

7.1.2. Control of process gas flow, pressure in metal-organic bubblers, temperature, and graphite heater rotation;

7.1.3. Data registration and storage;

7.1.4. Ability to analyse recorded data in the control software;

7.1.5. Storage of system logs, including data entered by the user;

7.1.6. System interlocks status display and diagnostics;

7.1.7. At least three user access levels (password protected);

7.2. Control both in manual and automatic mode enabling at least:

7.2.1. Defining recipes, including multi-stage recipes;

7.2.2. Ability to keep at least 10,000 multi-step recipes;

7.2.3. Optionally the ability to determine the deposition rate, layer thickness, and the actual surface temperature of the substrate.

8. Additional requirements:

8.1. System supplied with a basic set of consumables that includes at least: a pair of spare glovebox gloves, an additional susceptor, a set of filter elements for filter maintenance, and a set of tools required for reactor setup.

8.2. Electronic manual in English.

9. Safety and certificates:
   9.1. The system must be CE certified.
   9.2. The system must have an emergency off button (EMO).
   9.3. The system must be equipped with a detailed security system, audible and light alarms, and interlocks to protect users and equipment; interlocks system for cooling water (flow sensors), chamber, and vacuum to protect users and the system.
   9.4. The system must have a safe mode and enter it in the event of a power failure or in the absence of the remaining utilities necessary for the operation of the system and in the event of any threat detected by the control software. The system must be designed so that it can be quickly restored to operation after the failure has ceased. The safe mode is turned on when the alarm thresholds are exceeded, or a signal from the gas detection system, a signal from the Fire Alarm System, or an exhaust fan failure signal are received.

10. Warranty and other requirements:
   10.1. The Ordering Authority requires the proof that the system is fully functional in the form of delivery of 2-inch sapphire wafers with at least 95% coverage of thin (<10 nm): graphene, hexagonal boron nitride, and molybdenum or tungsten disulfide, or vertical heterostructures of these materials. The Ordering Authority will characterize the wafers using Raman spectroscopy to confirm the presence of characteristic Raman peaks of the grown materials (graphene: ~1580 and ~2700 cm^{-1}, hBN: ~1370 cm^{-1}, MoS_2: ~385 and 405 cm^{-1}, WS_2: ~355 cm^{-1}).
   10.2. The Contractor shall assemble the subject of the order, including levelling and connecting the main elements of the platform, start-up of the subject of the order, calibration, installation of the appropriate software, and test growth processes demonstrating the full functionality of the delivered subject of the order. The test growth processes will provide the initial growth conditions for the growth: graphene, hexagonal boron nitride, molybdenum disulfide, and tungsten disulfide.
   10.3. After carrying out the assembly described in 10.2, the Contractor will conduct training on the operation and maintenance of the subject of the order for min. 4 persons indicated by the Ordering Authority and will provide training materials in printed or electronic form.

10.4. The Ordering Authority also requires the Contractor to provide post-training support in the field of operation, use, and servicing of equipment provided by e-mail or telephone for a minimum period of 3 years from the date of completion of the training.

10.5. The Contractor undertakes to provide a minimum 12-month guarantee for the delivered subject of the order. Under warranty, the Contractor is obliged to:

10.5.1. Provide service in English;

10.5.2. Service response time: max. 24 hours from reporting the need for service to acting by the service;

10.5.3. Delivery of a set of basic elements and service tools together with the subject of the order.

10.6. The scope of the subject of the order includes:

10.6.1. The delivery of brand-new goods;

10.6.2. Assembled from brand new parts and unused;

10.6.3. In manufacturer's packaging;

10.6.4. Free from material and legal defects;

10.6.5. With the required approvals for use;

10.6.6. Unused;

10.6.7. Meeting the requirements of occupational health and safety regulations;

10.6.8. Be complete, that is, should be supplied with all the materials and accessories necessary to start it up and work as intended;

10.6.9. Come from the official distribution channel in accordance with the requirements of their respective manufacturers.