Imperial College London

CVD REACTORS - RISK ASSESSMENT AND STANDARD OPERATING PROCEDURE

1. PERSON CARRYING OUT ASSESSMENT					
Name	Dr. Andreas Kafizas	**Position**	Senior Lecturer	**Date**	27/02/2023

2. DESCRIPTION OF ACTIVITY (include storage, transport and disposal if relevant)

Setup, use of and deconstruction of a combinatorial atmospheric pressure chemical vapour deposition apparatus (cAPCVD) for flow chemistry and the growth of thin-films with controlled inhomogeneity in composition and thickness, comprising of:

- Cartridge heater with firebox, 2x thermocouples, a carbon rod, and a quartz tube.
- 3x stainless steel tubing that is suitable and safe at the required operating temperature and pressure. Heating wraps are close to the pipeline and are used to heat the pipeline to not higher than 200 degrees Celsius.
- 2x each contain four Tempatron temperature control boxes, including 4 relays and independent power supply, which can provide stable heating for the heating wrap and stainless-steel metal pipe, and ensure that the maximum temperature does not exceed the specified temperature.
- Raspberry Pi configured as a Proportional Integral Derivative (PID) controller and 4 power relays housed in a dedicated enclosure to control power to the cartridge heater

General operation [Details in section 7]:

- Precursor loading
- Piping, cartridge heater heating and cooling
- Cleaning and post-treatment

3. LOCATION					
Campus	White City	**Building**	MSRH	**Room**	402, FC L417

4. HAZARD SUMMARY			
Accessibility	FC L417	**Mechanical**	n/a
Manual Handling	n/a	**Hazardous Substances**	Chemicals and gases used are covered by separate COSHH assessments for each reaction.
Electrical	Mains power	**Noise**	n/a
Working at height	n/a	**Extreme temperature**	Not extreme, but up to 600 ^{o}C.
Falling objects	n/a	**Pressure/steam**	All reactions conducted at atmospheric pressure.
Trip hazards	n/a	**Other**	Use of glassware
Lone Working Permitted?	**Yes** ☐ **No** ☒	**Permit-to-Work required for planned maintenance?**	**Yes** ☐ **No** ☒ **N/A** ☐

5. Who might be harmed and how?			
Staff / students ☒		**Cleaners, engineers etc** ☐	
Support staff ☐		**Other**	

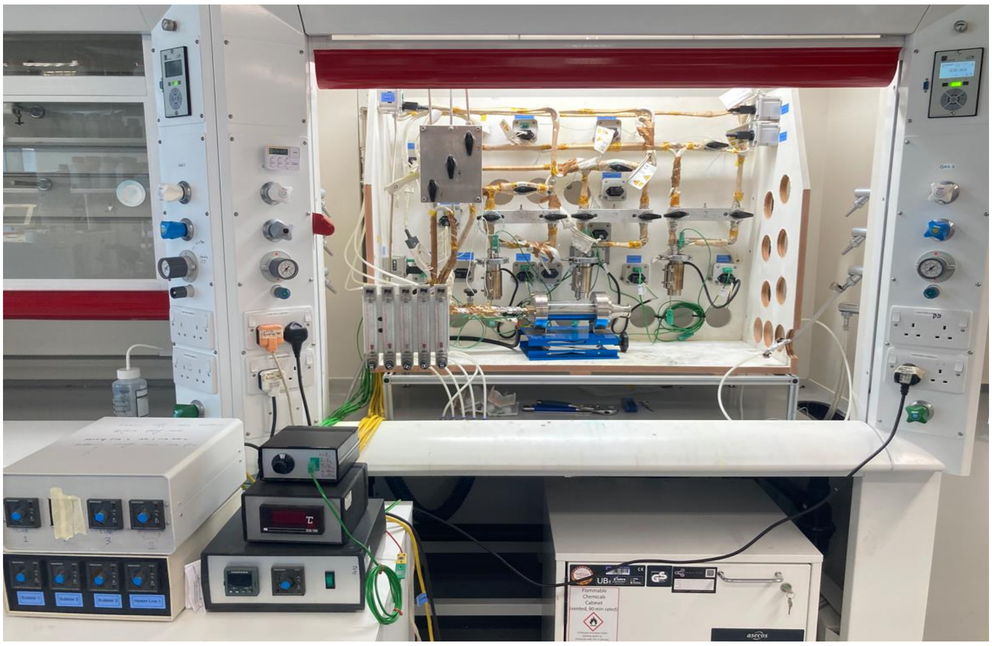
6. How often is the process being carried out?

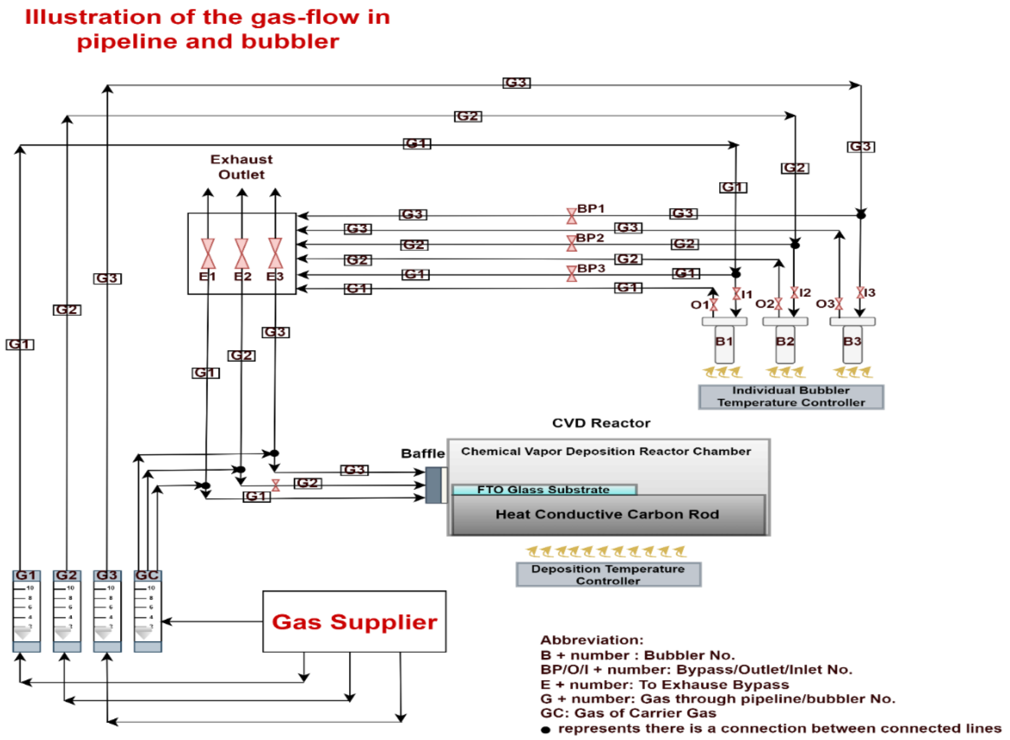
Once a day ☒ Once a week ☐ Once a month ☐ Every 6 months ☐ Annually ☐

Other – give details

7. Brief description of the procedure	Existing precautions (Controls)	Is risk high, medium or low?

General overview





The combinatorial atmospheric pressure chemical vapour deposition (cAPCVD) apparatus is a specialised piece of equipment that can be used to create inhomogeneous thin film coatings, with varying thickness and composition across the surface of the substrate. This facilitates the growth of a library of different materials in a single deposition, which can then be studied using high-throughput analytical methods, and therefore increase the speed in which thin film materials can be discovered and optimised for a specific purpose.

This system is in fume hood FC L417 on the 4th floor. It has a CVD reactor, with the capacity to hold substrates ~6 x 14 cm in area (and typically up to ~0.5 cm thick), that can operate at temperatures up to 600 °C. It has 3 discrete bubblers with pipework that can direct precursors from these bubblers to 3 discrete locations at the baffle manifold before entering the reactor. Each bubbler can be operated at a temperature of up to ~360 °C. The pipework that

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<td colspan="2">connects these bubblers to the baffle are heated with heating wrap and can be operated at temperatures of up to ~200 °C. Only a single type of carrier gas, currently either air or dinitrogen, can be used in this system.

Given the complexity of this equipment, only experienced CVD users can be trained to operate this equipment. This equipment CANNOT be used by master’s level students unsupervised.</td>
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Temperature control box

front side of heating line temperature control box and bubbler temperature control box

back side of heating line temperature control box and bubbler temperature control box

Insides of electric connections of heating line temperature control box and bubbler temperature control box

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The TC4800 temperature controller, which features a thermocouple input, enables microvolt measurements of sensor voltage changes and real-time feedback of detected temperatures to the supply box. Upon connection to a power source, a red LED illuminates, while activation of the relay prompts the green LED to light up and for heating to occur. In this setup, a series of temperature controllers have been be employed to control the heating of pipelines 1, 2, and 3, as well as bubblers 1, 2, and 3, respectively.

NOTE: THE BUBBLERS HEAT VERY QUICKLY, SO THE BUBBLER TEMPERATURE AT THE CONTROLLER SHOULD BE INCREASED IN SMALL ~10 °C INCREMENTS AND WAITING FOR THIS TO STABILISE BEFORE FURTHER INCREASES. THIS IS TO AVOID OVER-HEATING THE PRECURSOR AND POTENTIALLY DECOMPOSING IT AND/ OR CAUSING OVER-PRESSURE INSIDE THE BUBBLER AND THE SAFETY VALVE TO BLOW AND PRECURSOR TO EJECT FROM THE BUBBLER.

In the event of a Eurotherm controller malfunction, the Tempatron controller establishes a maximum temperature limit for the reactor. As a safety measure, the temperature control box ceases to supply any heating if either thermocouple fails, which is an automated process.

The temperature control box operates on a 230V input voltage, with the electrical components inside the control box being grounded to the metal sides of the box. The temperature controllers regulate circuit connection and disconnection via relays, with each unit equipped with a separate fuse to prevent short circuits.

The charger lines, indicated by the yellow wires on the backside of the control box, are controlled by the corresponding Tempatron at the front of the box, with voltage outputs being connected to labelled sockets in the cAPCVD box to heat the corresponding pipelines and bubblers, which will be discussed in more detail in the following sections.

It is crucial that the internal pin connections of the TC4800 temperature controller match the circuit input to avoid component damage or burning. Additionally, proper alignment of the thermocouple's positive and negative poles with the respective poles inside the temperature control box is imperative. Otherwise, the temperature may continue to rise until it reaches the maximum temperature limit, which is approximately 200 °C for the heating line temperature control box and 360 °C for the bubbler temperature control box.

NOTE: USERS SHOULD BE SURE TO PLUG THE CARTRIDGE HEATER INTO THE TEMPERATURE CONTROL BOX [BACK SIDE – LEFT SOCKET], AND NEVER DIRECTLY INTO THE MAINS.

USERS SHOULD NOT PLUG/UNPLUG ANY CABLES WHEN ANY TEMPERATURE CONTROL BOX IS ON!!!

NO MODIFICATION IS PERMITTED WITHOUT CONSULTING THE ELECTRICAL SAFETY OFFICER PRIOR TO COMMENCING WORK.

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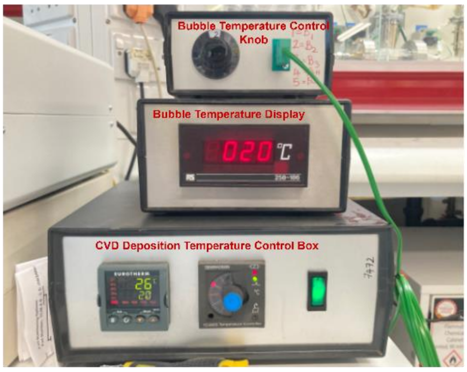
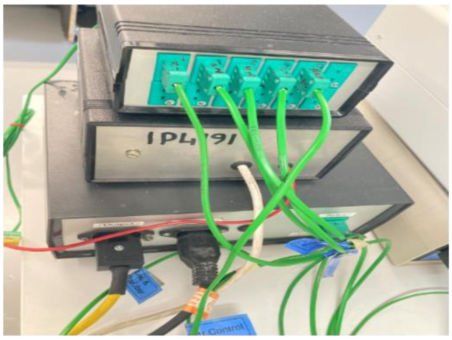


Front side of bubbler temperature display and CVD deposition temperature control box



Back side of bubbler temperature display and CVD reactor temperature control box.

<u>Setting the temperature control box</u>

level setting code

set-point high set-point 1

heating rate maximum power

The bubbler temperatures can be precisely determined by the three additional plug-in K-type thermocouples inside the bubbler. The temperatures of bubblers can be read on the display panel of monitor by turning the knob of monitor until the bubbler number is corresponding to where it needs to be (*i.e.* 1 = bubbler 1, 2 = bubbler 2, etc.). On the CVD reactor deposition temperature control box, the temperature of the CVD reactor can be directly read using EUROTHERM panel. Experiments should be commenced only once all heating lines, bubblers and reactor have reached a stable temperature that matches the settings on the controller.

The CVD deposition temperature control box contains a Eurotherm proportional–integral–derivative (PID) temperature controller (model 3216) to control the temperature inside the reactor. It applies electrical power to a cartridge heater, housed inside a carbon block, inside the reactor (see the next section on the reactor for more details). The Eurotherm controller monitors the temperature via k-type thermocouples. One thermocouple is connected to the Eurotherm controller, another is connected to a Tempatron temperature control unit. The temperature control box's Eurotherm controller, which can be programmed, allows the user to regulate the reactor's ramping rate by following operations:

1. Users hold the bottom left button [ ] until the level options show, and then cycle using the second from left button [ ] to reach level 2. The Eurotherm will ask for a code number, use the up/ down buttons to select CODE 2.
2. cycle to the option SPHI [set-point high], and select the maximum permissible temperature by press up and down button. You cannot set a set-point temperature that is higher than the maximum permissible temperature.
3. Continue to press the second from left button [ ] to set the ramping rate by using the SP.RAT option [heating rate]. In the example shown, the reactor has been set to heat at a rate of 9 °C per minute. Do not set the ramping rate too high to above 15 °C/ MIN to prevent your glass substrates from crack.
4. Continue to press the second from left button [ ] to set the the maximum output of the cartridge heater can be controlled during this programme using the OP.HI function. In the example shown, 80 % has been selected, which limits the heating output of the cartridge heater to 80 % of its maximum power (750 W).
5. To start the procedure, hold the up and down buttons together. You can then use the up/ down buttons to select one of three options: (i) AUTO, (ii) OFF or (iii) MANUAL. Select the option AUTO to run the programme detailed above. Select the OFF option to turn the reactor off. Do not use the manual option.

NOTE: THE REACTOR WILL NOT HEAT IF THE TEMPATRON SAFETY CONTROLLER IS SET TO A TEMPERATURE LOWER THAN THE TEMPERATURE SET ON THE EUROTHERM. THIS SERVES AS A SAFETY HEATING LIMIT ON THE REACTOR.

You can also use the Tempatron with the knob to set the maximum temperature the CVD reactor can reach for protection, if the temperature goes above this, power to the Eurotherm will be cut off and the reactor will stop heating until the temperature goes below this value again.

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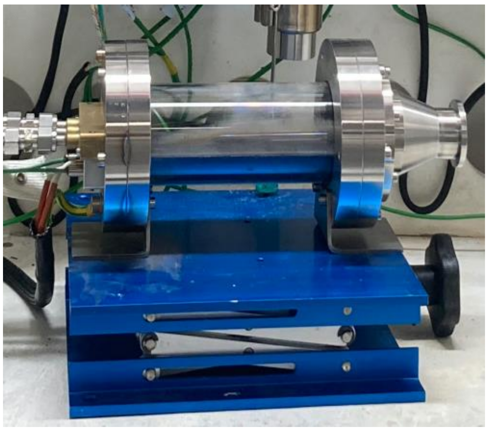
<u>Reactor</u>



CVD reactor side on view

CVD reactor disassembled and carbon block removed

Inside the baffle manifold (perforated steel plates, etc.)

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The chemical vapour deposition reactor consists of two metal flanges, separated by a quartz tube [reactor]. O-rings are placed between each set of metal flanges to achieve a gas tight seal. Screws are used to hold the metal flanges in place, which can be tightened using the appropriate alum key.

A hemi-cylindrical graphite carbon block sits inside the quartz tube. This carbon block has a cartridge heater inserted in its core, and two k-type thermocouples placed either side of the cartridge. The carbon block is the bed where reactions take place, on substrates that are placed on top of this flat, heated surface (such as FTO coated glass, barrier glass and metal plates *e.g.* Ti or steel).

The CVD reactor is on a raised lab jack stack. This has a two-fold purpose: (i) to avoid encountering any accidental solvent spills and (ii) to adjust the height for connections to the gas stream, which carriers the precursors into the reactor via the baffle manifold.

NOTE: THE FUSED CONNECTION OF THE STEEL TO BRASS BAFFLE IS OF MODERATE STRENGTH. DO NOT RAISE OR LOWER THE LAB JACK WITHOUT DUE CONSIDERATION OF PROTECTING THIS CONNECTION FROM BREAKING.

The baffle is directly connect to the reactor at the end of the precursor pipeline. The distribution of the precursors in the reactor can be controlled by use of a perforated steel plate, with a range of plates being available for use (NOTE: the distribution of precursors in the reactor can also be controlled by the gas flow rate and bubbler temperature).

The cartridge heater (750 W, Firerod), and two k-type thermocouples, are connected to the temperature control unit (see above section for more details). Given the power of the cartridge heater, the reactor cannot reach above 600 °C.

The ground wire of the fire rod is located directly below the inserted location of the fire rod and is firmly connected to the metal shell through a screw to shield static electricity. Be sure to check the integrity and looseness of this screw before starting the experiment. The connection between the fire rod and its wire is very fragile and bending of the wire should be avoided to prevent breakage.

Each thermocouple is held in place by a grub screw, allowing for easy replacement of a faulty thermocouple.

Each wire is individually insulated within silicon casing. The earth wire is connected to the extended metal piping by a crimped metallic clip [reactor – bottom view of front flange].

THE INTEGRITY OF THE BRAIDED CASING WILL BE REGULARLY ASSESSED. IF ANY WIRING BECOMES EXPOSED, THE BRAIDING MUST BE REPLACED BEFORE THE UNIT IS USED.

THE REACTOR CANNOT BE USED OUTSIDE OF THE FUMEHOOD. WHEN THE REACTOR IS IN OPERATION, THE “CAUTION! HOT SURFACE” SIGN SHOULD BE POSTED ON THE FUMEHOOD SASH TO WARN OTHERS THAT THE REACTOR IS HOT AND A POTENTIAL ELECTRICAL HAZARD. THE FUMEHOOD SASH MUST BE KEPT LOW WHEN THE REACTOR IS IN OPERATION.

NO ADDITIONAL EXPERIMENTS MAY BE PERFORMED IN THE FUMEHOOD, AS THE USE OF SOLVENTS MAY RESULT IN AUTO-IGNITION FIRES. THIS FUMEHOOD

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<tr><td></td><td>IS DESIGNATED FOR THE SOLE PURPOSE OF CHEMICAL VAPOUR DEPOSITION CHEMISTRY.</td><td></td></tr>
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<u>Bubbler Filling</u>

Bubbler loading in air

Bubbler Injection with N_2 Protection

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When loading a bubbler with a precursor that reacts with air, it is important to exercise caution and follow the recommended procedures. In such cases, it is a requirement to fill the bubbler under a flow of nitrogen to prevent any reaction with air. This can be achieved by flowing nitrogen through the bubbler pipeline and opening the valves in the following order (outlet - inlet - bypass). Once the bubbler is under nitrogen flow, the precursor can be injected into the bubbler through the safety blow valve. Before extracting the precursor with your syringe, we recommend pumping the syringe under the nitrogen atmosphere first. However, if the precursor is stable in air, it can be filled in the open air without any issues.

It is crucial to pay attention to the characteristic of the safety valve used in releasing at a moderate pressure. Typically, the pressure is estimated at around 3 bar, and it is essential to avoid heating the precursor close to its boiling point. When heated to a temperature close to the boiling point, there is a sudden increase in pressure, leading to popping of the safety valve and the likely ejection of your liquid precursor through the safety valve hole.

As an example, TTIP has a boiling point of 232°C, and when heated to 207°C, the vapor pressure will reach 1530 mmHg, approximately 2 bar. Considering the pressure of nitrogen/air inside the bubbler (1 bar), the total pressure will reach 3 bar, leading to the safety valve popping and the precursor shooting out.

THIS FEATURE IS ADDED TO PREVENT THE BUBBLER FROM EXPLODING, AND IT IS A REQUIREMENT THAT USERS CHECK THE VP CURVE AND AVOID PRESSURES CLOSE TO THE RATED PRESSURE OF THE VALVE.

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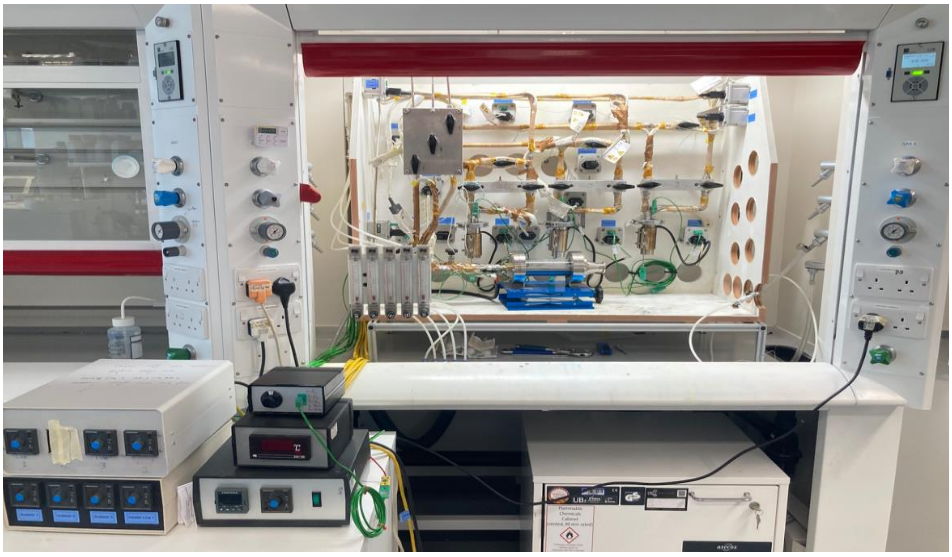
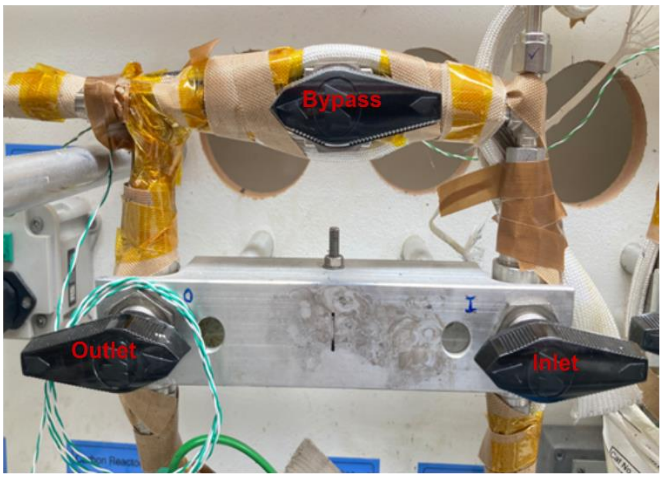
General operation





Bubbler (Left)/ and Valves (Right)

Standard Operation of apparatus (note, a video of the general operation will be made available here)

1. All users should be trained by a competent user before starting. They should be at PhD level or above if operating the device independently. Master's level students should be supervised at all times by a competent user of PhD level or above.
2. Prior to conducting the experiment, it is important for the user to possess a comprehensive understanding of the precursor's boiling point, vapor pressure curve, and other pertinent information. The user should design the experiment so that they have knowledge of the expected mass flows of each precursor based on their vapour pressure (at a given temperature) and flow rates using appropriate equations. At the outset of the experiment, an appropriate amount of different reaction precursors should be loaded into the corresponding bubbler, while ensuring that the load does not exceed 1/3 of the bubbler's capacity, and that the temperature of operation does not result in a pressure that exceeds the rating of the safety valve (see the bubbler section for more details). All reactions should be written up within a COSHH form and review by Dr. Kafizas before starting the work.
3. In the experiment, gas flow is introduced into the pipeline through the gas control valve located on the right side of the fume hood (air or dinitrogen can be used, depending on where the pipe has been connected to). The flow is regulated by four flow rate meters to control the total system flow rate and each separated gas flow. The resting state of the exhaust valves should be pointing in the up position (pushing precursors up into the FC if the bubblers are opened).
4. Correct installation of the CVD deposition reactor is necessary. Prior to heating, one should ensure that the thermocouple and cartridge heater are securely attached to the reactor, that the cartridge heater is secured in the heating block, and that the ground wire is connected to the heating block. All cables must be connected to the temperature control box in the appropriate location. To prevent contact with the reactor, all wiring and cables should be checked before heating the reactor via the temperature chamber. The set point temperature and Tempatron safety limiter should be inspected to ensure that they are suitable for the reaction. When the reactor is not being heated, the six screws at the front flange can be removed using the appropriate key to insert and load the sample.
5. Turn on all temperature control boxes, set the pipeline temperature, bubbler temperature and CVD deposition temperature to the corresponding target temperature. Note that when only Tempatron is used as the heating part, the feedback device of the system may not be very timely, which will cause the corresponding temperature to continuing rise after the heating control is even turned off (it will not exceed the maximum limit temperature for protection), so manual operation is required. Control the heating rate, see the above section [Temperature control box] for details. Use the bubbler temperature display knob to observe the temperatures inside bubblers meanwhile to avoid overheating.
6. When your reactor reaches required temperature, open the Outlet, Inlet, and close the Bypass above each bubbler successively. When all the bubblers that participating in the reaction have completed this step, turn three Exhaust Bypasses to where they are in the direction of To-Reactor [arrow to down].
7. After the deposition, turn the direction of three Exhaust Bypasses successively so that they are in the direction of To-Exhaust [arrow to up]. Open the Bypass and close the inlet and outlet above each participating bubbler in sequence.
8. You can switch off the heating of the reactor via the temperature control box by first closing the program and then setting the Eurotherm to off mode (see section Setting the temperature control box for more information). The Tempatron controllers on all temperature chambers were then turned below zero to ensure that no further heat was being applied to the reactor.
9. Check that the reactor is cool (i.e. around room temperature) before handling it (you can do this by turning on the temperature control, which will give you a temperature reading). If the reactor is cold enough (i.e., load the substrate into the reactor from the exhaust end (you can do this by unscrewing the six screws from the flange on the back of the reactor). Remove the sample, replace the sample, and the last experiment operator should clean all non-electrical components [Section. Cleaning and maintenance].

NOTE:

EACH DEPOSITION REACTION MUST HAVE AN ASSOCIATED COSHH FORM. THERE IS NO RISK OF FIRE IF THE PROCEDURES OUTLINED ABOVE ARE STRICKTLY ADHERED TO. IN THE RESULT OF A FIRE, TURN OFF ALL ELECTRICAL EQUIPMENT FROM WALL PLUG, TURN OFF ALL GAS FLOW FROM AND CLOSE THE FUMEHOOD SASH. IF ADEQUATELY TRAINED, TACKLE THE FIRE USING THE APPROPRIATE EXTINGUISHER (LOCATED OUTSIDE OF THE LAB, TO THE LEFT IN THE CORRIDOR). SOLVENTS MUST NOT BE STORED INSIDE THE REACTOR TO AVOID THE SPREADING OF A POTENTIAL FIRE.

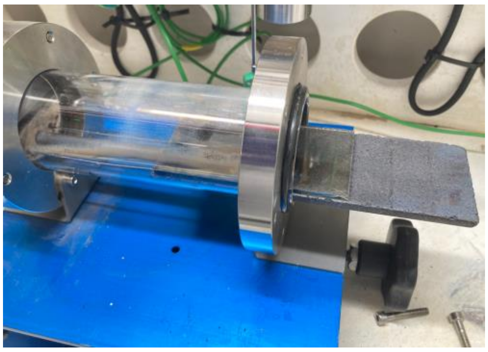
IN THE CASE THAT THE CENTRAL QUARTZ CYLINDER CRACKS, DUE TO POOR HANDLING, REPLACE IMMEDIATELY. THE USE OF A CRACKED QUARTZ CYLINDER IS NOT PERMITTED.

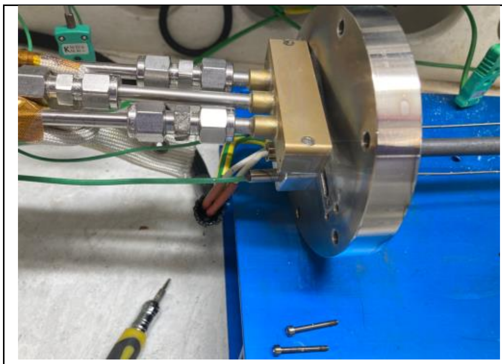
ENSURE THAT THE TEMPATRON CONTROLLER IS SET TO ZERO WHEN THE REACTOR IS NOT IN USE.

USERS SHOULD NOT PLUG/UNPLUG ANY CABLES WHEN ANY TEMPERATURE CONTROL BOX IS ON!!!!

Is risk high, medium or low?

Overall risk is low to medium. Highly toxic, volatile or explosive precursors are not permitted to be used on this apparatus.

Shut down	DO NOT SWITCH OFF THE TEMPERATURE CONTROL BOX. Instead, set the Eurotherm to the OFF setting, and allow the heating block to cool down naturally (see setting the temperature control box for more details). Heating can also be stopped by turning the Tempatron control temperature to below zero. This will automatically stop power being delivered to the cartridge heater. Keeping the temperature control box on will serve as a reminder that the heat block is hot while you are clearing up and serve as a warning to other lab users that the heater is hot. The reactor should be purged with carrier gas flow on cool-down, to ensure the complete release of all aerosols from the reactor. A trickle flow will suffice, to be economical.	low
Cleaning and maintenance  loading/ unloading precursors in bubbler  loading/ unloading samples  CVD Reactor disassemble and carbon block remove	With a hexagonal wrench or a flat-head screwdriver of the corresponding size, all screws can be unscrewed. After the experiment, make sure the reactor is completely cool (i.e., at room temperature), that the gas flow to the cylinder head is shut off, and that the electronics are disconnected from the plug before handling the reactor. Disconnect the cables from the temperature control box (cartridge heater and two thermocouples). Make sure that no gas is flowing into or out of the reactor. All the disassembly procedures need to be done in a fume hood. The users will unload and reload their substrates in between each deposition reaction [loading/ unloading samples]. The exhaust flange is the best access point for the reaction chamber (where the substrate is loaded) when loading or unloading samples. To load/unload their base board, the user should remove the exhaust flange by loosening the 6 external screws. NOTE: O-RINGS SHOULD BE REPLACED IF THEY ARE WORN BECAUSE THEY DEGRADE OVER TIME. THE O-RINGS IN THE SAFETY BLOW VALVES ON THE BUBBLER SHOULD ALSO BE REGULARLY CHECKED FOR DEFECTS AND REPLACED AS AND WHEN REQUIRED. After a typical CVD reaction, the reactor develops powdery deposits inside the quartz tubes, on the exhaust flange, and can block the baffle manifold due to the low deposition rate of CVD. The reactor flange, the interior of the quartz tube, and the deposits on the baffle manifold must therefore be cleaned after each chemical vapour deposition experiment. The baffle manifold can be removed by unscrewing the two front screws [Baffle Manifold - Separate]. The best way to clean the baffle manifold is to remove the bottom plate and remove the two screws [inside the baffle manifold] under the baffle. All non-electric reactor parts should be cleaned in two stages: (I) Quick wipe with damp BLUEROLL to remove most of the powdery deposits. Dirty blue rolls should be discarded in designated clinical bins (II) Clean more thoroughly with TEEPOL, sponge and tap water in the sink.	low



Baffle disassemble

Inside baffle manifold

replacing thermocouples

(III) Either oven-dried/ sufficiently air dried so that all water has evaporated before use.

For more stubborn parts can be sonicated in a sonic bath in a fume hood to avoid harmful vapours.

Carbon blocks can be removed by sliding the block out of the reactor [Remove Carbon Block]. Carbon blocks are brittle and can break easily and should be handled with care. Removing the carbon block reveals the cartridge heater and two thermocouples. During the deposition of the carbon block, material with similar thickness and material as deposition substrates should be used to cover the carbon block as much as possible to prevent the sediment from contaminating the carbon block. When replacing deposits, carbon rods should be replaced. Carbon rods need regular maintenance. A smooth sandpaper can be used to scrape off a thin layer of carbon from the surface, and then use rolls to wipe off the residual carbon. This should be done carefully so not to damage the integrity of the carbon block. Carbon blocks that have developed significant cracks due to handling/ use should not be used. They should be disposed of and replaced.

We also need to eliminate the unreacted samples inside the Bubbler. The remaining liquid can be taken out and poured into the corresponding waste liquid bucket. If the amount of remaining sample is small, we can discharge the unreacted material through the exhaust outlet.

Disassemble the bubbler [loading/unloading precursors in bubbler], wipe the wall inside the bubbler in the fume hood and place it in an appropriate waste bin for disposal, then clean the bubbler with water, ethanol, and isopropanol (ultrasonication required if the residue is stubborn).

A faulty thermocouple can be easily replaced by unscrewing the grub screw that holds it in place and accessing it from under the inlet flange [replacing a thermocouple]. Replacing a faulty fire rod is a more difficult process (as it involves removing the safety ground wire that is crimped to the extended metal support barrel). Since the connection between the fire rod and its wire is very fragile, we can ask more experienced electrical engineers to help us replace the fire rod.

Quartz tubes are fragile and can break easily and should be handled with extreme care. It's also a rolling hazard that could roll off the edge of the workbench and shatter. For this reason, all cleaning and maintenance work should be performed in a fume hood. Quartz tubes with any cracking faults should not be used. They should be disposed of in the glass recycling and replaced. They are a significant expense, so adequate care should be taken when handling it.

When switching to a different chemical system for combinatorial APCVD testing, it is necessary to clean both the bubbler and pipeline. It is important to note that all pipelines should use high-temperature (300°C)-tolerant tape and fibre. During the cleaning process, it is recommended to detach pipes in segments and use ultra-sonification with soap water and deionized water, scrubbing with soapy water, washing with copious water and then oven drying (~60 to 80 C) before re-attached.

	When dismantling the pipelines, it is important to take them apart in sections to prevent the pipelines from not being able to be reassembled to their working-state. NOTE: IF THE PIPES ARE FUMING WHEN DISASEMBLED DUE TO REACTION OF UNSPENT CHEMICALS, THEN THE PIPES SHOULD BE LEFT IN THE FUMEHOOD UNTIL THE FUMING STOPS BEFORE REMOVING AND CLEANING AT THE SINK. IF HEAVY/ DANGEROUS METALS ARE USED, WASHING SHOULD BE DISPOSED OF IN THE CORRECT MANNER.	

9. EMERGENCY ACTIONS

In case of skin contact: without contaminating other areas immediately wash contact area with copious water and rinse hands for c.a. 15 minutes. Report incident via SALUS within 24 hours.

In case of cut: run cut under warm water for 10 minutes to encourage bleeding (flushes the wound out rather than sealing the wound). Then, apply cold water for 15 minutes to stop bleeding. Seek first aid assistance. Report incident via SALUS within 24 hours.

In case of hazardous chemicals inhalation makes you feel unwell: stop all experiments, open the doors and windows, and find an appropriate and fresh air location. Report the chemical compound you inhaled to SALUS by noting its name and features. In an emergency case, call 999 immediately and proceed to the hospital for assistance.

In case of fire: Shut down all the electric equipment. Use fire alarm boxes to raise the fire alarm, and then, use CO_2 fire extinguisher to put out the flames if you were confidentially trained. Separate all the electrical equipment and close the lab door before leaving. Leave the area through the main entrance by stairs and find a fire officer.

10. Monitor and review

Controls should be monitored: daily ☒ weekly ☐ monthly ☐ 6 monthly ☐ annually ☐ other☐

I will review this risk assessment at least every 6 months ☐ every 12 months ☒

Immediately in the event of process / location change or incident or accident

11. Training record – use this section to record the names and date of any persons you are training in this risk assessment and associated procedures

Name	Date	Name	Date
Andreas Kafizas	2023/02/27		
Yuankai Li	2023/02/27		
Zhipeng Lin	2023/02/27		

Note: http://www3.imperial.ac.uk/safety/formsandchecklists/raforms1 for specific risk assessment forms and guidance
http://www3.imperial.ac.uk/safety/guidanceandadvice on gases, biological agents, chemicals, offsite work etc

Despite my recommendations for improvements to this design to make this unit safe for use in experiments, some of the changes I think necessary have not been included in the design, so the unit falls below the standard recommended by the HSE and IET.I therefore cannot pass this unit for use in its present condition.

However if the PI would like to write something to take full responsibility for any problems occurring with the use of this unit by the researchers then it can be released.