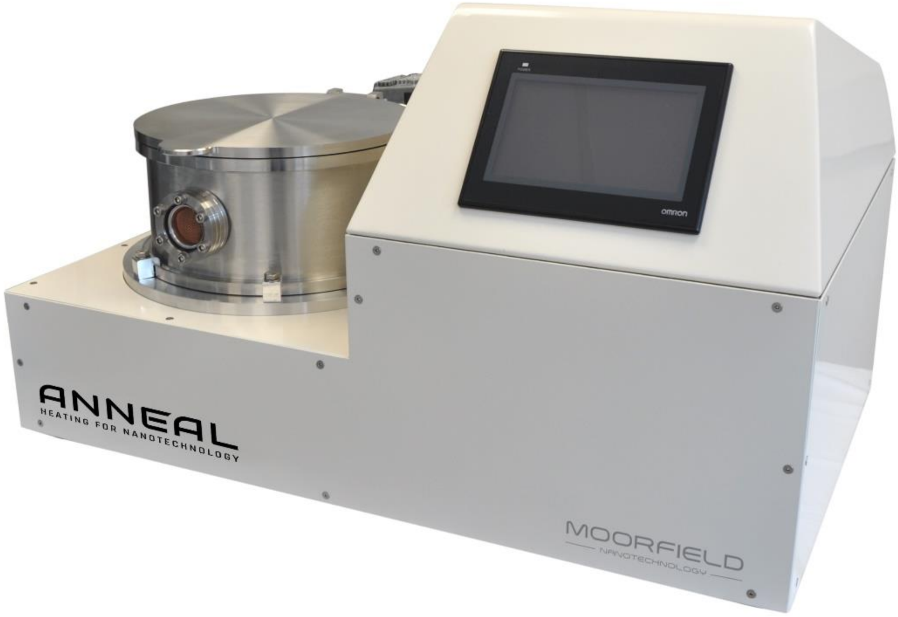
ANNEAL

HEATING FOR NANOTECHNOLOGY



Benchtop Substrate Annealing System

Installation/Operation Manual

MOORFIELD

NANOTECHNOLOGY

ANNEAL

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Table of Contents

Table of Acronyms

APC	Automatic pressure control
DC	Direct current
HMI	Human-machine interface
MFC	Mass flow controller
PSU	Power supply unit
RF	Radio frequency
RPM	Revolutions per minute
WRG	Wide-range gauge

1. Health and Safety

The ANNEAL system has been designed to account for user safety when operated as intended. The system is intended to be used with this manual as a guide. All users should read this manual fully prior to using the system. Where clarification is required, users should contact the manufacturer (see section 12 for contact details).

1.1 Safety Interlocks and Features

The system has the following safety interlocks and safety features:

- The system continuously monitors for adequate coolant flow of at least 1 L/min via a coolant flow switch mounted inside the unit.
- It is not possible to start the chamber pump routine unless the coolant flow switch indicates that there is adequate flow.
- It is not possible to switch on heating power until the chamber is in the pumped state (i.e., the chamber pressure has dropped below 5×10^{-5} mbar since the pump routine has been initialised leading to deactivation of the vacuum interlock) and without sufficient coolant flow as indicated by the coolant flow switch.
- If the flow switch indicates a decrease in coolant flow below the required level while the system is in the pumped state, then the heating power supply unit (PSU) and mass-flow controllers (MFCs) will be switched off and the chamber vent routine will be initiated.
- Should the system detect that the door is not closed after the chamber pump routine has been initiated (through a failure to reach the door vacuum setpoint level sufficiently quickly), then the chamber vent routine will be started.
- Should chamber pressure not decrease sufficiently quickly after the pumping system has been started, to the setpoint that indicates the chamber has reached the pumped state, the pumping system will be switched off and the vent routine will be initiated.
- Should the MFCs be unable to provide their setpoint flow rates, users will be presented with an error message.
- In case of a detected electronics error, the system will terminate any running process, and will initiate the chamber vent routine.
- The backing pump is fitted with a mesh guard on its inlet to catch any debris/substrate material originating from the chamber.
- Various locations of the system are fitted with earth connections.
- Upon power failure, the system is designed to terminate the heating PSU and all MFC gas flows and switch off the pumping system.
- Chamber external surfaces have temperature warning stickers to indicate when they are hot.

1.2 User Precautions

Users should always take the following precautions while the tool is being operated:

- Only the correct process gases should be connected to the unit. The process gas connections are labelled with the gases they are to be supplied with.

- The process gas supply pressures should always be set to 20–25 psi. Improper operation and/or damage to system hardware may result from process gas pressures outside this range.
- Only dry, particulate-free high-purity process gases should be connected to the unit. Impurities can produce undesirable results, may damage the system and may lead to unsafe operating conditions.
- No electrical or gas connections to the unit should be removed or tampered with while the system is switched on.
- Electrical and vacuum connections between the unit and the backing pump should not be disconnected while the pump is running.
- The system should not be used prior to correct installation, or in any situation where operating requirements are not being met (see Section 5).
- Users should not attempt to open the chamber while the pumping system is running and before it has been vented.
- The unit should only be placed on a flat, hard surface capable of securely supporting the system weight.
- The unit should be situated away from exposure to direct sunlight.
- Nothing should be placed on any side of the unit less than 20 cm away from its side panels.
- The unit has cooling air inlets and outlets on the base and rear. These vents should be kept clear.
- The system should never be moved while it is switched on.
- Users should ensure that substrates inserted into the system are compatible with process conditions to be employed, and carry out appropriate risk assessments, including consultation of corresponding material safety data sheets (MSDS), to identify possible dangers whenever new substrate types are inserted.
- Substrates should only be placed onto the designated substrate support area on the heating stage.
- Substrates larger than that for which the system is designed should never be placed within the chamber.
- Users should wear gloves when working with all internal chamber components, to avoid the introduction of contamination that can affect system performance and deposition results.
- System exhaust that emerges from the pump outlet must be vented appropriately (e.g., into an appropriately specified fumehood, and according to site-specific regulations). Failure to provide adequate venting could result in the creation of hazardous atmospheres depending on the substrate and deposition materials, and processes gases being employed.
- For periods of no use, the system should be isolated from its process gas supplies (but may be left switched on).
- Following any work that may result in contamination being introduced into process gas supplies (e.g., swapping a process gas cylinder), steps should be taken to ensure such contamination is adequately purged before any process is carried out.
- For any process that could generate hazardous material (e.g., fine floating particulates), always ensure adequate personal protective equipment is worn before opening the chamber.
- Users should always ensure that the chamber door is closed before starting the pump routine.

- Users should never attempt to switch on the heating PSU while the chamber is open or before the pump routine has finished and the system is in the pumped state.
- Never attempt to modify, reconfigure, repair or open the system without first consulting the manufacturer.
- Users should avoid contacting chamber external surfaces while the substrate heater is on and before they have cooled down to a safe temperature (<50 °C) after heating has been switched off. If in any doubt, use a thermocouple probe to check surface temperatures.
- Users should ensure that chamber internal hardware such as the substrate support stage has cooled to a safe temperature (< 50 °C) after heating has been switched off and before contact is made with any of these parts. If in any doubt, use a thermocouple probe to check component temperatures.
- Users should never touch any part or surfaces of the substrate heating stage assembly! They may be extremely hot! This may also apply to other in-chamber surfaces after substrate heating has been carried out. The current heater temperature can be accessed via the Manual Control screen of the touchscreen HMI (but note that some in-chamber surfaces may still be hotter than the temperature displayed).
- Users should never tamper with, modify or remove heat shielding. Otherwise system damage and unsafe internal and external surface temperatures could result.
- Users should not make any adjustments to pneumatic actuators while there is a chance they could be operated or without first disconnecting their service gas supply lines! Else, injury to users may result.

2. System Description

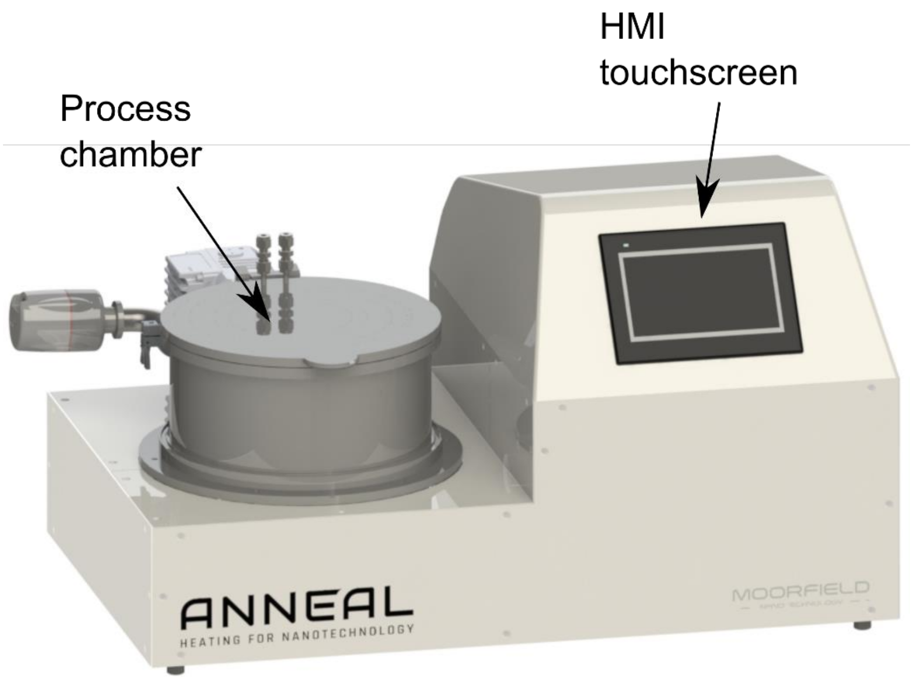
The following sections provide an introductory description to the ANNEAL system and its functionality.

Note that some sections are only relevant where the system has been fitted with corresponding modules.

2.1 Overview and Key Features

The ANNEAL is a compact substrate annealing system designed to provide for the thermal treatment of 2D material and wafer substrates under controlled atmospheres. Substrates up to 3 mm thick and 4”/100 mm diameter can be accommodated. Figures 1 (a) and (b) show the front and back of the main unit of the system (the backing pump is omitted).

(a)



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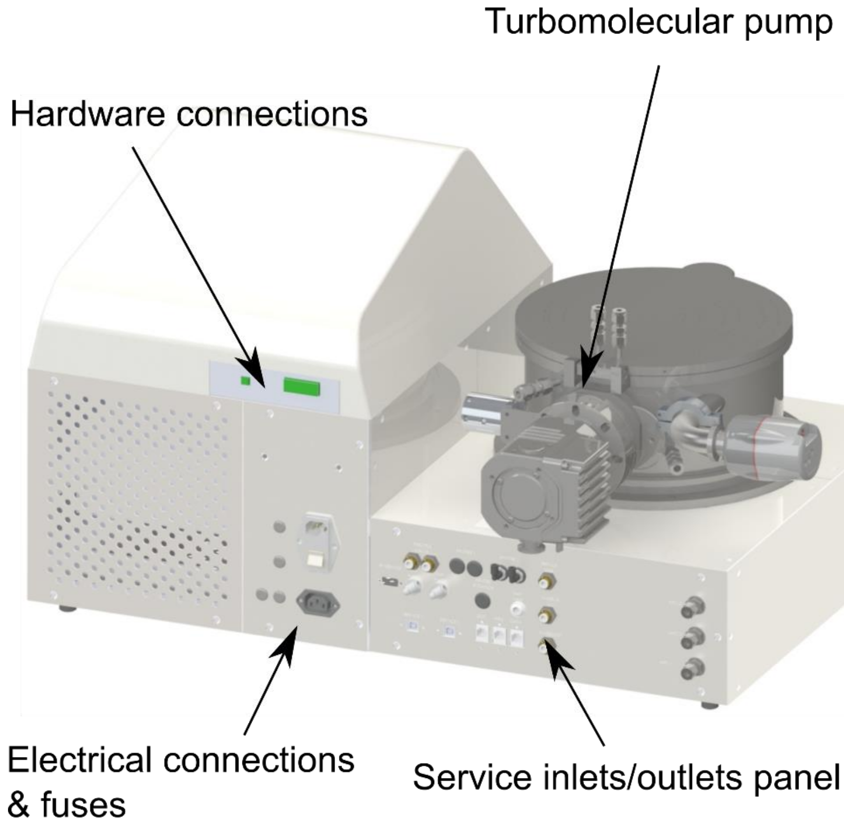


Figure 1: Overview of the ANNEAL main unit, from (a) front and (b) rear perspectives. Key features are indicated. Note that exact system appearance may change depending on configuration.

2.2 Interlocks

Each ANNEAL system is fitted with 3 primary interlocks:

1. Coolant: This interlock is active when the coolant flow rate through the system falls below 1 L/min. When active, the system prevents use of the heating PSU and shuts down the pumping system if it is in use (initiates the chamber vent routine).
2. Door: This interlock is active when the WRG chamber pressure is above that defined as the door interlock pressure setpoint (default 100 mbar). When active, this interlock prevents use of the heating PSU, and prevents processes from being run in automatic operation mode.
3. Vacuum: This interlock is active when the WRG chamber pressure has not fallen below 5×10^{-5} mbar after the chamber pump routine has been started. Key system hardware such as the heating PSU and processes in automatic operation mode cannot be started until this interlock has been deactivated.

2.3 Process Chamber

The system contains a cylindrical high-vacuum chamber that is fixed to a baseplate on which it sits. The baseplate contains four 1” ports. At the top of the chamber, there is a door that allows for access. This door is connected to the chamber by a hinge at the back.

The chamber baseplate ports are fitted with various components including the substrate heating stage and supporting feedthroughs, and process gas inlets. The chamber sidewall is fitted with ports for vacuum gauges and the pumping system. Exact port allocations depend on the system configuration selected (see Sections 3 and 4). Unused ports are fitted with blank feedthroughs that seal the chamber against the external atmosphere.

The process chamber may be fitted with coolant channels (required for systems fitted with 1000 °C heater stages).

2.4 Turbomolecular Pumping System

Note: This section is relevant for tools fitted with the turbomolecular pumping system.

The pumping system consists of a turbomolecular pump that sits directly on a port on the rear of the chamber. A backing pump is connected to the outlet of the turbomolecular pump by a flexible bellows.

For systems fitted with MFC process gas introduction, a pneumatically actuated two-position throttle valve is positioned inside the chamber immediately before the front face of the turbomolecular pump. This throttle valve is normally fully open to allow for maximum conductance between the turbomolecular pump and the chamber. However, it is closed to a fixed position whenever MFC process gas flows are in effect.

Figure 2 is a schematic of the ANNEAL turbomolecular-pumped vacuum system.

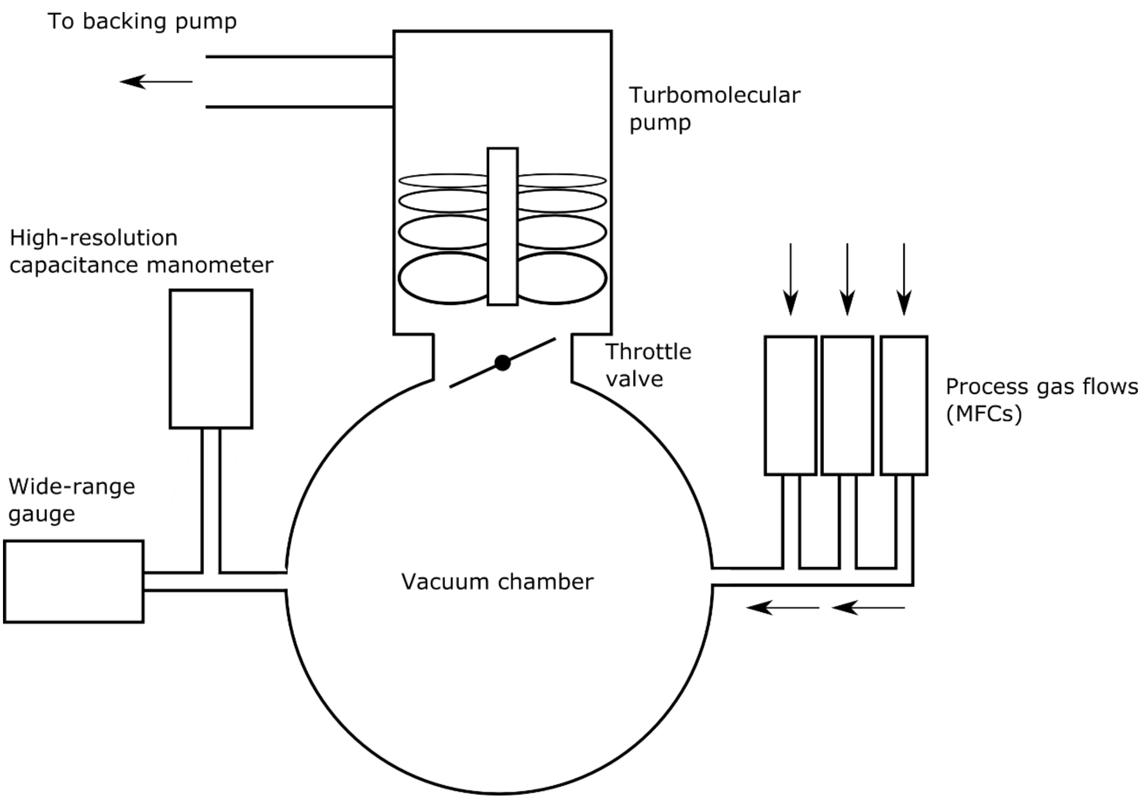


Figure 2: Schematic indicating the key features of the vacuum system of the ANNEAL unit. Note that the presence of some features such as the capacitance manometer, MFCs, throttle valve and TMP is subject to the specific configuration of the unit.

Further details regarding the pumping system are available in the pump-specific manuals supplied with the ANNEAL system.

2.5 Chamber Pressure Measurement

Every ANNEAL system contains a wide-range gauge (WRG) for measurement of chamber pressure. This is a mounted on a port on the chamber sidewall. The WRG is suitable for obtaining approximate pressure readings in the range 10^{-9} to 1000 mbar.

Optionally, the system may also be fitted with a high-resolution capacitance manometer. This will enable accurate measurement of chamber pressures during annealing processes.

2.6 Process Gas Control

Note: This section is relevant for tools fitted with MFCs for process gas introduction.

Process gases are introduced into the chamber through MFCs that connect to a manifold that terminates in a feedthrough that passes through the chamber baseplate. The system can be fitted with up to 3 MFCs that can be calibrated for a variety of different gases (check Sections

3 and 4 for details). For systems fitted with multiple MFCs users can operate a single or multiple MFCs as a process demands.

With process gas introduction, it is also possible to control the chamber pressure. (For systems with no MFCs, the chamber pressure is simply the pressure that the pumping system has been able to achieve considering the pumping time and outgassing from substrates and other internal chamber surfaces, etc.) Control of chamber pressure can be done in two different ways, depending on system configuration:

1. Flow-rate control. For this, the simplest method of pressure control, the user specifies MFC flow rates. When these are initiated, the ANNEAL system automatically closes the throttle valve between the chamber and the pumping system to a fixed, low conductance setting. This system state leads to a particular chamber pressure.
2. Automatic pressure control (APC). For this advanced control mode, the user defines a setpoint pressure and the system automatically controls the chamber pressure at that value by running a feedback loop between a pressure gauge (wide-range gauge, or capacitance manometer if this is fitted) and the MFC flow rates. For this latter mode, the system must be fitted with the automatic pressure control module.

2.7 Substrate Heating Stage (Quartz Lamp, 4”, 500 °C)

Note: This section is relevant for systems fitted with the quartz lamp heating stage for maximum substrate diameters and temperatures of 4” and 500 °C, respectively.

The substrate heating stage is mounted to the chamber baseplate, with power and thermocouple connections positioned on other feedthroughs to the side. Figure 3 is a model of the stage inside the chamber.

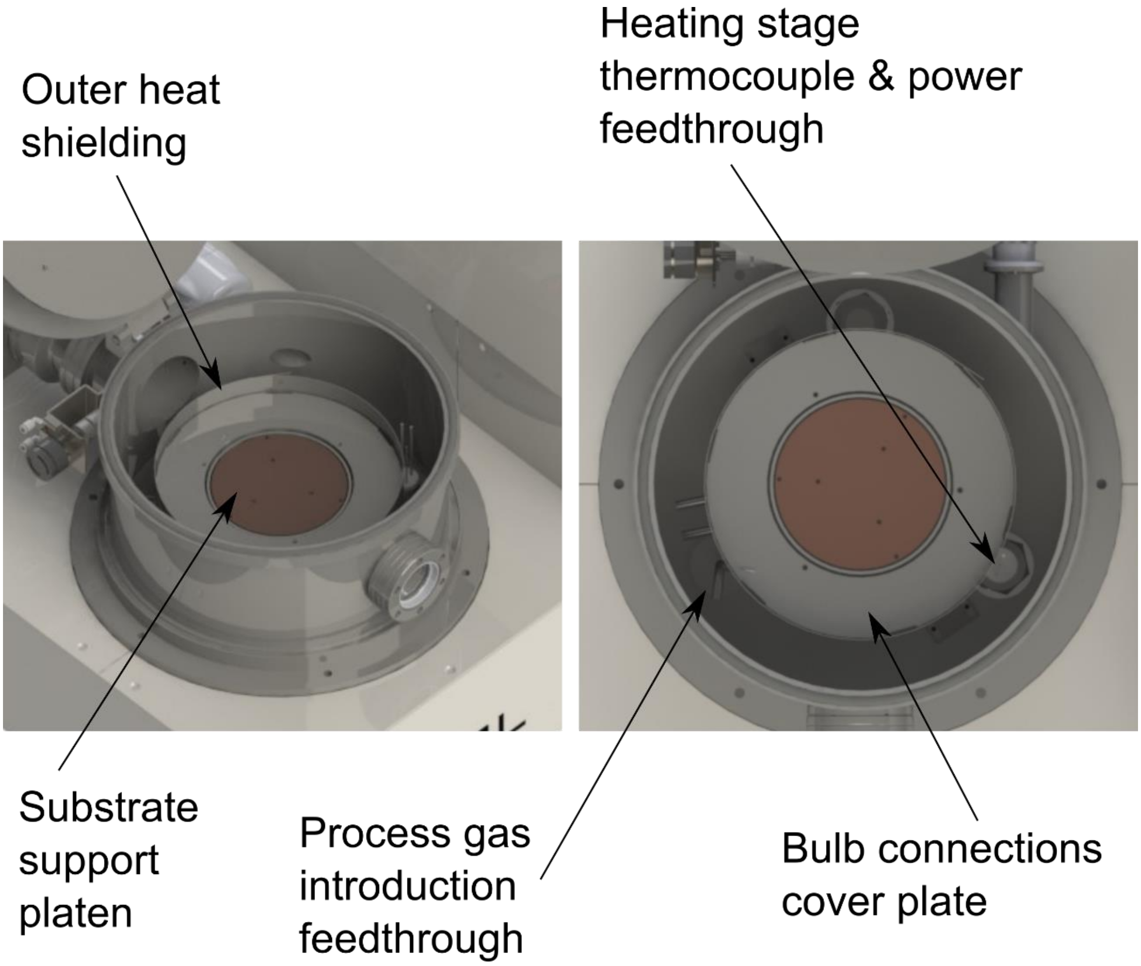


Figure 3: Model showing the quartz lamp substrate heating stage positioned on the baseplate inside the ANNEAL process chamber. Key features are labelled.

During operation, substrates are placed on the substrate platen (substrates should be located entirely within the platen area, as shown above). The platen is machined from copper for best heat conductivity and temperature uniformity. When heating is switched on, electrical power is supplied to the quartz lamp bulbs which then radiate infra-red to the back of the substrate platen (this is aided through reflections from the heat shielding below and to the sides of the bulb containment area). The IR radiation results in heating of the platen to high temperatures up to 500 °C (platen front-face).

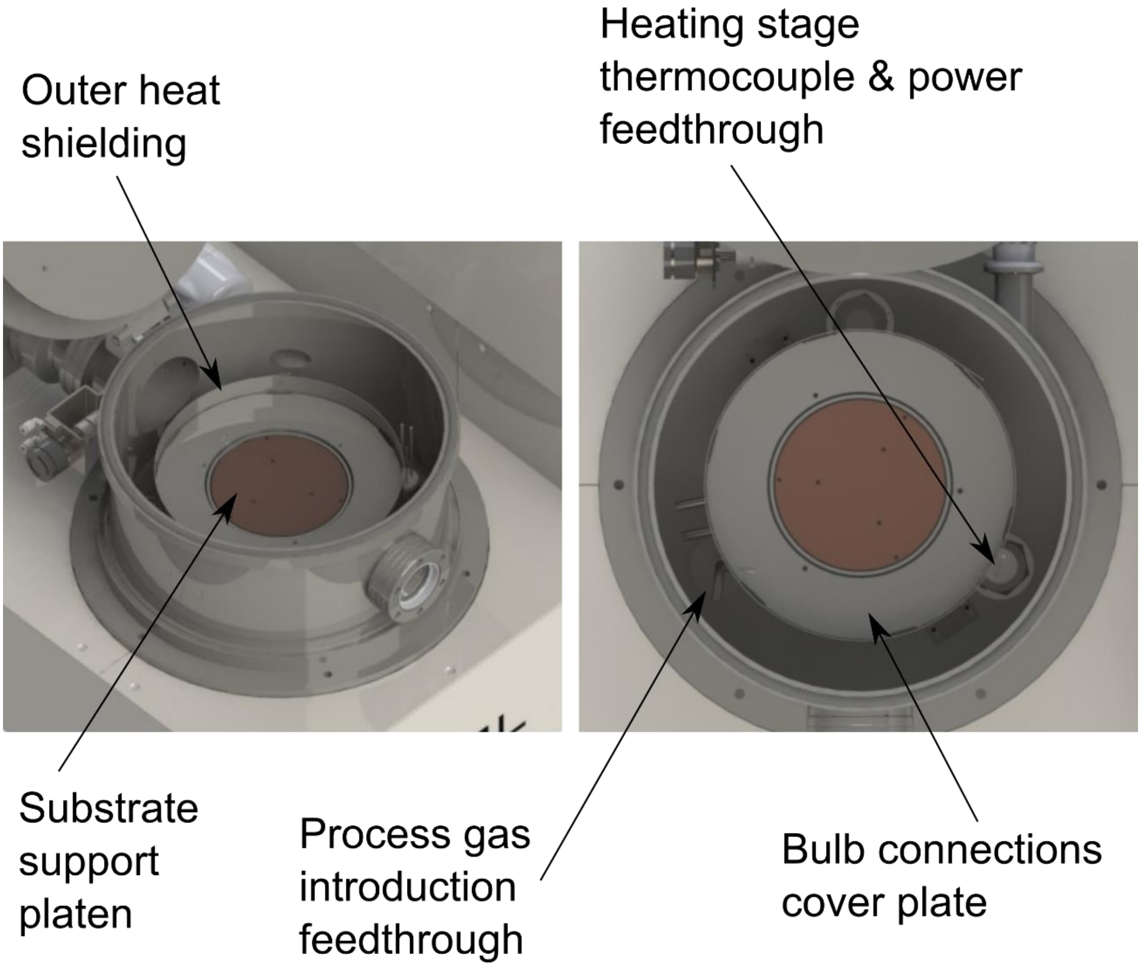
During operation, the temperature of the platen is measured by a K-type thermocouple that is attached to its lower surface. Note that the substrate temperature may differ from that of the platen due to thermal resistance of the platen and also due to any process gases it is in contact with, which will exert a cooling effect (the extent of which will depend on gas chemistry, flow rate and pressure). As such, it may be necessary to carry out a platen-substrate temperature calibration for a set of process conditions, before use.

The substrate heating assembly is fitted with extensive shielding to restrict the transmission of IR to other in-chamber surfaces. This acts to reduce the amount of power required to achieve a set platen temperature, but also keeps heating of unwanted surfaces to a minimum.

2.9 Substrate Heating Stage (Resistive Element, 4”, 1000 °C)

Note: This section is relevant for systems fitted with the resistive element heating stage for maximum substrate diameters and temperatures of 4” and 1000 °C, respectively.

The substrate heating stage is mounted to the chamber baseplate, with power, coolant and thermocouple connections positioned on other feedthroughs to the side or beneath. Figure 4 is a model of the stage inside the chamber.



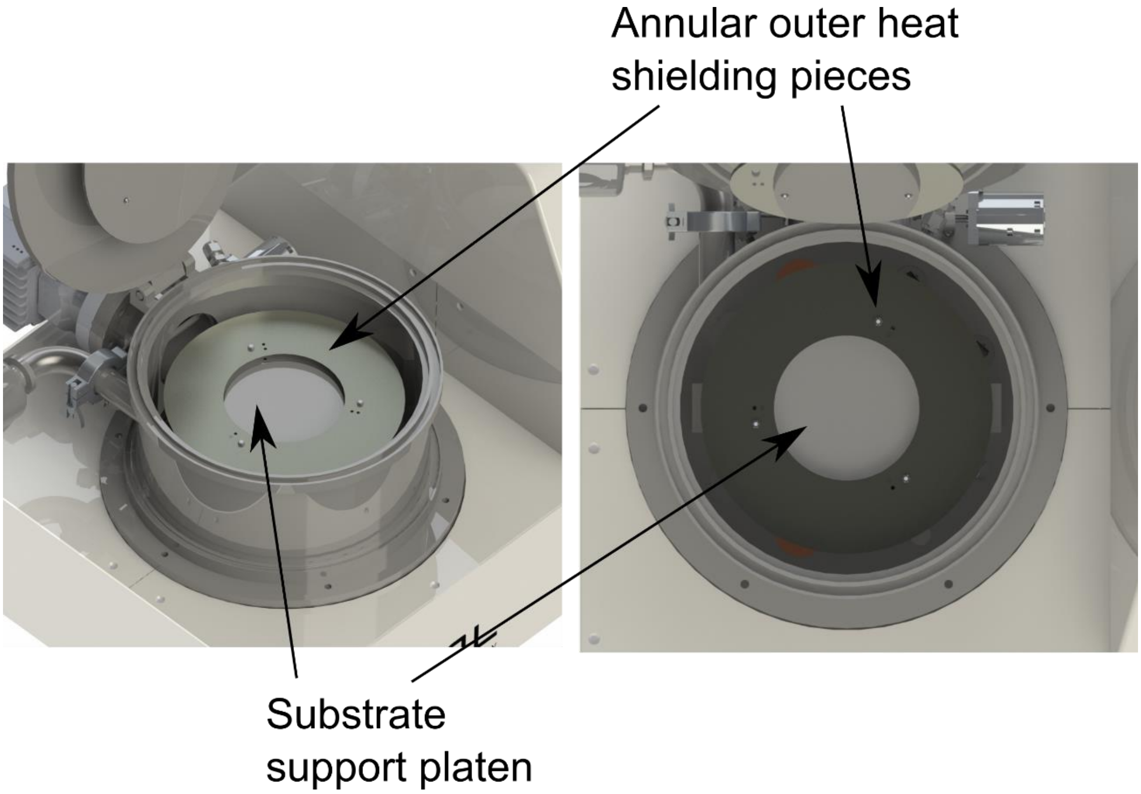


Figure 4: Model showing the resistive element heating stage positioned on the baseplate inside the ANNEAL process chamber. Key features are labelled.

During operation, substrates are placed on the substrate platen (substrates should be located entirely within the platen area, as shown above). The platen is machined from ceramic. When heating is switched on, electrical power is supplied to the resistive element (graphite) which then radiates infra-red to the back of the substrate platen. The IR radiation results in heating of the platen to high temperatures up to 1000 °C (platen front-face).

During operation, the temperature of the platen is measured by a K-type thermocouple that is passes through small holes in the side of the platen and emerges into a small hole on the underneath of the platen. Note that the substrate temperature may differ from that of the platen front face due to thermal resistance of the platen and also due to any process gases it is in contact with, which will exert a cooling effect (the extent of which will depend on gas chemistry, flow rate and pressure). As such, it may be necessary to carry out a platen-substrate temperature calibration for a set of process conditions, before use.

The substrate heating assembly is fitted with extensive shielding to restrict the transmission of IR to other in-chamber surfaces. This acts to reduce the amount of power required to achieve a set platen temperature, but also keeps heating of unwanted surfaces to a minimum.

To allow for use with oxygen process gas, the graphite element may be supplied with an oxygen-resistant silicon carbide (SiC) coating. Note, however, that this coating does not impart perfect resistance and deterioration will still occur with use. This will be accelerated if using oxygen partial pressures above 1E-5 mbar. (Note that the element is a consumable part.)

2.10 In-Chamber Heat Shielding

The ANNEAL chamber is fitted with extensive internal heat shielding. Depending on the design of the tool, this may be attached to the chamber lid, around the sides of the substrate heating and stage and within and below the heating stage itself. The purpose of this shielding is to restrict heat transfer from the heating element to unwanted surfaces inside the chamber—such as the chamber walls. It also increases the rate at which the heating stage is able to achieve a setpoint temperature and reduces the amount of power required for holding at that temperature.

Figure 5 shows the locations of heat shielding within the chamber.

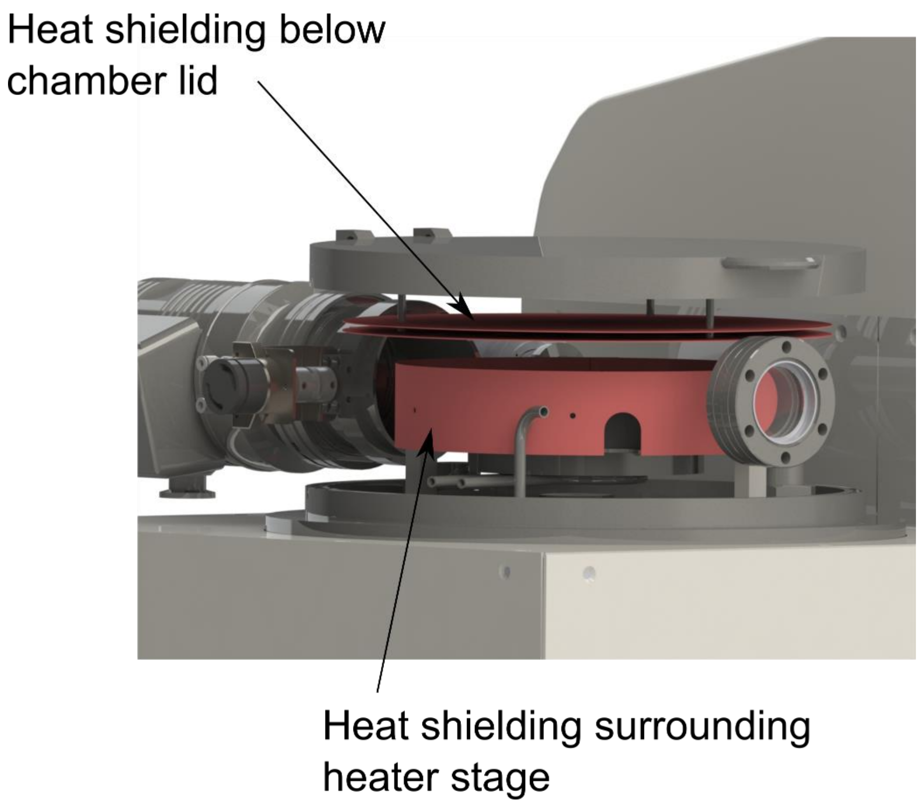


Figure 5: Model showing the locations of heat shielding within an ANNEAL process chamber. Note that the exact locations of heat shielding will depend on the specific configuration.

Warning—heat shielding should never be tampered with, modified or removed! Otherwise system damage and unsafe internal and external surface temperatures could result.

Warning—never touch any part or surfaces of the substrate heating stage assembly! They may be extremely hot! This may also apply to other in-chamber surfaces after substrate heating has been carried out. The current heater temperature can be accessed via the *Manual Control* screen of the touchscreen HMI.

2.11 User Interface

All system operation is via the 7” touchscreen human-machine interface (HMI) mounted on the front of the ANNEAL main unit. A detailed explanation of the use of this touchscreen HMI is given in Section 8, below.

2.12 Manual/Automatic Operation

Annealing processes can be carried out in two different modes: Manual and automatic.

In manual mode, the user operates all hardware directly, as and when required. For example, the user can dynamically choose when to start substrate heating to a temperature setpoint, set process gas flow rates, and run automatic pressure control (depending on system configuration).

In automatic mode, the user first defines and saves a process using the system software. When this process is selected and run, the system controls all hardware, automatically, until the process is finished.

3. Technical Specification

The technical specifications of the base ANNEAL system are as follows:

- Process chamber: Stainless steel (304 grade), approx. 8 L internal volume
- Pressure measurement: Wide-range gauge; 10^{-9} to 1000 mbar
- Backing pump: Rotary (3 m^3/hour or 8 m^3/hour) or scroll (6 m^3/hour) pump
- User interface: 7" touchscreen HMI display
- Cooling: Chilled coolant circulation (an appropriate system must be provided for installation)
- Interlocks: Coolant flow switch (1 L/min) and vacuum
- Dimensions (main unit, approximate): 750 mm (width) × 500 mm (depth) × 460 mm (height to top of chamber door)
- Weight (main unit): 45–70 kg (depending on exact configuration)

4. Specific Configuration and Available Upgrades

When shipped from the manufacturer, the exact configuration of the specific unit with which this manual was supplied was as follows:

- Serial number: 3589
- MFC1: Argon, 50 SCCM full scale
- MFC2: Oxygen, 50 SCCM full scale
- MFC3: Nitrogen, 50 SCCM full scale
- Capacitance manometer: Not fitted
- Automatic pressure control: Fitted, based on feedback to wide-range gauge reading
- Substrate heating stage: Resistive element heating technology (graphite element, SiC coated), 1000 °C maximum platen temperature, 4"/100 mm maximum substrate diameter, 2 kVA transformer.
- Substrate platen: Ceramic, 4"/100 mm diameter
- Backing pump: Edwards RV3 rotary-type pump
- Backing pump gas dilution module: Not fitted
- Turbomolecular pump: Edwards nEXT85D
- TMP cooling: Coolant-cooled
- Chamber coolant channels: Fitted
- Fast chamber vent: Not fitted

Where components are not present, it is possible for the manufacturer or their representative to retrofit these as upgrades later. Please contact the manufacturer for advice in this regard (for safety reasons, unauthorised upgrades should not be attempted by the user).

5. Installation

The system is intended to be installed by the manufacturer or its authorized representative.

The system is shipped disassembled, with the following components:

- Main unit: Sealed process/service gas connections; power switch off; touchscreen HMI protective cover in place; turbomolecular pump outlet connection covered.
- Turbomolecular pump: In original packaging, with manual and fittings for attaching to main unit.
- Backing pump: In original packaging, with manual. Includes oil where appropriate. Power switch off.
- Electrical power cables: 1 IEC male-to-female cable for connecting the main unit to the backing pump; 1 IEC mains plug cable.

The system has the following operating requirements:

- Process gases (if fitted): Recommended high purity, dry, 20–25 psi pressure per supply. Connection via 1/4” tube Swagelok fittings. Maximum flow rates in accordance with MFCs fitted (see Sections 3 and 4).
- Service gas: Dry gas at 60–80 psi. Examples of suitable gases are dry compressed air or nitrogen. Connection via 6 mm outer diameter push-in pneumatic fitting.
- Electrical power: 230 V, single-phase 50 Hz, 10 A.
- Chilled coolant: Flow rate of at least 1 L/min, recommended chilled to 20 °C with cooling power of at least 1 kW (requirements can depend on local conditions; contact manufacturer for advice). Must contain bio/corrosion inhibitor.

The unit should not be used in any situation where it is suspected or possible that these requirements are not being met, for even short periods of time.

Figure 5 shows the connections on the back panel of the unit. These connections are used during installation.

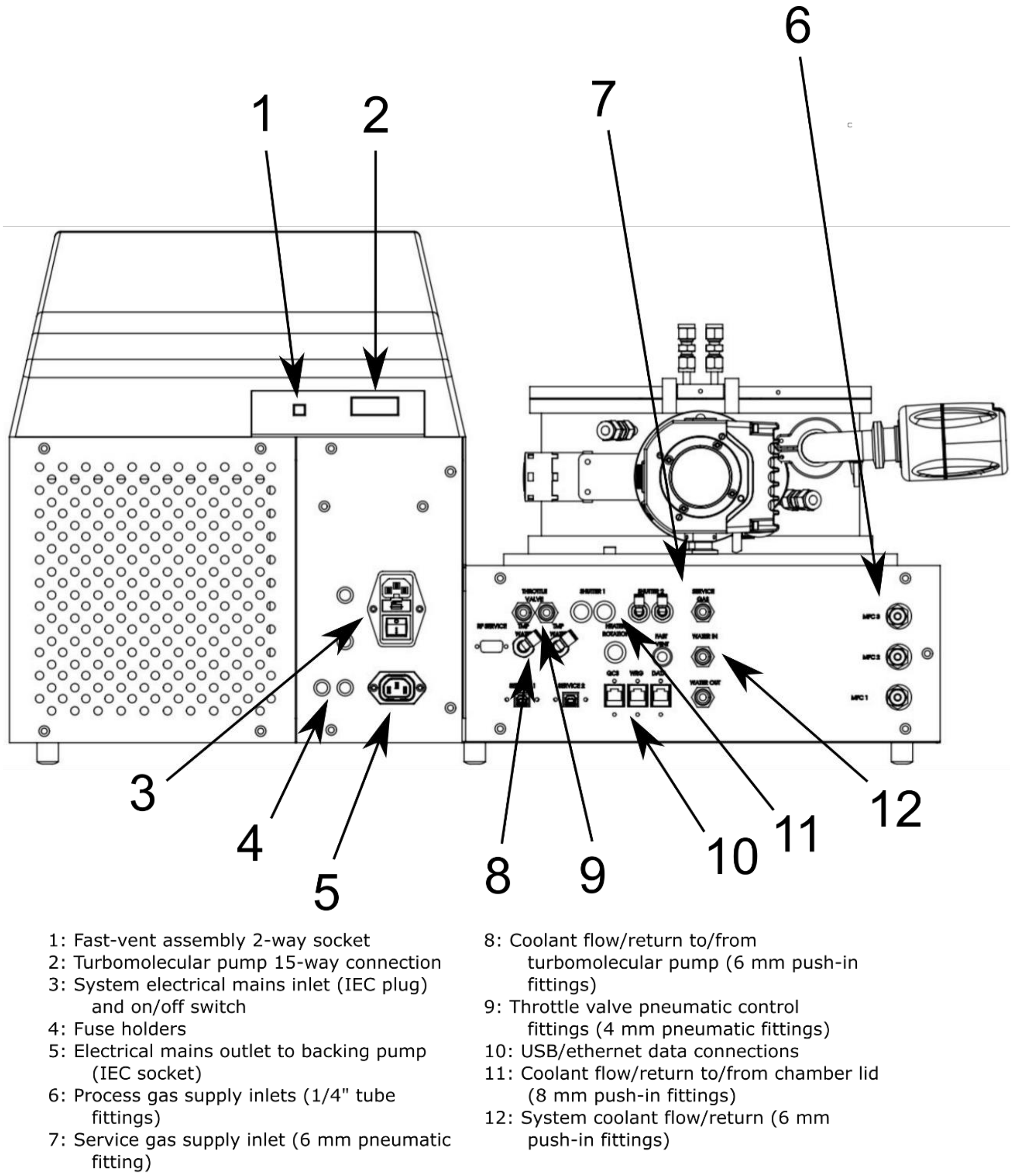


Figure 5: Layout of the system's back panel indicating the nature of the various connections present.

The following procedure describes general system installation (note that some sections may not be necessary, depending on exact unit configuration):

1. Unpack all system components and check they are in the condition described above.
2. Place the main unit on a hard, level surface capable of securely supporting the system weight.
   - There should be at least 20 cm clear space on each side.

   - There should be clear space available above the unit for opening the chamber door.
3. Attach the turbomolecular pump (if included) to the main unit, using the fittings supplier.
4. Place the backing pump where it is to be situated.
   - The backing pump can be positioned next to, behind, or below the main unit.
   - Ensure there is adequate ventilation to the backing pump (see separate backing pump manual for further details).
   - Position the backing pump as close as possible to the main unit for optimum performance.
5. Connect the backing pump to the outlet of the turbomolecular pump using the flexible stainless-steel bellows and the KF25 fittings supplied.
   - Minimize the number of sharp bends in the bellows for optimum performance.
6. Follow any pump-specific setup procedures (see pump manual for further details), e.g., oil-filling for oil-based rotary pumps.
7. Securely connect the process gas supply lines to the appropriate fittings (labelled with the MFC number; consult Section 4 for the calibration gas for each MFC) on the back of the unit.
   - At this stage, there should be no gas pressure supplied to the process gas supply lines.
8. Turn on the process gas pressure on each process gas line fitted to 20–25 psi. Use leak checking fluid or a leak sniffer to check that there are no leaks where the process gases are connected to the main unit. Once leak checking is complete, turn off the process gas supplies to the system.
9. Ensure the service gas lines from the rear of the main unit to the throttle valve (if this is included) are connected. The appropriate outlets on the back of the main unit are labelled 'THROTTLE VALVE'.
10. Connect the turbomolecular pump control cable to the appropriate connections on the unit's back panel. The back-panel connection is indicated in Figure 5.
11. Ensure the TMP coolant tubes are connected to the ‘TMP WATER’ connections on the main unit’s back panel.
12. Connect the coolant flow supply to the ‘WATER IN’ connection on the back panel.
13. Connect the coolant flow return to the ‘WATER OUT’ connection on the back panel.
14. Switch on the coolant flow, briefly, to check for any leaks.
15. Connect the electrical mains IEC cable between the pump and the main unit. The appropriate connection on the back of the main unit is labelled in Figure 5
16. Ensure the switch on the pump is turned on and the pump is configured correctly for local mains electrical supply (see pump manual for further details).
17. Connect the electrical mains IEC cable to the main unit (connection labelled in Figure 3) and insert the plug into a mains socket.

Warning—never connect any gas to the system's process gas connections other than that for which the system has been designed. The process gas fittings are clearly labelled; always ensure the correct process gas is supplied to the correct back panel fitting.
Warning—always use dry, particulate-free high-purity process gases. Impurities can produce undesirable results, may damage the system and may lead to unsafe operating conditions.

6. System Setup

This section provides detailed information regarding the calibration and setup of the hardware present in the ANNEAL system.

Note that some sections only apply where certain options have been selected, e.g., setup of the automatic pressure control module.

In this section, *italic formatting* is used to indicate references to the displayed names (titles) of software screens and interface controls displayed on the touchscreen HMI.

6.1 Throttle Valve

Note: This section is relevant only for systems with the throttle valve fitted between the pumping system and the chamber.

In some cases, it may be necessary to adjust the fixed positions of the throttle valve that is situated between the pumping system and the chamber. This may be necessary, for example, when the correct pressures are not being achieved in the chamber during process operation.

To adjust the throttle valve fixed positions, the procedure below should be followed:

1. Disconnect the service gas lines from the pneumatic actuator mounted on the throttle valve.
2. Use an allen key and 9 mm spanner to adjust the mechanical stop positions of the pneumatic actuator, per the guidance below.
3. Reconnect the service gas lines to the pneumatic actuator (ensure the correct line is connected to either side).

If it is the case that the maximum pressure that is being achieved is too low (i.e., it is not possible to raise the pressure to sufficiently high levels), then the mechanical stops need to be adjusted such that there is lower conductance between the chamber and the pumping system when the throttle valve is in the closed position. On the other hand, if the minimum pressure that can be achieved is too high (e.g., due to minimum flow rates through the MFCs), then the mechanical stops need to be adjusted such that there is greater conductance between the chamber and the pumping system.

Warning—do not make any adjustments to pneumatic actuators while there is a chance they could be operated or without first disconnecting their service gas supply lines! Else, injury to users may result.

6.2 Automatic Pressure-Control

Note: This section is only relevant for systems that have the automatic pressure-control module fitted.

It is possible to check whether the current system setup will allow for a particular pressure to be achieved using APC. To do this, users should navigate to the *Gas/Pressure Control* section of the *Manual Control* screen, enter the MFC flow rates and setpoint pressure corresponding to the deposition conditions to be used and then engage pressure-control.

If this procedure reveals that the setpoint pressure cannot be achieved, it may be necessary to adjust the position of the throttle valve located between the pumping system and the chamber (see Section 6.1).

If the pressure-control mode is seen to provide poor performance (e.g., slow to achieve setpoint pressure, or oscillatory behaviour) it may be necessary to tune the feedback loop involved. To do this, with APC engaged, press the *Pressure control AT* switch on the *Manual Control* screen.

Note that the ability of the pressure-control routine to achieve the setpoint pressure also depends on the defined proportions of the gas flow rates relative to the minimum and maximum flow rates allowed by the system MFCs. As the relative proportions of the gas flow rates deviates further from the ratios of the full scales of the corresponding MFCs, the ability of the system to automatically control pressure will become increasingly restricted.

6.3 Substrate Heating Stage (Quartz Lamp, 4”, 500 °C)

Once installed, the substrate heating stage is ready to use.

From time-to-time, it may be necessary to change the quartz lamp heater bulbs inside the heater assembly. To do this, follow the procedure below:

1. Power down the tool and disconnect from electrical mains
2. Push down gently on side of the substrate support platen and gently lift away from the substrate heating stage
3. Once the platen has been lifted a short distance away from the stage, access the underside to loosen the bolt securing the K-type thermocouple to the underside—pull the thermocouple away and then remove the platen away completely
4. Remove the heater connections cover plate—to do this, remove the 3 bolts securing this down
5. Identify the ceramic terminal block corresponding to the bulb that needs to be replaced and remove the two screws in this terminal block that are closest to the bulb
6. Slide the bulb legs out of the terminal block and remove the ceramic beads
7. Insert the new bulb, ensuring that the legs are isolated from the heater body by placing the four ceramic beads (removed from the old bulb) onto each leg
8. Replace and tighten the screws in the terminal block
9. Replace the heater cover
10. Fit the thermocouple back onto the platen and replace this onto the top of the stage

The following figure indicates some features associated with this procedure.

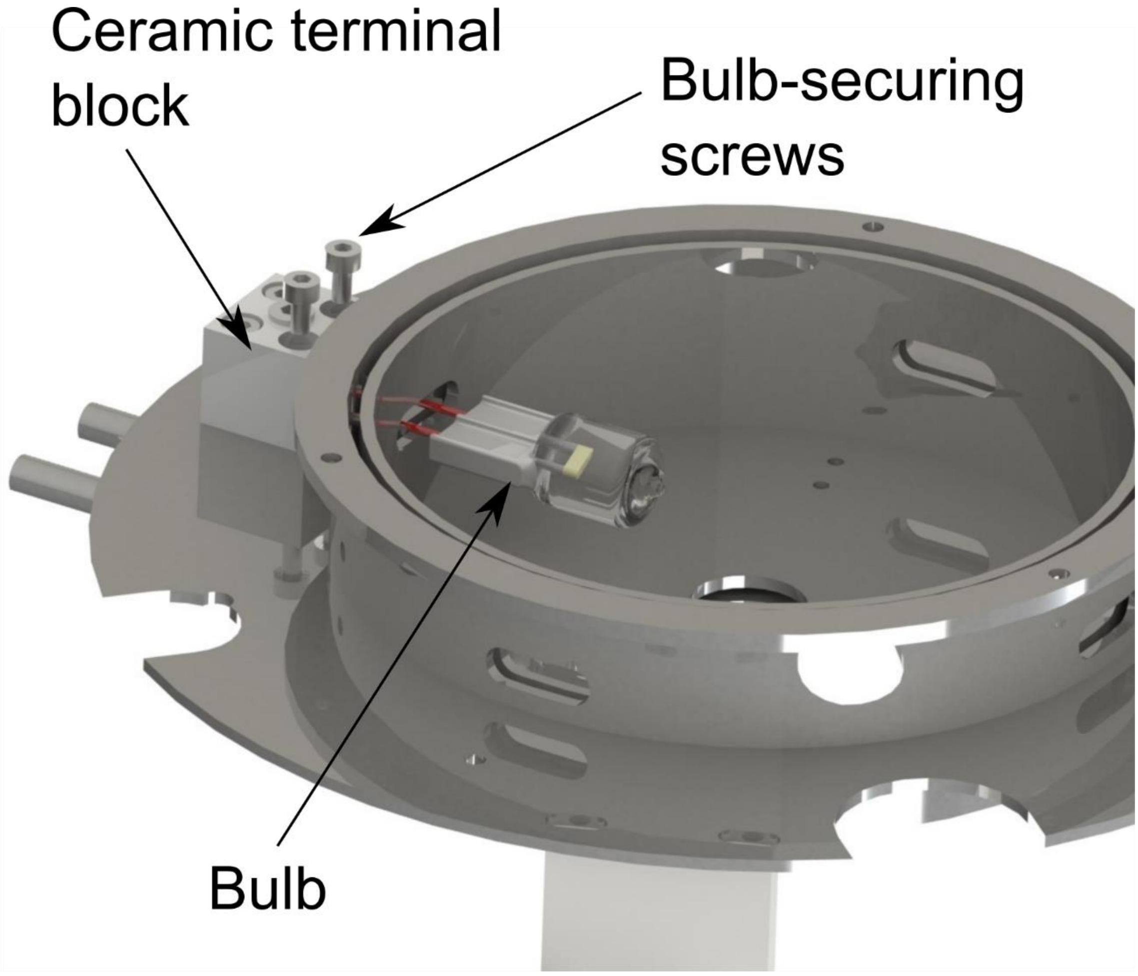


Figure 6: Model showing internal features of the substrate heating stage associated with the bulb replacement procedure. For clarity, this model shows the heating stage with just one bulb, and with the platen, thermocouple and heater connections cover plate removed.

Note that after bulbs have been replaced, it may be necessary to recalibrate the substrate heating stage and control feedback loop—see Sections 6.5 and 6.6.

6.4 Substrate Heating Stage (Resistive Element, 4”, 1000 °C)

Once installed, the substrate heating stage is ready to use.

From time-to-time, it may be necessary to change the resistive element inside the heater assembly. To do this, follow the procedure below:

1. Power down the tool and disconnect from electrical mains
2. Remove the 3 inconel nuts securing the upper annular heat shield, and put to one side.
3. Remove the upper annular heat shield
4. On the thermocouple feedthrough connections, unscrew the connections between the feedthrough prongs and the platen thermocouple wires. Take care not to let any of the ceramic beads fall from the wires
5. Remove the platen including the thermocouple and place to one side

6. Remove the second annular heat shield and the ceramic spacers that sit on top; place to one side
7. The element connections are now exposed, either side of the element itself. Very carefully (the element is extremely brittle) unscrew the screws on either side that hold the element in place. Remove the screws together with the graphite washers
8. The element can now be removed gently
9. At this point, a new element can be installed by following the reverse of the procedure above. Note that all screws must be tightened gently and only to finger-tightness

The following figure indicates some features associated with this procedure.

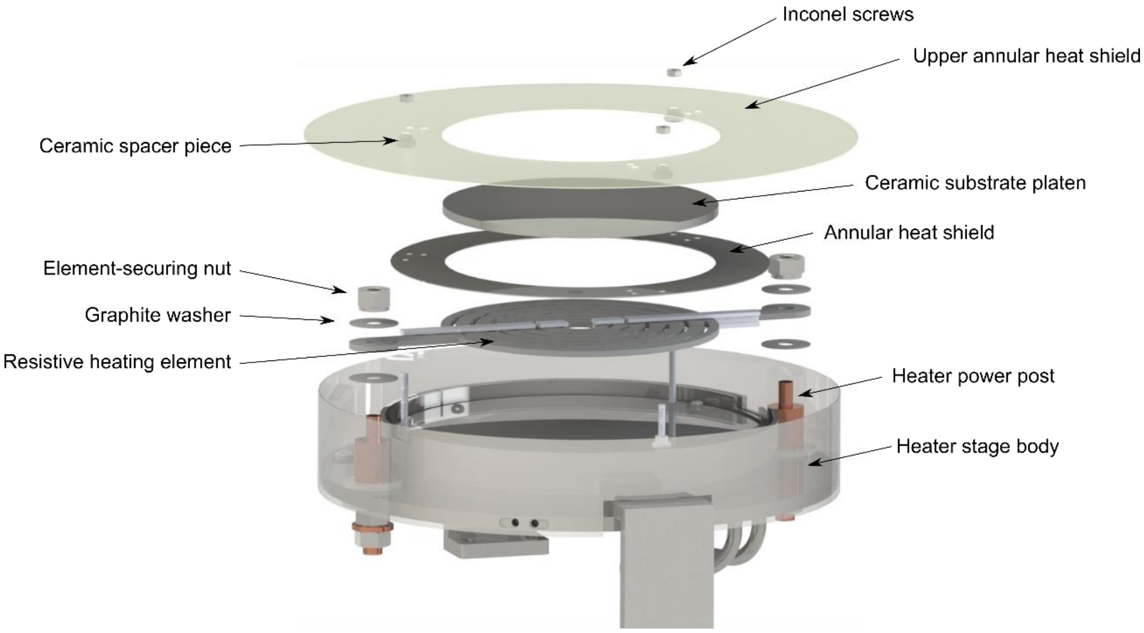


Figure 7: Model showing internal features of the substrate heating stage associated with the resistive element replacement procedure. For clarity, this model shows the heating stage with the platen, thermocouple and heater connections cover plate removed.

Note that after the resistive element has been replaced, it may be necessary to recalibrate the substrate heating stage and control feedback loop—see Sections 6.5 and 6.6.

6.5 Temperature Control Feedback Loop

To tune the feedback loop controlling the heater temperature, navigate to the *Temperature Control Calibration* screen. Here, the user can start an automatic tuning routine that calibrates the feedback loop across the full temperature range over which the system is capable of operating. The heater is calibrated with no gas flows passing through the chamber.

Note that the tuning routine can take more than one hour to complete.

The tuning routine should be carried out periodically or whenever it is suspected that temperature control has begun to drift.

6.6 Temperature Control Calibration Curve

The thermocouple used to measure the temperature is attached via a flexible wire to a small hole in the underneath of the substrate platen. This means that there can be an offset between the measured temperature and the temperatures of the platen front-face or a substrate. If desired, a calibration curve (for the platen or substrate front-face versus the embedded thermocouple), may be acquired. This allows users to operate temperature control in two ways:

1. Direct setpoint: For this, the system works to control the embedded thermocouple temperature at the setpoint entered
2. Adjusted setpoint: For this, the system takes the entered setpoint and uses calibration data to adjust this in order to make the temperature of the calibration location equal to the entered setpoint (typically, this means the embedded thermocouple temperature will be higher than the entered setpoint)

The mode in operation is set via the *Settings* screen; calibration data is also displayed and adjusted using this screen.

Note that the suitability of a calibration curve will be determined, to some extent, on process conditions and platen design, and may also wander with time. As such, it may be necessary to re-acquire calibration data from time-to-time. To do this, use a separate thermocouple positioned at the calibration location (via a feedthrough attached to the chamber's spare baseplate thermocouple feedthrough) and measure the stable temperature as a function of the platen base setpoint temperature—this can be done using the *Manual Control* screen.

The system is also fitted with an auxiliary K-type thermocouple connection (attached to the cable set at the back of the tool); optionally, this may be used for direct reading of temperatures through the touchscreen HMI (*Manual Control*) screen. This sensor can be enabled through the *Heater Settings* screen.

Warning—users should ensure that chamber internal hardware such as the substrate platen and the heater assembly have cooled to a safe temperature (< 50 °C) after the heater has been used and before contact is made with any of these parts. If in any doubt, use a thermocouple probe to check component temperatures.

7. Operating Instructions

This section provides detailed instructions for system operation. The underlying states of system hardware are also explained to provide the user with an understanding of processes taking place inside the ANNEAL unit.

For detailed information regarding the software screens described, refer to Section 8 of this manual.

In this section, *italic formatting* is used to indicate references to the displayed names (titles) of software screens and interface controls displayed on the touchscreen HMI.

During typical use, an operator will first open the chamber and mount a substrate on the support platen that sits on top of the heating stage. They would then close the chamber and initiate the chamber pump routine. Once the chamber is pumped, they can then run annealing hardware as required. With processing finished, the chamber can be vented, and the processed substrate removed, ready for application. Each of these stages is described in detail below.

Warning—the system should not be used prior to correct installation, or in any situation where operating requirements are not being met (see Section 5).

7.1 Turning the System On

To switch on the system, ensure the unit is connected to mains power and all services as described above, and then press the power switch on its back panel. The touchscreen HMI will display a startup screen followed by the *Main Menu*.

Inside the system, the control electronics and hardware are initialized. Hardware is continuously checked for any errors while electrical power is being supplied to the system.

7.2 Inserting a Substrate

To insert a substrate, the chamber must first be opened. To do this, use the extending piece at the front of the chamber door to lift the door on its hinge. Move the door fully back, so that it rests on its hinge and stays there by itself. Note that it will not be possible to open the door until the chamber vent routine has been carried out. When the chamber is fully vented, the internal atmosphere will be at atmospheric pressure and the chamber may be opened easily be gently lifting the lid. Excessive force should not be applied to the door to prematurely open it.

With the door open, the substrate heating stage will be visible at the base of the chamber. The substrate should be placed, carefully and securely, to the substrate platen that sits on top of the substrate heating stage. If necessary (for example, if the substrate weight and form is such that it may be moved by in-chamber gas flows), the substrate can be fixed in several ways, such as using spring clips, Kapton tape or screw clamps. The platen is machined with several tapped holes to facilitate this (optional).

Figures 8 and 9 are photographs of substrate heating stages inside ANNEAL process chambers. Note that substrates must be situated entirely within the central circular copper or ceramic platen areas.

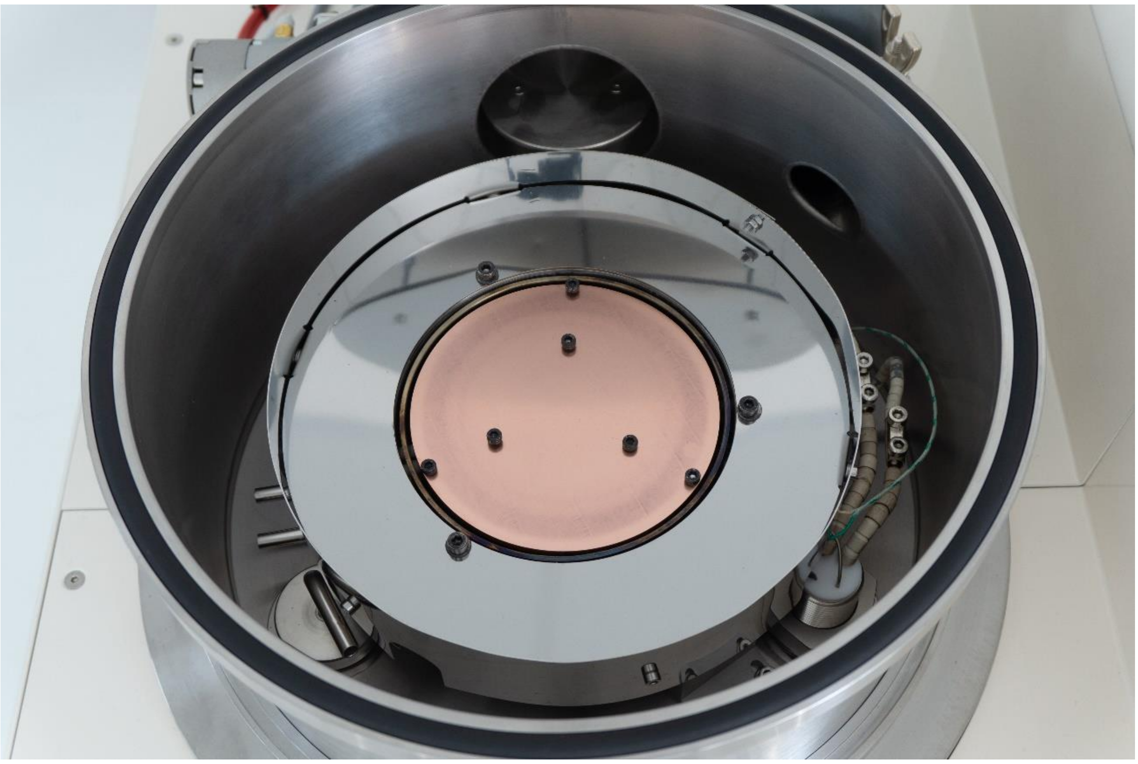


Figure 8: Photograph of a quartz lamp substrate heating stage inside an ANNEAL chamber.

Figure 9: Photograph of a resistive element substrate heating stage inside an ANNEAL chamber.

Once a substrate has been fixed securely to the substrate stage, the chamber door should be carefully lowered back into its closed position. The chamber is now ready to be pumped.

Warning—never touch any part or surfaces of the substrate heating stage assembly! They may be extremely hot! This may also apply to other in-chamber surfaces after substrate heating has been carried out. The current heater temperature can be accessed via the *Manual Control* screen of the touchscreen HMI.
Warning—chamber components are delicate! Do not apply excessive force.
Warning—ensure that substrates are located entirely within the diameter of the substrate platen.
Warning—users should ensure that substrates inserted into the system are compatible with process conditions. Appropriate risk assessments must be carried out prior to any process operation.
Warning—users should wear gloves when working with all internal chamber components, to avoid the introduction of contamination that can affect system performance and deposition results.

7.3 Pumping the Chamber

Note: This section is relevant for systems fitted with the turbomolecular pumping system.

Before carrying out any deposition, it is necessary to pump the chamber to a suitable vacuum level by carrying out the pump routine. To initiate the pump routine, press *Pump Chamber* on the *Main Menu*.

When the pump routine is started, the backing pump is immediately switched on. This rough pumps the vacuum system of the ANNEAL unit. Once the chamber pressure has dropped below the 'door' pressure setpoint (i.e., the pressure at which the system detects that the door is closed during pumping), and at least 30 s after the pump routine was initiated, the turbomolecular pump is switched on. As the turbomolecular pump speed increases, the chamber pressure will drop rapidly. When the pressure drops below 5×10^{-5} mbar, the vacuum interlock will be deactivated and it will then be possible to use interlocked annealing hardware such as substrate heating stage and process gases (depending on the system configuration).

While the pump routine is in operation, the *Status* text on the *Main Menu* reads 'Pumping...'. When the pump routine has finished, and the system is ready to start substrate processing, this changes to 'Pumped'. The green/red indicators on the *Main Menu* always report the status of the system interlocks.

Warning—ensure the chamber door is closed before starting the chamber pump routine! Attempting to evacuate a non-sealed chamber could result in damage to the system and to unsafe operating conditions.

7.4 Automatic Mode: Process Definition

For automatic operation, hardware is operated in accordance with pre-defined processes. Each process can consist of multiple stages. When a process is run, the system starts with the first stage (i.e., stage 1) and sets the system hardware according to the conditions defined in that stage. Once a stage has finished (as it reaches a defined endpoint—see below), the system moves to the next stage and adjusts the system hardware according to the conditions corresponding to that stage. A running program finishes when the system moves into a stage that contains zero settings for all conditions.

To define a program, first enter a program ID using the *Process Selection* screen. At this point, process author and description fields can be updated. Once a process is selected, navigate to the *Stage Editing* screen by pressing the *Process Edit* button.
The system can store up to 30 processes, each having up to 20 stages. Using the *Stage Editing* screen, it is possible to move between stages and to define the system conditions corresponding to each stage.

Stage parameters indicate how the system will operate when a program is run, and what conditions should be achieved before the system moves to the next stage (i.e., what state constitutes the endpoint). The following important guidelines should be considered during stage definition.

Guidelines relating to the substrate heating stage temperature:

1. If a stage's setpoint temperature is the same as that for the previous stage, the system will maintain the setpoint temperature for the stage time.
2. If the setpoint temperature differs from that of the previous stage, the system will carry out a linear ramp of setpoint temperature between the values for the previous stage and the current stage, with the rate being defined by the stage time (i.e., ramping rate = temp. difference / stage time). Note that the ramping rate magnitude must be equal to or lower than the maximum ramping rate the substrate heating stage can provide for (will be different for heating and cooling), otherwise the actual temperature will not be correct for the start of the following stage.
3. If a setpoint heater stage temperature differs from that of the previous stage, and the stage time is zero, the system will attempt to achieve the setpoint temperature as quickly as possible. The stage will end once the measured temperature is equal to the setpoint temperature.

Guidelines relating to the operation of MFCs and automatic pressure control (only relevant for systems fitted with one or both features):

1. If the setpoint pressure is 0.0 mbar * 10^{-3}, the system will not attempt to control pressure.
2. If the setpoint pressure is greater than 0.0 mbar * 10^{-3}, the system will attempt to control pressure by changing the total MFC flow rate while keeping the ratios between the flow rates of the different gases constant.

Finally, if the stage time and heater temperature are both set to zero, the stage will be interpreted as a signal to terminate the running program. This is true even if there are stages with non-zero settings following that stage (the system will never move into these stages).

Note that any changes made to stages or processes are saved to memory immediately.

7.5 Automatic Mode: Process Operation

To run a defined anneal process, the user should first navigate to the *Process Selection* screen and select the process to be run.

Once the desired process has been selected, the user should enter the *Process Execution* screen and press *Process Start* to begin the process. The system will then automatically carry out the process according to the stages that have been defined.

While a process is running, the *Process Execution* screen displays a variety of information relating to system conditions. In addition, the *Plots* screen provides a summary of conditions in a graphical format.

During automatic operation mode, it is possible to skip to the next stage and hold at the hardware settings defined for the current stage. A running process will be terminated when the system moves into a stage that has zero values for stage time and heater stage temperature.

It is also possible to manually terminate a running process at any time using the *Process Stop* button on the *Process Execution* screen.

Note that the system will automatically move to the next stage once the current stage has run for more than 167 minutes, regardless of whether the endpoint conditions have been achieved.

If the ANNEAL system is fitted with the automatic pressure-control module, then the system can operate in either flow-rate or pressure-control modes (otherwise only flow-rate control is available). During automatic operation, the mode in effect depends on the setpoint pressure. If the pressure is set to exactly zero, then the system will operate in flow-rate control mode. But if the setpoint pressure is greater than 0 then pressure-control mode will be enabled.

When a process ends, the system reverts to its standby, pumped state.

In case an error occurs while a process is running, a dialog box will be displayed on the *Process Execution* and *Plots* screens to warn the user. For some errors, a running process will be immediately terminated. Detailed error information is available via the *System Log* and *Diagnostics* screens.

7.6 Manual Operation

For operation in manual mode, the user should navigate to the *Manual Control* screen. Here, it is possible to manually control all aspects of system hardware. For example, the user can specify MFC flow rates and ratios, enter a setpoint pressure for pressure-control mode, and set the substrate heating stage setpoint temperature. Exact control options that are available will depend on system configuration.

As an example of an annealing process carried out in manual mode, a user might first introduce a process gas flow through an MFC to bring the chamber pressure to that required for processing a particular substrate (flow-rate pressure control). Once the pressure had stabilised, the user would then set the heating stage setpoint and switch heating power on. After some period of time, the user would switch heating and the process gas flows off.

Manual operation is useful for initial process development. Once a set of conditions has been established for annealing a particular substrate, these can be packaged into a recipe for automatic operation (as above).

7.7 Venting the Chamber

Note: This section is relevant for systems fitted with the turbomolecular pump.

After the chamber has been pumped, it is possible to vent the chamber at any time (except when a process is in operation).

To vent the chamber, users should navigate to the *Main Menu* screen and press *Vent Chamber*. The chamber vent routine is then activated. This routine starts by stopping power to the turbomolecular pump. The system then waits for the rotor speed on this pump to decrease. To aid this, gas may be passed through an MFC (if these are fitted, and the MFC Vent setting is enabled, see Section 8.8). Once the TMP speed has dropped to a safe level, the backing pump will be terminated. Gas is then passed into the chamber to bring it to atmospheric pressure. This gas is passed through the vent valve connected to the turbomolecular pump, but also the fast vent valve and through the MFCs (depending on the system configuration).

While the vent routine is running, the status display on the *Main Menu* screen shows 'Venting...'. When the vent routine has finished, this changes to 'Vented'.

Note that the chamber may not be at atmospheric pressure, even if the status has changed to 'Vented’, if the vent time setting is not long enough. It is possible to tell if venting has finished by checking for gas flow through the vent valve (this will cease when atmospheric pressure has been reached).

7.8 Removing a Substrate

To remove a substrate after a process has finished, first carry out the chamber vent routine as described above.

Once the vent routine has finished, the chamber can be accessed as per the procedure given in the 'Inserting a Substrate' section above.

Warning— never touch any part or surfaces of the substrate heating stage assembly! They may be extremely hot! This may also apply to other in-chamber surfaces after substrate heating has been carried out. The current heater temperature can be accessed via the *Manual Control* screen of the touchscreen HMI.
Warning—chamber components are delicate! Do not apply excessive force.
Warning— ensure that substrates are located entirely within the diameter of the substrate platen.
Warning—users should ensure that substrates inserted into the system are compatible with process conditions. Appropriate risk assessments must be carried out prior to any process operation.
Warning—users should wear gloves when working with all internal chamber components, to avoid the introduction of contamination that can affect system performance and deposition results.

7.9 Periods of Inactivity

The system is designed to be left switched on when not in use, with the pumping system on and the chamber in the pumped state. To this end, users should close the chamber door and carry out a chamber pump routine before finishing a session of use. They should also isolate the system from process gas supplies (but leave the service gas supply on).

For long, sustained periods of inactivity, or where the system is to be relocated, etc., it may be necessary to switch the system off. For the applicable procedure in this case, see the following section.

7.10 Turning the System Off

When it is necessary to turn the system off, the following procedure should be followed:

1. Ensure the chamber has been vented (if necessary, carry out a chamber vent routine—see above).
2. Isolate the system from process and service gas supplies.
3. Turn the system off using the switch on the electrical inlet on the back panel.

8. Software Reference

All system operation is carried out through software that is controlled via the touchscreen HMI. User interaction with the software is via interface controls. Four different types of interface control are employed: buttons, switches, indicators and data-entry areas.

- A button is an area that can be touched to move between software menu screens or to access a particular function. Each button consists of blue text within a light blue box. Buttons with red outlines must be pressed and held for 2 s for operation.
- A switch is an area that can be pressed to turn on/off a specific functionality. Switches change their appearance depending on whether they are on or off. When on, a switch is a black box with a cross inside. When off, a switch consists of an empty black box.
- An indicator is an area that changes its appearance depending on whether a particular functionality is on or off. Indicators appear as filled green boxes when representing an on state, and empty red boxes when representing off.
- A data-entry area is a location that can be pressed to show a keyboard through which data (e.g., parameter values and text) can be entered.

The following guide indicates the locations of all buttons/switches/indicators/data-entry areas and describes their use.

The buttons, switches, indicators and data-entry areas that are available depends on which menu screen is currently being displayed and the configuration of the system (controls may be invisible where the system has not been configured with corresponding hardware).

In this section, *italic formatting* is used to indicate references to the displayed names (titles) of software screens and interface controls.

Once the software has loaded, it is possible to move through the different menus and screens that constitute the software using buttons present on each screen. Figure 10 displays the navigation routes between all menu screens present in the software.

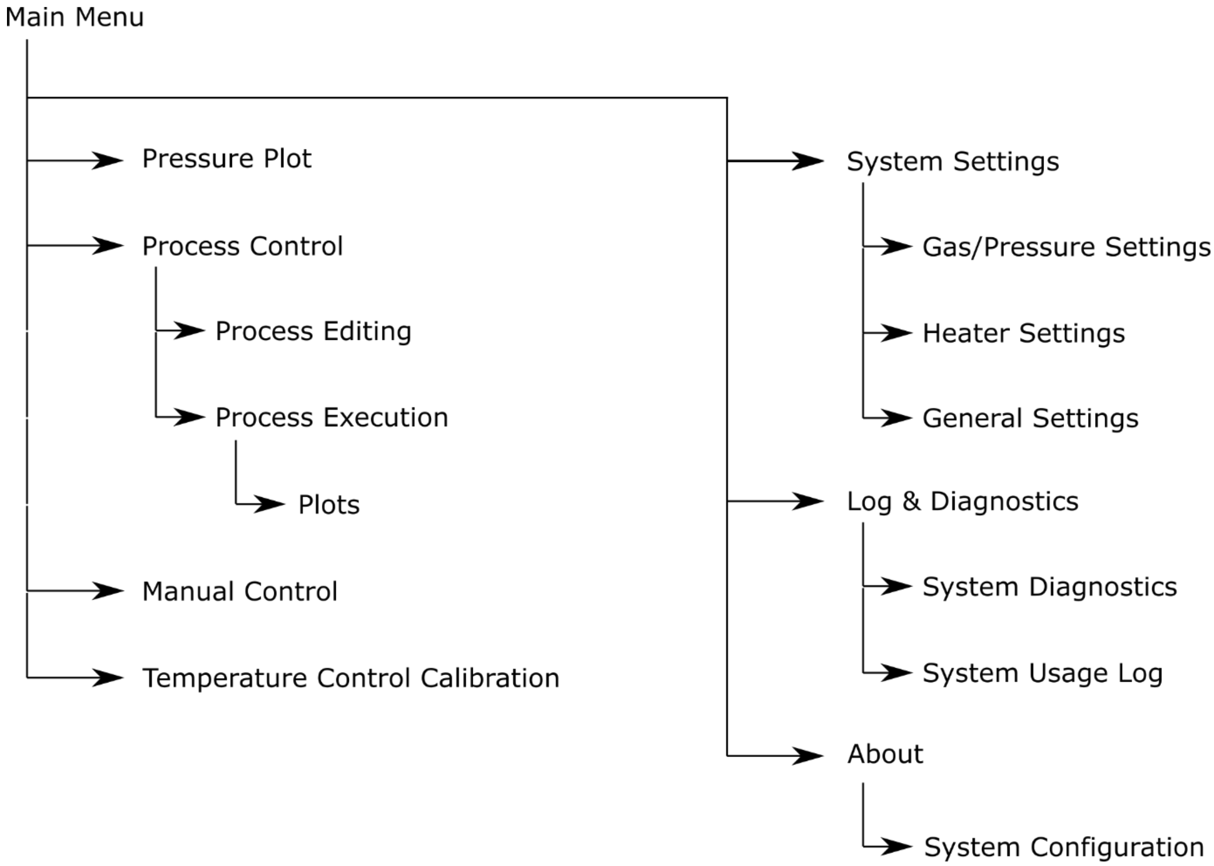


Figure 10: The relationships between the menu screens present within the software. Arrowed lines indicate where direct navigation between two menu screens is possible.

The following descriptions cover the structure and function of each menu screen.

8.1 Main Menu

The *Main Menu* screen is the root menu from which all software functionality is accessed.

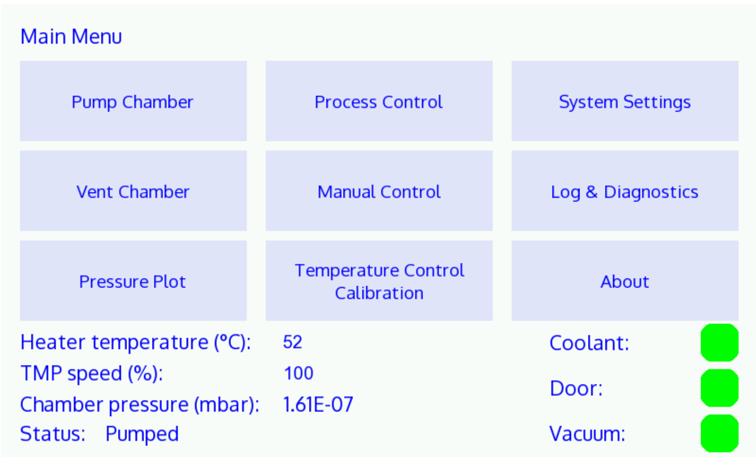


Figure 11: Main Menu screen.

The *Main Menu* contains several buttons:

- *Pump Chamber*: When pressed, this button starts the chamber pump routine. When pressed, this button will terminate any running vent routine.
- *Vent Chamber:* When pressed, this button initiates the chamber vent routine. When pressed, this button will terminate any running pump routine and turn off the vacuum interlock.
- *Pressure Plot:* This button displays a plot of the system WRG pressure over the last 30 minutes.
- *Process Control*: Press this button to move to the *Process Selection* screen. From there, it is possible to define and run processes.
- *Manual Control:* Press this button to navigate to the manual control screen. There, it is possible to control all system hardware, manually.
- *Temperature Control Calibration*: Press this to access the *Temperature Control Calibration* screen where parameters related to temperature control can be tuned.
- *System Settings*: This button will take the user to a screen that allows various general settings to be viewed and altered.
- *Log & Diagnostics:* Press this to access the *System Log* screen, where system messages are displayed.
- *About:* Press this button to view system information.

The *Main Menu* screen also displays the current heater temperature and TMP speed, WRG chamber pressure, text relating to the current system status, and indicators that show the states of all interlocks.

8.2 Pressure Plot

The *Pressure Plot* screen (note that this screen is untitled, for clarity) allows users to follow the WRG chamber pressure over time, graphically.

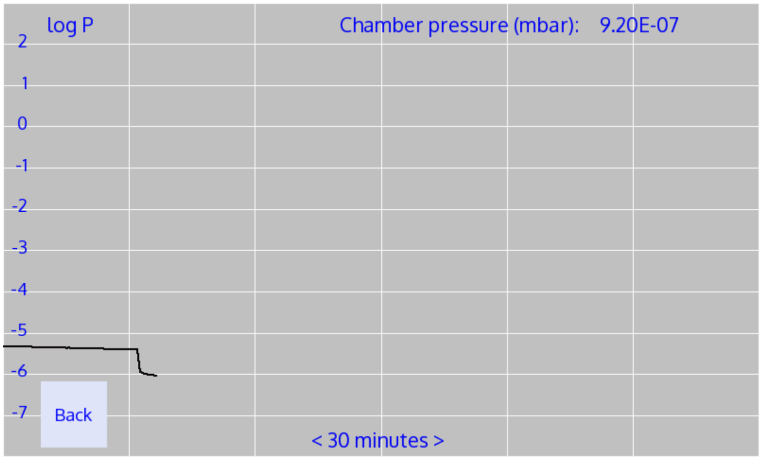


Figure 12: Pressure Plot screen.

In the horizontal direction, the spacing between gridlines represents 5 minutes (30 minutes full width). In the vertical direction, the spacing between each gridline represents 1 decade of the WRG pressure (this is a logarithmic scale). As such, the full vertical scale is from 10^{-8} to 10^{3} mbar.

The *Pressure Plot* screen contains one button: *Back*. Pressing this button allows the user to return to the *Main Menu*.

8.3 Process Selection

The *Process Selection* screen allows the user to select a process for operation in automatic mode. Each process describes a progression of stages (each defined stage consists of a set of defined parameters) that a user would like to subject a substrate to.

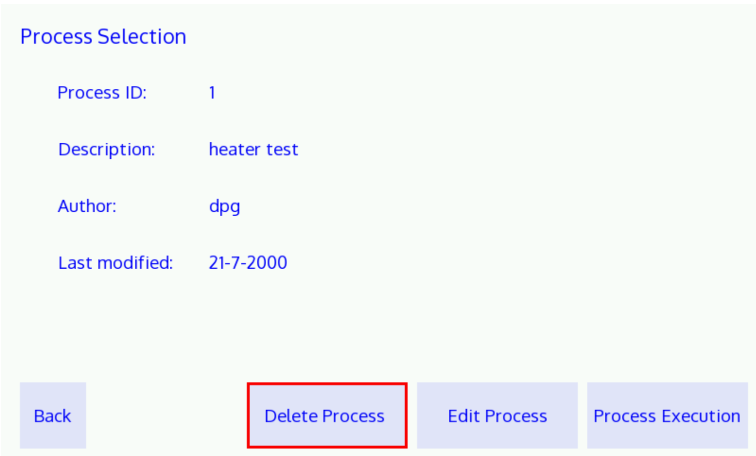


Figure 13: Process Selection screen.

The *Process Selection* screen contains several data-entry areas:

- *Process ID:* This data-entry area allows the user to specify which process they would like to work with. Valid process IDs are in the range 1–30 (inclusive). When the process ID is changed, the selected process is loaded and the other text on the *Process Selection* screen is updated.
- *Description:* This data-entry area allows a user to modify/enter text that describes a process. A maximum of 20 characters can be entered.
- *Author:* Here, the process author can enter their initials/name. Maximum of 12 characters.

Also displayed on this screen is the date on which the selected process was last modified.

The screen also contains several buttons:

- *Back:* Pressing this button returns the user to the *Main Menu* screen.
- *Delete Process:* Pressing this button clears the currently-selected process. This button must be pressed and held for 2 s; a confirmation dialog is also displayed. Warning—clearing a process is an irreversible operation!

- *Edit Process:* Pressing this button takes the user to the *Stage Editing* screen, where an anneal process' constituent stages can be defined.
- *Process Execution*: This button allows the user to navigate to the *Process Execution* screen, where processes can be run and those in operation can be monitored.

8.4 Process Editing

The *Process Editing* screen allows a user to edit the stages that define the selected process.

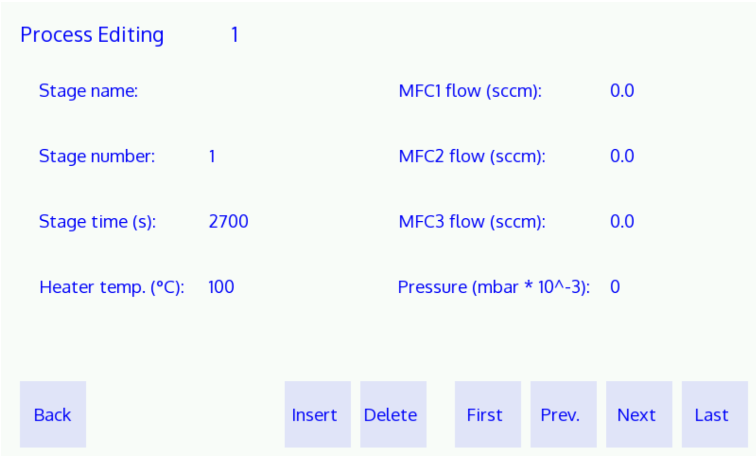


Figure 14: Process Editing screen.

This screen contains several data-entry areas:

- *Stage name*: This allows the user to assign a name to the current stage. Maximum of 12 characters.
- *Stage number*: This allows the user to move between the different stages that make up the selected process.
- *Stage time (s)*: This allows the user to specify the deposition time associated with the selected stage. The time entered must be in the range 0–9999 s.
- *Heater temp. (° C)*: This allows the user to specify the heater assembly temperature associated with the selected stage. Valid settings are from 0 °C to 600 °C.
- *MFC1 flow (SCCM)*: The flow rate of gas through MFC1. Valid settings are from 0 SCCM to the full scale of the MFC.
- *MFC2 flow (SCCM)*: The flow rate of gas through MFC2. Valid settings are from 0 SCCM to the full scale of the MFC.
- *MFC3 flow (SCCM)*: The flow rate of gas through MFC3. Valid settings are from 0 SCCM to the full scale of the MFC.
- *Pressure (mbar * 10^-3)*: Here, the user can enter the chamber pressure setpoint for automatic pressure control.

Note that the data-entry areas that are enabled depends on the exact system configuration.

In addition to data-entry areas, this screen also displays multiple buttons:

- *Back*: This allows the user to navigate back to the *Process Selection* screen.
- *Delete*: This deletes the current stage. All stages following the current stage are moved backwards in system memory (e.g., if stage 3 is deleted, stage 4 becomes stage 3, stage 5 becomes stage 4, etc.). A new stage is inserted at position 30. Warning—deleting a setpoint is an irreversible operation!
- *Insert*: This inserts a stage at the current position. All stages from the current position onwards are shifted forwards by one position (e.g., if a stage is inserted while stage 4 is selected, then stage 4 becomes stage 5, stage 5 becomes stage 6, etc.). Warning—this operation results in stage 30 being deleted!
- *First*: By pressing this button, the first stage (stage 1) is selected.
- *Prev.*: This moves to the stage before that currently selected.
- *Next*: The moves to the stage after that currently selected.
- *Last*: This moves to the last stage in the program (stage 30).

Warning—any changes made to stages are saved to memory immediately! Care should be taken when overwriting previously defined processes.

8.5 Process Execution

The *Process Execution* screen allows a user to run or stop the currently selected process.

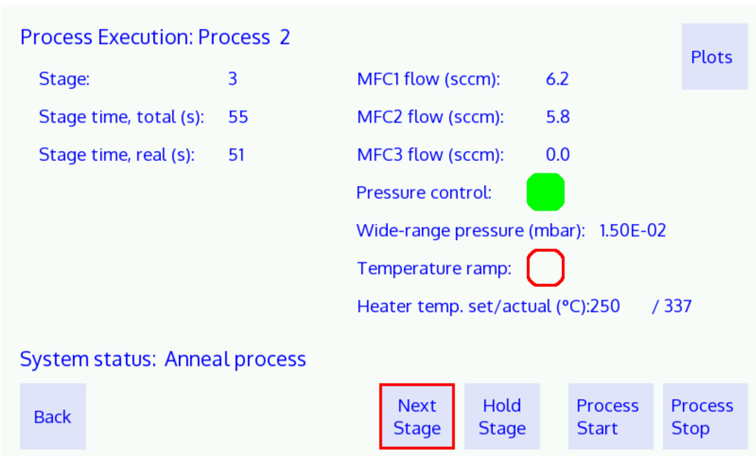


Figure 15: Process Execution screen.

This screen also displays information about the system hardware and the status of any running process. This information includes:

- The current stage number.
- The total time that has passed since the current stage was started.
- The time that has passed since the stage was started and after any gas stabilisation time and inter-stage delay has finished.
- The current flow rates through all MFCs.
- An indicator to show when pressure control is active.
- The current WRG chamber pressure.

- An indicator to show when a temperature ramp is in progress.
- The current heater assembly setpoint, temperature and power.

The screen contains the following buttons:

- *Back*: This allows the user to navigate back to the *Process Selection* screen. This button is disabled while a process is running.
- *Plots*: This displays the *Plots* screen, where a graphical view of system state is displayed.
- *Next Stage*: This moves the process to the next stage. If the current stage is the last, then the process will end.
- *Hold Stage*: This maintains the process at the deposition stage of the current stage. System conditions will remain as defined for this stage until this button is re-pressed (button is darkened while a stage is being held).
- *Process Start*: Used to run the selected process.
- *Process Stop*: Prematurely stops a running process.

Note that once a process has been started, it is not possible to return to lower-level screens until the process has finished or has been terminated.

While a process is running, a dialog will appear on this screen should an error occur. Detailed error information can then be obtained via the *System Log* and *Diagnostics* screens.

8.6 Plots

The *Plots* screen (note that this screen is untitled, for clarity) allows users to follow a running process, graphically.

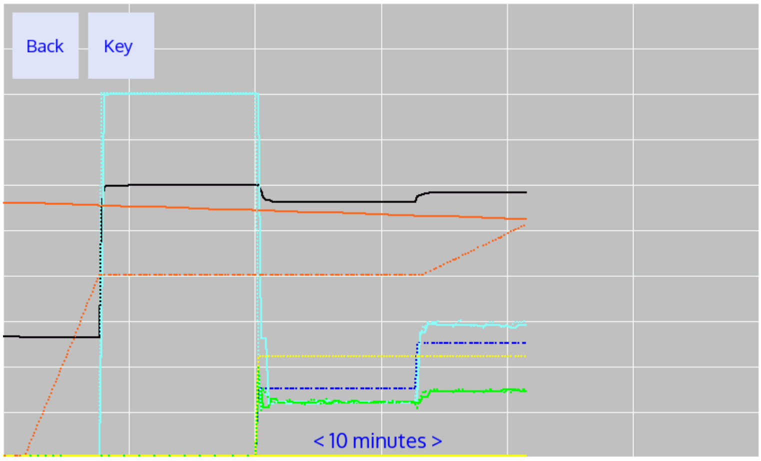


Figure 16: Plots screen.

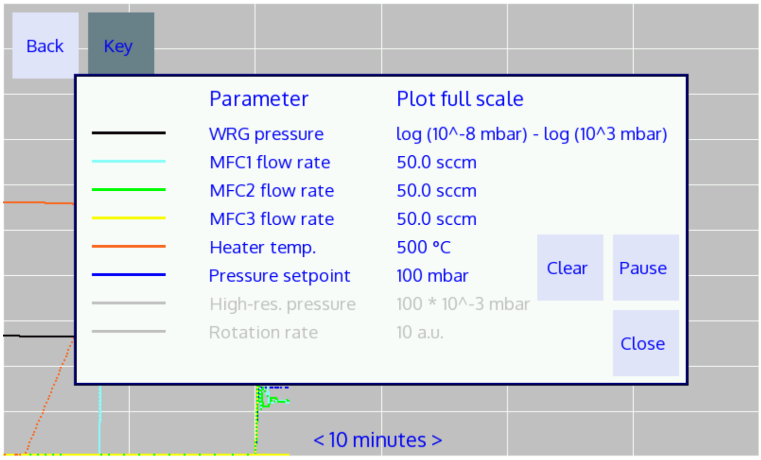


Figure 17: Plots key screen.

The screen displays a grid, and several differently coloured lines that represent various system conditions. In the horizontal direction, the spacing between gridlines represents 1.67 minutes (10 minutes full width). In the vertical direction, the spacing between each gridline represents 10% of the full scale for each condition plotted.

On the plot, solid lines indicate actual condition values. Dotted lines indicate current setpoint values.

The *Plots* screen contains two buttons:

- *Key*: Displays a legend screen that indicates which colors correspond to which conditions, and details the full vertical scale for each. The legend screen also allows users to pause plotting or reset the plot.
- *Back*. Pressing this button allows the user to return to the *Process Execution* screen.

8.7 Manual Control

The *Manual Control* screen allows the user to operate system annealing hardware manually, and dynamically.

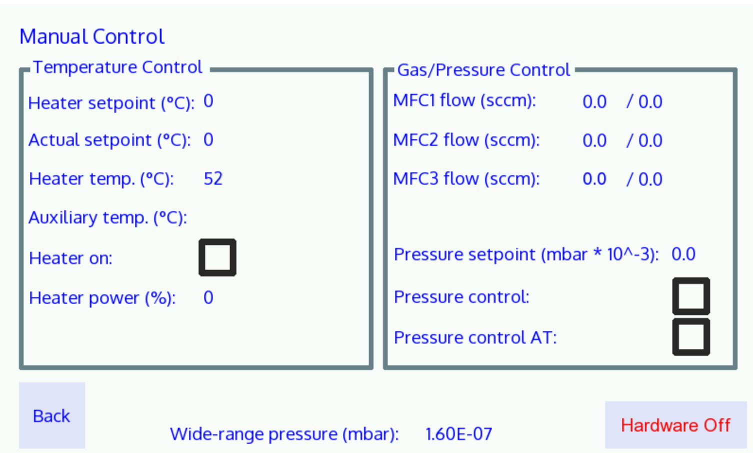


Figure 18: Manual Control screen.

The screen is split into two halves: for *Temperature Control* and *Gas/Pressure Control*.

The *Temperature Control* section contains the following controls and indicators:

- *Heater setpoint (° C)*: This allows the user to specify the heater assembly temperature setpoint.
- *Actual. setpoint (° C)*: If the system is set to adjust the temperature setpoint per calibration data, then this displays the effective setpoint applied to the heater in order to control the calibrated position to the setpoint.
- *Heater temp. (° C)*: Displays the current measured heater assembly temperature.
- *Aux. temp. (° C)*: If the system is set to measure the temperature through the auxiliary thermocouple connection, then this will display that measured temperature.
- *Heater on*: Allows the user to turn substrate heating on and off.
- *Heater power (%)*: Indicates the current heater power level

The *Gas/Pressure Control* section has the following controls and indicators:

- *MFC setpoints/actuals*: The setpoint and actual flow rates (in SCCM) through each of the MFCs. For the setpoints, valid settings are from 0 SCCM to the full scale of the MFC.
- *Pressure setpoint (mbar * 10^-3)*: Here, the user can enter the setpoint chamber pressure for automatic pressure control.
- *Pressure control:* Allows the user to switch on pressure control.
- *Pressure control AT*: Allows the user to auto-tune the feedback loop responsible for automatic pressure control.

In addition to the above, the Manual Control screen always displays the current WRG chamber pressure.

There is also a *Back* button that allows the user to return to the *Main Menu*, and a *Hardware Off* button that switches off all hardware.

Note that the exact appearance of the *Manual Control* screen will depend on the configuration of the current system.

8.8 Temperature Control Calibration

The *Temperature Control Calibration* screen allows the user to run a full heater PID tuning routine.

The screen contains the following controls and indicators:

- *Heater full autotune*: This control allows the user to enable the heater auto-tune routine.
- *Auto-tuning PID*: This indicator is green when the auto-tune routine is active.

- *Heater temperature actual (° C)*: Displays the current measured heater assembly temperature.
- *Heater temperature setpoint (° C)*: Displays the current heater setpoint.
- *Chamber pressure(mbar)*: Displays the current WRG chamber pressure,

8.9 System Settings

The *System Settings* screen is the starting point for changing various settings related to system operation. The settings are split across three sections:

- *Gas/Pressure Settings*: Displays controls relating to the gas and pressure hardware.

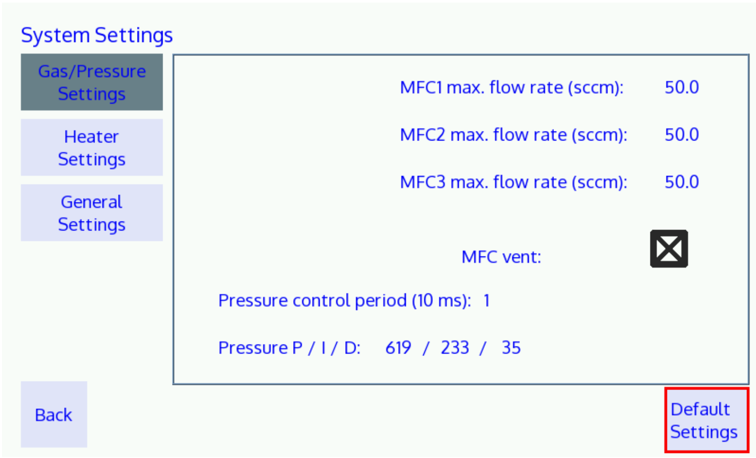


Figure 19: Gas/Pressure Settings screen.

- *Heater Settings*: Displays controls relating to the heating stage.

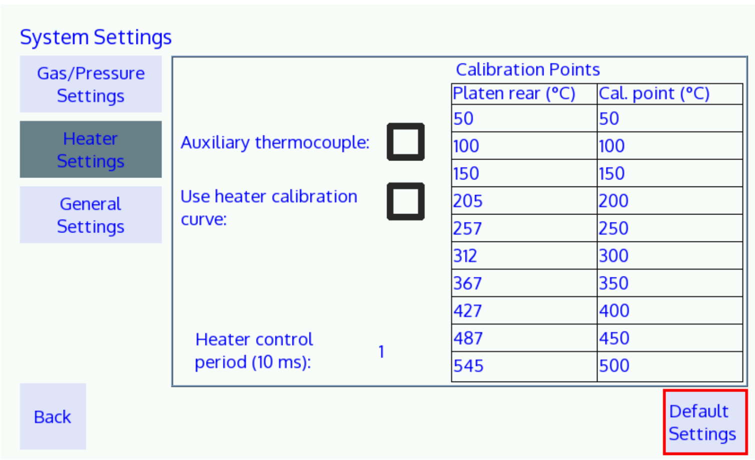


Figure 20: Heater Settings screen.

- *General Settings*: Displays controls relating to general system operation.

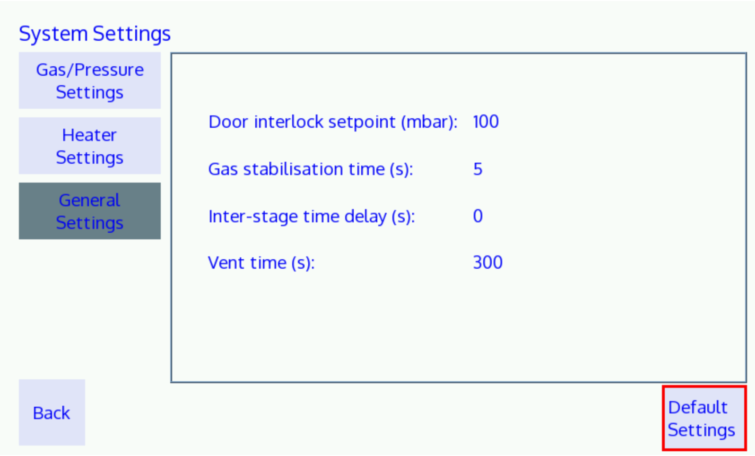


Figure 21: General Settings screen.

The *Gas/Pressure Settings* section contains the following data-entry areas:

- *MFC1 max. flow rate (SCCM)*: The maximum flow rate that can be passed through MFC1.
- *MFC2 max. flow rate (SCCM)*: The maximum flow rate that can be passed through MFC2.
- *MFC3 max. flow rate (SCCM)*: The maximum flow rate that can be passed through MFC3.
- *Pressure control period (10 ms)*: The control period, in multiples of 10 ms, used for the PID feedback loop that is responsible for automatic pressure control.
- *Pressure P/I/D*: The P, I, and D parameters for the feedback loop responsible for automatic pressure control. Note that these will be reset when this feedback loop is auto-tuned.

This section also contains a switch:

- *MFC vent*: If this is selected, then the chamber vent routine is assisted in its initial stage (for slowing the TMP) speed by a flow of argon process gas.

The *Heater Settings* section contains the following data entry areas:

- *Auxiliary thermocouple*: If this is selected, then the system will display the measured temperature from a K-type thermocouple connected to the systems auxiliary thermocouple connection.
- *Use heater calibration curve*: If this is selected, then the system will use calibration data (see below) to adjust the applied setpoint in order to control the temperature of the calibrated position to the entered setpoint. Otherwise, the system will control the heater temperature directly to the entered setpoint (but note that there will be a discrepancy between this temperature and the temperature of the platen front-face).

There is also a data entry table for the heater calibration curve. If inconsistent data is entered (i.e., not an increasing temperature with each entry point) then an error message will be displayed and the data must be corrected before the user can exit the screen.

The *General Settings* section contains the following data entry areas:

- *Door interlock setpoint (mbar):* The chamber pressure at which the system deactivates the door interlock during the pump routine. Valid settings are between 1 and 600 mbar.
- *Gas stabilisation time (s):* The length of time, at the start of each stage, when the chamber pressure is allowed to stabilise. Only used for operation in automatic mode. Valid entries are between 0 and 600 s.
- *Inter-stage time delay (s)*: This allows the user to specify a time for which the system should wait between stages of a running process (when operating in automatic mode).
- *Vent time (s)*: The length of time the vent valve remains open when venting the chamber. Valid settings are between 60 and 1800 seconds.

There are also two buttons:

- *Default Settings*: When this is pressed, the system will revert the settings back to factory default values.
- *Back*: Returns the user to the *Main Menu*.

8.10 System Log

The *System Log* screen displays a list of messages generated by the system. Next to each message, the time and date on which it was generated is displayed.

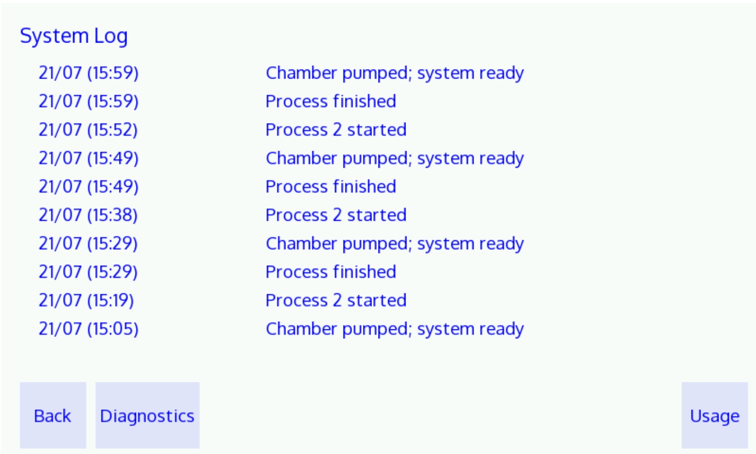


Figure 22: System Log screen.

Messages are stored in permanent memory that is not erased when the system is turned off.

This screen presents the user with two buttons, for software navigation:

- *Diagnostics*: This button allows the user to access the *Diagnostics* screen.
- *Usage*: This button takes the user to the *System Usage Log* screen.
- *Back*: This button enables the user to return to the *Main Menu* screen.

Error messages displayed here include a letter code. Refer to the Troubleshooting section of this manual for explanation of errors associated with each letter code.

8.11 System Diagnostics

The *System Diagnostics* provides extended information about errors that may have occurred.

Figure 23: System Diagnostics screen.

Errors are grouped into categories, the names of which are clearly displayed. Against each name is a numeric error code. A code of 0 indicates that no errors have occurred. Any non-zero code indicates that an error has occurred.

The numeric error codes displayed on this screen are intended to provide the manufacturer with diagnostic information. For error codes that can be deciphered by users, the *System Log* screen should be consulted.

While some errors will cause the system to terminate any running deposition hardware or process, and prevent deposition hardware from being operated, this does not apply in all cases. In addition, it is possible to clear discontinuous errors that do not frequently recur in order to return the system to a usable state. However, users must take steps to identify the nature of errors as they occur (see the Troubleshooting section) and to assess the requirement for action in response to these errors. In case of any doubt, contact the manufacturer.

If it is appropriate to clear an error category, then press the *Clear* button next to the category name. The numerical error code will return to zero when the errors have been successfully cleared (but will quickly acquire a non-zero value if this has failed—e.g., due to a recurring/continuous error).

Further information regarding errors is provided in the Troubleshooting section of this manual.

8.12 System Usage Log

The *System Usage Log* screen provides the user with information relating to the usage of the system and the heater.

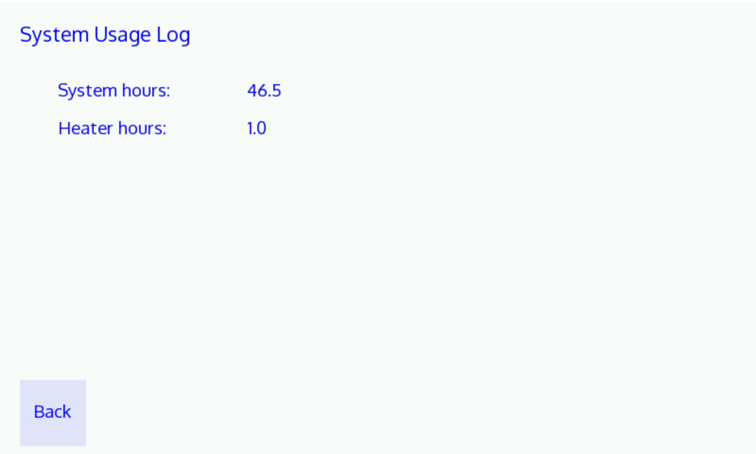


Figure 24: System Usage Log screen.

The screen contains one button:

- *Back*: Allows the user to return to the *Main Menu* screen.

8.13 About

The *About* screen displays information about the ANNEAL system.

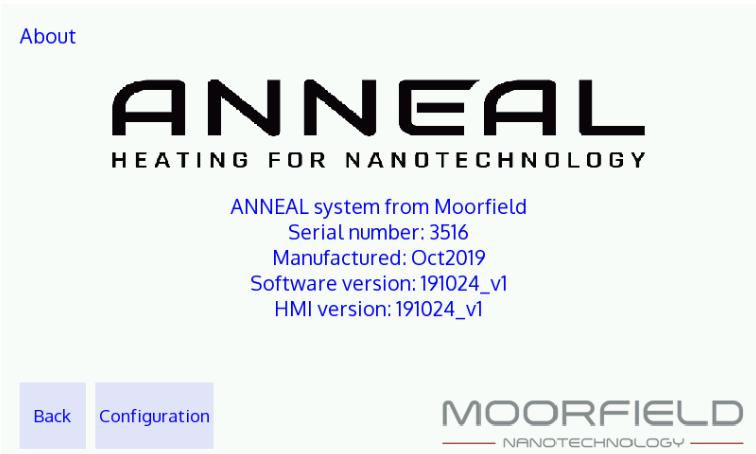


Figure 25: About screen.

The screen contains two buttons: *Configuration* and *Back*. The *Configuration* button navigates the user to the *Configuration* screen, while the *Back* button returns the user to the *Main Menu*.

8.14 Configuration

The *Configuration* screen displays a range of indicators that show how the ANNEAL system is configured.

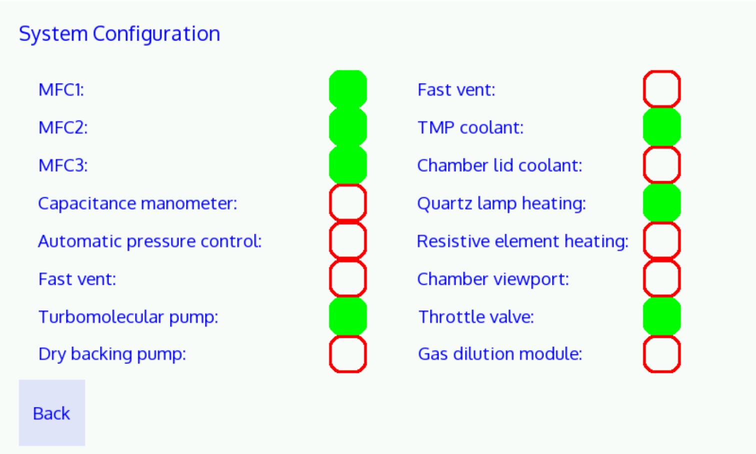


Figure 26: Configuration screen.

The *Back* button returns the user to the *About* screen.

9. Maintenance

The system is designed to require minimal maintenance but should be serviced annually by the manufacturer or a competent, authorized representative. In cases where it is suspected that serious maintenance is required, users should contact the manufacturer immediately.

Routine maintenance procedures that can be carried out periodically by users include:

- Chamber interior: Use an inert dusting gas canister to gently blow out any debris that may have collected.
- Chamber door o-ring seal: Ensure this is kept free of dirt/debris by wiping with a lint-free cloth wetted with isopropanol. Remove and replace cracked/extremely dirty o-rings (contact manufacturer for specifications).
- Chamber door: Watching for loose connections or feedthroughs (contact the manufacturer should loose connections be identified).
- Backing pump: Ensure pump is adequately maintained. Refer to pump-specific manual supplied with the system for instructions.
- Turbomolecular pump: Refer to the pump-specific manual supplied with the system for maintenance instructions.
- Heating stage: Check that thermocouple is responding correctly and that integrity of assembly is maintained.
- Touchscreen HMI: Remove dirt/grease by periodically wiping with a damp non-scratching cloth (do not apply solvents).
- Case ventilation slots: Ensure that slots are clear and free of obstruction.
- Case: As for touchscreen HMI.

Warning—never attempt to modify, repair or open the system without first consulting the manufacturer! Such activities may lead to hazardous situations.
Warning—never touch any part of the heater assembly or chamber interior surfaces! They may be extremely hot! The current heater temperature can be accessed via the touchscreen HMI.
Warning—chamber interior components are delicate! Do not apply excessive force.

10. Troubleshooting

When an error occurs, the touchscreen HMI displays a dialog box that informs them that this is the case. For further information regarding the nature of the error, users should visit the *System Log* screen. For each error, this screen will name the category of the error and provide a letter error code. The different error categories are as follows:

- Pressure: Error related to pumping performance and pressure control.
- Temperature: Error related to the heater assembly and heating performance.
- Controller: Error related to the control electronics.
- Gas delivery: Error related to operation of the on-board MFCs and purge valve.
- Coolant: Error related to the chilled coolant flow.
- Process: Error related to a process being carried out.

When an error occurs, the system will automatically respond by taking appropriate action. For minor errors, this may simply involve displaying the error dialog box and writing an error message to the *System Log* screen. For more serious errors, and those that could cause a hazardous situation to arise, the system may take more severe action such as terminating any running process and preventing processes from being started.

The specific meanings of each letter code for each category, together with an explanation of responsive actions taken by the system are provided in the table below:

Category	**Letter Code**	**Explanation**	**System Response**
Pressure	A	Chamber door interlock timeout during pump routine	Error message displayed; chamber vent routine initiated; prevent initiation of pump routine
	B	Chamber pressure rises above door interlock setpoint while in pumped state	
	C	Chamber pressure rises above door interlock setpoint while process is in operation	Error message displayed; running processes are terminated; chamber vent routine initiated; prevent initiation of pump routine
	D	Chamber low-vacuum interlock timeout during pump routine	Error message displayed; chamber vent routine initiated; prevent initiation of pump routine
	E	Wide-range gauge reading error	Error message displayed; running processes are terminated; chamber vent routine initiated
	F	Chamber high-vacuum interlock timeout during pump routine	Error message displayed; prevent initiation of pump routine
	G	TMP upspeed timeout during	

		pump routine	
Temperature	A	Heater assembly cannot achieve setpoint temperature	Error message displayed
	B	Slow heater assembly temperature increase	Error message displayed
	C	Heater assembly thermocouple disconnection	Error message displayed; heating terminated
	D	Error with thermocouple module cold junction	
	E	Substrate heating stage over-temperature error	
Controller	A	Error in core control electronics	Error message displayed; running processes are terminated; chamber vent routine initiated; prevent initiation of pump routine
Gas delivery	A	MFC1 error	Error message displayed
	B	MFC2 error	
	C	MFC3 error	
Coolant	A	Coolant flow failure while pumping system is active	Error message displayed; running processes are terminated; chamber vent routine initiated; prevent initiation of pump routine
	B	Coolant flow failure while process is running	
	C	Chamber pump routine initiated without coolant flow	
Process	A	Attempt to start process while uncleared error(s)	Error message displayed; process operation prohibited

The following table provides a list of suggested action to be taken by users in the event of errors occurring:

Category	**Letter Code**	**Suggested Action**
Pressure	A	Check chamber door o-ring is clean and sealing correctly; check chamber door is fully closed before starting pump routine; check for obvious leaks around vacuum system; contact manufacturer with diagnostic codes if issue persists
	B	Contact manufacturer with diagnostic codes
	C	
	D	Check chamber door o-ring is clean and sealing correctly; check

		chamber door is fully closed before starting pump routine; check for obvious leaks around vacuum system; contact manufacturer with diagnostic codes if issue persists
	E	Check cable to wide-range gauge; contact manufacturer if error persists
	F	Check chamber door o-ring is clean and sealing correctly; check chamber door is fully closed before starting pump routine; check for obvious leaks around vacuum system; contact manufacturer with diagnostic codes if issue persists
	G	
Temperature	A	Reduce setpoint temperatures; use different pressure/flow rate settings; check thermocouple position and quartz lamp integrity; contact manufacturer with diagnostic codes if error persists.
	B	Reduce setpoint temperatures; use different pressure/flow rate settings; check thermocouple position and quartz lamp integrity; contact manufacturer with diagnostic codes if error persists.
	C	Contact manufacturer with diagnostic codes.
	D	
	E	
Controller	A	Examine system for obvious malfunctions; contact manufacturer with diagnostic codes.
Gas delivery	A	Check MFC1 process gas supply pressure is in range of 20–25 psi; if supply pressure to system recently changed, allow 30 minutes to settle before using; re-calibrate zero offsets; contact manufacturer with diagnostic codes if error persists.
	B	Check MFC2 process gas supply pressure is in range of 20–25 psi; if supply pressure to system recently changed, allow 30 minutes to settle before using; re-calibrate zero offsets; contact manufacturer with diagnostic codes if error persists.
	C	Check MFC3 process gas supply pressure is in range of 20–25 psi; if supply pressure to system recently changed, allow 30 minutes to settle before using; re-calibrate zero offsets; contact manufacturer with diagnostic codes if error persists.
Coolant	A	Check for obvious malfunctions in chilled coolant supply; contact manufacturer with error codes if issue persists
	B	Check for obvious malfunctions in chilled coolant supply; contact manufacturer with error codes if issue persists
	C	Check for obvious malfunctions in chilled coolant supply; contact manufacturer with error codes if issue persists

Errors can be cleared through the *Diagnostics* screen. Here, users can press *Clear* buttons to clear all errors in corresponding categories. Note that it is not possible to clear continuously occurring errors. Recurring errors must be cleared each time they occur. Clearing errors may allow the user to continue using the system for process operation.

The *Diagnostics* screen also displays a list of numeric error codes for all error categories. These error codes are intended to aid the manufacturer in diagnosing any faults.

For serious errors, e.g., controller or thermocouple errors, remedial action must be taken. Further information regarding errors and remedial action is available from the manufacturer.

11. Warranty

The ANNEAL system is shipped with a 12-month warranty valid from date of installation or 2 months following date of shipment, whichever date is earliest.

Warranty extensions and service contracts are available. Please contact the manufacturer for details.

12. Manufacturer Contact Details

The manufacturer of ANNEAL systems is Moorfield Nanotechnology Limited.

The manufacturer's address is:

Moorfield Nanotechnology Limited,
Unit 1 Wolfe Close,
Parkgate Industrial Estate,
Knutsford,
Cheshire,
WA16 8XJ.
United Kingdom.

Telephone number: +44 (0) 1565 722609
Fax number: +44 (0) 1565 722758
Email address: sales@moorfield.co.uk
Website: http://www.moorfield.co.uk