CambridgeNanoTech
Simply ALD

Fiji 200

Fiji F200

200mm Thermal/Plasma ALD systems

Installation and Use Manual

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Cambridge NanoTech Inc. welcomes requests for information, comments and inquiries about its products.

Cambridge NanoTech Simply ALD

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SECTION 1: System Overview – Base System

System Description – Base System with Plasma

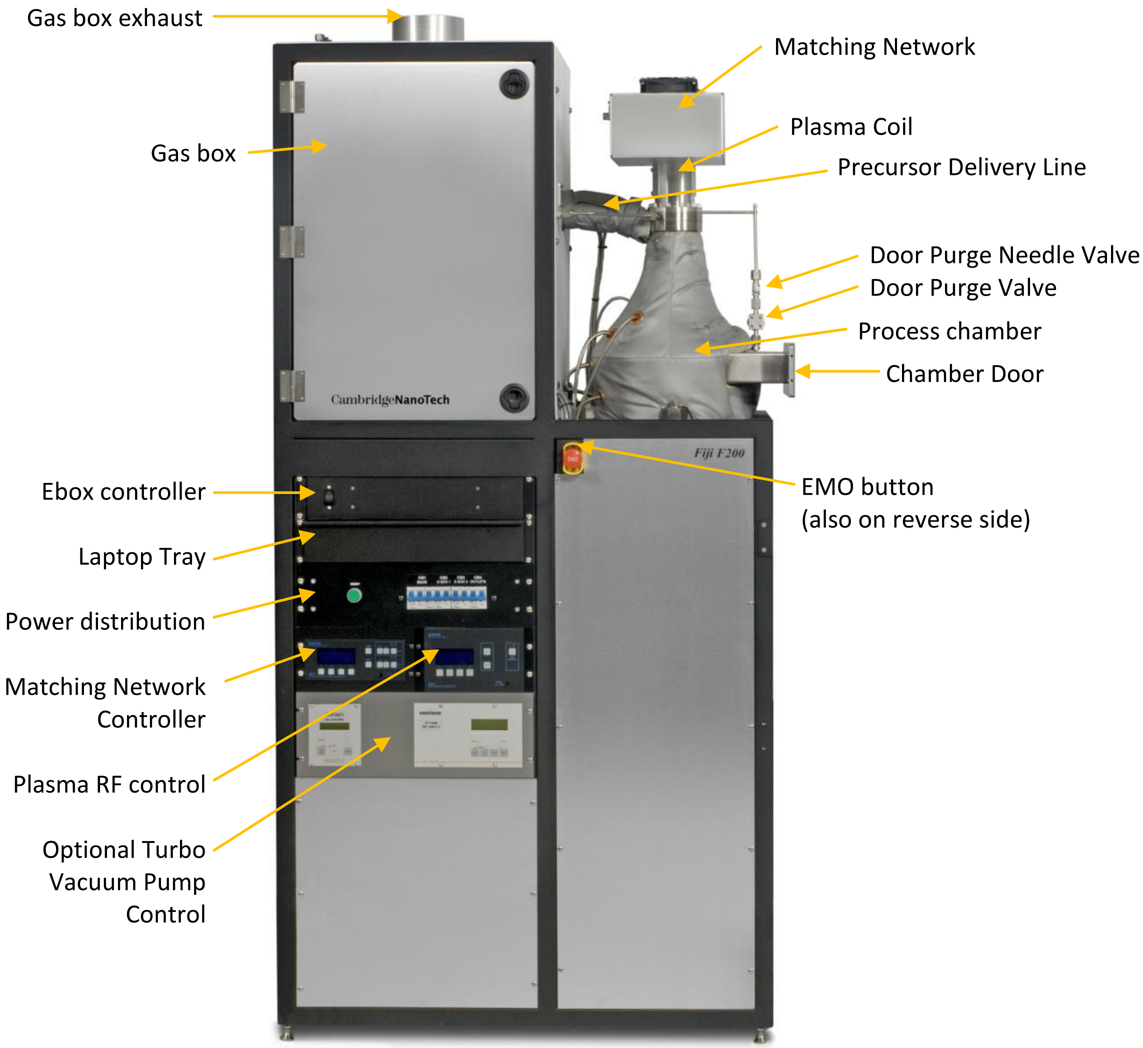
The Cambridge NanoTech Fiji F200 series is a modular medium to high-vacuum ALD system that accommodates a wide range of deposition modes using a flexible system architecture and multiple configurations of precursors and plasma gases. Main features include of a base system include:

- 200mm Thermal/Plasma ALD system
- 500^{o}C chuck heater
- Remote inductively coupled plasma source
- 4 plasma gases standard, 6 optional
- Ultra-high cycle / high speed actuation ALD Diaphragm valves
- 4 precursors standard, 6 optional
- Integrated ALD Shield^{TM} vapor trap
- Dual Pirani / Convection Pressure gauge
- Multiple Heaters: Precursor Heater Jackets, ALD Valve Manifold heater, Reactor Heater Jackets, and Heated Isolation Valve
- Intuitive software
- Hardware and Software Intelocks
- Revolutionary chamber design
- Modular design
- Compact footprint
- Maximum experimental flexibility

The Fiji F200 ALD process chamber, heater and trap geometries have been optimized for ALD processing: the hyperboloid chamber geometry combined with the paraboloid substrate heater creates a laminar precursor and remote plasma generated radical flow. This design optimizes deposition uniformity and minimizes cycle time and precursor use.

The Fiji F200 is available in several configurations and can be equipped with a maximum of 6 heated precursor cylinders and a maximum of 6 plasma gas lines, offering experimental flexibility in a compact footprint.

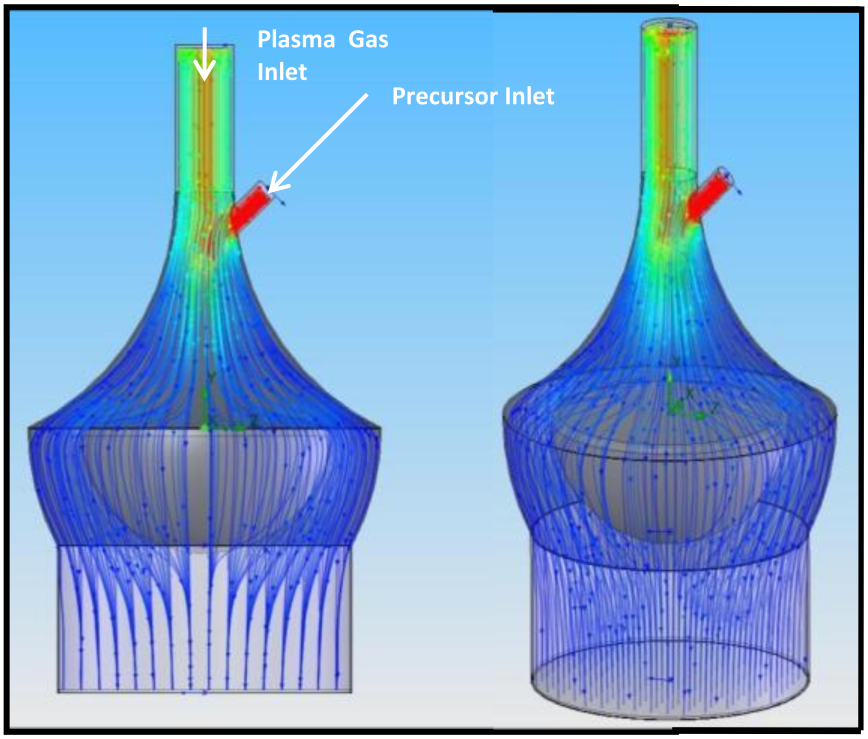
System Main Components Overview



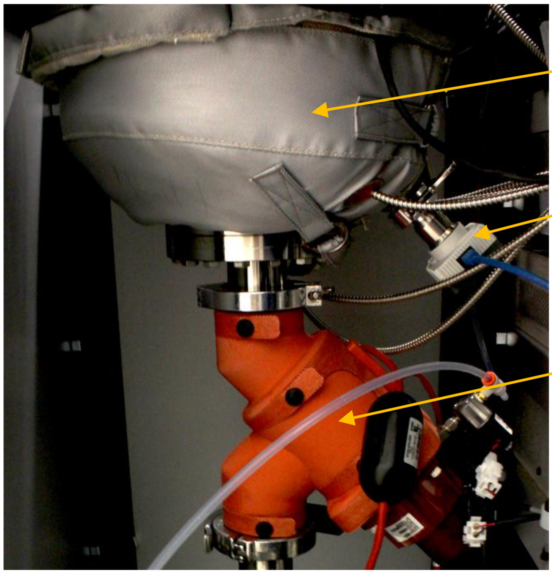
Fiji F200 Base System

Process Chamber

- Designed with computational flow analysis to determine optimal chamber and chuck geometry
- Uniquely shaped chamber yields laminar flow, maximum radical efficiency and uniform depositions
- Minimal precursor and plasma gas consumption
- Reduced cycle times



ALD Shield™



Trap - ALD Shield™ 'Trap' inside heated blanket

Vacuum Gauge

Stop Valve
(also called 'Jalapeño Valve')

Cambridge NanoTech's ALD Shield™ allows excess reactive vapors to form a film before they reach the pumping system, thus reducing deposits on the plumbing and in the pump. This saves money in maintenance costs and prevents excess gases from being exhausted to the environment. The ALD Shield's high conductance hot foil design causes gases to deposit until depleted. Over time, excess precursor collects on the ultra-high surface area trap. The trap must be removed and sent out for cleaning at regular intervals to protect the system vacuum pump.

- Reduces build-up of deposits on the downstream plumbing and inside the pump
- Reduces maintenance costs
- High conductance, hot foil design
- Easily cleaned and re-used
- Prevents excess unreacted precursor material from being exhausted to the environment
- Integrated within the Fiji

Stop Valve

The MKS Jalapeño heated stop valve is a normally closed automatically controlled vacuum shutoff valve which isolates the process chamber from the vacuum pumping system. The stop valve is closed when venting the process chamber to atmosphere to load/unload a substrate. In certain process conditions, the valve can also be closed as desired during processing to allow additional precursor residence time in the process chamber to allow full saturation/exposure of precursor chemicals for uniform conformal coatings of high aspect ratio features or porous substrates. The stop valves are heated to prevent condensation of precursor materials. The heaters have an internal temperature controller with a setpoint of 150°C.

Vacuum Gauge

Edwards APGX-H pressure gauge is dual Pirani and convection gauge which provides direct readout of process chamber pressure at all times. Since the gauge is exposed to the process environment to measure the chamber pressure, excess precursor will coat the gauge sensor and cause an apparent drift in pressure over time. The gauge should be calibrated during all standard maintenance intervals, and replaced periodically, depending on system use and precursor buildup on the sensor tubing.

Heaters

The Fiji System allows operation and of multiple zone heating for control of reactor temperature. From an upstream to downstream flow direction, the heaters include: precursor heater jackets, ALD valve manifold heater, precursor delivery line heater, top reactor heater jacket with 2 zone heating, heater chuck, and cone (or trap heater).

Factory default heater setpoints are shown below:

Heater Location	Temperature		Notes
	Default	Max.	
Cone/Trap	250°C	300°C	
Process Chamber Heater 1 & 2	250°C	300°C	
Chuck	250°C	500°C	
Precursor delivery line	150°C	200°C	
Precursor manifold	150C	150°C	
Precursor cylinders (jackets)	0°C	120°C (ball valve) 220°C (bellows valve)	**WARNING**: Temperature of the precursors should not exceed safety or decomposition temperature of the chemical used. Precursor temperatures need to be set manually to meet the heat needs of specific precursors.
Stop valve	-	-	Not adjustable – internal setpoint of 150°C

Inductively Coupled Plasma

The Fiji system includes a remote Inductively Coupled Plasma (ICP) source, 300W standard, 600W optional. The ICP provides excellent film uniformity with minimal substrate damage - allowing the growth of ALD films with lower organic incorporation. The Fiji generates plasma in the remote ICP source outside of the reaction chamber, protecting the substrate from damage. The ICP source has a constant gas flow to provide a constant downward laminar flow to prevent condensation and reaction of precursor material within the plasma source.

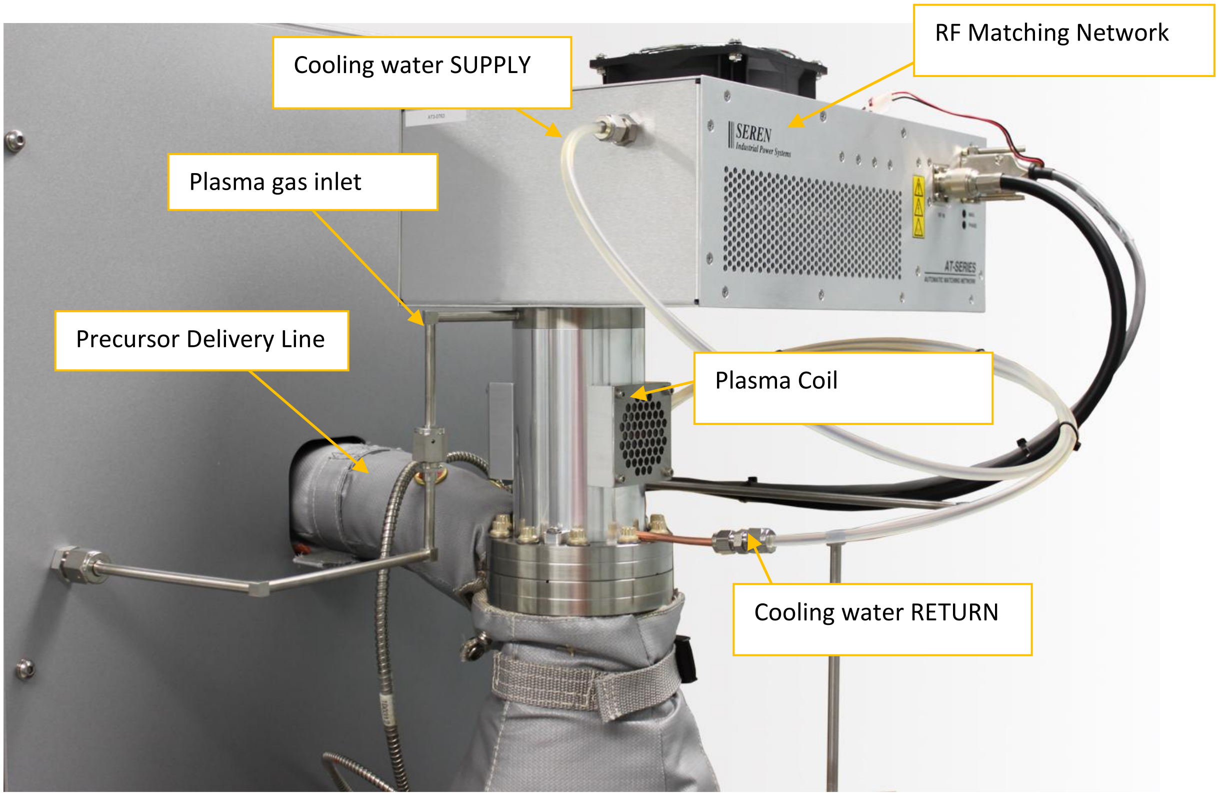
Plasma-generated co-reactants

Advantages:

- Increased growth rates at lower deposition temperatures
- Decreased processing temperatures
- Decreased purge steps
- Decreased nucleation delay
- Reduced film impurities
- New materials/alternative precursors

Plasma Components

The plasma coil and RF Matching Network are mounted on the top of the process chamber, as shown below:



Plasma Mounted on Process Chamber

Standard Gas Box Configurations

Each system is configured with a gas box which contains components as necessary to deliver and then purge precursor material and reactive plasma gases with an inert carrier gases to the process chamber as well as vent/purge of system component. Typical components include:

- ALD valves for repeatable introduction of precursors to the process chamber
- Precursor cylinders
- Mass Flow Controllers (MFCs) to control the flow of gases in the system
  Pneumatically-controlled shutoff valves
- and supporting manifolds, tubing, and components (described below)

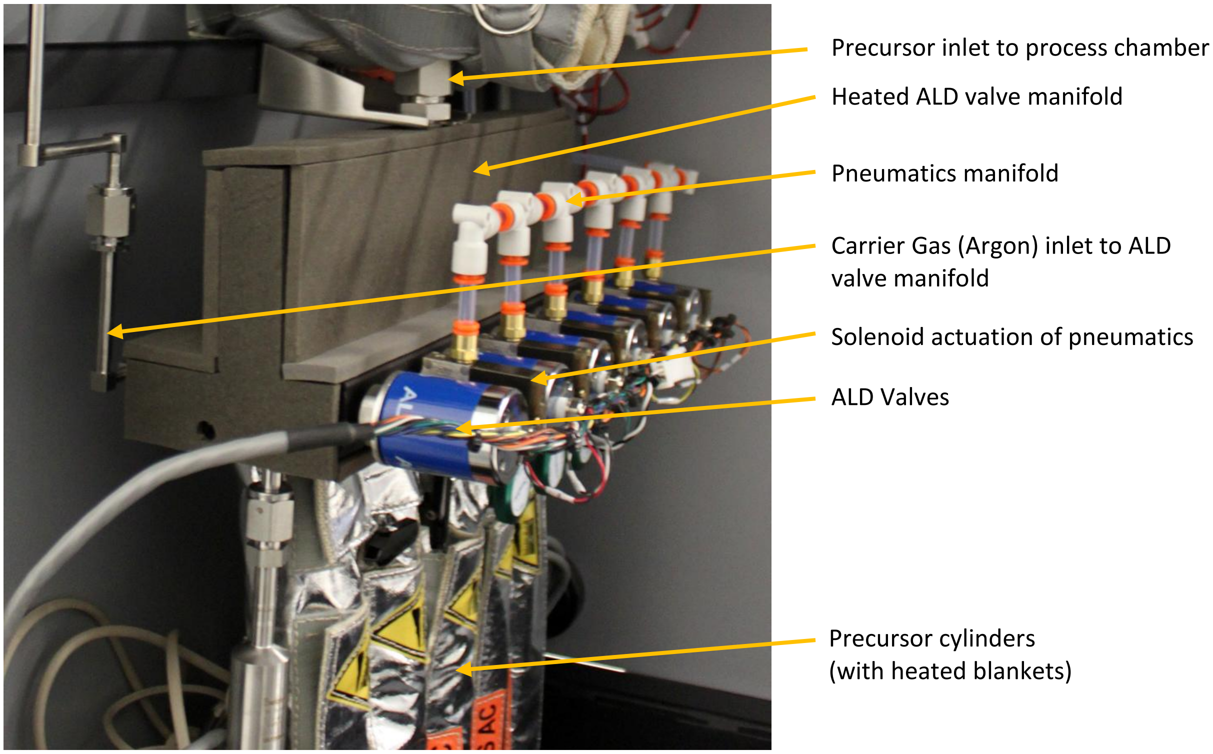
ALD Valve Manifold

ALD valves are ultra-fast action valves which open and close rapidly to precisely control precursor introduction to the process chamber.

The valves are called “3-way valves” for the three ports on the valves:

- Precursor inlet
- Ar carrier gas inlet
- Outlet to process chamber

The 3-way valves allow continuous flow of argon through the valves (carrier gas) to entrain the flow precursor material into the process chamber and keeps the valves and lines purged of precursor material between pulses.



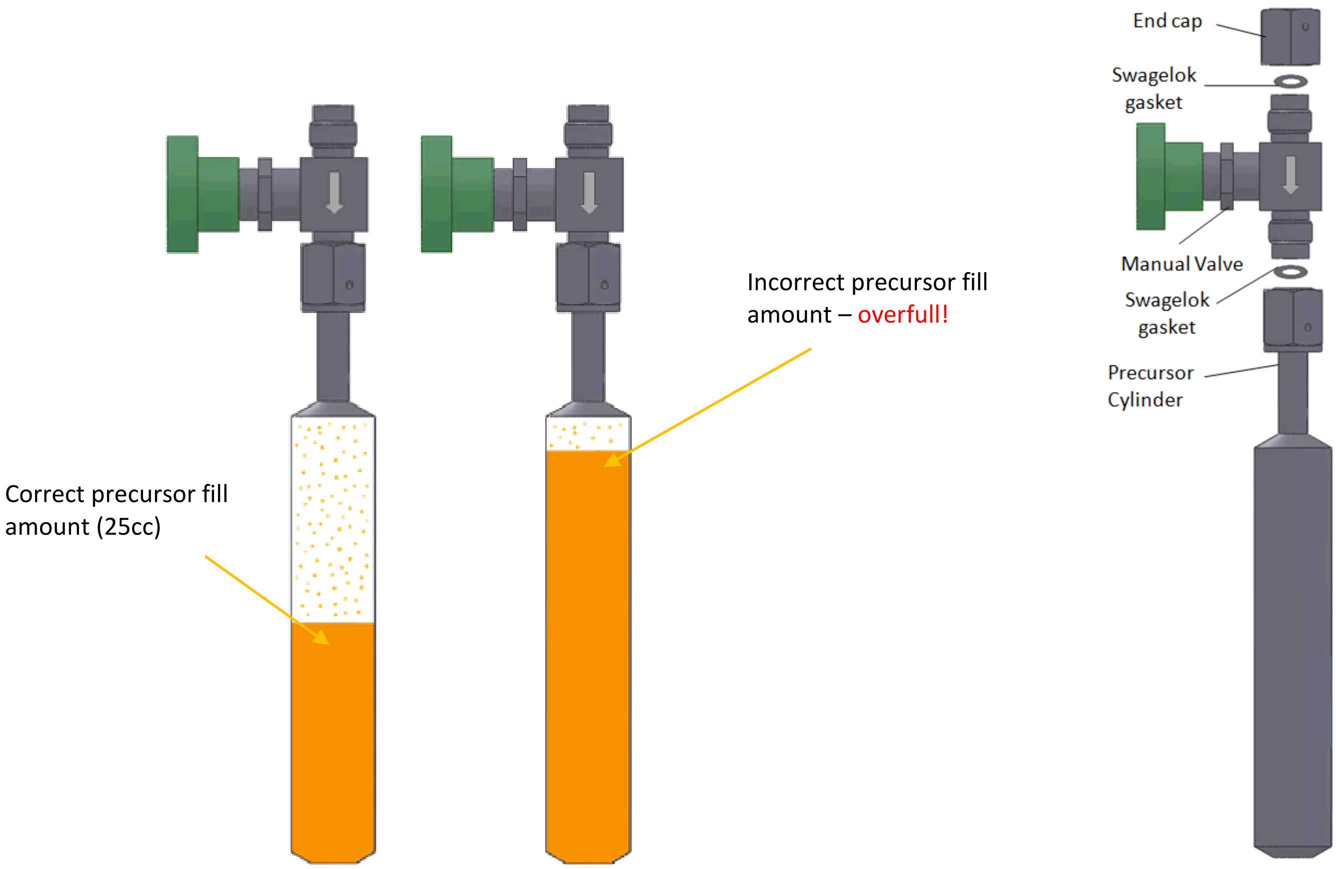
Precursor Cylinders

Many ALD precursors are air sensitive and/or pyrophoric. Therefore, precursor cylinders should be filled under an inert atmosphere (such as inside a glovebox) by the chemical supplier. Never disconnect manual valves from the precursor cylinders. Please contact support@cambridgenanotech.com for recommended chemistries and suppliers.

Precursors should be dispensed into the cylinder so that they are no more than half full (or 25cc of material).
This allows sufficient room for the precursor to volatilize. As the precursor dose is based on the vapor phase in the cylinder, if the cylinder is filled more than half full the precursor dose may be smaller than expected.
This may result in no film growing.

CAUTION: OVERFILLING THE CYLINDER MAY RESULT IN LIQUID BEING PULLED INTO THE SYSTEM.

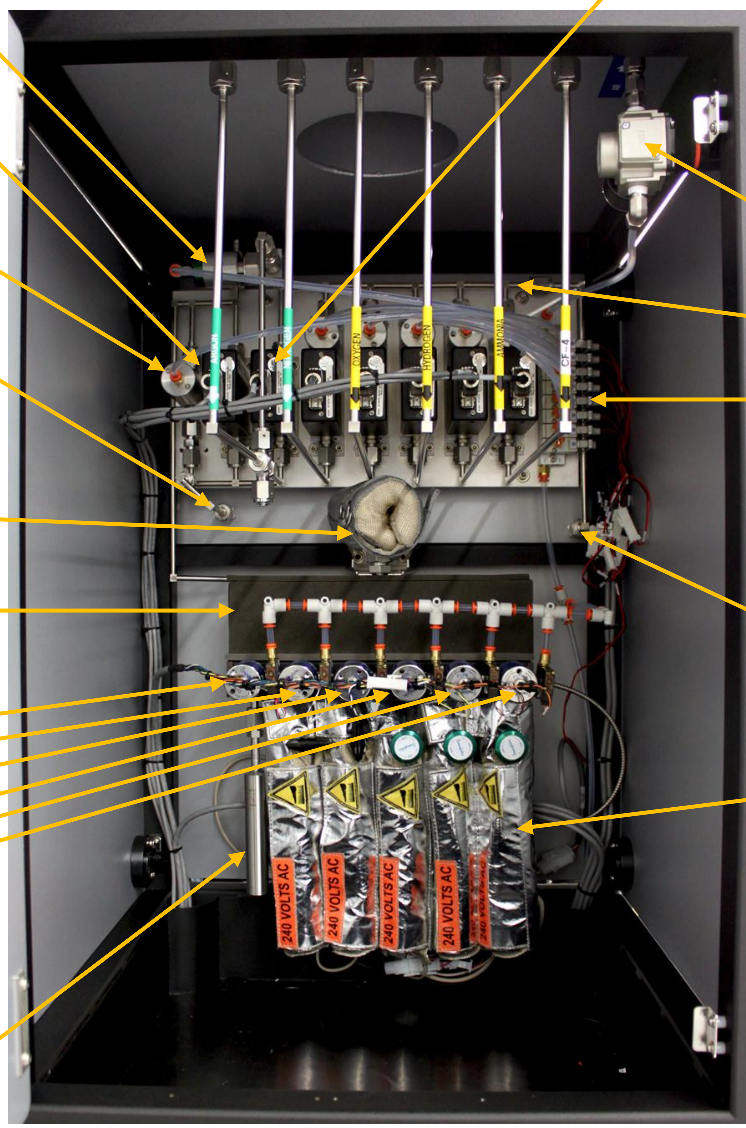
The green headed bellows valve (SS-4H-VCR) is a bellows valve and can be heated to 220°C. The valve should be assembled with the arrow facing down into the cylinder. This configuration leaves a smaller dead space between for precursor to accumulate into helps to prevent clogged valves. While Cambridge NanoTech systems ship with SS-4H-VCR bellows valves, an optional ball valve SS-42GVCR4 can also be used. These valves are not for use with precursors requiring heating over 120°C.



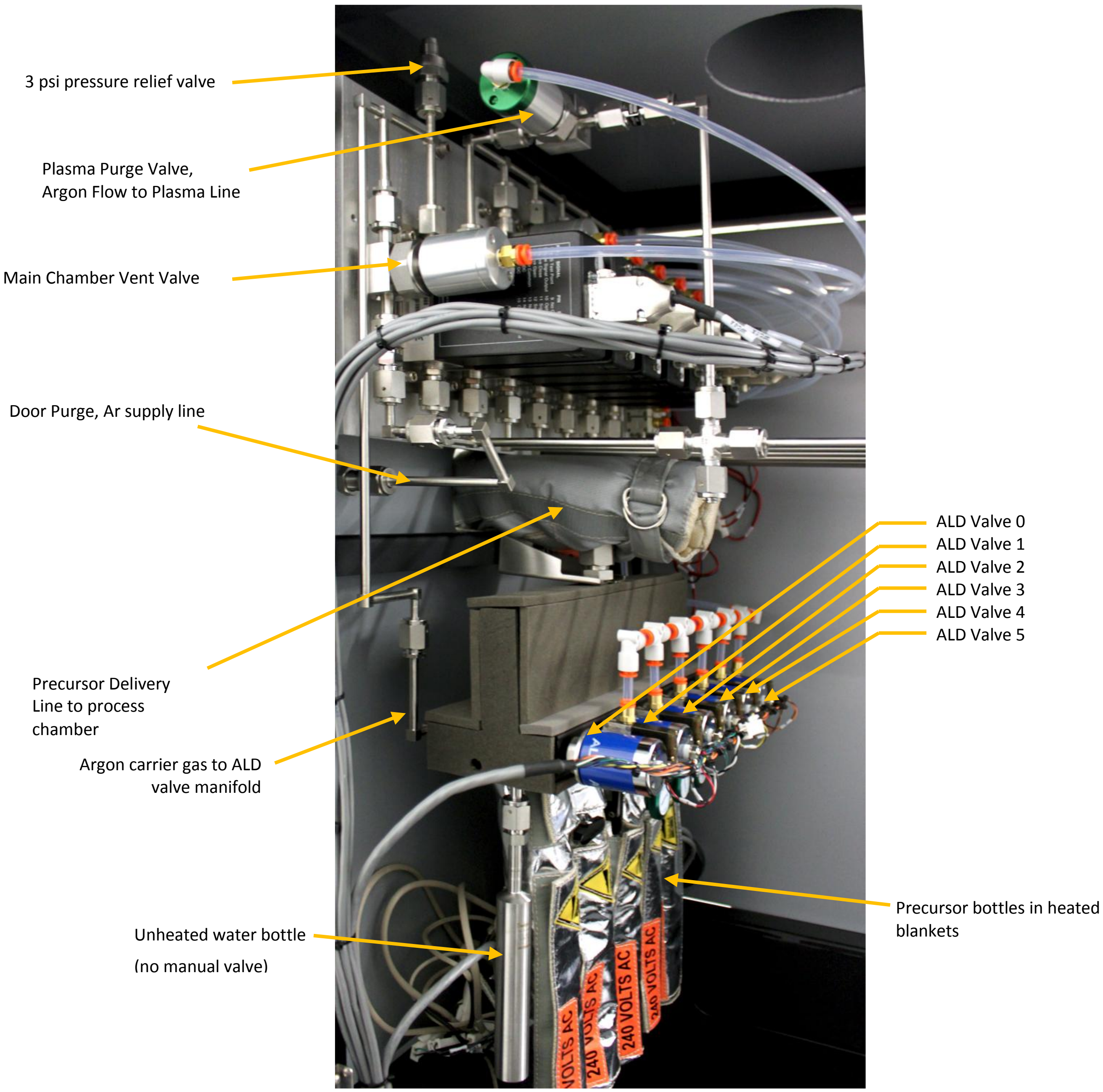
MFCs

- Each reactive plasma gas is provided with an MFC and shutoff valve to control the flow of gas into the system and prevent cross-contamination.
- A carrier gas MFC delivers Argon flow to the ALD manifold block. The carrier gas entrains precursor material into the process chamber and purges the system between precursor pulses.
- The Ar Plasma MFC flow is maintained at a higher flow rate than the Ar Carrier MFC during processing. This ensures a downward gas flow during processing, preventing condensation of precursor material in the plasma source.

Gas Box with Six Precursor Cylinders



Gas Box, Typical, 6-bottle, front view

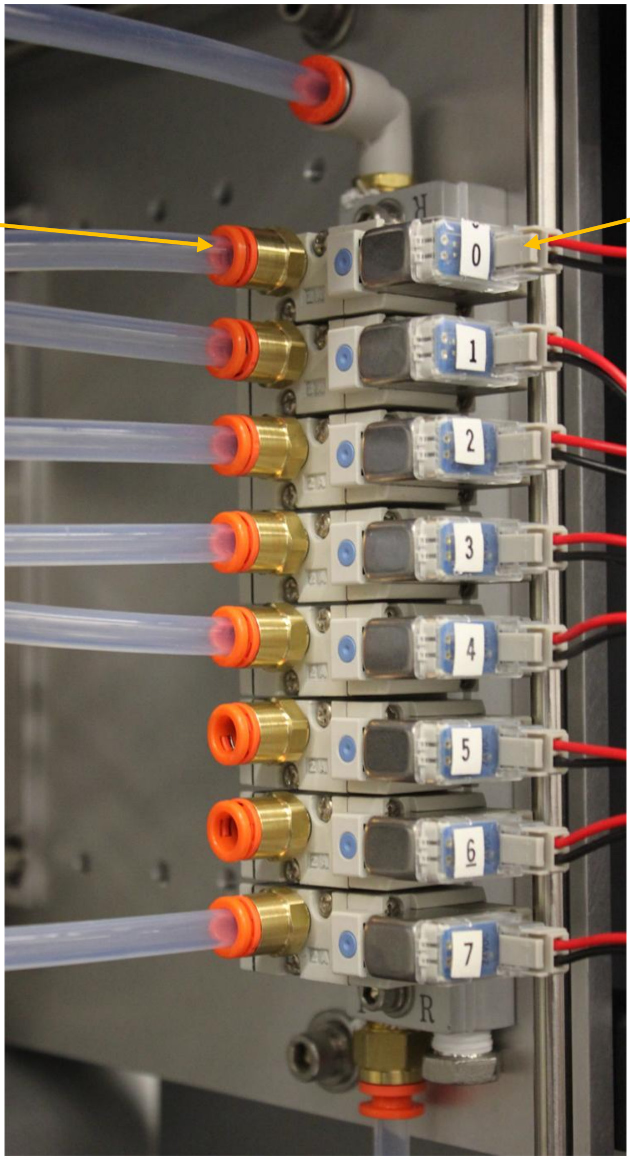


Gas Box, Typical, 6-bottle, side view

Pneumatics Control Bank

The gas box contains multiple pneumatically controlled shutoff valves. Valves are opened or closed through the system software by sending a 24V signal to individual solenoids on the pneumatics bank.
Typical layout is shown below:

0 = Main Chamber Vent Valve
1 = Ar Plasma Purge Valve
2 = N2 Plasma – MFC Valve 2
3 = O2 Plasma – MFC Valve 3
4 = H2 Plasma – MFC Valve 4
5 =NH3 (optional) Plasma – MFC Valve 5
6 = CF4 (optional) Plasma – MFC Valve 6
7 = O2/O3 (optional) – MFC Valve 7

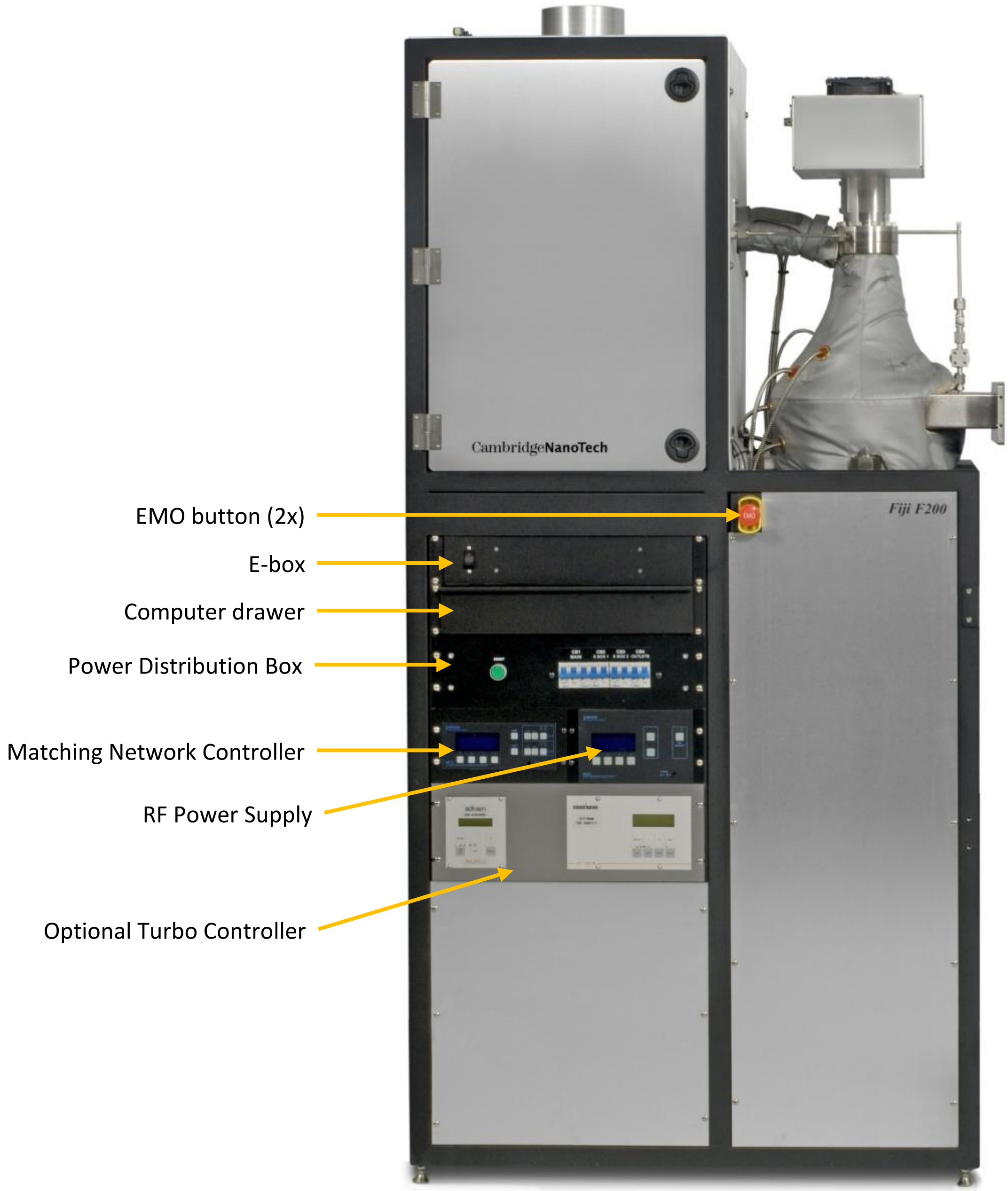


Electrical signal connections to pneumatic bank

Controls Pneumatic Bank

System Electronics Rack

The electronics rack includes the system computer, electronics box (main electronics control box), power distribution box, plasma control, and related controllers. Additional controllers and internal components including power distribution and gas box interlock are factory-configured.



System Control

Process recipes and system startup/shutdown, configuration, and settings are performed via the supplied Windows® platform laptop computer. The computer is stored in a "computer drawer" on the electronics cabinet (below the gas box):

System Software on Control Laptop

Main Features

- Process control is through LabVIEW™ software
- USB connection to PC/laptop
- Intuitive GUI: <1 hr learning

Software Control

- Temperature
- Gas flow
- Pulse duration
- Plasma pulse
- Deposition Mode
- Pressure
- Turbo (optional)

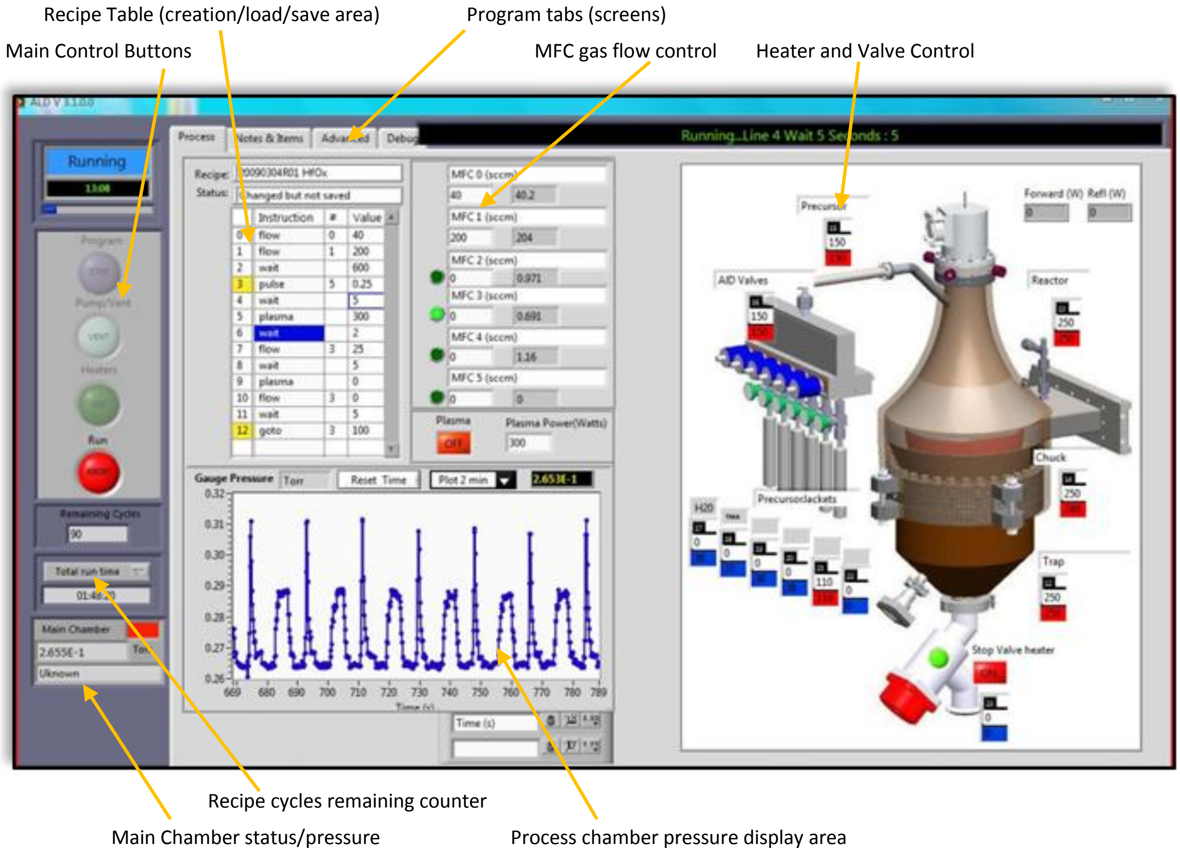
Safety

- Software safety interlocks
- Overpressure abort
- Faulty recipe entry warnings

Program Features

- Edit, save and load recipes
- Example recipes and right-mouse click recipe save
- Automatic data logging

A brief overview of the process screen is summarized below:



Process Screen

Operation Principle

The Fiji Atomic Layer Deposition (ALD) system automates the creation of precisely controlled films on substrates. Films are created by pulsing a precursor material into the ALD reaction chamber where the precursor reacts with the substrate surface. Excess, non-reacted precursor is then purged from the chamber. The cycle repeats with appropriate precursor materials to grow the ALD film layer by layer. A key element of the deposition is the self-limiting nature of the process which allows repeatable, uniform, monolayer-by-monolayer growth, with a fairly broad process window. The resulting films are pinhole-free, uniform, high density, and extremely conformal.

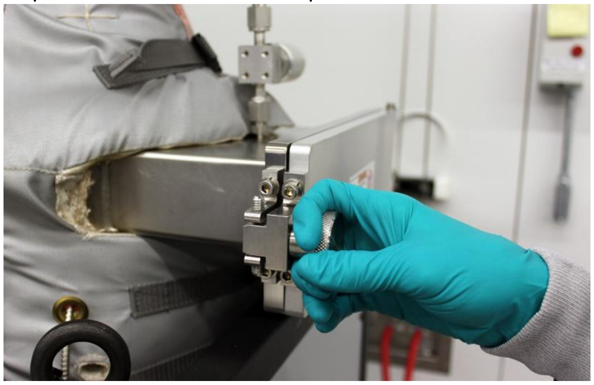
Typical Substrate Loading Sequence

Manual Load System	Load/Lock System
The process chamber is vented up to atmospheric pressure to open the chamber door A user loads a substrate onto the substrate carrier, manually loads the substrate carrier into the system, then closes the chamber door. The user then uses the main control button 'PUMP' to pump down the system, then a recipe may be created or loaded and started by clicking 'RUN' Process modes are described on the following pages.	1. The loadlock is vented (high flow of inert gas) up to atmospheric pressure to open the load port (the process chamber remains under vacuum) 2. A user loads a substrate onto the substrate carrier then closes the load port 3. The loadlock is pumped down under vacuum (and optional turbo pump) until the loadlock pressure is equalized with the process chamber pressure. 4. The gate valve between the loadlock and the process chamber is then opened. The loader is then used to transfer a substrate from the load lock to the process chamber, then the loader is retracted out of the process chamber and the gate valve between the chamber and the lolalock is closed. 5. Process modes are described on the following pages.

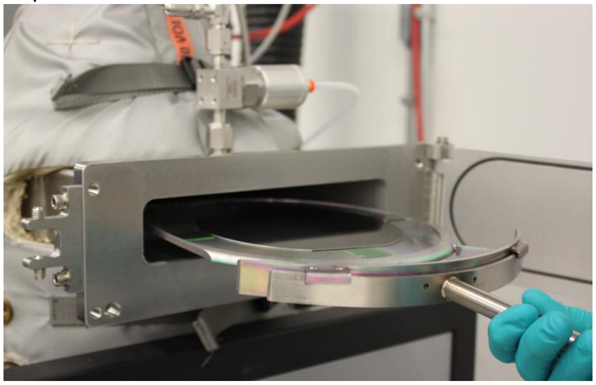
Manual Substrate Loading

The base Fiji F200 system is equipped with a manual loading door. A substrate is placed onto a substrate carrier, then the manual load arm is used to lift up the carrier, and place the substrate carrier inside the process chamber on the heated chuck. After loading, the door is closed and the process chamber is pumped down. The sequence is summarized below:

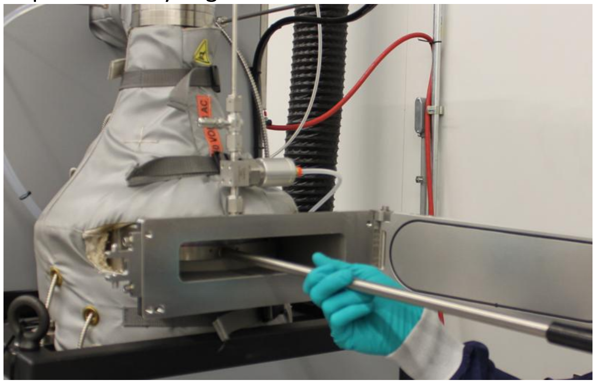
Step 1: Vent chamber then open the manual door



Step 2: Load the substrate carrier into the chamber



Step 3: Carefully align the carrier on the heated chuck



Deposition Modes

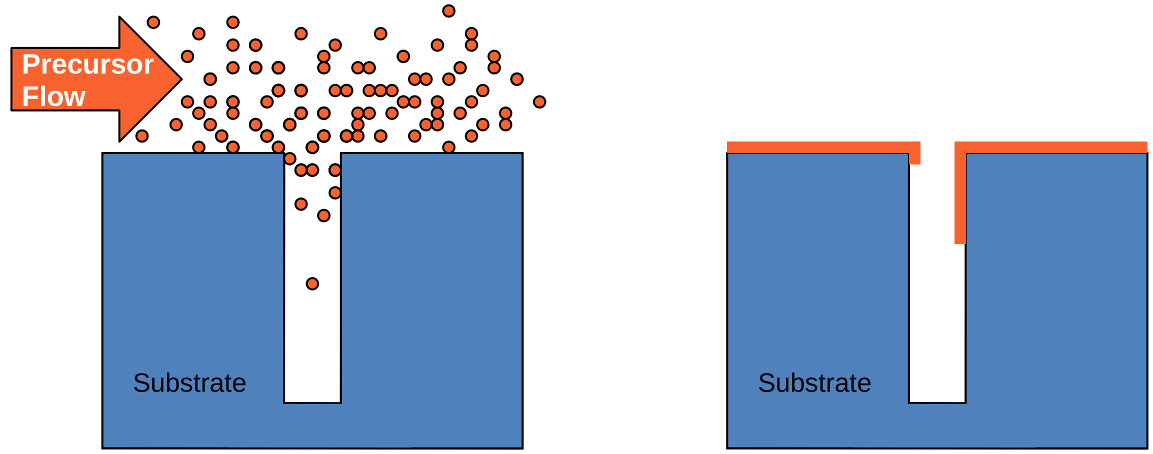
The Fiji system can be run in one of three deposition modes, as summarized below:

	Continuous Mode™	Exposure Mode™	Plasma-Mode™
			
Feature	High Speed	High Aspect Ratio	Plasma-Assisted
Typical Use	• Thermal • Rapid film growth	• Thermal • Ultra-high aspect ratio structures	• Plasma-assisted • Difficult nitrides and metals • Film optimization
Process Sequence	1. Carrier gas is flown continuously into the process chamber and drawn out of the chamber by the system's vacuum pump. 2. An ALD valve opens briefly to allow a "pulse" or vapor draw of the selected precursor into the process chamber. 3. The software "waits" a user-defined time in the programmed recipe for the precursor to react on the substrate and for the carrier gas to remove or "purge" the unreacted (excess) precursor and chemical reactants from the chamber. 4. An ALD valve opens briefly to allow a "pulse" of a second precursor into the process chamber. 5. The pulse/wait-purge sequence continues as programmed, for the user-defined software sequence of precursor introduction to the process chamber.	1. Carrier gas is flown continuously into the process chamber and drawn out of the chamber by the system's vacuum pump. 2. The stop valve is closed to isolate the process chamber from the vacuum exhaust line. 3. An ALD valve opens briefly to allow a "pulse" or vapor draw of the selected precursor into the process chamber. 4. The precursor is allowed increased residence time in the process chamber to diffuse and react on high aspect ratio feature surface sites for full saturation (exposure). 5.4. The stop valve is opened to allow the vacuum pump to resume normal operation of evacuating (purging) excess precursor and carrier gas from the process chamber. 6.5. The process repeats (close stop valve, pulse precursor, wait, then open stop valve), as required to create ALD growth.	1. Carrier gas is flown continuously into the process chamber and drawn out of the chamber by the system's vacuum pump. 2. An ALD valve opens briefly to allow a "pulse" or vapor draw of the selected precursor into the process chamber. 3. An MFC opens to flow the selected process gas into the process chamber (Oxygen, Hydrogen, etc.). 4. The plasma source is turned on to expose the substrate in the process chamber to the plasma generated radicals. 5. The software "waits" a user-defined time in the programmed recipe for the precursor to react on the substrate and for the carrier gas to remove unreacted (excess) precursor and chemical reactants from the chamber. 6. The pulse/plasma/wait-purge sequence continues as programmed, for the user-defined software sequence of precursor introduction to the process chamber.

Exposure Mode Summary - Coating High Aspect Ratio Structures

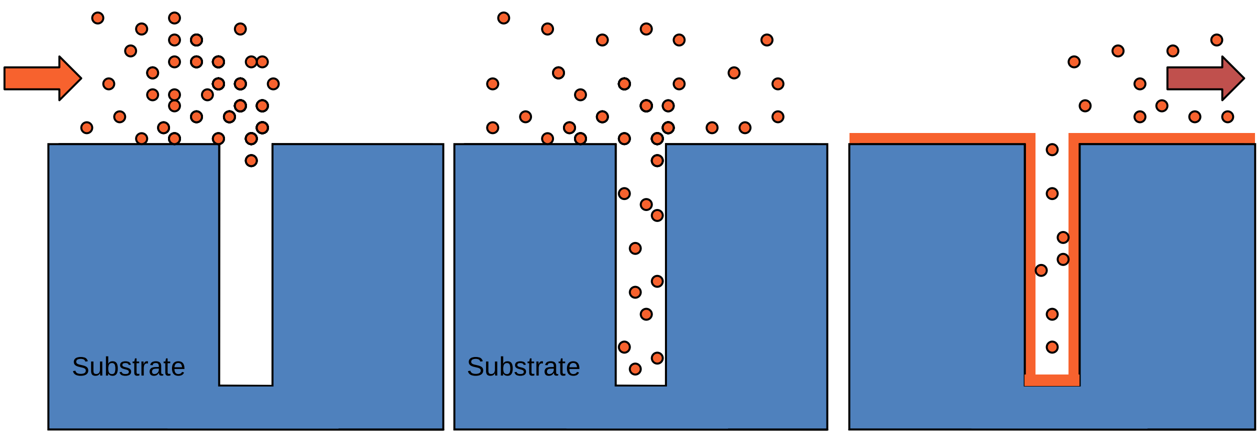
Without Exposure Mode

Continuous dosing and cross-flow of precursor does not allow for diffusion of precursor down into trenches



Higher doses of precursor increase the reactant partial pressure at the top of the feature.

With Exposure Mode – Uniform Coatings



Isolate chamber to static vacuum;

Introduce a dose of precursor

Allow time X for precursor to diffuse into trenches, pores,

Purge for time > X to remove excess precursor. Repeat for second precursor.

Enjoy uniform coatings.

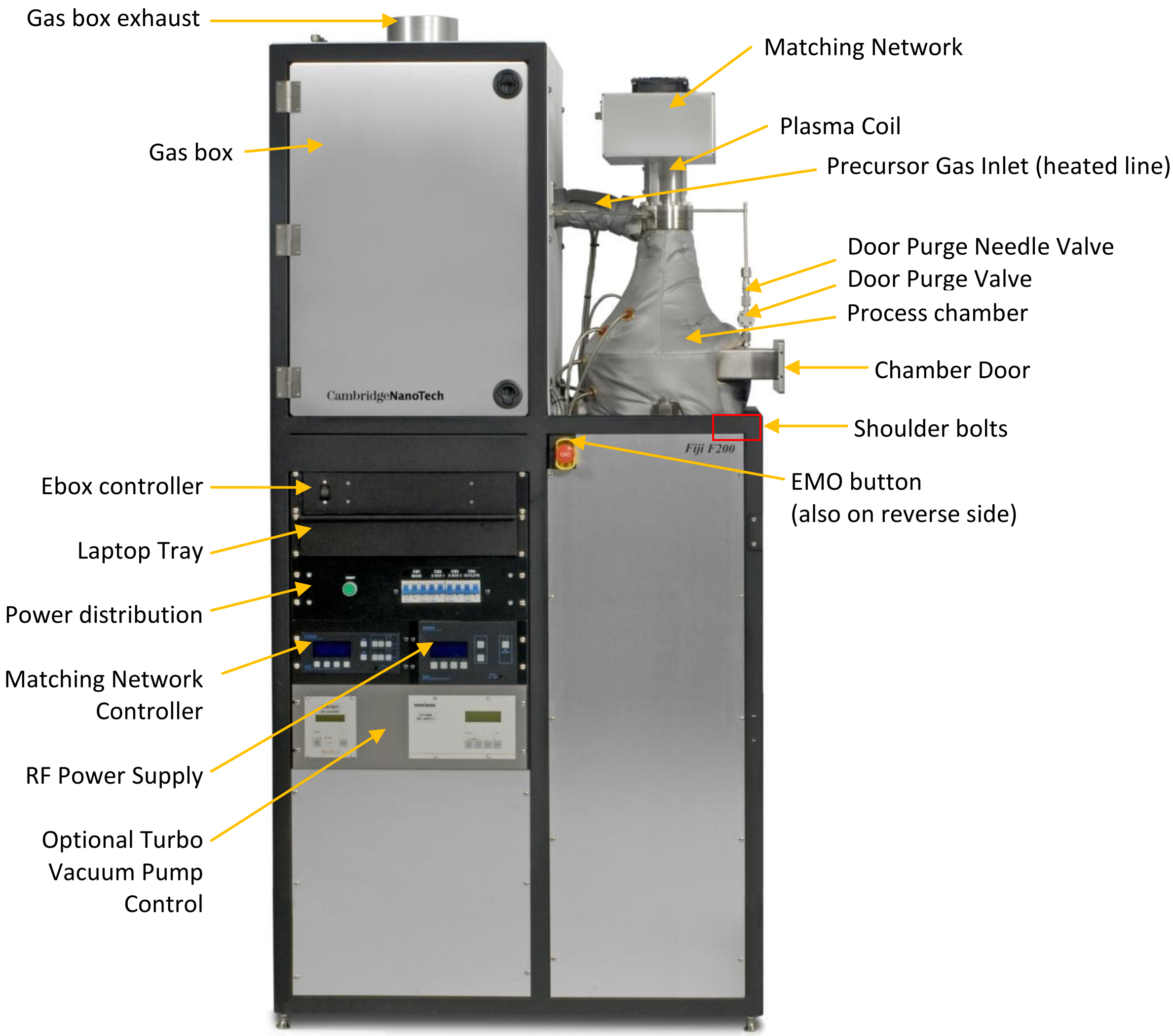
Fiji Base System Standard Specifications

Item	Specification
Substrate size	Up to 200 mm with a maximum sample height of 6.35mm
Dimensions	Length: 114 cm (45”) Width: 89 cm (35”) Height: 216 cm (85”)
Cabinet	Removable Aluminum panels, adjustable feet, optional cleanroom interface
Deposition Modes	Continuous Mode (high speed) Exposure Mode (high aspect ratio) Plasma Mode (plasma-assisted)
Power	220-240 VAC, 4500 W per reactor (excluding pump)
Control	LabVIEW®, USB, Windows® PC
Substrate Temperature	500°C (800°C optional)
Vacuum Pump	Optional integrated dry pump, >50 CFM required, optional mag-lev turbo pump
Compliance	CE, CSA

SECTION 2: Human Interface (Loading) Options

Fiji F200 System with Manual Load Door

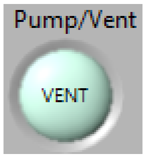
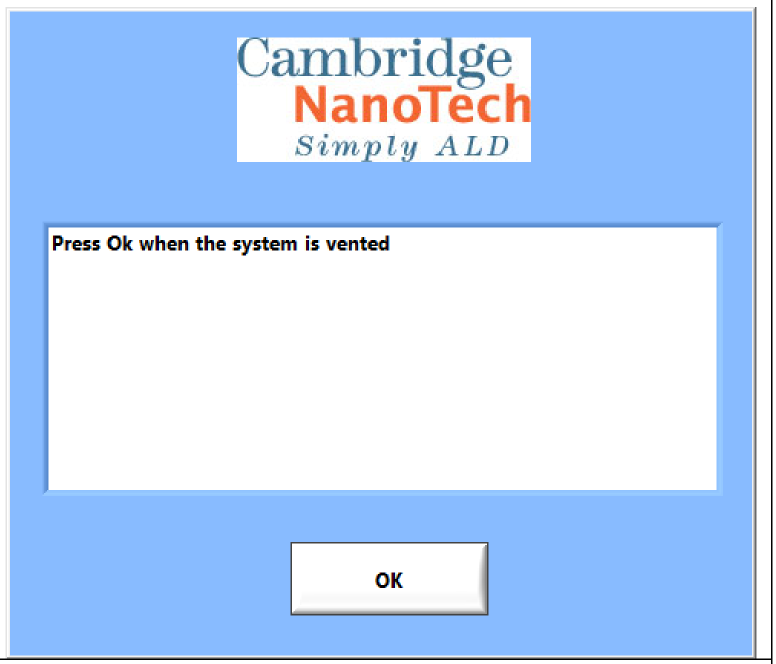
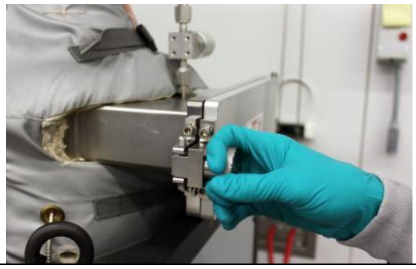
The base Fiji F200 system is a single chamber system equipped with a hinged chamber door for manual loading. A substrate is placed onto a substrate carrier, then the substrate carrier loader arm is used to lift the carrier and place the substrate carrier inside the process chamber on the heated chuck. After loading, the door is closed and the process chamber is pumped down. A pair of shoulder bolts is installed on the side of the Fiji frame so that the substrate carrier loader arm may be stored while not in use. It is recommended that a stainless steel table or other heat resistant surface be available in proximity to the Fiji system for setting down the hot substrate carrier in between processing for transferring samples. The sequence is summarized in the photos below:

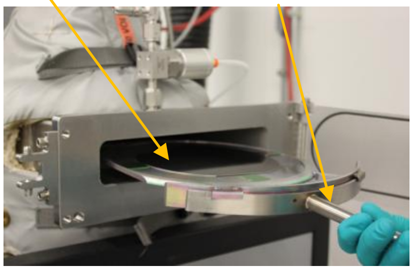
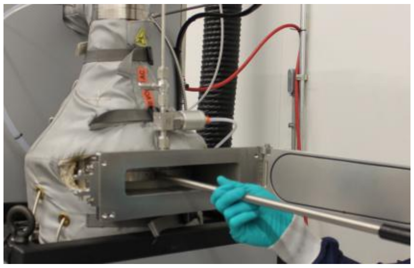
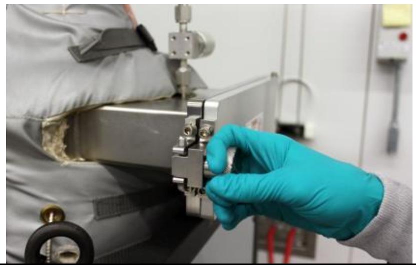
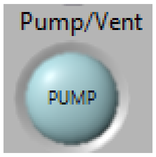


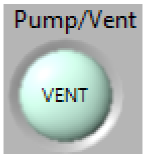
Fiji F200 Base System

Manual Load Door: Processing a Substrate

Use this procedure AFTER completing the **Error! Reference source not found.** procedure.

Step	Action	Details
1.	From the **Process** tab, press "**VENT**" to vent the process chamber.	 The system automatically performs the following sequence of steps (summarized): • The main vacuum stop valve will close to isolate the chamber from the vacuum system • The main chamber vent valve will open to vent the main chamber to atmospheric pressure. • Once atmospheric pressure has been reached, the chamber door can be opened
2.	Press **OK** on the software popup screen to turn off the main chamber vent valve.	
3.	Open chamber door	

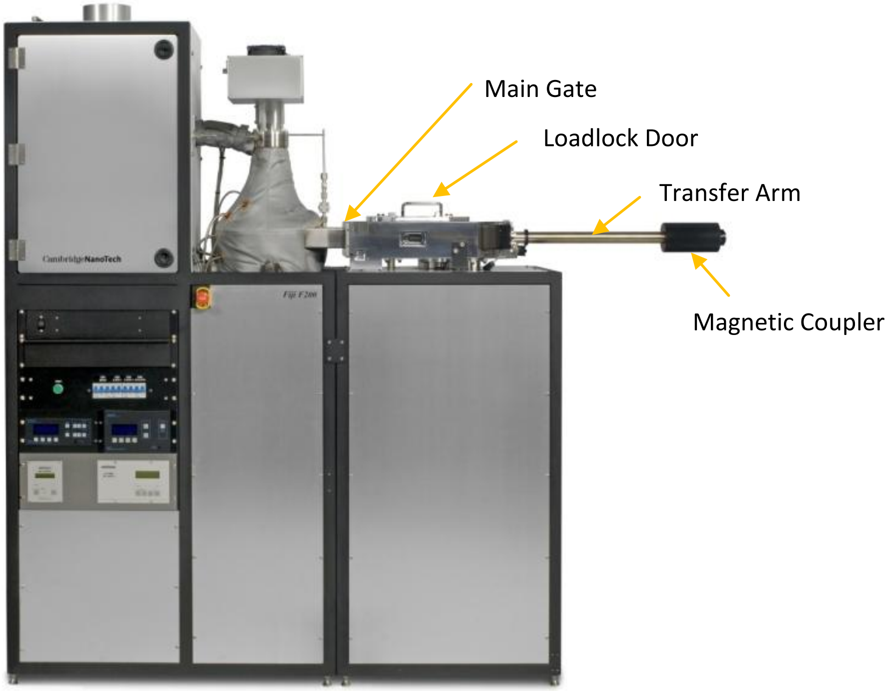
4.	Load substrate carrier into chamber and carefully align carrier on heated chuck. Note: Be careful not to damage polished vaccum sealing surfaces on the face of the reactor at the chamber door.	
5.	Close chamber door	
6.	From the **Process** tab, select **Pump** to pump down the process chamber**.** Follow the system prompts.	

7.	Create/load a recipe. Refer to the Software Reference section of this manual for details on process steps.	Load or create your process recipe as necessary for your run. Refer to the software reference section of this manual for details.
8.	From the **Process** tab, press the run **Start** button to begin processing.	
9.	After the process run has completed, from the **Process** tab, select **Vent** and follow the system prompts to unload the sample from the system.	

Fiji F200 System with VAT Loadlock

The Fiji F200 system is available with a VAT loadlock system which isolates the process chamber from atmosphere and the surrounding lab environment. The VAT loadloack with transfer arm allows the process chamber to remain under vacuum while a substrate is manually placed onto the substrate carrier in the loadlock, as shown below.

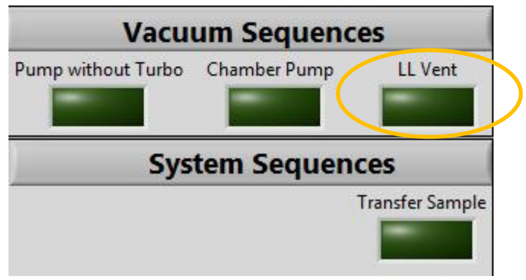
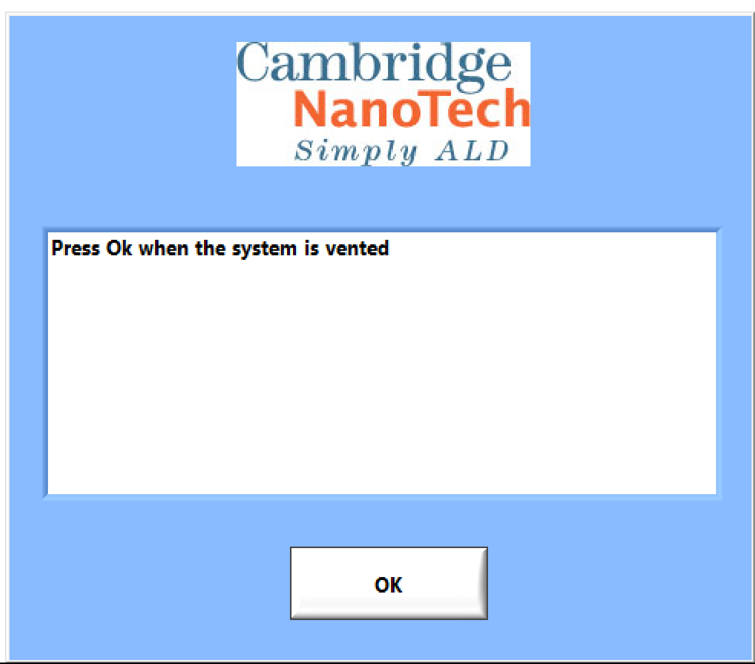
After loading a substrate, the loadlock chamber is closed then pumped down. After reaching the appropriate differential pressure between the loadlock and process chamber, the main gate valve between the loadlock and process chamber is opened. The substrate carrier is then manually transferred via a magnetically-coupled transfer arm onto the heated chuck in the process chamber.

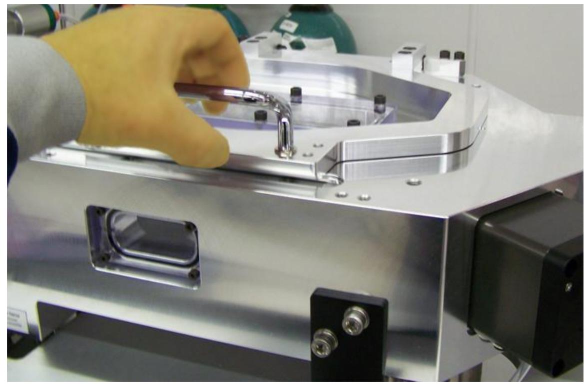
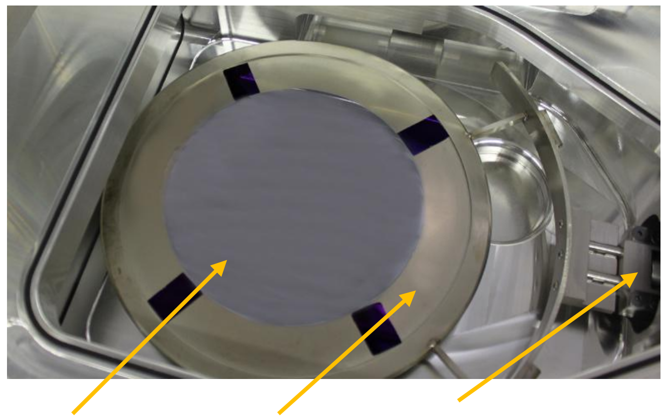
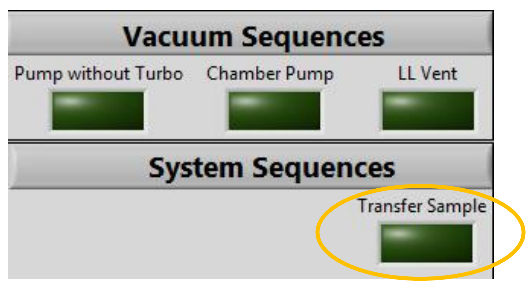


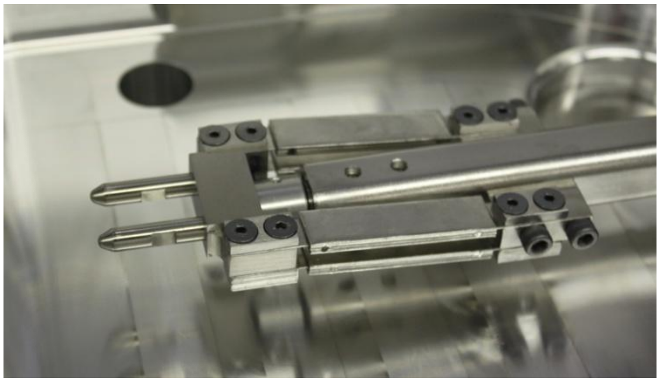
Fiji F200 System with VAT loadlock with manual transfer

VAT loadlock with Manual Transfer: Processing a Substrate

Use this procedure AFTER completing the **Error! Reference source not found.** procedure.

Step	Action	Details
1.	From the **Vacuum System** tab, press "**LL VENT**" to vent the load lock chamber.	 The system automatically performs the following sequence of steps (summarized): • The main gate valve will remain closed or the user will be prompted to close the gate valve • The loadlock rough vacuum valve / LL turbo gate valve (if applicable) will close to isolate the loadlock from the vacuum system • The loadlock vent valve will open to vent the loadlock to atmospheric pressure. • Once atmospheric pressure has been reached, the loadlock door can be opened.
2.	Press **OK** on the software popup screen to turn off the loadloack vent valve.	
3.	Open the loadlock door after venting, carefully place a substrate onto the substrate carrier, then close the loadlock door.	Lift door when LL reaches atmospheric pressure:

		  substrate on carrier substrate carrier end effector
4.	From the **Vacuum System** tab, select **Transfer Sample** and follow the system prompts to load a sample into the system and then fully retract the transfer arm to the home position after loading.	 The system will automatically pump down the load lock. After the pressure in the process chamber and in the load lock is equilibrated, the main gate valve separating the two chambers will automatically open. After the gate valve is opened, the transfer arm can be used to perform the load or unload. **The following series of steps is to LOAD the sample into the process chamber:** **CAUTION**: DO NOT PRESS ANY BUTTONS UNTIL AFTER THE SUBSTRATE IS LOADED AND THE LOAD ARM IS <u>FULLY RETRACTED</u> OUT OF THE PROCESS CHAMBER. 1. Rotate the transfer arm's magnetic coupling so that the substrate carrier is raised.

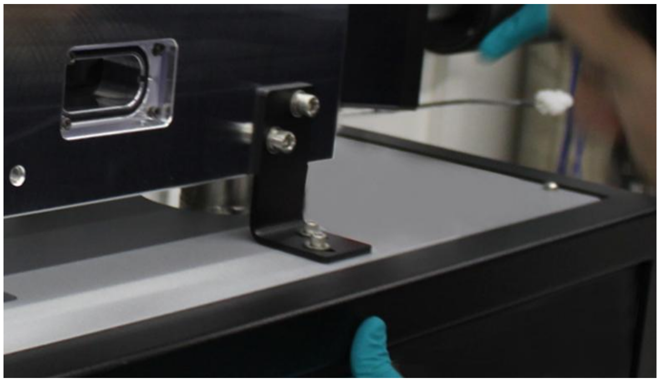


'End effector' of transfer arm in a rasied position when transfer arm is rotated.

2. While keeping the substrate carrier in the raised position, carefully slide the magnetic-coupler toward process chamber. The collar on the transfer tube located near the loadlock provides a hard stop.

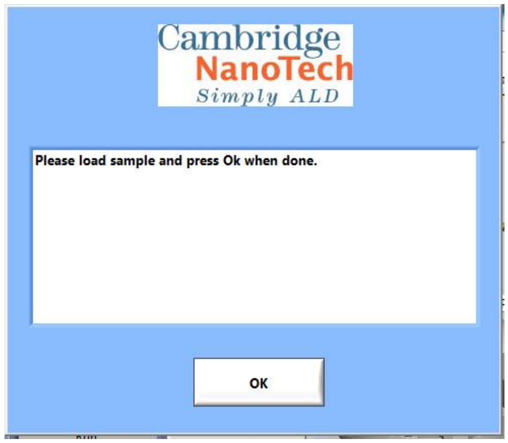
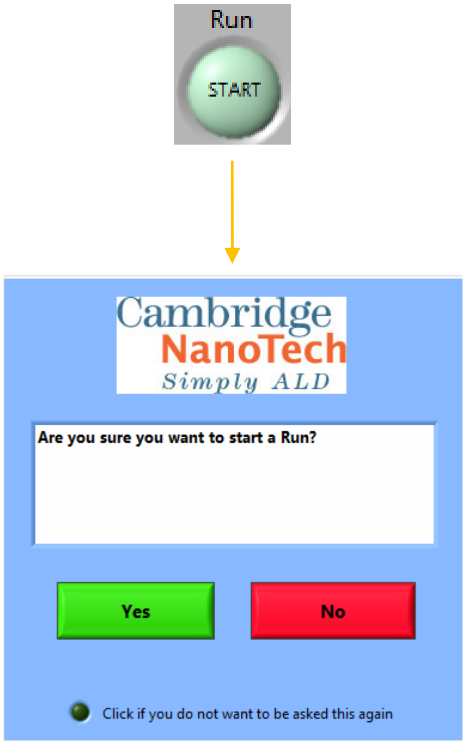
3. Gently release the magnetic coupling, it will rotate until the substrate carrier vertical position has reached equilibrium. This is the neutral position, lowering the substrate carrier onto the process chamber's chuck.

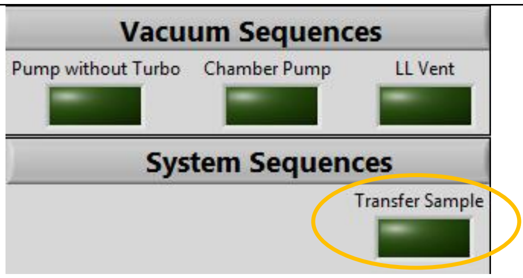
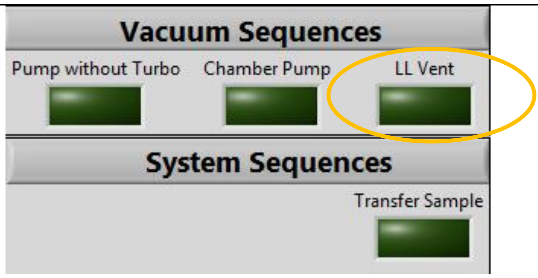
4. Gently move the transfer arm out of the process chamber. Look into the window on the load lock and verify that the substrate holder is in position in the process chamber.



Be sure to slide the magnetic coupling to the end or home stop, depressing the transfer arm interlock switch. This provides the signal to the interlock circuit that the arm is out of the process chamber and will not obstruct the main gate valve.

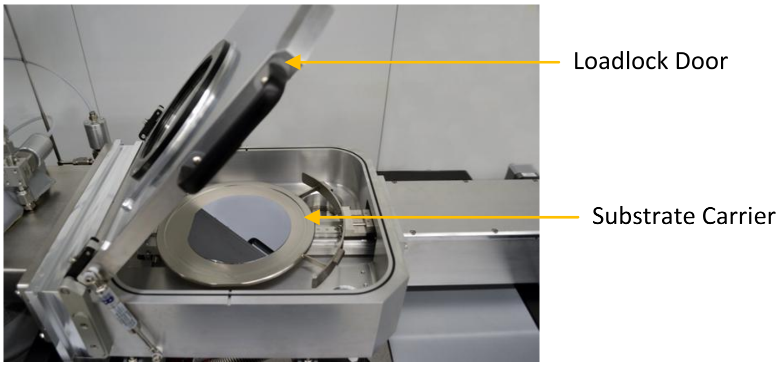
5. Press OK on the popup dialogue box and the main gate valve will close.

		CAUTION: DO NOT PRESS OK UNTIL THE LOAD ARM IS <u>FULLY RETRACTED</u> OUT OF THE PROCESS CHAMBER. 
5.	Create/load a recipe. Refer to the Software Reference section of this manual for details on process steps.	Load or create your process recipe as necessary for your run. Refer to the software reference section of this manual for details. Note: Enter a plasma energy level, if desired, in the recipe. The plasma power during a recipe can only be controlled as a parameter in the recipe, not from the control screen.
6.	From the **Process** tab, press the run **Start** button to begin processing.	

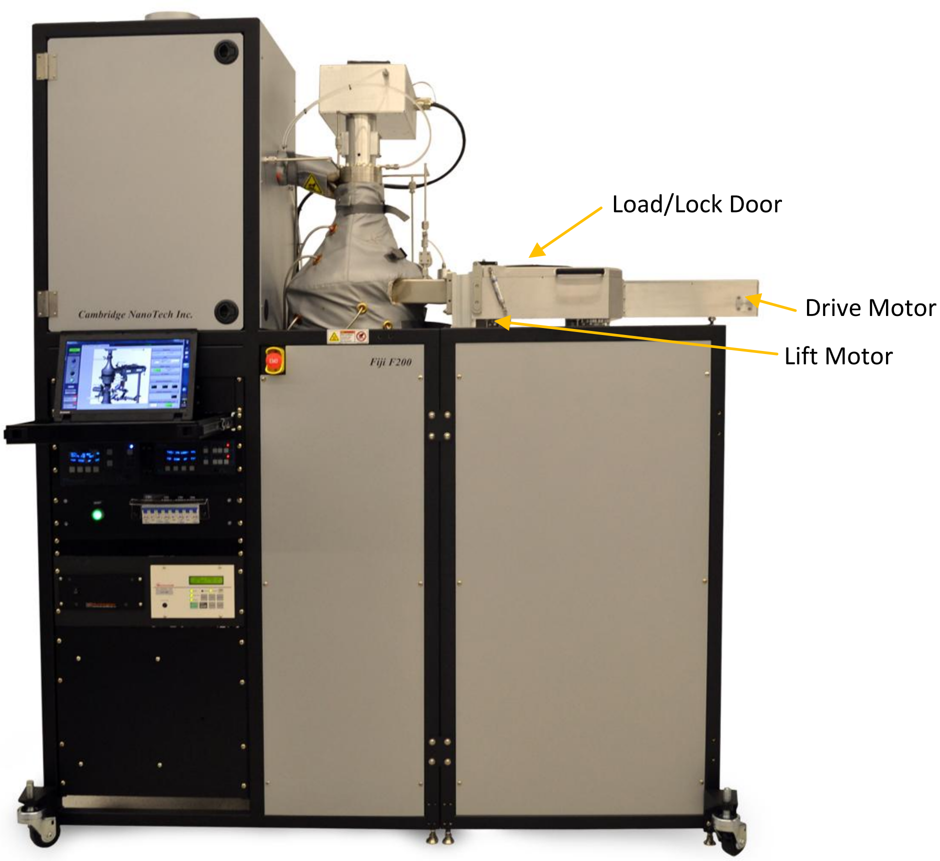
7.	After the process run has completed, from the **Vacuum System** tab, select **Transfer Sample** and follow the system prompts to unload the sample from the system.	 Press the “Load/Unload” button. After the pressure in the process chamber and in the load lock is equilibrated, the main gate valve separating the two chambers will open. **The following series of steps is to UNLOAD the sample.** **CAUTION**: DO NOT PRESS OK UNTIL YOU HAVE UNLOADED THE SUBSTRATE CARRIER AND THE LOAD ARM IS FULLY RETRACTED OUT OF THE PROCESS CHAMBER. 1. Verify that the flat portion on the magnetic coupling is facing towards the rear of the system (rotate the coupling to LOWER the load arm end effector). 2. Slide the carrier arm to the left, into the process chamber slowly. Within the last 2” of movement the end effector will interact with the substrate carrier (wafer holder). Slide the end effector in the last 2”. The end effector will adjust itself to the correct height to slide in properly. 3. Rotate the magnetic coupling so that its flat portion faces up (maximum height) WHILE sliding it to the right 4”. This maneuver takes some practice (you must raise the substrate carrier while gently pulling the collar to the right). If successful the substrate carrier will now be captured on the end effector of the carrier arm. 3. Slide the magnetic coupling to the right while keeping it at maximum height, this will extract the wafer holder from chamber. Be sure to slide the coupling to the far right end stop, depressing the interlock switch. This will ensure that the load arm is clear of the process chamber gate valve. 4. Press OK on the popup dialogue box to close the main gate valve. **CAUTION**: DO NOT PRESS OK UNTIL THE LOAD ARM IS FULLY RETRACTED OUT OF THE PROCESS CHAMBER.
8.	Select **LL Vent** to vent the loadlock and remove the sample.	 Note: An evacuated system can take 2-2½ minutes to reach atmospheric pressure.

Fiji F200 System with Hine Loadlock

The Fiji F200 system is available with a Hine Automation loadlock with auto-transfer which isolates the process chamber from atmosphere and the surrounding lab environment. The Hine loader with automatic transfer system allows the process chamber to remain under vacuum while a substrate is manually placed onto the substrate carrier in the loadlock.



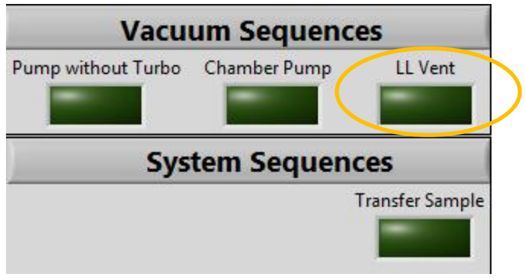
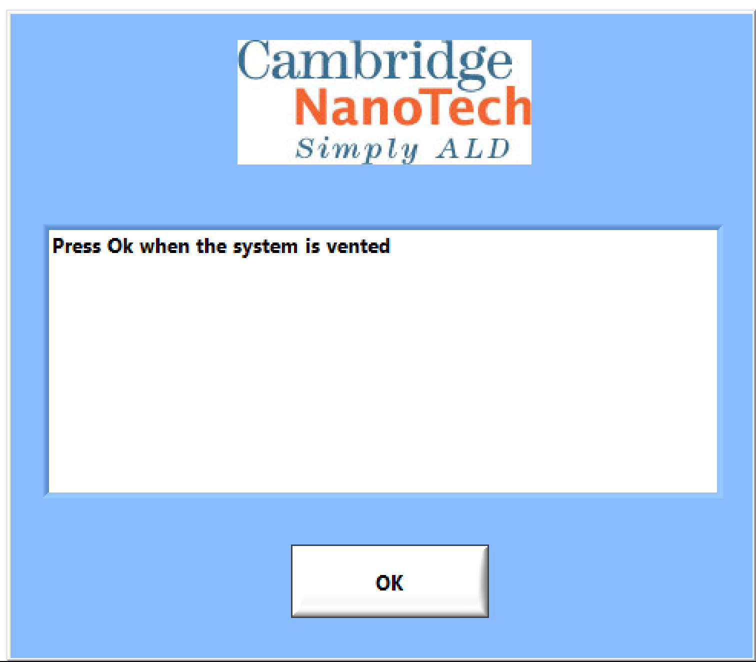
After loading a substrate, the loadlock door is closed then pumped down. After reaching the appropriate differential pressure between the loadlock and process chamber, the main gate valve between the loadlock and process chamber is opened. The substrate carrier is then transferred via an automated robot transfer arm onto the heated chuck in the process chamber.

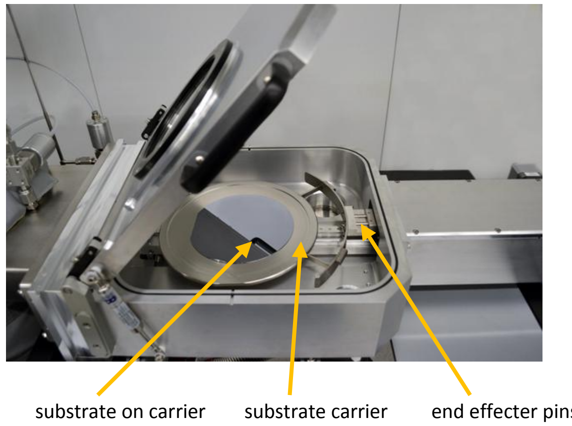
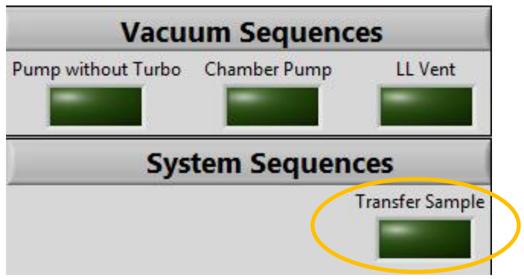


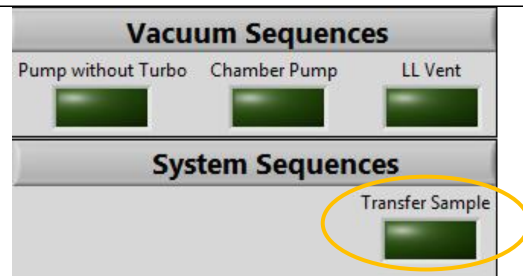
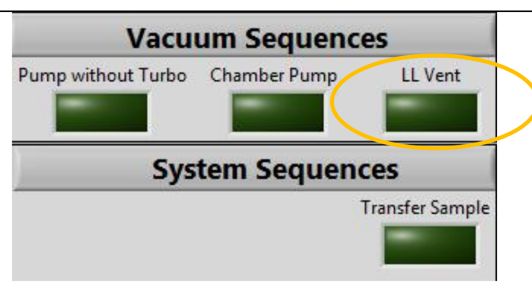
Fiji F200 System with Hine loadlock with automatic transfer

Hine Loader: Processing a Substrate

Use this procedure AFTER completing the **Error! Reference source not found.** procedure.

Step	Action	Details
10.	From the **Vacuum System** tab, press "**LL VENT**" to vent the load lock chamber.	 The system automatically performs the following sequence of steps (summarized): • The main gate valve will remain closed or the user will be prompted to close the gate valve • The loadlock rough vacuum valve / LL turbo gate valve (if applicable) will close to isolate the loadlock from the vacuum system • The loadlock vent valve will open to vent the loadlock to atmospheric pressure. • Once atmospheric pressure has been reached, the loadlock door can be opened
11.	Press **OK** on the software popup screen to turn off the loadloack vent valve.	
12.	Open the loadlock door and carefully place a substrate onto the substrate carrier, then close the loadlock door	Lift door up when LL reaches atmospheric pressure:  If not already installed, carefully place a substrate carrier onto the transfer pins as shown. Press securely. Then, load a substrate onto the substrate

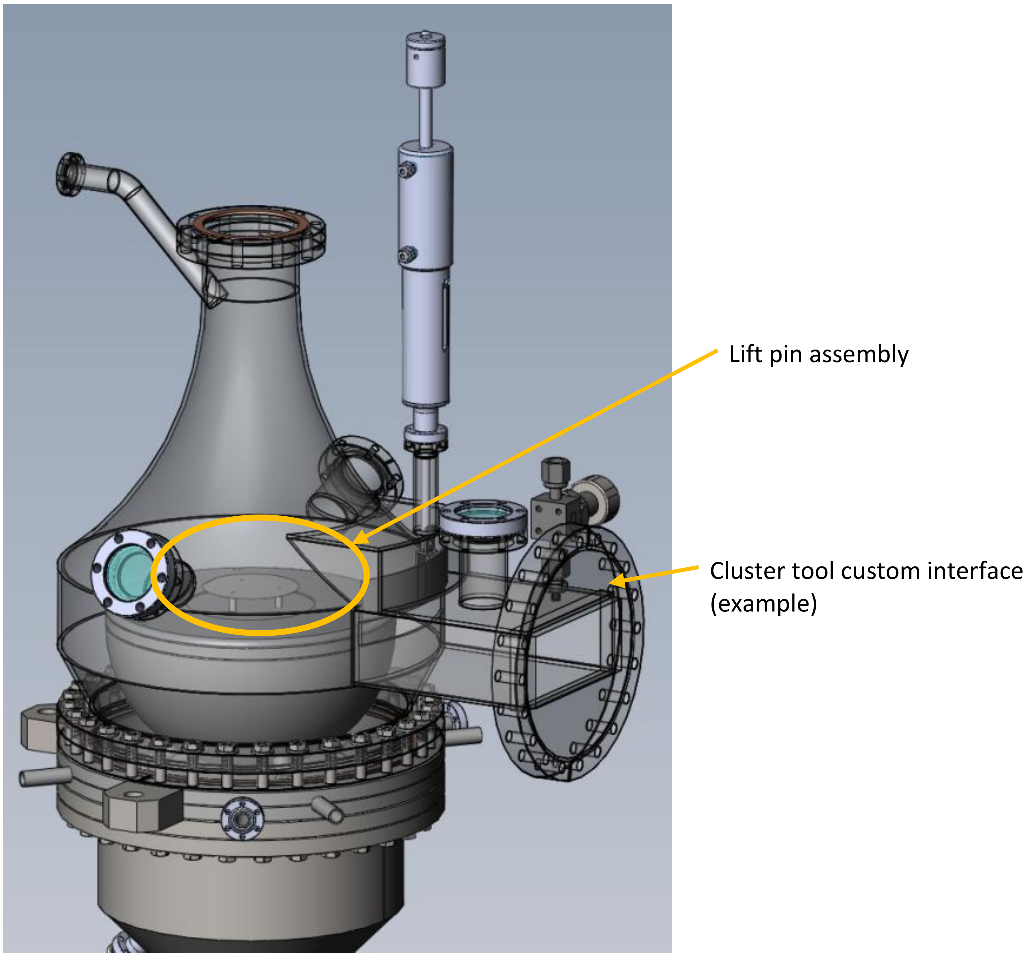
		carrier: 
13.	From the **Vacuum System** tab, select **Transfer Sample.** Follow the system prompts.	 The system will automatically pump down the loadlock. After the pressure in the loadlock and the process chamber is equilibrated, the main gate valve separating the two chambers will automatically open, the substrate carrier will then be loaded onto the heated chuck in the process chamber. Follow the system prompts to visually verify the main gate is clear, then click OK to close the gate valve. Once closed, the door purge (and main turbo/ellipsometer port purge, if applicable) will turn on and the Argon Carrier gas and the Argon Plasma Gas will be set to idle flows.
14.	Create/load a recipe. Refer to the Software Reference section of this manual for details on process steps.	Load or create your process recipe as necessary for your run. Refer to the software reference section of this manual for details.
15.	From the **Process** tab, press the run **Start** button to begin processing.	

		
16.	After processing, from the **Vacuum System** tab, select **Transfer Sample** and follow the system prompts to unload the sample from the system.	 Press the "Transfer Sample" button. After the pressure in the process chamber and in the load lock has equilibrated, the main gate valve separating the two chambers will open. The robot transfer arm will automatically remove the substrate carrier from the process chamber, and close the gate valve. Follow any system prompts.
17.	Select **LL Vent** to vent the load/lock and remove the sample.	

Cluster Tool Option

The Fiji system can be configured for use in a cluster tool configuration. Several interface options and custom interface configurations can be created, as required. Consult Cambridge NanoTech with your specific configuration needs.

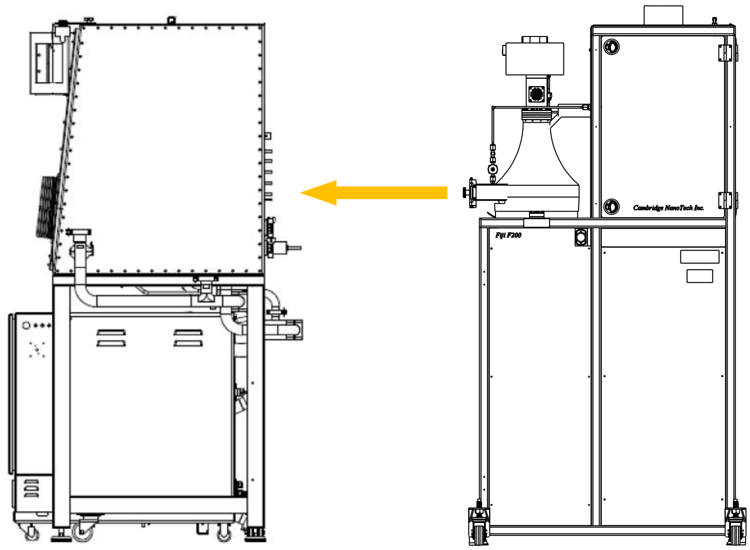
- Features advanced heated chuck with integrated lift pin assembly for substrate loading.
- Standard system is suitable for substrates that are 4" – 8"



Glove Box Option

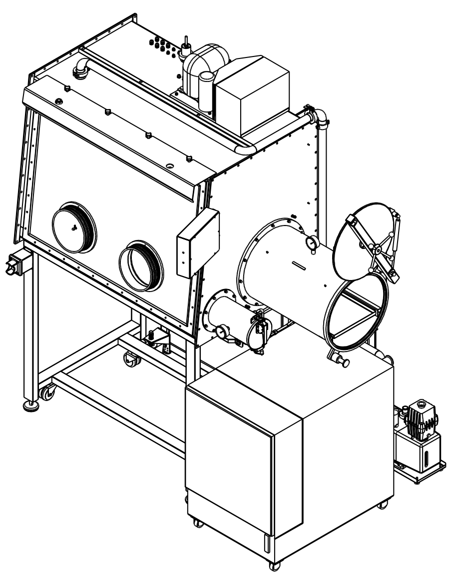
A glove box can be specially modified with a custom rear panel opening or door to allow connection to a standard Fiji system. The glove box can provide a clean substrate handling environment as may be required for advanced and/or special handling of substrates. A loadlock can also be custom-configured with a glove box. Consult Cambridge NanoTech for available options and recommendations for your process requirements.

Example glove box configuration:



STANDARD GLOVE BOX FIJI F200 SYSTEM

An alternative glove box with multiple load locks, rear automated door, and air conditioning system is also available:



SECTION 3: Turbo with APC Control

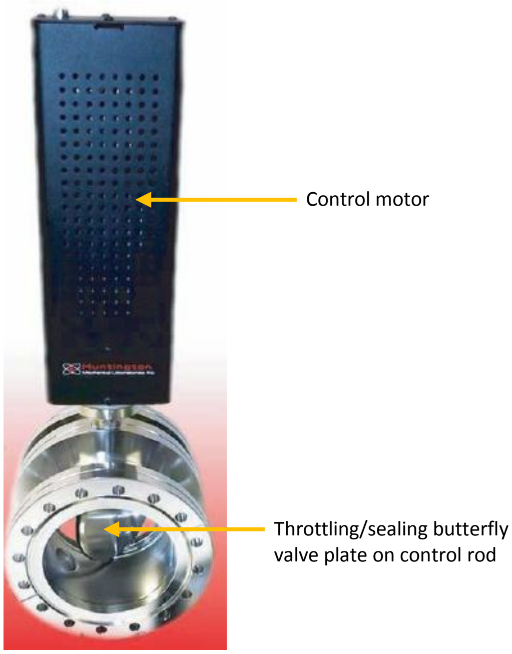
Fiji F200 Systems with Turbo Pumps and APC Controller

Turbomolecular Pump

A turbomolecular pump option allows the Fiji to achieve base pressures in the high vacuum range. The standard turbomolecular pump and controller kitted are the Edwards STPH301 and SCU800. The Edwards STPH301 typically operates at maximum speed (48,000 rpm). The pump is also fitted with a temperature monitoring system which tightly regulates the temperature via heating band and cooling circuit. A purge port with valve control is also included in order to dilute potential precursor effluent and inhibit deposition from occurring within the pump and turbines.

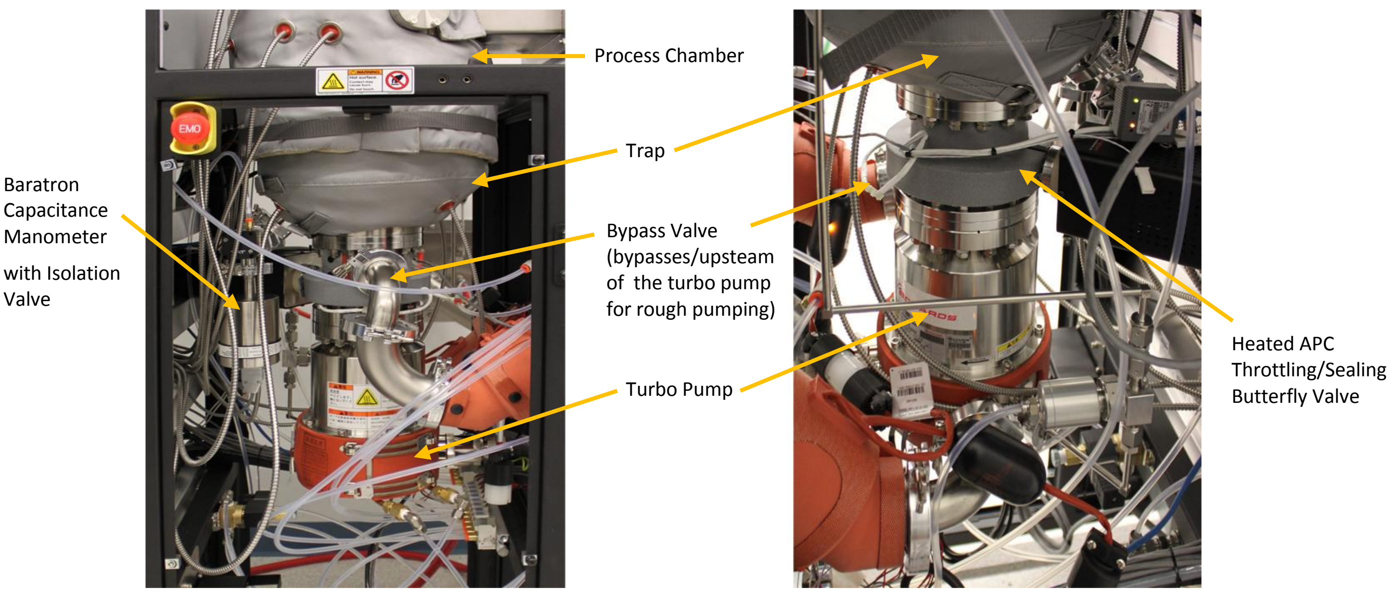
APC Controller

Included with the turbomolecular pump option is a Huntington Automatic Pressure Controller (APC) unit.   The APC unit consists of a heated throttling and sealing butterfly valve which is installed upstream of the turbo pump. The APC unit is either operated manually or recipe controlled.   The APC provides downstream pressure control by making precision adjustments to the conductance, as required. Please not that the APC is not operated automatically on the Fiji system, i.e. providing closed loop downstream pressure control. The nature of Cambridge Nanotech's ALD systems utilizing the vapor draw technique necessitates a dynamic upstream flow and pressure as the ALD valves are pulsed open to introduce higher vapor pressure precursor material. Instead, the APC percent open throttle position should be set manually prior to processing or within the process recipe itself given a particular process gas flow - ignoring any pressure fluctuations resulting from pulsing ALD valves for precursor dosing. The APC is also used to temporarily isolate the pumping system by providing a vacuum seal during Exposure mode processing. The valve is typically operated with heater setpoint of 150°C. Heating of the valve prevent condensation of precursor material and is also critical for achieving a vaccuum seal.



Baratron Capacitance Manometer

A 1 Torr full-scale, heated Baratron capacitance manometer is provided and interfaces with the Huntington APC controller. An isolation valve is installed to prevent the Baratron from exposure to process chemistry. Since the main chamber process pressure gauge is wetted (i.e. exposed to process chemistry), deposition on the gauges filament will inevitable occur causing an apparent drift in pressure reading. The Baratron is intended to be used a reference gauge when setting the APC throttle position. Please note that the gauge may be rezeroed periodically for accuracy.

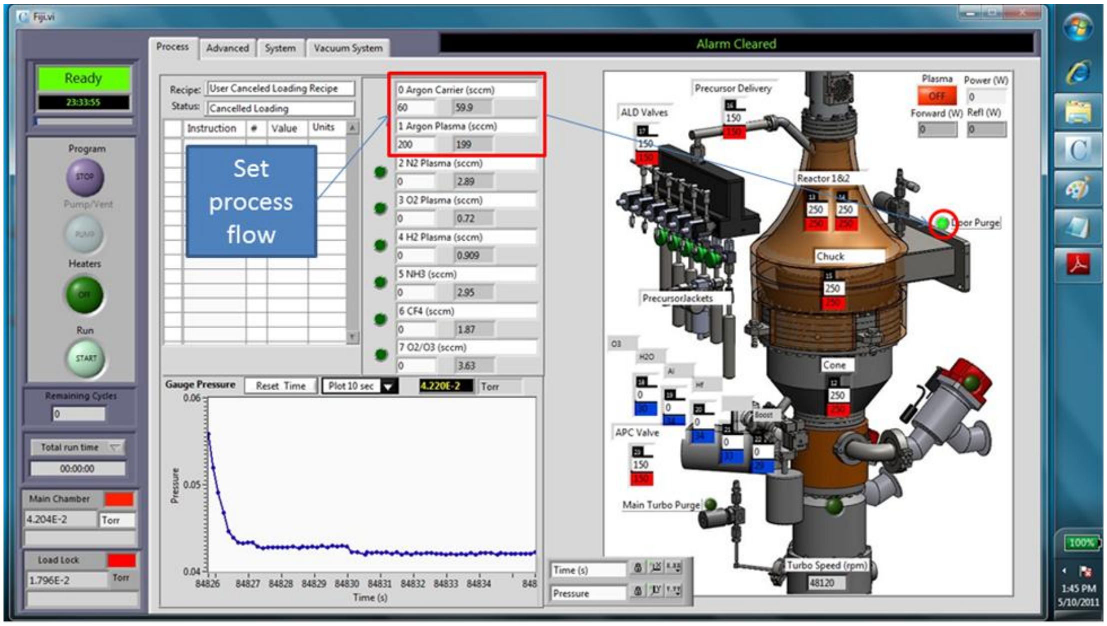


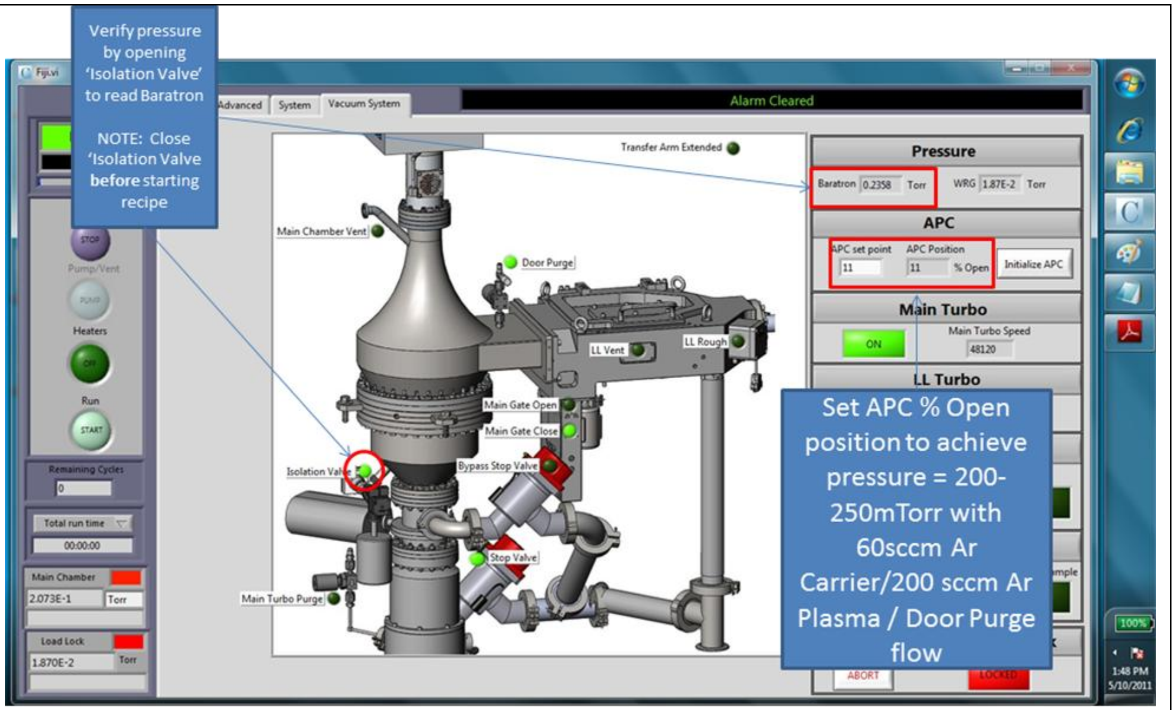
Front View ***Rear View***

Setting APC Throttle

Setting the APC throttle position is critical for good process results. During the sample transfer operation the APC is driven to 100% open in order to pump out the main chamber to a base pressure. If the process were to operate with the APC at 100% open, the process pressure may be in the single digit mTorr range with the 60/200 sccm or 30/100sccm Ar carrier/plasma flow with 50 sccm Door purge. This would significantly reduce the residence time of the precursor material in the process chamber such that very low growth rate and poor uniformity would be observed. Operating in a lower pressure regime may unnecessarily waste precursor material due to the higher pumping speed.

It is recommended to target a process pressure window of 200-250mTorr, targeting 230 mTorr, with a process flow 60 sccm Ar Carrier / 200 sccm Ar Plasma / 50 sccm Door Purge / (20 sccm Ellipsometer Purge if applicable).

Refer to the Human Interface (Loading) Options section and Operation section of this manual for specific operation and substrate loading instructions for the loadlock option on your system. Follow all steps to load a substrate.	
Step	
1.	Complete the system startup procedure to ensure that the main process chamber is pumped down with turbo pump, the system is at temperature, and the precursors have been properly installed.
2.	Use the following method to determine the correct throttle position of the APC valve: 1. Set the process flow (MFC 0 - Ar Carrier = 60 sccm / MFC 1 – Ar Plasma = 200 sccm) Note: As of this moment new processes are being developed or revisited at a lower process flow (MFC 0 - Ar Carrier = 30 sccm / MFC 1 – Ar Plasma = 100 sccm). Please use the same procedure for setting APC throttle position targeting the same pressure window (200-250 mTorr) 2. Turn on Door Purge (and Ellipsometer Purge if available) Note: Main Turbo purge can be turned on, however it should have no effect on main chamber (process) pressure.  3. Open the Baratron Isolation Valve (See Maintenance manual for section on zeroing the Baratron Capacitance Manometer)



4. Adjust APC throttle position by typing setpoint into white box and pressing enter.
5. Continue adjust until Baratron pressure reading is between 200-250mTorr
6. Once adjusted, make note of the APC throttle position. Close the Baratron isolation valve.

   Note: It is best practice to incorporate this APC throttle setpoint within the recipe.

Example:

	Instruction	#	value
	APC		11

7. After setting the pressure in the chamber for a given set of flows using the Baratron capacitance manometer as a reference gauge, close the Baratron isolation valve. Use the Edwards APGX-H gauge to monitor pressure during growth.

SECTION 4: Options

Ozone Generator

System Description

The ozone generator provides a constant flow of ozone (O_3) generated from oxygen gas (O_2). The oxygen flow rate and ozone cell back pressure can be adjusted (via a 1000 sccm MFC and back pressure regulator) by the end user to develop recipes at characterized ozone concentrations. The ozone concentration can be adjusted by varying the O_2 flow and ozone cell back pressure. Process ozone is delivered to the system using a standard rapid response ALD valve. The ozone generator is shown installed on a Fiji system in Figure 1 (below). A simple schematic of the ozone delivery system is outlined on the following page.

The ozone kit is fully integrated into the Fiji system and includes:

- recipe controlled operation
- adjustable concentration (O_2 Flow to Ozone Generator)
- pulse delivered ozone
- H_2 interlock
- ozone destruct
- ozone generator components also include: ballast tank, ozone cell backpressure regulator, under pressure switch, LED indicators, check valve, and Mass Flow Controller (MFC)

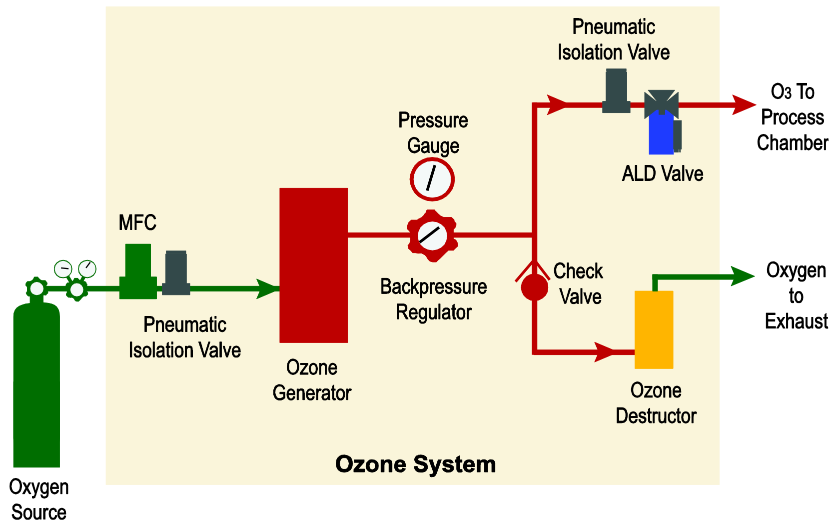
Figure 1: Fiji Ozone Generator Installed on System

Ozone Use to Dose a Film

The stream of O_3 from the generator is directed through internal tubing to the Fiji ALD valve manifold. Ozone can be connected to any of the ALD ports. To use O_3 as an oxidant in an ALD process:

1. Open MFCValve 7 (oxygen feed to the ozone generator), via a recipe command
2. Set a flow rate of O_2 through the MFC feed to the ozone generator, via a recipe command
3. Verify ozone cell backpressure (adjust backpressure regulator if necessary)
4. Turn on the ozone generator power, via the lineacout recipe command
5. Verify the 'Inverter ON' and 'Locked' LEDs are on

   Purge the ozone lines with initial pulses prior to starting ALD process (use the "pulse" command in the recipe and the correct ALD port number).

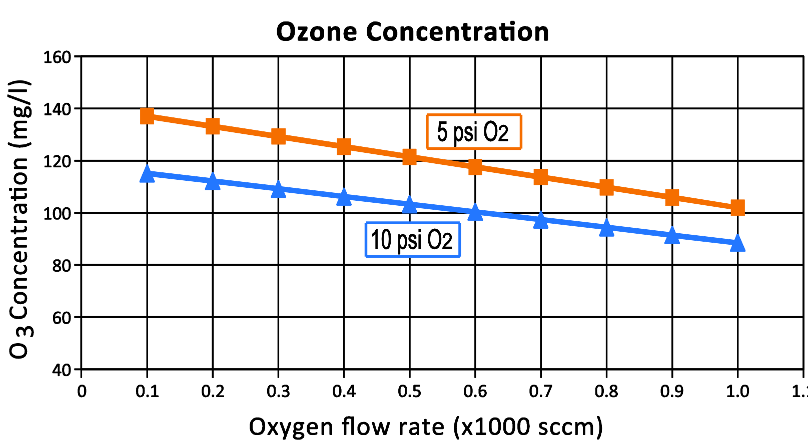


*Ozone generator arrangement (simplified)**

**This figure does not include the ozone ballast tank, internal ozone generator components, nor the safety interlocks*

Ozone Output Concentrations

Process ozone is adjusted as a recipe selectable parameter using the ALD pulse time. Typical ozone pulse times range from 0.015sec to 0.5sec depending upon the amount of ozone required for your ALD process. The oxygen flow to the ozone unit (MFC 7, O2/O3) can be adjusted in the recipe from 50sccm to 1000sccm. The recommended O2/O3 flow is 500sccm. The ozone output is summarized in the charts below for the recommended operating pressure of 5 psi.



Ozone Generator Output at 5psi and 10psi O_2 as a function of oxygen flow rate

Ozone Destruct

When the O_3 is not being used to dose a film (i.e. the ALD valve is closed), a 1/3 psid check valve diverts the O_3 stream to an O_3 destruct unit located within ozone kit enclosure. The destruct will recombine all excess, unused ozone as O_2. The recombined O_2 is exhausted from the ozone kit enclosure via a 2" outer diameter duct.

Minimum Oxygen Flow Interlock

The ozone generator will not turn ON at oxygen supply pressures below 2 PSIG. This oxygen pressure interlock is designed to protect internal electronics from operating with insufficient gas flow or at vacuum. Operation of the ozone generator at sub atmospheric pressures (<760 Torr) will damage the ozone cell and internal components.

Ozone Leak and Safety Monitoring System

A customer-supplied ozone detector system MUST be installed to monitor the destruct efficiency and safety of the exhaust stream and the surrounding work environment. At a minimum, ozone detectors must be installed:

- at the top inside of the gas delivery box
- in the exhaust line of the ozone generator kit

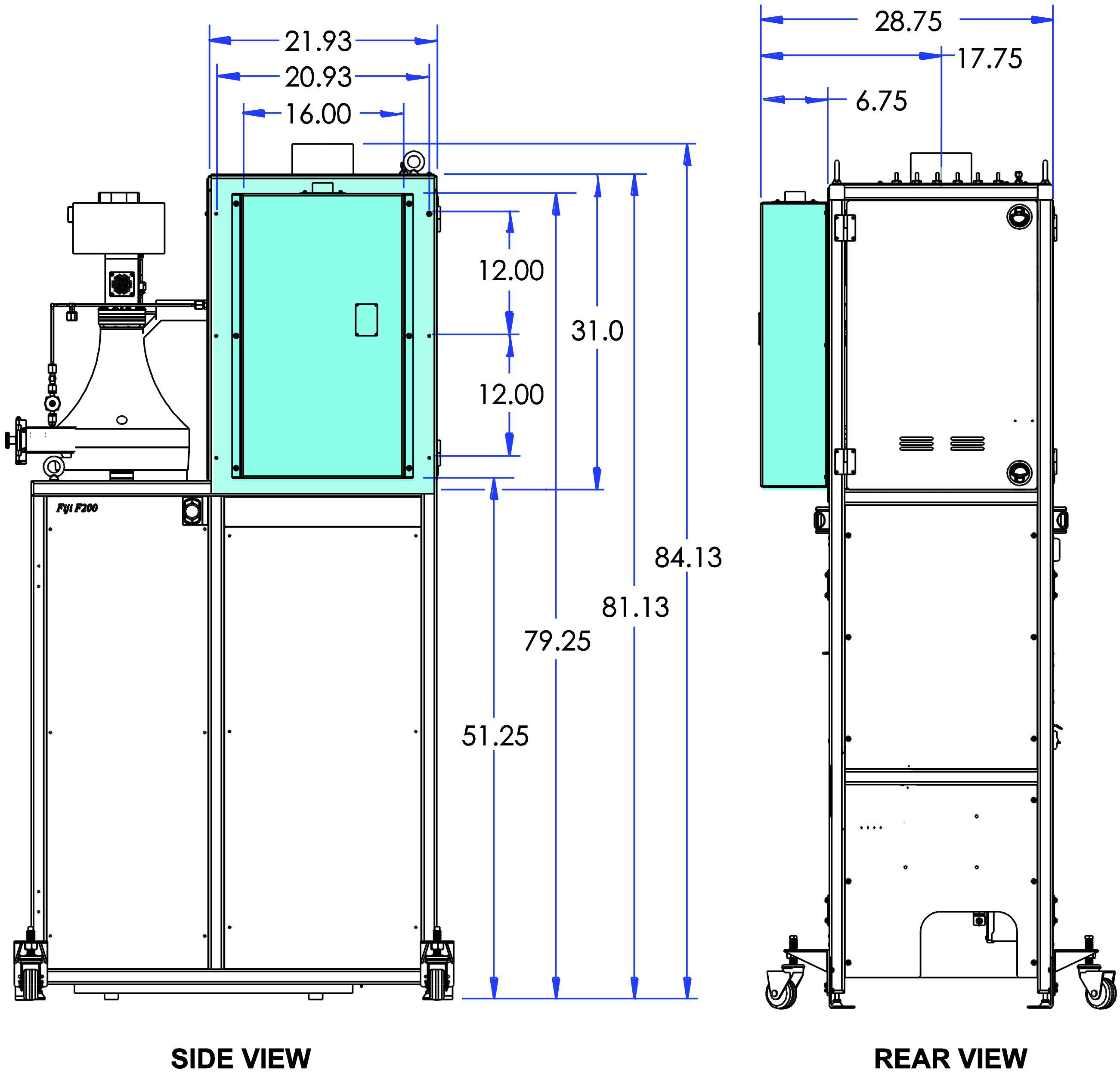
Ozone detectors should be hard-wired per industry, local, and national code standards to disable the production of ozone in the event of a detected leak.
Installation, service, and verification of ozone detector and safety monitoring equipment is solely the responsibility of the end user. No ozone detection equipment and hardwired leak detection interlocks are provided with the unit.

Ozone can NOT be used with H_2 or H_2 Plasma. The Fiji system is interlocked to prevent H_2 and O_2 or O_3 flow without purging the chamber. Do not defeat or circumvent this safety interlock.

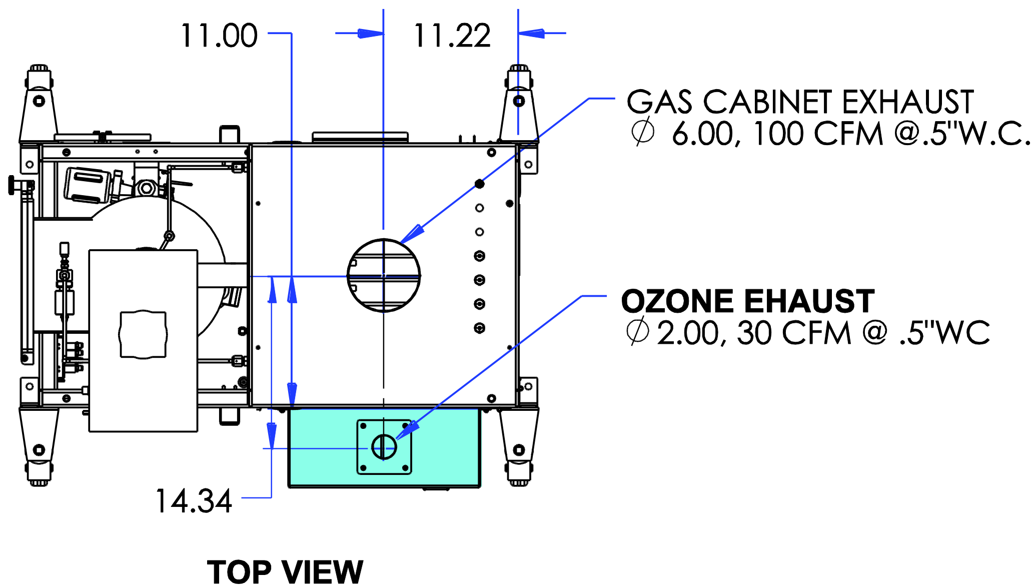
Ozone Generator Specifications

Item	Specification
Dimensions (W x H x D) inclusive of integrated mounting panel	310 mm x 325 mm x 493 mm (21.93" x 31" x 6.75")
Approximate weight	21 kg (46.3 Lb.)
Gas connections	Oxygen inlet: ¼" Swagelok compression fitting Ozone generator cell backpressure regulator: Two-stage, capable of controlling at 5-10 PSIG Ozone outlet: ¼" Swagelok compression fitting
Generator AC power	110/220 VAC
Oxygen flow	0 –1000 sccm
Required ozone generator cell backpressure	5 – 10 PSIG
Maximum ozone output concentration	120 mg/l @ 500 sccm pure O_2 flow @ 72°F
Cooling requirements	The system is air-cooled. Do not block vents which are located on the bottom of the ozone generator enclosure

System Dimensions – Ozone Generator on Base System Frame:



Side and Rear Views– Ozone System on Fiji F200
Note: All dimensions in inches



Top View – Ozone System on Fiji F200
Note: All dimensions in inches

Ozone Hardware

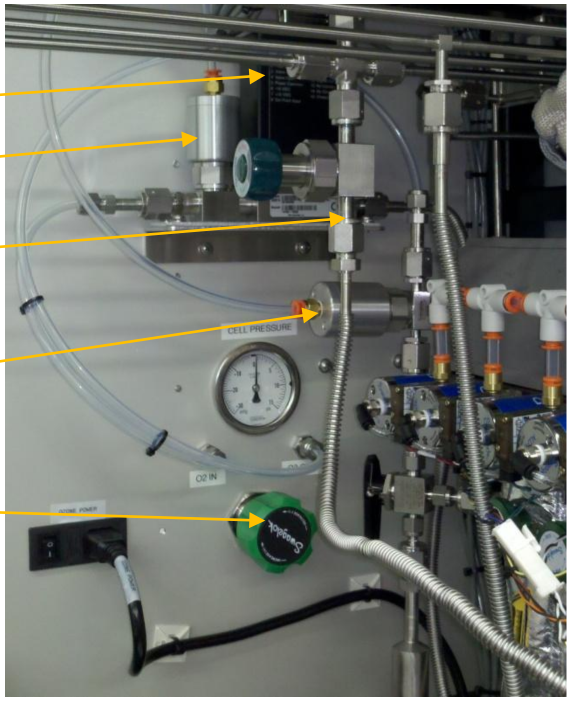
O_2 MFC 7

MFCvalve 7

O_2/H_2 Safety Interlock valve

Ozone Generator
Cell Back-Pressure Gauge

Back-Pressure Regulator



Internal View as Mounted
Note: Electrical power switch optional.

Operation of System with Ozone Generator

Ozone Unit Manual Operation

CAUTION! Temperature Sensitive.

The ozone generator is sensitive to temperature and should be kept as cool as possible. Never block the cooling vents at the bottom of the unit. The unit will flash a red LED labeled 'HS TEMP' through the top viewing window if it overheats, and may automatically shut down to cool.

Ozone Operation Summary

1. Open the O_2 feed MFC 7 valve to the ozone generator (via software)
2. The O_2 feed MFC 7 to the ozone generator flow must be turned on.
3. Wait 10 sec.
4. Confirm ozone generator cell backpressure of 5 to 10 psi. Adjust with Back Pressure Regulator (if necessary).
5. The ozone generator can be turned on.
6. Run Recipe.
7. Turn off Ozone Generator.
8. Purge Ozone generator with oxygen (0_2) for 60 sec.
9. Close the O_2/O_3 MFC valve.

These steps are executed automatically in the provided standard process and ozone test recipe examples.

Step	Action	Details
1.	Verify O2 supply pressure > 20 psi	
2.	Open the O_2/O_3 MFC valve(Valve # 7, MFCvalve, 7, 1) through the control software.	
3.	Turn on the flow of O2 through the MFC at the desired rate of flow.	Flow range: 50sccm to 1000sccm Recommend flow rate: 500sccm
4.	Wait 10 seconds for the oxygen flow to stabilize.	
5.	Open the panel to the vented precursor gas box and adjust the backpressure regulator to achieve the desired cell backpressure (typically 5 psi to 10 psi).	
6.	Turn ON the ozone generator: Recipe command: line ac out, 1, 1	The FIJI ozone unit is powered "ON" with 220V (or 208 V) from the e-box controller using the recipe command "line ac out, 1, 1". The first "1" is the E-box ac out location. The second "1" is the command "ON". For example: line ac out, 1, 1 turns ON outlet # 1 line ac out, 1, 0 turns OFF outlet # 1 There is also a safety "ON" switch located inside the precursor gas box on the left which must also be in the "ON" position.

		Upon powering up the ozone generator the ozone box will turn on the cooling fan and sequence through all of the indicator lights (3x green, 2x yellow, 5x red). This is normal behavior. When the unit is powered and running in steady state and the oxygen pressure in the unit is greater than 3psi there will be three green lights displayed on the ozone bock unit (verify the INV ON, +5V, LOCKED LEDs maintain green). This is required for ozone generation and proper recipe operation.
7.	Run a process recipe, as desired.	See example recipes.
8.	Turn off the ozone generator: Recipe command: line ac out, 1, 0	This action will turn off the ozone generator unit and the indicator lights will turn OFF.
9.	With the ozone generator's power OFF, flow oxygen through the ozone generator for 1-2 minutes to purge any remaining ozone out of the unit.	
10.	Set O_2 flow to zero then close the O_2 inlet MFC valve.	

Standard Ozone Process Recipe

Below is a standard ozone recipe for Al_2O_3 deposition at 200ºC - 250ºC using trimethylaluminum (TMA) on ALD-1 and Ozone on ALD-0. MFCvalve-7 controls the oxygen flow to the ozone generator and “line ac out 1*” is the power to the ozone unit (O = OFF, 1 = ON).

Step	Instruction	#	Value	Units	Comments
0	flow	0	60	sccm	Carrier gas
1	Flow	1	200	sccm	Plasma gas
2	Wait		10	sec	
3	MFCvalve	7	1		Open MFC valve (MFC7 Oxygen feed to ozone generator)
4	Flow	7	500	sccm	Flow MFC7, Oxygen feed to ozone generator Flow range: 50sccm to 1000sccm Recommend flow rate: 500sccm
5	Wait		15	sec	Allow oxygen to flow through the ozone generator for 15 seconds to flush the ozone generator lines
6	Line ac out	1*	1		Turn ON ozone generator to begin creating ozone
7	Wait		120	Sec	Enter 60 to 120 sec to fill the ozone ballast with O_3
8	Pulse	0	0.15	sec	Purge and fill ozone delivery line to tool
9	Wait		15	sec	
10	Goto	7	20		Purge and fill loop
11	Wait		10	sec	
12	Pulse	1	0.06	sec	Pulse TMA
13	Wait		10	sec	
14	Pulse	0	0.15	sec	Pulse Ozone
15	Wait		10	sec	
16	Goto	11	200		Process loop
17	Line ac out	1*	0		Turn OFF ozone generator
18	Wait		60	Sec	Purge ozone generator with oxygen
19	Flow	7	0		Turn off flow of oxygen through MFC7 valve (oxygen feed to ozone generator)
20	MFCvalve	7	0		Close MFC7 valve (turn off flow of oxygen to ozone generator)
21					
22					End of recipe

***** Line ac out location is dependent on which power connector is used on the E-box to power the ozone generator. Make changes to the commands as necessary for your system configuration.

In the recipe the first “goto” loop, highlighted in yellow, is designed to repeatedly pulses ozone into the chamber and purge the ozone gas delivery line. After purging the ozone delivery line, ALD process can begin with steady state concentration of ozone and oxygen in the process ozone gas line. The ALD process loop, shown in blue, alternately pulses TMA and ozone for 200 cycles of alumina (Al_2O_3) film growth. The growth rate for TMA + O_3 is typical in the range of 0.8 to 0.9 Angstrom/cycle.

When developing new process recipes using the ozone generator, pulse times longer than 1.0 sec will evacuate the O2/O3 gas delivery line to the ALD valve. Sub-atmospheric pressure in the gas delivery line may damage your ozone hardware and effect the integrity of your ozone process recipe. The underpressure switch is designed to shut off power to the ozone generator at cell pressures less than (2) psi. If your process demands more ozone exposure than 1.0 sec, we suggest that multiple ozone pulses can be used, for example 2x ozone pulse followed by 1x precursor pulse.

Ozone Test Recipe

Below is an ozone test recipe to determine if the ozone unit is operating correctly.

The ozone unit is turned ON and pulsed as specified in the process recipe. Ozone is installed on ALD-0, MFCvalve-7 controls the oxygen flow to the ozone generator, and “line ac out 0” provides power to the ozone generator.

Step	Instruction	#	Value	Units	Comments
0	flow	0	60	sccm	Carrier gas
1	Flow	1	200	sccm	Plasma gas
2	Wait		3	Sec	
3	MFCvalve	7	1		Open MFC valve (MFC7 Oxygen feed to ozone generator)
4	Flow	7	500	sccm	Flow MFC7, Oxygen feed to ozone generator Flow range: 50sccm to 1000sccm Recommend flow rate: 500sccm
5	Wait		15	Sec	Allow oxygen to flow through the ozone generator for 15 seconds to flush the ozone generator lines
6	Line ac out	1*	1		Turn ON ozone generator to begin creating ozone
7	Pulse	0	0.15	Sec	Purge and fill ozone delivery line to tool
8	Wait		15	Sec	
9	Goto	7	4		Purge and fill loop
10	Line ac out	1*	0		Turn OFF ozone generator
11	Wait		60	Sec	Purge ozone generator with oxygen
12	Flow	7	0		Turn off flow of oxygen through MFC7 valve (oxygen feed to ozone generator)
13	MFCvalve	7	0		Close MFC7 valve (turn off flow of oxygen to ozone generator)
14					
15					End of recipe

***** Line ac out location is dependent on which power connector is used on the E-box to power the ozone generator. Make changes to the commands as necessary for your system configuration.

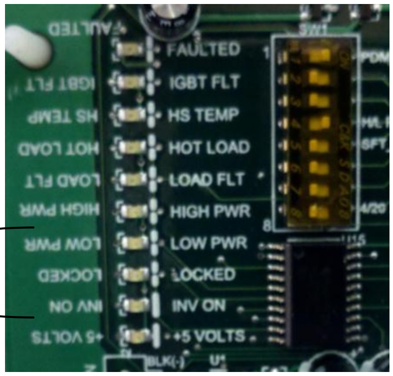
Ozone Generator Indicator Lights

During power up, the ozone generator will turn on the cooling fan and sequence through all of the indicator lights (3x green, 2x yellow, 5x red). This is normal behavior. The ozone generator indicator lights are viewed through the window on the side of the unit. During normal operation, three green lights will be lit:

- The green “+5 VOLTS” light indicates proper cell voltage.
- The “INV ON” green light is lit when the ozone generator inverter board is powered and operating.
- The “LOCKED” light is lit when the inverter is locked into its proper operating range.

If either the “HS TEMP” red light or “HOT LOAD” light flashes, the unit is too hot and needs to be cooled.

Ozone Generator Indicator lights (3 green lights - proper operation)
LOCKED – Locked in output
INV ON - Inverter is powered and operating
+5 Volts - Proper Cell Voltage



Ozone generator operating and fault Lights

Ozone Generator Troubleshooting

<table>
<tr><th>Sympton</th><th>Solution</th></tr>
<tr><td>Ozone leak detected from ozone kit enclosure</td><td>Before performing any troubleshooting techniques, review Appendix A – Safety. Ozone is a hazardous and toxic gas.

Check all fittings in the ozone kit enclosure then perform a static pressure test to determine system integrity:
<table>
<tr><th>Step</th><th>Action</th><th>Details</th></tr>
<tr><td>11.</td><td>Remove the ozone kit enclosure.</td><td>Remove exhaust at top, then remove screws as necessary to remove the cover panel.</td></tr>
<tr><td>12.</td><td>Use a ¼” Swagelok compression cap to seal the outlet of ozone destruct unit.</td><td></td></tr>
<tr><td>13.</td><td>Pressurize the cell:</td><td>Open MFCValve 7
Set MFC 7 O2 flow
Adjust the backpressure regulator to achiev 15 psi</td></tr>
<tr><td>14.</td><td>Close MFCValve 7.</td><td></td></tr>
<tr><td>15.</td><td>Set MFC 7 O2 flow to 0</td><td></td></tr>
<tr><td>16.</td><td>Monitor the pressure decay (if any) in the cell.</td><td>Record cell pressure from the backpressure gauge at regular intervals of 8 hours, 16 hours, and 24 hours.</td></tr>
</table></td></tr>
<tr><td>Ozone generator shuts down with “HS TEMP” red light or “HOT LOAD” light flashing</td><td>The unit is too hot and needs to be cooled.
Check vents at bottom of unit. Ensure vents are clear. Avoid flow of hot air from adjacent equipment onto the ozone generator housing.</td></tr>
</table>

Ozone Generator, Additional Safety Notices

Ozone Safety Notice

For use with systems equipped with an ozone generator.

WARNING!

Ozone (O_3) is a toxic gas. High concentrations of ozone are dangerous and harmful to humans. The current maximum 8-hour exposure limit for ozone is 0.1 ppm (0.2 mg/m^3) according to U.S. OSHA® and NIOSH. Use all-stainless steel gaskets for VCR® gas connections. Use ozone-compatible materials including 316L Stainless steel, Teflon®, Chemraz® and Kynar®.

The ozone generator unit should only be operated as specified in this manual.
Consult the MSDS (Material Safety Data Sheet) in regards to the hazards associated with ozone use.

If ozone is detected, immediately turn off the ozone generator unit and consult the Cambridge NanoTech Service Department.

Ozone is an powerful oxidant and should not be simultaneously pulsed/mixed in the chamber with H_2 gas or other flammable precursor.

Electrical Hazards		
Hazard Type	**Hazard Location**	**Hazard Notes**
 Electrical shock hazard	Internal to precursor gas box at wiring connection, and internal to unit (behind covers).	The ozone generator is powered by 110 VAC, 1 Phase 50/60 Hz. The Fiji system is typically powered by 208 VAC. Please consult the *Fiji Installation and Use Manual* before removing any covers on the system. The main input power connection is located at the rear of the unit. **DANGER:** Electrical Hazard. DO NOT OPEN COVERS to access electrical equipment with the power on, unless you are certified to perform specific troubleshooting/repair tasks.

Chemical and Fire Hazards		
Hazard Type	**Hazard Location**	**Hazard Notes**
  Chemical and Fire Hazards	System	**DANGER! TOXIC HAZARD** Ozone (O_3) is a toxic gas. High concentrations of Ozone are dangerous to humans. Take reasonable steps to avoid exposure. The OSHA maximum 8-hour exposure limit for Ozone is 0.1 ppm. If ozone is detected, immediately turn off the ozone generator unit and consult the Cambridge NanoTech Service department. Ozone can NOT be used with H_2, or formic acid. OZONE DETECTION EQUIPMENT: Install safety monitoring equipment to stop the generation of ozone in the event of a system leak. MATERIAL COMPATIBILITY: Use 316L Stainless, Teflon®, Chemraz® and Kynar®. Do NOT use Viton® seals! Use only **stainless steel** unplated gaskets for VCR® gas connections. **Do NOT** use silver-plated gaskets.
	Material Safety Data Sheets (MSDS)	Material Safety Data Sheets (MSDS) for every chemical used with the system should be available to all users of the system at all times. Each user should be trained on the specific gases/chemicals used with the system, and be certified in safe operation of the system. The MSDS covering all materials used in the process must be prominently displayed in the immediate vicinity of the machine.

*Refer to OSHA standards for updates.

ALD Booster™

The ALD Booster option provides an in-line solution to delivering low-vapor-pressure precursors into the process chamber. The ALD Booster provides an effective solution for efficient precursor utilization and delivery.

- The ALD Booster dramatically improves uniformity and enables ALD growth
- The ALD Booster allows for:
  - Lower vaporization temperatures, preventing decomposition of precursor in cylinder
  - Efficient transport of precursor across substrate surface
  - Prevents decomposition in reactor chamber
- The ALD Booster is not appropriate for all ALD precursors; poor volatility and precursor utilization can preclude ALD process

ALD Booster Purpose/Overview

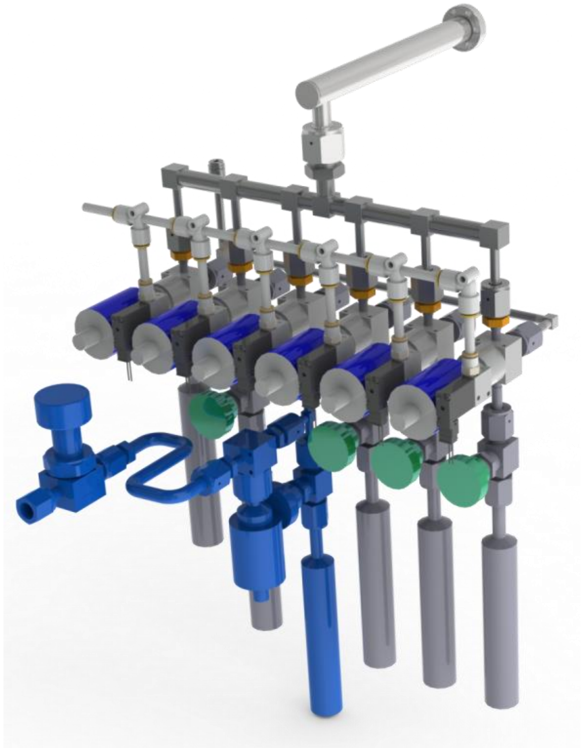
Ideal ALD precursors have a high enough vapor pressure at normal operating temperature, typically at < 200°C to readily enter the process stream. Some precursors have lower vapor pressures at their maximum operating temperatures. Low vapor pressure leads to low precursor dose, potentially resulting in:

- unsaturated growth rate
- poor thickness uniformity

Cambridge NanoTech developed the ALD Booster™ to assist in the deposition of films that are grown from lower vapor pressure precursors. Examples of films that may be assisted with the help of the ALD Booster™ include, but are not limited to Er_2O_3, NiO, La_2O_3, and CoO.

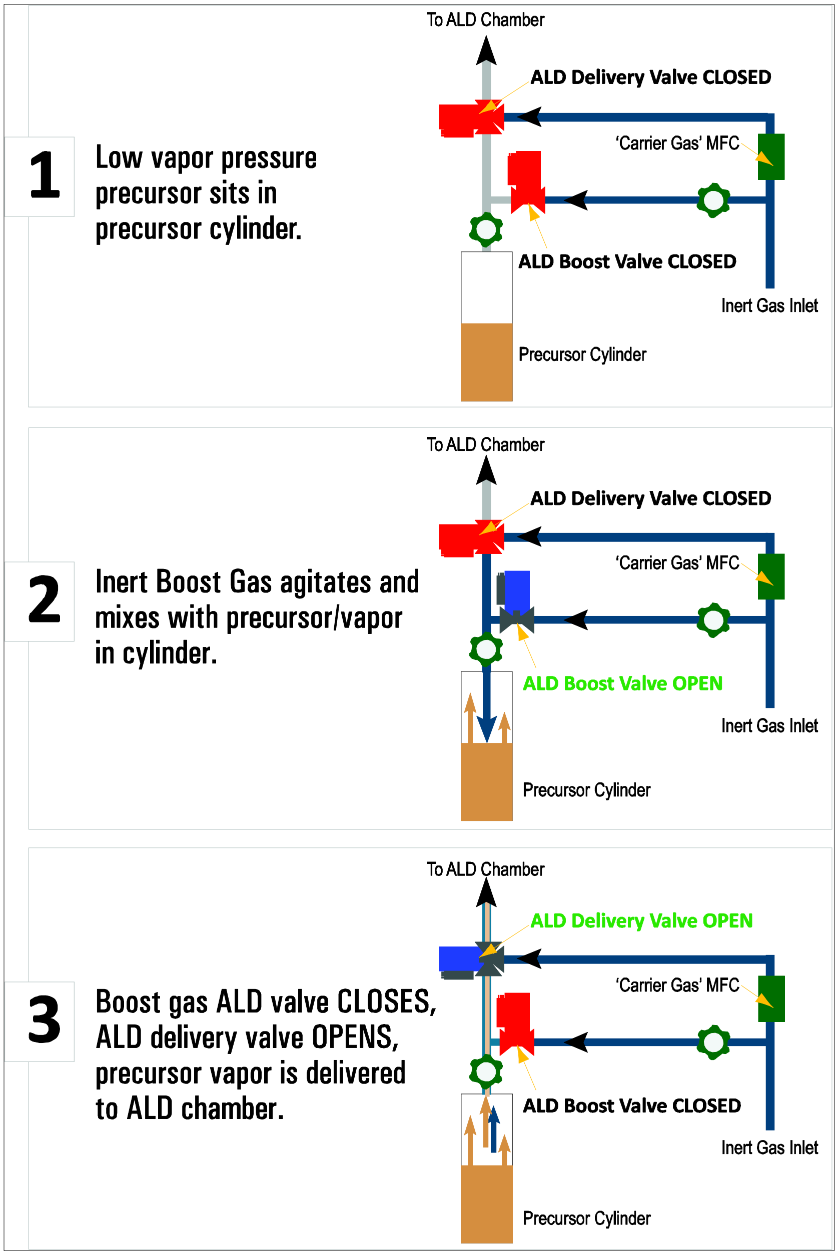
ALD Booster™ System Integration

- Fully integrated into precursor delivery system
- Constant volume of inert gas (Ar or N_2) is introduced into the cylinder, assisting transport of precursor into ALD reactor
- Low pressure differential creates reproducible doses of precursor into reactor; high pressure/flow systems (bubblers) can decrease volatility
- Under recipe & software control
- No additional mass flow controllers, heating jackets or precursor cylinders required



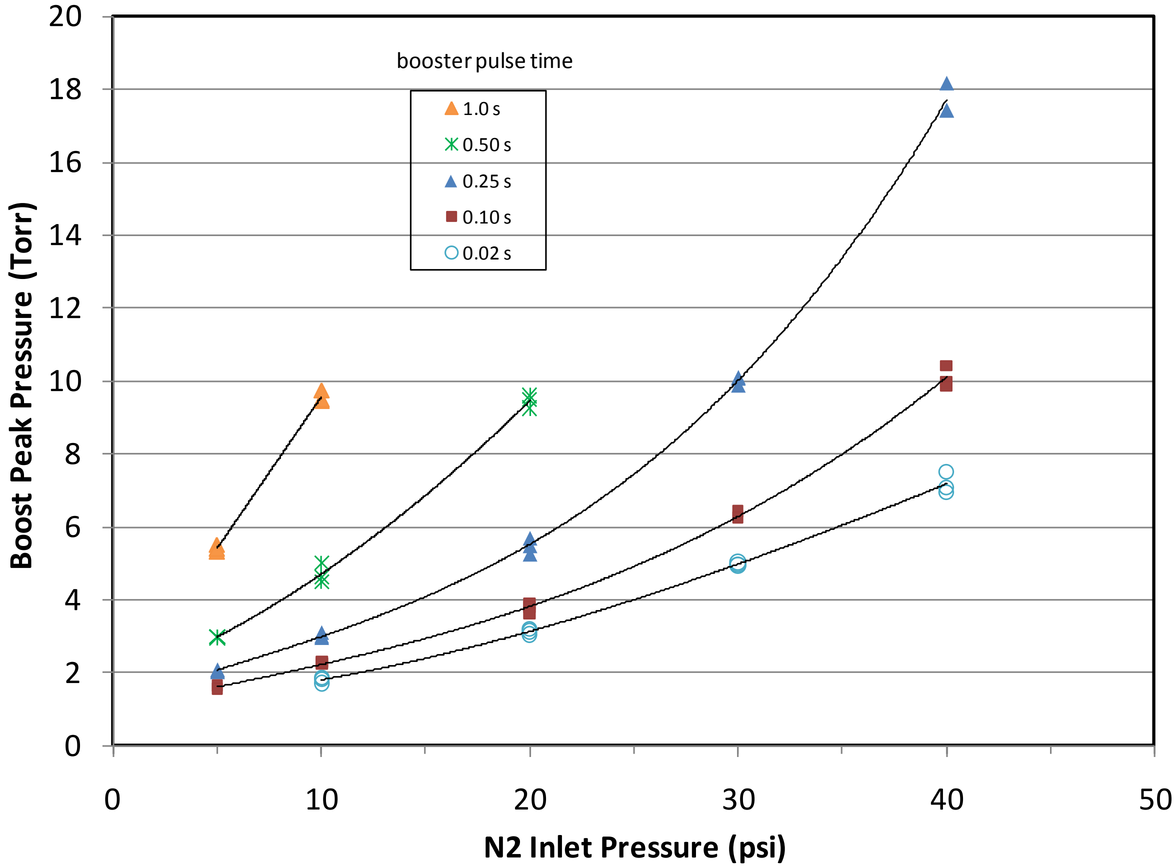
Booster components are shown in blue

ALD Booster™ Process



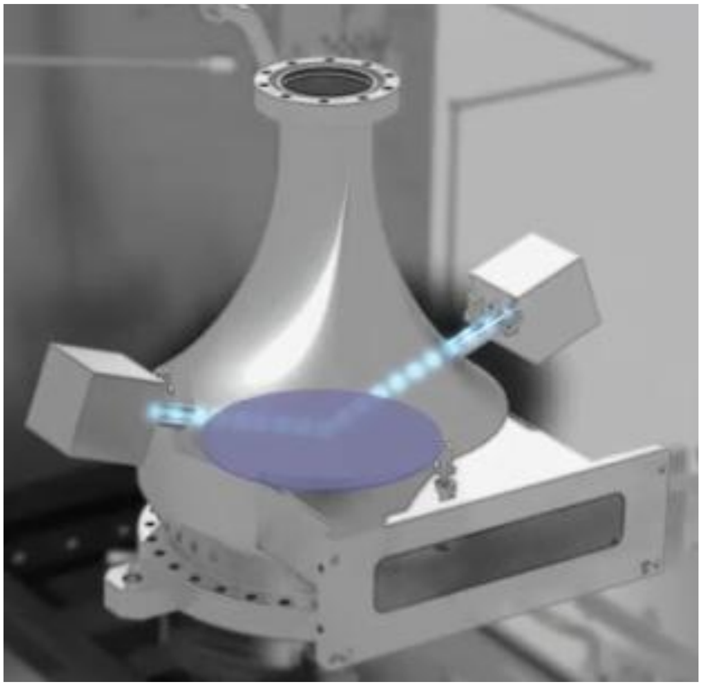
Adjustable Boost Gas Volume

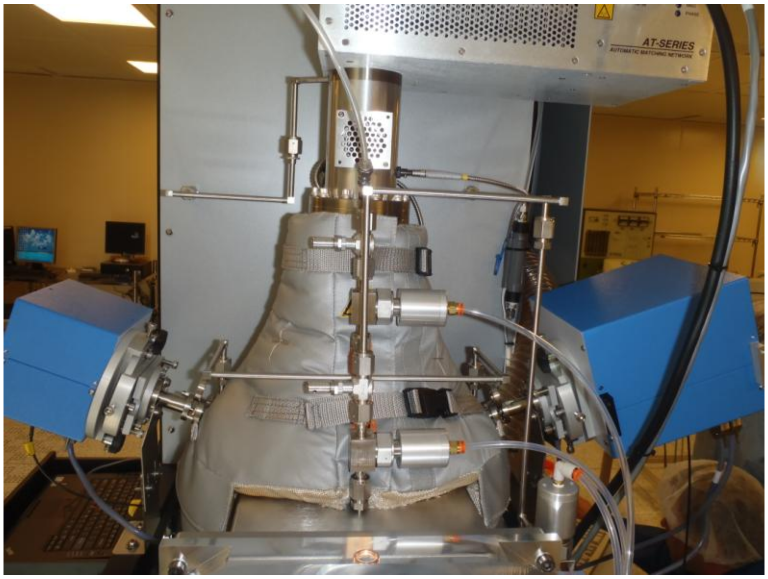
The chart below shows the effect of adjusting the boost gas volume with inlet pressure and/or pulse time.



Ellipsometer Ports and In-situ Option

In-situ observation of the substrate is available via optional ellipsometer ports and related equipment.
As shown below, the system can be configured with an ellispometer for real-time analysis. Refer to the following pages for additional chamber ports and usage.





Ports: RGA, QCM, etc.

Optional analysis ports for in-chamber film characterization are available, including connections for:

- Quartz Crystal Microbalance (QCM)
- Ellipsometry (see previous page)
- Langmuir Probe
- Residual Gas Analysis (RGA)
- Mass Spectrometry
- Optical Emissions Spectroscopy (OES)

Fiji High Temp Package

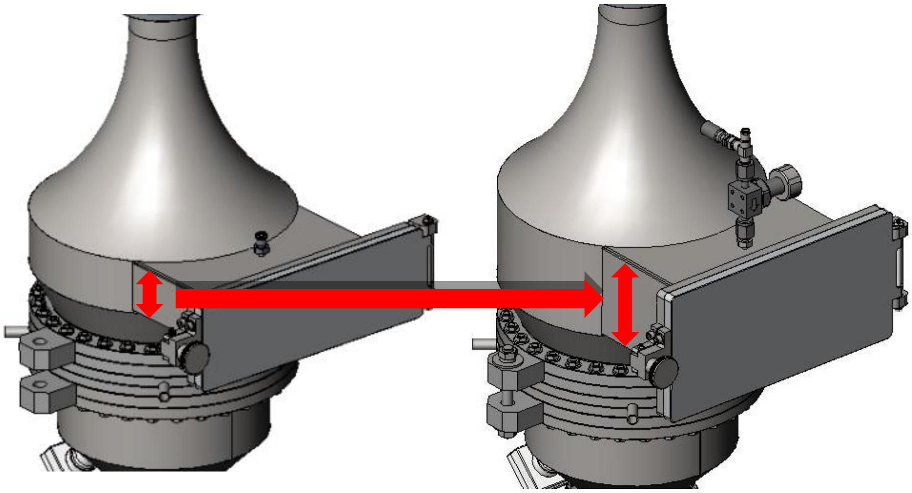
- 1000^{o}C, 8" heated chuck
- Anneal films inside chamber after ALD process
- Ideal for nitrides, complex oxides, crystalline films

No-Plasma Fiji Package

The Fiji system is available without a plasma source. The plasma source can be field-retrofitted, if desired. Consult Cambridge NanoTech regarding the requirements of your individual processes.

Wafer-Plus™ Chamber

The Fiji system can be ordered with an extended size chamber for processing of products other than wafers. The larger chamber opening accommodates larger products. Consult Cambridge NanoTech with details for your specific process requirements.



Standard Fiji Chamber

Wafer-Plus Fiji Chamber

SECTION 5: Operation

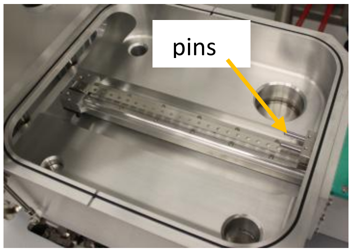
Safety Notice

All users of this equipment must review and understand the contents of the safety system of this manual, prior to working on this equipment. See *Appendix B: Safety*.

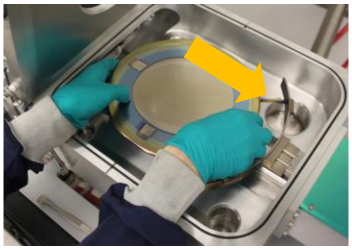
System Start-Up

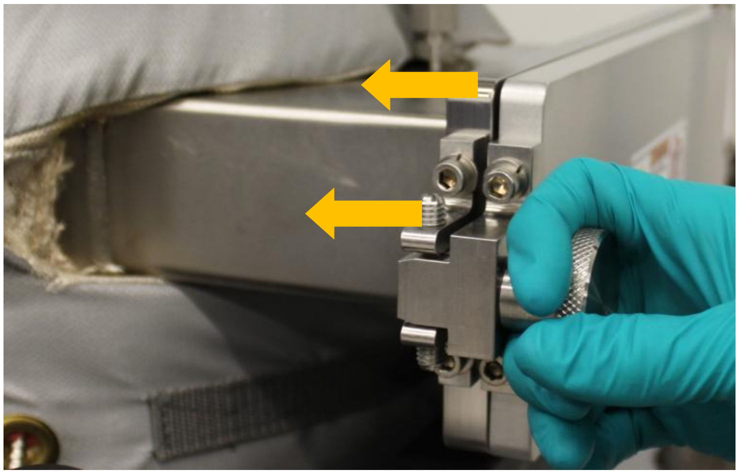
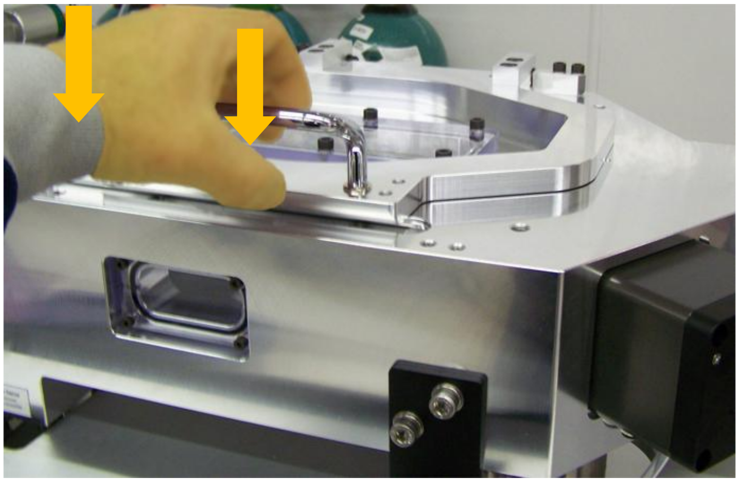
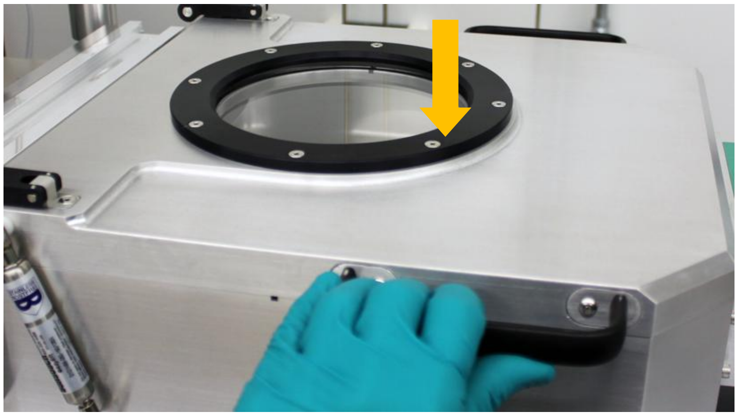
Follow the start-up sequence EXACTLY as detailed. DO NOT turn on the E-Box until AFTER the computer has fully booted-up in Windows®.

<table>
<tr><th>Step</th><th>Action</th><th>Details</th></tr>
<tr><td>1.</td><td>Verify system condition:
☐ all facility gases, feeds, exhaust, and related equipment are properly installed and certified for use
☐ all panels are in place and the system is clear of any materials and hazards
☐ the work area is clear and safe for operation
☐ Verify coolant flow and N_2 purge pressure to the vacuum pump</td><td>Refer to the Installation documentation to ensure that the system is properly installed and that all facility supplies and/or external sensors are certified to be working properly before proceeding.

Verify that all system panels are in place and any covers/doors are in proper position.</td></tr>
<tr><td>2.</td><td>Turn on or verify that all facility supplies are on:
☐ turn on the water chiller
☐ turn on the facility power
☐ turn on the facility gases
☐ verify the facility exhaust</td><td>Exhaust Requirements:
<table>
<tr><th>Location</th><th>Requirement</th></tr>
<tr><td>Cabinet Exhaust</td><td>150 CFM at 0.5” W.C.</td></tr>
<tr><td>(optional) Ozone Cabinet Exhaust</td><td>30 CFM and 0.5” WC.</td></tr>
<tr><td>Pump Exhaust</td><td>Refer to pump manual</td></tr>
</table>
Note: The Argon gas supply could be bleeding through the plasma purge valve continuously if connected and pressurized prior to supplying facility power/pneumatic pressure. (The valve is a normally-open pneumatically-controlled valve and must be energized to close.)</td></tr>
<tr><td>3.</td><td>For systems with a Hine loadlock, lift the door on the Hine loader and install the substrate carrier. Push the carrier fully onto the transfer pins.</td><td>1. Open top lid


2. Align substrate carrier with pins

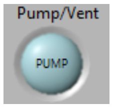
3. Slide carrier onto pins

4. Fully push onto pins
</td></tr>
</table>

4.	Close the process chamber load door.	**Manual load system: Push door in as shown.**  **VAT Load Door: Push down:**  Hine Load Door: Push down: 
5.	Verify the Emergency Stop buttons are unlatched (turn to the right).	

6.	If the RESET button is not set (bright green), press the Reset button.	
7.	Switch on each circuit breaker: ☐ CB1 MAIN (Main Power) ☐ CB2 EBOX 1 (EBOX Power) ☐ CB3 EBOX 2 (Main Turbo Power, if installed) ☐ CB4 OUTLETS (Various system controller outlets/connection supplies)	 UP (RED) = ON DOWN (GREEN) = OFF Circuit breakers
8.	Turn ON the RF power supply and tuner ☐ RF Power Supply (Seren R301) ☐ Matching Network Controller (Seren MC2)	 Computer Drawer RF Power Supply Matching Network Controller
9.	FOR SYSTEMS WITH TURBO PUMPS: Turn on the APC throttling valve controller.	

10.	Turn ON the laptop and allow the computer to boot-up.	Open the computer drawer and turn on the laptop computer  **Note**: After boot-up, the laptop can be closed at any time as it will continue to run in the closed position.
11.	Turn ON the E-box power switch	
12.	Start the ALD program by double-clicking on the program icon. 	 If the software program had been previously stopped, click the white arrow on the top-left corner to re-initialize communication. If 'MPUSB error' window appears and the program aborts upon initialization, power cycle Ebox and reinitialize. If initialization error persists, see the Troubleshooting section of this manual. The software automatically boots-up and displays the *Process* screen
13.	Verify that the system's vacuum pump is turned on.	Edwards iGX100N: • Using pump display terminal verify *PDT1 in Control* is displayed (use *Control* button to set control) • Push 'Power' button then 'Enter' and allow pump to spin up

14.

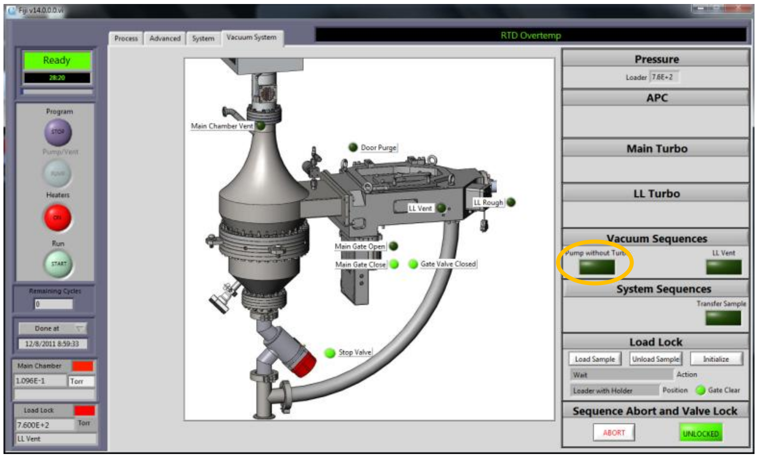
Press the 

button to begin pumping down the process chamber

The PUMP button functions ONLY on the base system without loadlock. The button is disabled (greyed out) or removed from the software screen for all loadlock systems.

<u>If the system has a loadlock:</u>

From the **Vacuum System tab**, press **Pump without Turbo** to automatically pump down the loadlock and the main chamber and set the Ar gas flows at idle.



The system automatically performs the following sequence of steps (summarized):

- Checks that the gate valve is closed
- Closes all purge and vent valves
- Closes the stop valve
- Opens the loadlock rough valve to pump down the loadlock (≤ 50 m Torr*)
- Closes the loadlock rough valve
- Opens the stop valve to pump down the process chamber to ≤ 50 m Torr*
- Sets carrier gas Argon flow to 20 sccm*
- Sets plasma gas Argon purge flow to 40 sccm*

* defined in the Setup.ini file

15.

Press the 

button to turn on the system heaters to their default setpoints.

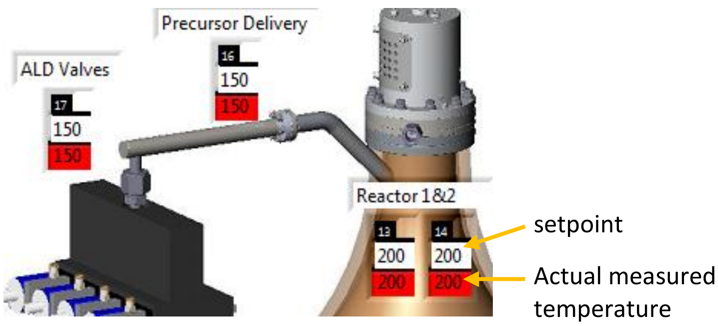
- It normally takes a few hours to reach all set temperatures when starting from cold
- Process chamber needs long baking, pumping and purging (minimal 24 hours) before good ALD processes can be obtained if system has not been pumped with heating or chamber has been exposed to air for a long time.

Factory heater default setpoints are shown below:

Heater Location	Temperature Typical	Temperature Max.	Notes
Cone/Trap	250°C	300°C	
Process Chamber Heater 1 & 2	250°C	300°C	
Chuck	250°C	500°C	
Precursor delivery line	150°C	200°C	
ALD Valve manifold	150°C	150°C	ALD valves are rated to 200°C and should not be heated above that temperature.
Precursor cylinders	0°C	120°C (ball	Precursor temperatures need to be set manually to meet the heat

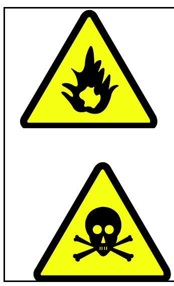
(jackets)		valve) or 220°C (bellows valve)	needs of specific precursors. **WARNING**: Temperature of the precursors should not exceed safety or decomposition temperature of the chemical used. Precursor temperatures need to be set manually to meet the heat needs of specific precursors.
APC valve	150°C	150°C	Optional item
Stop valve	-	-	Not adjustable – internal setpoint of 150°C
Bypass stop valve (if installed)	-	-	Not adjustable – internal setpoint of 150°C

If the default heater settings have not been entered, manually select each heater and enter the desired value.



Heater setpoints are entered in the white boxes.
The actual measured temperature is displayed in the box below; red (if heaters are turned on) or blue (if heaters are turned off).

The default heater settings can be reconfigured on the System screen. See the software reference section of this manual.



WARNING

FIRE HAZARD/LEAK HAZARD

Temperature of the precursors should not exceed safety or decomposition temperature of the chemical used. Consult Cambridge NanoTech for recommendations for your specific precursors.

IMPORTANT: The heaters should remain on during all system use to prevent condensation of precursor material in delivery lines and in the process chamber, chuck, and trap assemblies. Cycling of the heat can also cause flaking of materials and particles from the process chamber components over time.

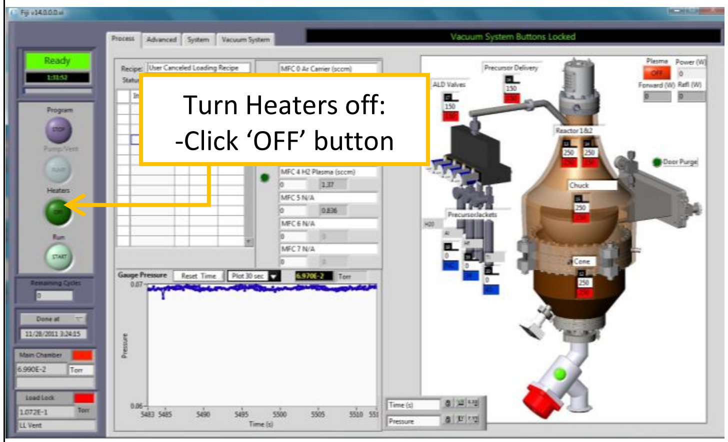
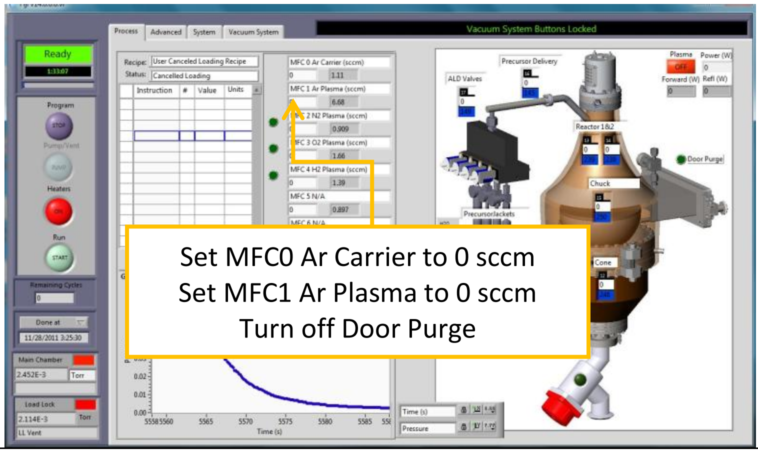
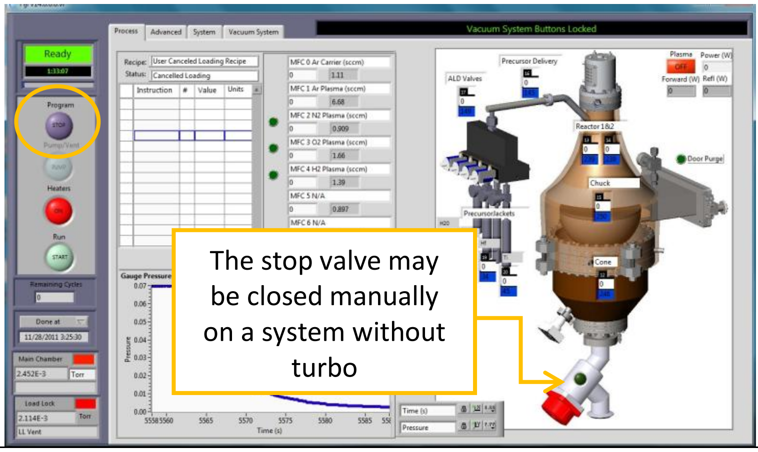
- It normally takes a few hours to reach all set temperatures when starting from room temperature
- The reactor chamber needs long baking, pumping and purging (minimal 24 hours) before good ALD processes can be obtained if the system has not been pumped with heating on, or if the chamber has been exposed to air for a long time.

16.	Wait for the system to pump down and for the heaters to stabilize at setpoint temperature.	

System Shutdown

Normal Shutdown

It is recommended to keep the system powered on at all times under vacuum with idle gas flows and at temperature. Minimizing temperature cycling can help ensure cleanliness of the chamber components (prevent flaking of any ALD residual material).

Step	Action	Details
1.	Press the Heater OFF button on the Process screen to turn off all system heaters.	
2.	Turn off all purges and idle gas flow:	
3.	Click Program **STOP** to end the programs. For systems equipped with turbo pumps, the program will automatically decelerate the turbo before exiting which takes approximately 3 minutes. Any Ebox outputs will automatically be turned off after 30 seconds of no software communication.	

4.	Close the ALD software window then Exit Windows® (shut down the computer).	
5.	Turn OFF the E-box power switch	
6.	Switch OFF each circuit breaker: ☐ CB4 OUTLETS (Various system controller outlets/connection supplies) ☐ CB3 EBOX 2 (Main Turbo Power, if installed) ☐ CB2 EBOX 1 (EBOX Power) ☐ CB1 MAIN (Main Power)	 Circuit breakers UP (RED) = ON DOWN (GREEN) = OFF
7.	Turn OFF (isolate) facility supplies: ☐ water chiller ☐ facility gases ☐ facility power ☐ system vacuum	**IMPORTANT! THE ARGON gas supply MUST BE TURNED OFF at the source or Argon will continue to flow into the system through the normally-open purge valve in the gas box when the system power or pneumatic supply is turned off.**

Emergency Shutdown

All personnel should be trained in the safe operation of the equipment and in equipment emergency procedures for the facility installation. Refer to your safety personnel for details prior to operating the system.

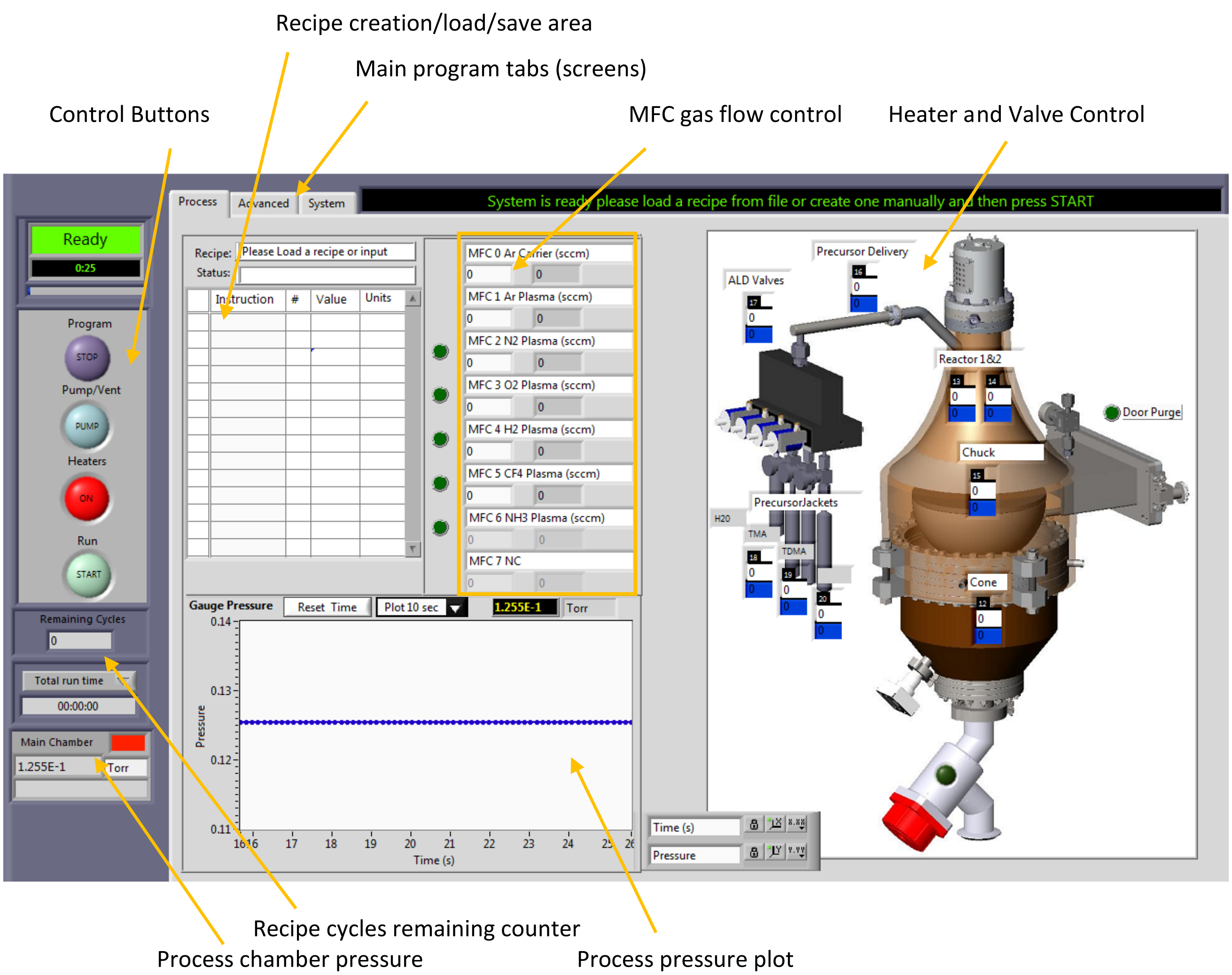
1.	Press an EMO button in the event of an emergency to disable system power and stop the flow of all process gases.	• Power to the system will be immediately disabled.  **WARNING** **SHOCK HAZARD!** Live power feed remains internal to the system at the power distribution box and power may remain in transformers, power supplies and other charge-holding equipment.
2.	When the system is in a safe state, turn OFF (isolate) facility supplies: ☐ water chiller ☐ facility gases ☐ facility power ☐ system vacuum	**IMPORTANT! THE ARGON gas supply MUST BE TURNED OFF at its source or Argon will continue to flow into the system through the normally-open purge valve in the gas box when the system power or pneumatic supply is turned off.**

Software Reference

The control program allows the operator to control the ALD valves, pumping system, heaters, RF power, auxiliary devices, and to set deposition recipes. The user-interface consists of tab pages (Process , Advanced, System, *and Vacuum System for control of turbomolecular pumps*) and a series of control buttons.

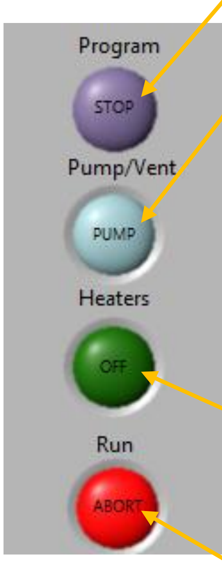
Process Tab

The Process Tab is used to create/save/load and run recipes to perform ALD. The screen is also used to perform basic functions such as pumping down the system, turning on the heaters, setting gas flows and opening/closing valves. The features are described below.



Process Screen

Control Buttons



Stops the Fiji software and turns off all outputs. Typically this button is not used except to exit the system software prior to shutting down the system. For systems equipped with a turbo, stopping the program will automatically decelerate the turbo before exiting.

Pump/Vent Toggle switch (Radials display 'next-state' rather than 'current state):

This button is disabled on systems with load/locks. Refer to the Vacuum System tab.

PUMP - pumps the system down to base pressure
VENT - vents the process chamber to atmospheric pressure:
Closes the main stop valve to isolate the process chamber from the vacuum pump then opens the main chamber vent valve. A window prompts the user to click **OK** to close the main chamber vent valve once atmospheric pressure is achieved.

Heaters Toggle switch (Radials display 'next-state' rather than 'current state):

ON - turns heaters ON (to default setpoints)

OFF - turns heaters OFF (all temperature setpoints are set to 0^{o}C)

Run Toggle switch (Radials display 'next-state' rather than 'current state):

START - runs the recipe program

ABORT - aborts a current recipe run

When a process is running, "Program", "Pump/Vent" and "Heaters" buttons are grey and not clickable. To abort a run, simply click on Run **ABORT** button.

Recipes

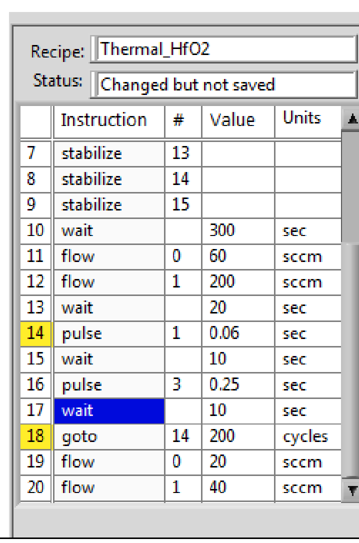
This Recipe table allows programming, loading and saving of a process sequence (recipe). For a more detailed guide on the recipe development, please refer to the Applications section.

Recipe Command Listing*
Right click with on the recipe table to display the recipe commands and functions list.

After right click, the row that the mouse cursor is pointing to becomes selected and is highlighted with a blue frame.

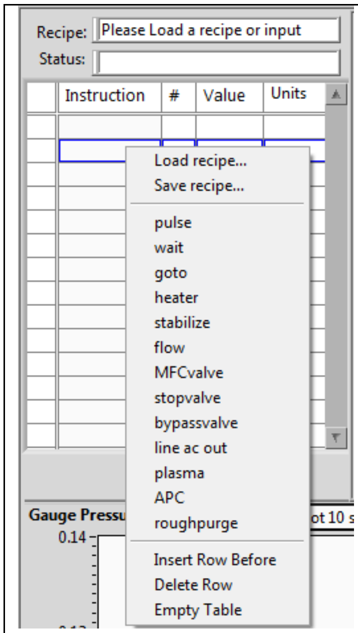
Select commands in the menu (right-click menu), then enter numeric values as required (see listing on follow pages of examples).

Recipe Table with Example Recipe
Each command line in the table consists of an automatically assigned line number, an instruction, and two numerical parameters: "#" and "value".



Recipe: Thermal_HfO2
Status: Changed but not saved

	Instruction	#	Value	Units
7	stabilize	13		
8	stabilize	14		
9	stabilize	15		
10	wait		300	sec
11	flow	0	60	sccm
12	flow	1	200	sccm
13	wait		20	sec
14	pulse	1	0.06	sec
15	wait		10	sec
16	pulse	3	0.25	sec
17	wait		10	sec
18	goto	14	200	cycles
19	flow	0	20	sccm
20	flow	1	40	sccm



*Command listing varies with system configuration. Not all commands shown in example above. Not all commands shown are available on each system.

Recipe Commands

Recipe Command	Example	Purpose	Notes
Pulse (#, value)*	Pulse 0, 0.05 (Pulses ALD 0 for 0.05 seconds)	Opens the "**#**" ALD valve for "**value**" seconds and then closes the valve, which completes a precursor pulsing.	The valid value of "**#**" is 0, 1, 2, 3, 4, and 5, corresponding to cylinder (0 = water, 1-5 = precursor cylinders) that the ALD valve is connected to on the electronic box. The range of "**value**" is 0.015 to 10 seconds.
Wait (value)	Wait 10 (waits 10 seconds before proceeding to next recipe command in table)	Tells the program to wait "**value**" seconds before executing the next command. This command is usually used right after a "pulse" command for purging the pulsed precursor.	Can be any non-negative number.
Goto (#, value)	Goto 14, 200 (goes to row 14 and repeats this loop 200 times)	Jump to line number "**#**" for "**value**" times	"**#**" must be a non-negative integer and no greater than the largest line number in the recipe. "**value**" must be a positive integer
Heater (#, value)	Heater 9, 200 (sets heater 9 setpoint to 200°C)	Sets a heater temperature setpoint	
Stabilize (#)	Stabilize 9 (waits until heater 9 reaches setpoint ± 1°C)	Waits until heater # has reached its setpoint within 2 degree	
Flow (#, value)	Flow 1, 50 (sets MFC 1 to flow at 50 sccm)	Sets MFC # to flow rate "**value**".	# = MFC number Value = any non-negative number up to limit of gas MFC.
Stopvalve (value)	Stopvalve 0 (closes stop valve)	Opens or closes the main vacuum valve.	closes (**value**=0) or opens (**value**=1)
Line ac out (#, value)	Line ac out 1, 0 (turns off line AC out # 1)	The Ebox provides multiple AC outputs for optional/accessory equipment (for example, ozone generators, etc.)	Value of O = OFF Value of 1 = ON # = 200-240 V output plug position (0-11)
MFCValve (#, value)	MFCValve 2, 1 (opens MFC valve 2 – Nitrogen)	Opens or closes the downstream MFC valve.	Value of 0 = CLOSE Value of 1 = OPEN # = MFC Valve number (2-7): MFCValve 2 – N2 MFCValve 5 – NH3 MFCValve 3 – O2 MFCVAlve 6 – CF4 MFCValve 4 – H2 MFC Valve 7 – O2/O3 generator
Bypass Stop Valve (value)	Bypass Stop Valve 1 (opens the bypass stop valve)	Opens or closes the bypass stop valve.	Value of 0 = CLOSE Value of 1 = OPEN
Plasma (value)	Plasma 300 (sets plasma power to 300 watts)	The wattage for the plasma setting	0, 300 Watts A setting of 0 is used to turn the RF power off.

Note: When entering a value, never us a comma. For example, enter 0.015, not 0,015. The system does not recognize commas and will not pulse.

Recipe Functions

Function	Use	Usage
Load recipe…	Click to select and load a previously saved recipe	Navigate to the hard drive storage area or a USB device to load a recipe for display/editing/running
Save recipe…	Click to save the currently-displayed recipe	Enter a file name for the recipe when prompted
Insert Row Before	Inserts a row above the currently highlighted recipe command	
Delete Row	Deletes the currently selected recipe row	
Empty table	Deletes all rows from the current recipe table	

Example Recipes

The following recipes are presented to demonstrate the use of the Recipe commands. These recipes can be adapted to meet your individual system's configuration and process needs. Consult Cambridge NanoTech with any questions.

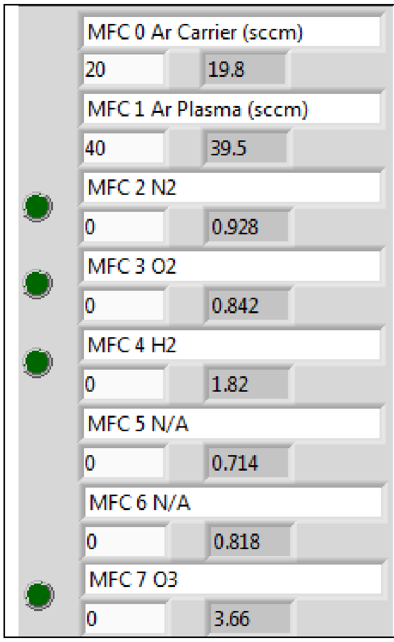
Example 1: Thermal Alumina (ALD 0 = H20, ALD 1 = TMA)

	Instruction	#	Value	Units	
0	flow	0	20		Flow carrier gas (0) at 20 sccm
1	flow	1	40		Flow plasma gas (1) at 40 sccm
2	heater	12	250	C	Set heater 12 (cone heater) to 250°C
3	heater	13	250	C	Set heater 13 (Reactor Heater 1) to 250°C
4	heater	14	250	C	Set heater 14 (Reactor Heater 2) to 250°C
5	heater	15	250	C	Set heater 15 (Chuck heater) to 250°C
6	stabilize	12			Wait for heater 12 to stabilize at setpoint
7	stabilize	13			Wait for heater 13 to stabilize at setpoint
8	stabilize	14			Wait for heater 14 to stabilize at setpoint
9	stabilize	15			Wait for heater 15 to stabilize at setpoint
10	wait		300	sec	Wait 300 seconds for temperature to stabilize
11	flow	0	60	sccm	Increase carrier gas flow to 60 sccm
12	flow	1	200	sccm	Increase plasma gas flow to 200 sccm
13	wait		20	sec	Wait 20 seconds
14	pulse	0	0.06	sec	**Pulse** ALD 0 (H20) for 0.06 seconds
15	wait		10	sec	Wait 10 seconds for carrier gas to flow through system
16	pulse	1	0.06	sec	Pulse ALD 1 (TMA) for 0.06 seconds
17	wait		10	sec	Wait 10 seconds for carrier gas to flow through system
18	goto	14	200	cycles	**Goto** step 14 (pulse) and repeat steps 14-17. Repeat for a total of 200 times
19	flow	0	20	sccm	Reduce carrier gas flow to idle flow of 20 sccm
20	flow	1	40	sccm	Reduce plasma gas flow to idle flow of 40 sccm

Example 2: Plasma Alumina (ALD 1 = TMA)

	Instruction	#	Value	Units	
0	flow	0	20	sccm	Flow carrier gas (0) at 20 sccm
1	flow	1	40	sccm	Flow plasma gas (1) at 40 sccm
2	heater	12	250	C	Set heater 12 (Cone heater) to 250°C
3	heater	13	250	C	Set heater 13 (Reactor Heater 1) to 250°C
4	heater	14	250	C	Set heater 14 (Reactor Heater 2) to 250°C
5	heater	15	250	C	Set heater 15 (Chuck heater) to 250°C
6	stabilize	12			Wait for heater 12 to stabilize at setpoint
7	stabilize	13			Wait for heater 13 to stabilize at setpoint
8	stabilize	14			Wait for heater 14 to stabilize at setpoint
9	stabilize	15			Wait for heater 15 to stabilize at setpoint
10	wait		300	sec	Wait 300 seconds (5 minutes for system to stabilize)
11	flow	0	60	sccm	Increase carrier gas flow to 60 sccm
12	flow	1	200	sccm	Increase plasma gas flow to 200 sccm
13	MFCvalve	3	1		Open MFC valve # 3 (oxygen)
14	wait		20	sec	Wait 20 seconds
15	pulse	1	0.06	sec	**Pulse ALD 1 for 0.06 seconds**
16	wait		5	sec	Wait 5 seconds for carrier gas to flow through system
17	flow	3	20	sccm	Flow MFC 3 (oxygen) at 20 sccm
18	wait		5	sec	Wait 5 seconds
19	plasma		300	Watts	Set plasma power to 300 Watts
20	wait		20	sec	Wait 20 seconds
21	plasma		0	Watts	Turn off plasma power
22	flow	3	0	sccm	Turn off MFC 3 (oxygen) gas flow
23	wait		5	sec	Wait 5 seconds
24	goto	15	200	cycles	**Goto** step 15 (pulse) and repeat steps 15-23. Repeat for a total of 200 times
25	flow	0	20	sccm	Reduce carrier gas to idle flow of 20 sccm
26	flow	1	40	sccm	Reduce plasma gas flow to idle flow of 40 sccm
27	MFCvalve	3	0		Close MFC valve # 3 (oxygen)

Mass Flow Controller Table

<table>
<tr>
<td>
</td>
<td>MFC flow setpoint displayed in white box for corresponding MFC 0-7.
Gas flow may be entered manually or set in a recipe.
Actual flow readback is displayed in grey box to the right of the setpoint.

Note: When the hydrogen or oxygen valves are closed, the gas interlock forces a several second argon purge of the gas lines.</td>
</tr>
</table>

Note:

= OPEN valve, illuminated (bright green) to show valve is open

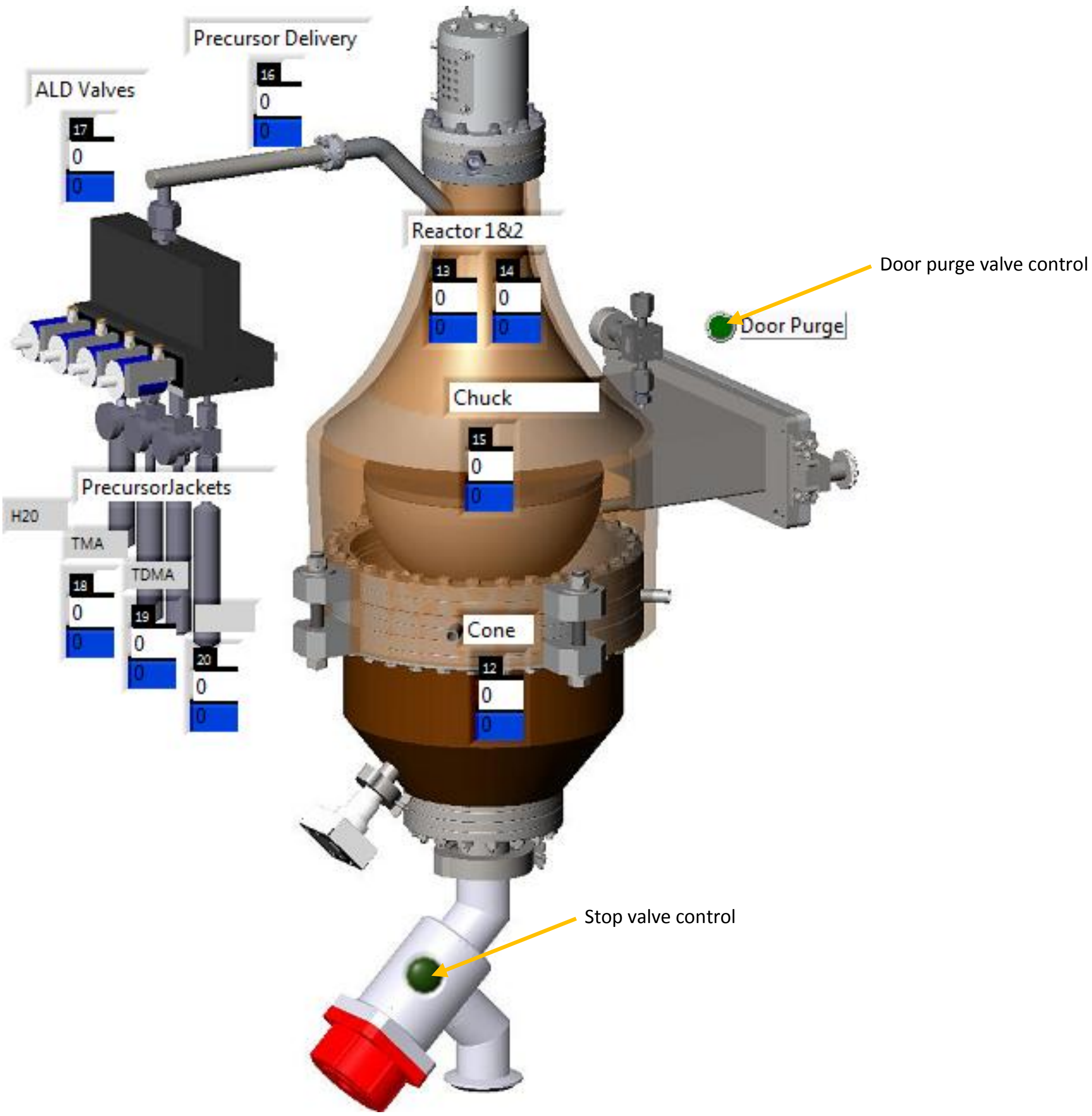
= CLOSED valve, dark, to show valve is closed

Heater Control Area

Heaters

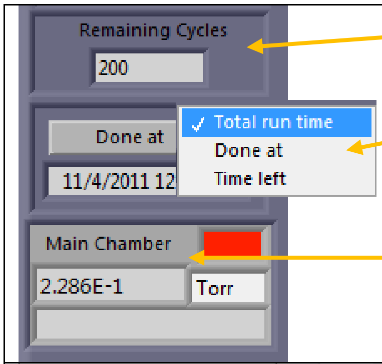
The heater control area (graphic on right side of screen) allows direct control of each heater.

Enter the temperature set point into the white area.
The current temperature reading is shown below the setpoint in blue (heaters turned off, setpoint = 0) or red (heaters turned on) area.



Note: If an RTD is not connected to the corresponding port, the temperature reading displays NC (not connected).

System Status Areas

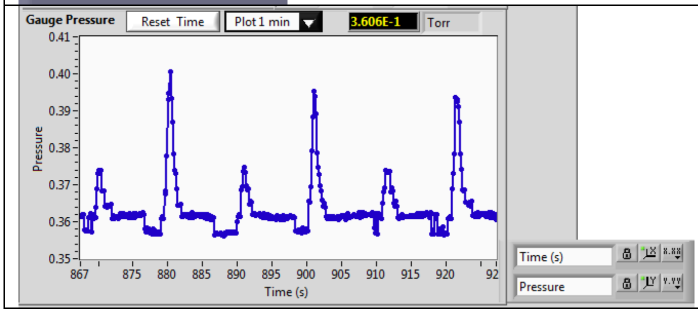


Displays cycles remaining on recipe loop. Note: Calculation for cycles remaining does not account for nested loops.

Time display: Displays Total run time, Done at time, or Time left (remaining)

Note: Total run time does not account for time required to stabilize heater temperature.

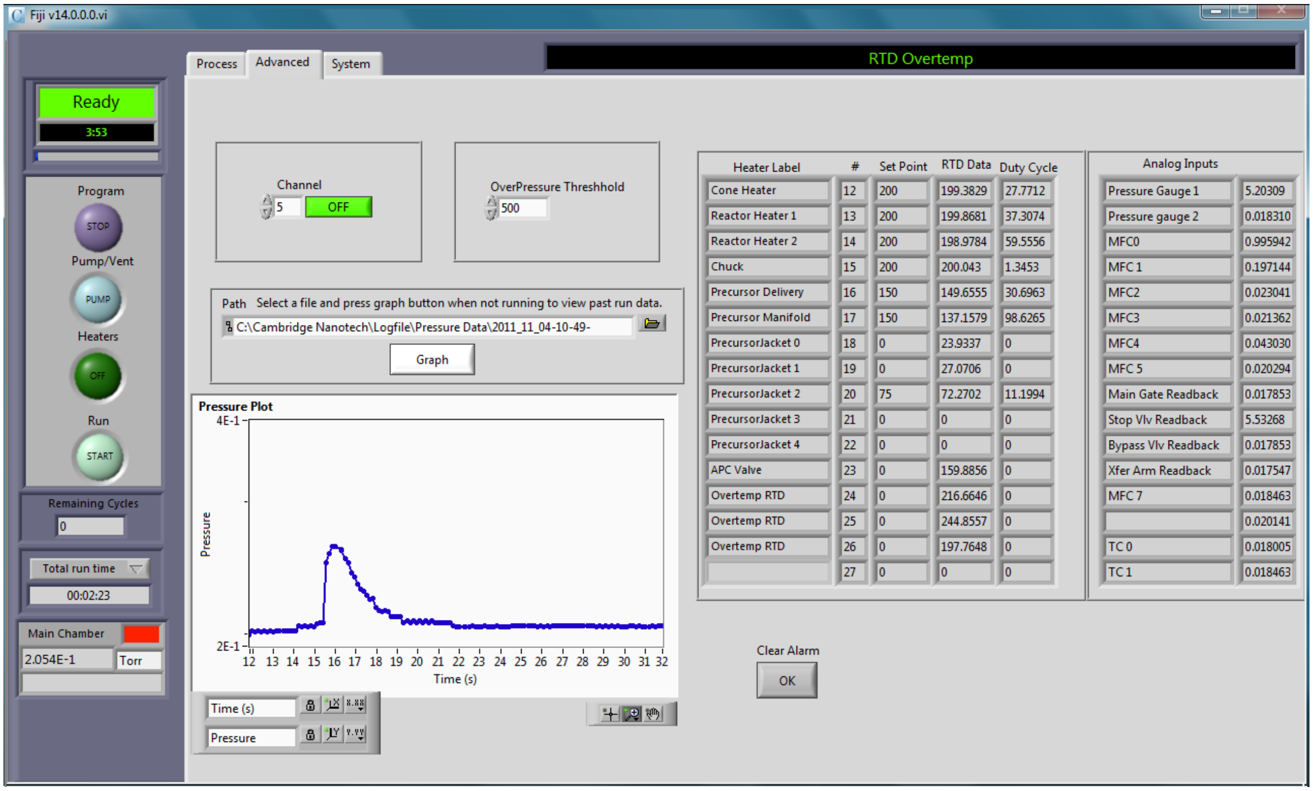
Displays digital readout of main chamber process pressure gauge in units of Torr



This plot tracks the process chamber pressure reading from the pressure gauge installed in the pumping line assembly. Pulses of the precursors show up clearly on the plot. Length of time plotted can be reset by selecting a new length and pressing the “Reset Time” button.

It is recommended to plot only a few cycles for easier monitoring, for example 30 seconds or 1 minute total plot time.

Advanced Tab



Displays/Controls are summarized below. Refer to the following pages for additional details.

Item	Description
Channel	allows switching on/off the (200-240V) power output from 3-pin ports 0-11 on the Ebox
Duty Cycle	monitors the heater power duty cycle outputs from 3-pin ports 12-23 on the Ebox.
Overpressure threshold (torr)	prevents running a process when the process chamber pressure is above a certain level. By default, the threshold is set to 500 Torr. If during an exposure mode run, the pressure rises above the threshold and interrupts the run, it is helpful to increase the threshold value.
Graphic Function	allows you to plot past data runs
Data Logging	The system automatically creates and maintains data of system parameters and events on the computer hard drive. Data is stored in the C:\Cambridge NanoTech\Logfiles" directory and stored in separate subfolders, for example: Pressure, Heaters, Event, Reports, etc.
Analog Input	Displays DC voltage from analog input of various components
Clear Alarm	Clears alarm or error message

Temperature Display Area

RTD

Actual temperature reading as measured by resistance temperature detector (RTD) provides feedback in closed-loop heater control

Setpoint

Heater setpoint temperature (target temperature)

Duty Cycle

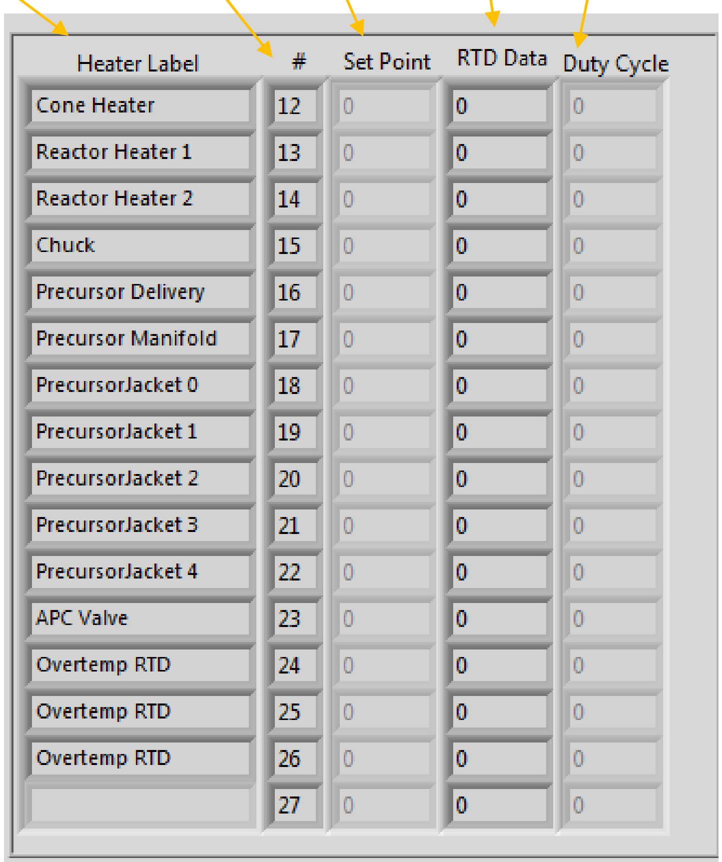
Percentage of time power is applied to heater to reach or maintain setpoint. Duty cycle is typically high (80%+) during ramp-up to temperature, then reduced significantly as only less power is required to maintain a setpoint without overshoot of the setpoint temperature

 # (number)

Heater number assigned in software / Ebox output

Heater Label

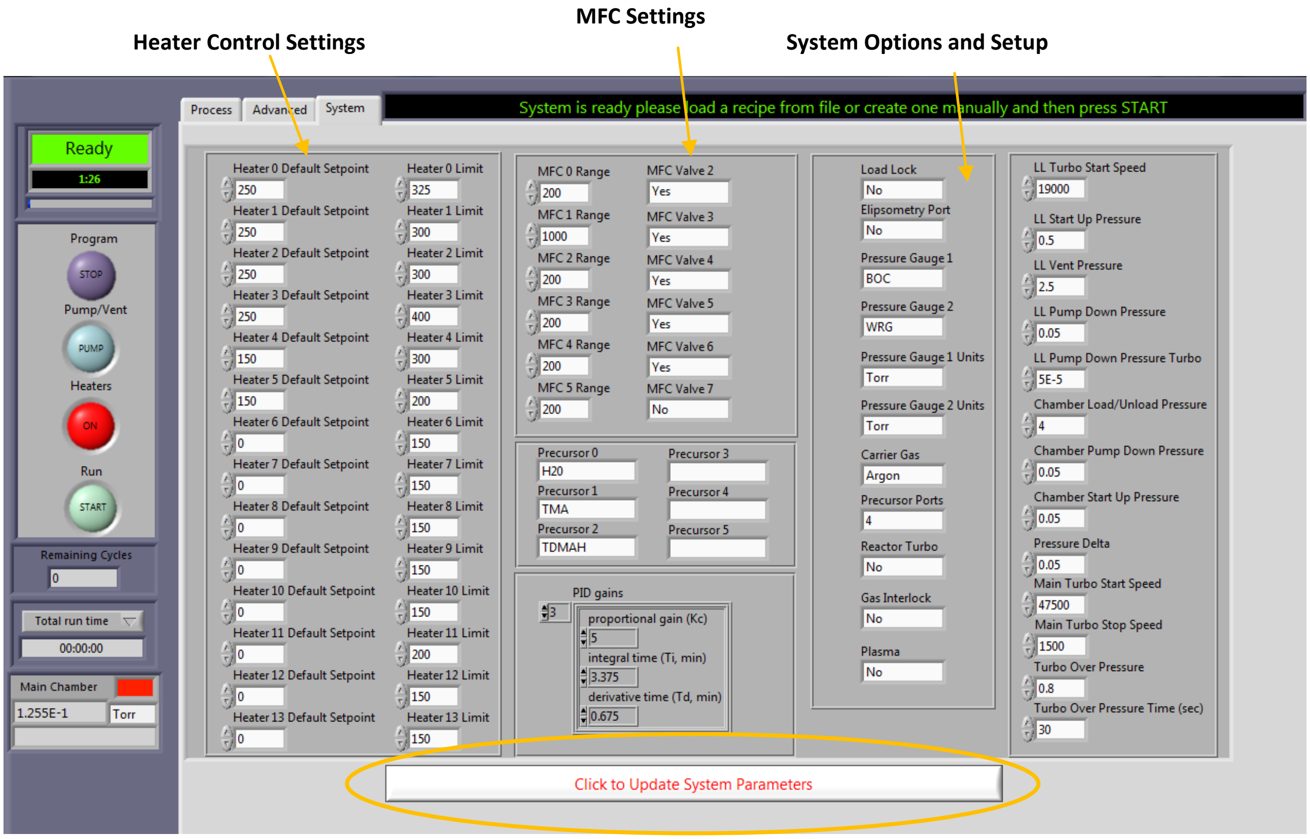
Heater name/location



System Tab

The system screen is used to enter default heater setpoints. The screen is also used to enter alarm, warning, and other setpoints for the system's sensors, as well as log times and intervals. Optional equipment is also configured on this screen.

IMPORTANT: Press the "Click to Update System Parameters" button after making any changes.



The table below shows standard as well as some optional equipment:

Item	Name	Description
1	Heater Default Setpoint	Enter default heater setpoint value ≤ heater limit value. Using the Main Control radial for Heaters ON will automatically set all heaters to their default value. Note: Heater number offset by 12 (i.e. Process Tab: Trap heater = #12 , Systems Tab: Trap Heater = #0)
2	Heater Limits	Sets the limit for maximum operating temperature for each heater.
3	MFC Range	Sets the full-scale flow for proper analog control of each MFC
4	MFC Valve	MFC Valves are installed downstream of each reactive plasma gas and O_2/O_3 delivery line
5	PID gains	Sets proportional, integral, and derivative constant for each heater

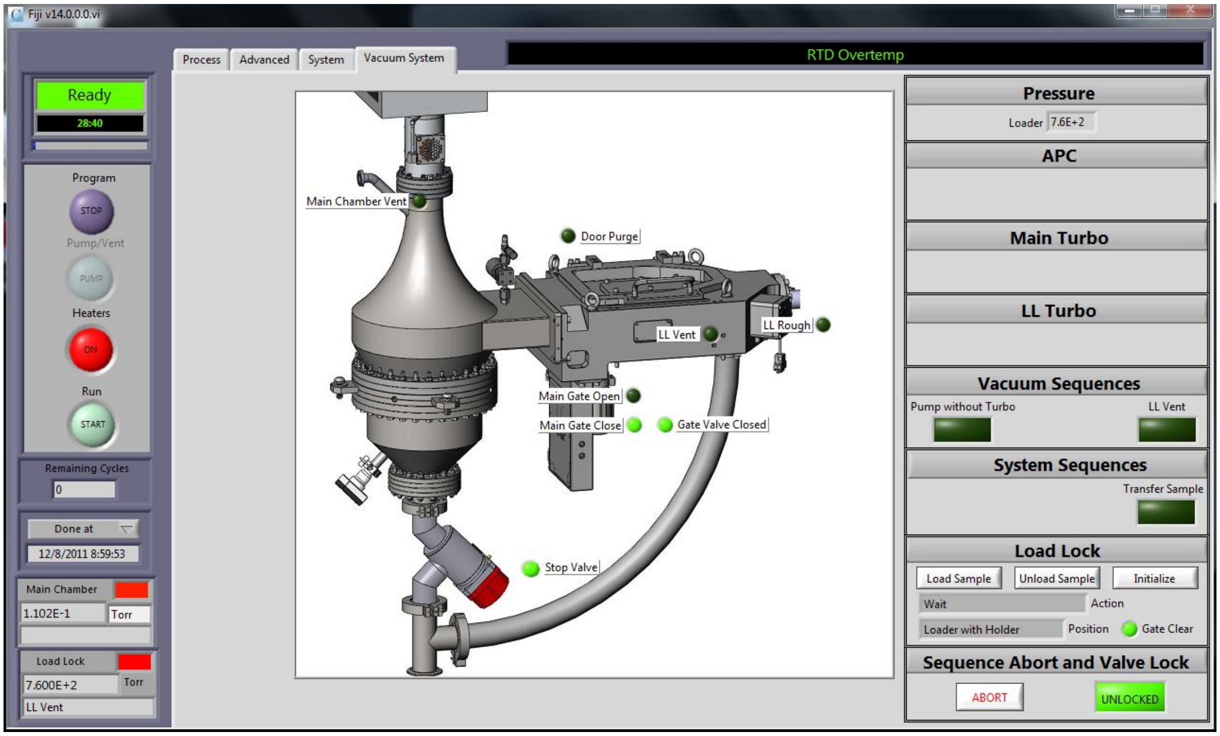
		Note: Heater number offset by 12 (i.e. Process Tab: Trap heater = #12 , Systems Tab: Trap Heater = #0)
6	Precursor Labels	Adjust precursor label displayed on the Process Tab – used to identify precursor material installed
7	Loadlock	Value of Yes/No enables/disables LL option
8	Ellipsometry Port	Value of Yes/No enables/disables Ellipsometer Purge
9	Pressure Gauge 1	PressureGauge1 indicates the type of process (main chamber) pressure gauge. Value of "BOC" specifies Edwards APGX-H pressure gauge; Value of "WRG" specifies Edwards WRG-S pressure gauge
10	Pressure Gauge 2	PressureGauge2 indicates the type of loadlock pressure gauge. Value of "BOC" specifies Edwards APGX-H pressure gauge; Value of "WRG" specifies Edwards WRG-S pressure gauge
11	Pressure Gauge 1 Units	Values for pressure reading display are "Torr" or "mBar"
12	Pressure Gauge 2 Units	Values for pressure reading display are "Torr" or "mBar"
13	Carrier Gas	Values for CarrierGas are "Argon" or "Nitrogen”
14	Precursor Ports	Assigns number of ALD ports on system (values: 2-6 - controlled via eBox outputs "ALD VLV OUTPUTS 0-5")
15	Reactor Turbo	Reactor Turbo setting no longer relevant. There is another setting in the setup.ini file for MainTurbo = True/False (Main Turbo; Value of TRUE/FALSE enables/disables Main Chamber Turbo option)
16	Gas Interlock	No longer relevant. Systems are hardwired for gas interlocks and/or interlocks are set in the setup.ini file.
17	Plasma	YES = Plasma enabled NO = Plasma disabled
18	LL Turbo Start Speed	Final maximum RPM required for completing LL Pump Down with Turbo sequence
19	LL Turbo Startup Pressure	Not used.
20	LL Turbo Vent Pressure	Not used.
21	LL Pump Down Pressure	Pressure setting (units=Torr) at which the LL crosses over from rough pump to high vacuum pump during the LL Pump with Turbo sequence.
22	LL Pump Down Pressure Turbo	Pressure setting (units=Torr) at which the LL Pump with Turbo sequence completes
23	Chamber Load/Unload Pressure	Not used.
24	Chamber Pump Down Pressure	Maximum pressure setting (units = Torr) at which the Pump Down sequence has completed.
25	Chamber Start Up Pressure	Not used.
26	Pressure Delta	Maximum pressure (units = Torr) differential between reactor and LL at which the Main Gate can be opened during the 'Transfer Sample' sequence.
27	Main Turbo Start Speed	Final minimum RPM required for completing Pump Down with Turbo sequence
28	Main Turbo Stop Speed	Final maximum turbo RPM required for completing Pump Down with Turbo sequence
29	Turbo Over Pressure	Maximum pressure setting allowable during processing. If the process pressure exceeds the OverPressDefaultValue for a duration of OverPTime during processing, the recipe will abort, turn off turbo, and close door purge.
30	Turbo Over Pressure Time	Maximum time allowable at OverPressure setting before recipe will abort.
31	Click to Update System Parameters	Need to click for any changes to take effect

Note: All of the settings in the Advanced Tab plus additional items may also be configured from the setup.ini file (see Maintenance manual for Setup.ini section). A saved change (saved by clicking the 'Click to Update System Parameters') in the Advanced Tab will be reflected in the setup.ini file. However, a saved change in the setup.ini file will not be reflected in the Advanced Tab unless the software has been reinitialized upon saving the change.

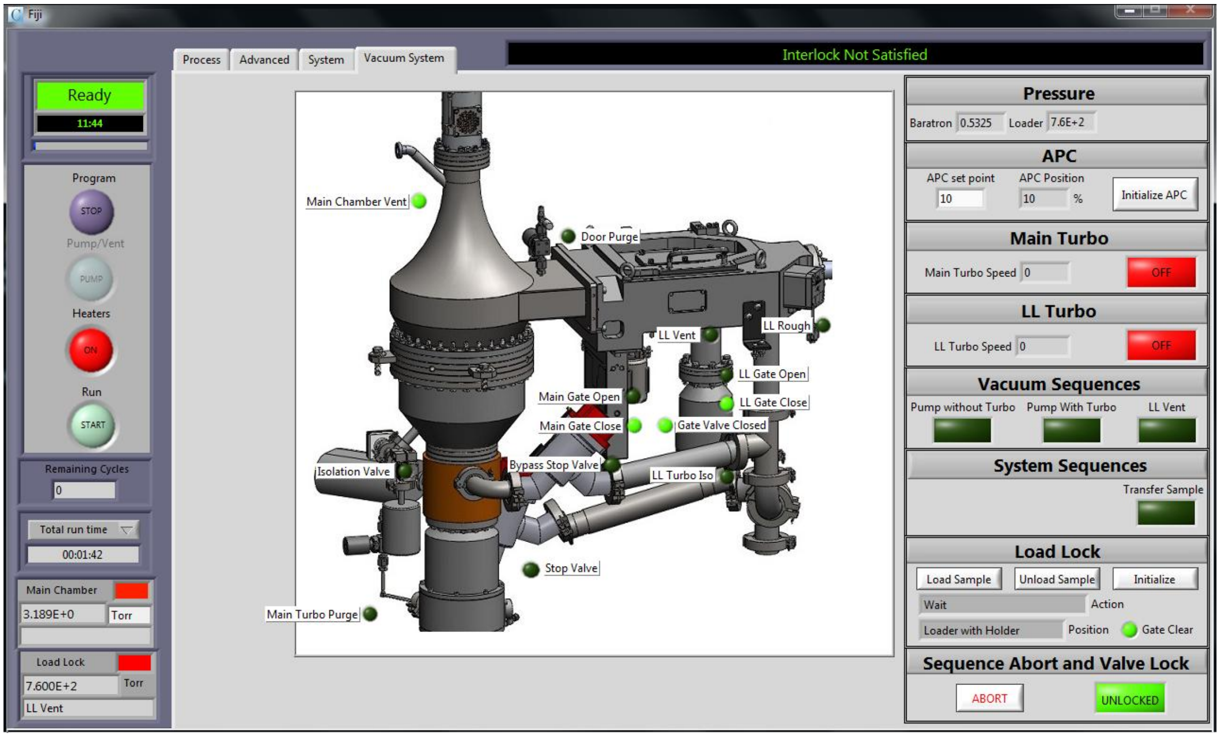
Vacuum System Tab (Loadlock systems only)

Systems with load/locks have an additional tab called "Vacuum System". From this tab, the user will typically:

- vent the load/lock (LL Vent)
- pump down the chamber (Pump without Turbo, Pump with Turbo, or Pump Chamber, depending on system configuration)
- Transfer samples (automatically equilibrate the pressure in the main chamber and the transfer chamber to allow loading of a substrate into or out of the process chamber)
- On systems with turbo pumps with APC control, enter APC values



Vacuum System – Without Turbo



Vacuum System – With Turbo and APC Control

Item	Description
Pressure	Displays load chamber pressure If a Baratron capacitance manometer gauge in installed, the gauge's pressure is also displayed.
APC (optional)	Automatic Pressure Control setpoint (% open) and actual APC Position is displayed. 10% = 10 percent open Intialize APC will cycle the APC throttling gate valve through its full range of motion (open then close)
Main Turbo (optional)	Use button to manually toggle Main Turbo (process chamber) ON/OFF. Actual speed (rpm) displayed in box.
LL Turbo (optional)	Use button to manually toggle Main Turbo (process chamber) ON/OFF. Actual speed (rpm) displayed in box.
Vacuum Sequences	**Pump without Turbo**: Pumps down load/lock and the process chamber The system automatically goes through the following sequence (summarized): 1. Set all MFC flows to 0 2. Close purge and vent valves: Door purge valve, chamber vent valve, load/lock vent valve, ellipsometer purge valve (if installed) 3. Close main gate valve 4. Close chamber stop valve (isolates chamber exhaust from Load/Lock exhaust) 5. OPEN load/lock rough valve (vacuum valve) 6. System waits for load/lock pressure to reach default (typically ≤ 50 mTorr) 7. Close load/lock rough valve 8. Open stop valve and wait for chamber pressure to reach default (typically ≤ 50 mTorr) 9. Set carrier gas flow to 20 sccm, and set plasma gas flow to 40 sccm **Pump with Turbo**:

	Pumps down load/lock and the process chamber, first with the system pump, then at the 'cross-over' threshold, with the turbo pump. Systems can be configured with a turbo pumps as follows: • Turbo pump on load/lock • Turbo pump on process chamber • Turbo pump on process chamber and on load/lock
	LL Vent: Vents the load/lock The system automatically performs the following sequence (summarized): 1. The main gate valve will remain closed or the user will be prompted to close the gate valve 2. Close loadlock rough valve 3. Open loadlock vent valve to vent to atmospheric pressure. Once reached, the loadlock door can be opened.
System Sequences	**Transfer Sample**: The system will automatically pump down the loadlock. After the pressure in the process chamber and in the loadlock is equilibrated, the main gate valve separating the two chambers will automatically open. **<u>VAT loadlock:</u>** After the gate valve is opened, the transfer arm can be used to manually perform the load or unload sequence. **<u>Hine loadlock:</u>** The system will automatically pump down the loadlock. After the pressure in the process chamber and in the loadlock is equilibrated, the main gate valve separating the two chambers will automatically open. After the gate valve is opened, the loader will automatically load or unload the substrate carrier.
Load Lock (for Hine loadlock with automatic transfer)	**<u>Load Sample</u>**: For manual recovery, etc., the "Load Sample" button can be used to load the substrate carrier plate into the process chamber.
	<u>Unload Sample</u>: For manual recovery, the "Unload Sample" button can be used to unload the substrate carrier plate from the process chamber.
	<u>Initialize</u>: The initialize button can be used during system troubleshooting to cycle the loader and return it to the home position.
Sequence Abort and Valve Lock	**<u>ABORT</u>**: Stops the current process. For example, stops the transfer of a sample.
	<u>LOCKED/UNLOCKED</u>: Default position is LOCKED which prevents manually opening or closing valves. If required, the user can press the LOCK/UNLOCKED button to unlock the system to manually open or close various valves (purge, vent, gate valve, etc.)

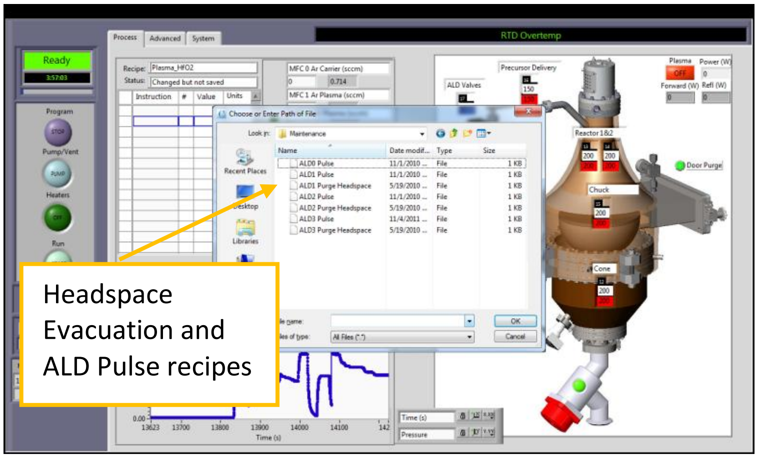
Evacuating Precursor 'Head-Space'

A critical step for installing/removing precursor cylinders from the Fiji system requires evacuating the precursor head space. The goal is to remove air (cylinder install) or precursor material (cylinder removal) from the "head-space" between the precursor cylinder manual valve and the inlet of the ALD valve. Refer to the **Installation** section of this manual for details on filling a precursor cylinder.

An evacuation of the precursor 'head-space' MUST be performed <u>every time</u> a precursor cylinder is changed.

<table>
<tr><th>Step</th><th>Action</th><th>Details</th></tr>
<tr><td>1.</td><td>Wait for the system to pump down and for the heaters to stabilize at setpoint temperature.</td><td></td></tr>
<tr><td>2.</td><td>Perform system rate of rise</td><td>It is best practice to perform a system rate of rise test (see Maintenance manual) both pre- and post-precursor installation to verify the vacuum integrity of the system.</td></tr>
<tr><td>3.</td><td>If installed, degas the WATER cylinder precursor and allow pulses to stabilize.</td><td>
Degassing removes air from the empty volume of water precursor cylinder allowing pulse pressure peak heights to stabilize.

Load (or create) and run a recipe to degas and pulse the H2O precursor cylinder. When initially pulsing newly installed precursors, it is recommended that the duration of pulse and process gas flow be similar to that required in the process recipe. Allow the pulse pressure peaks to stabilize to a magnitude exhibited under a steady state process condition.

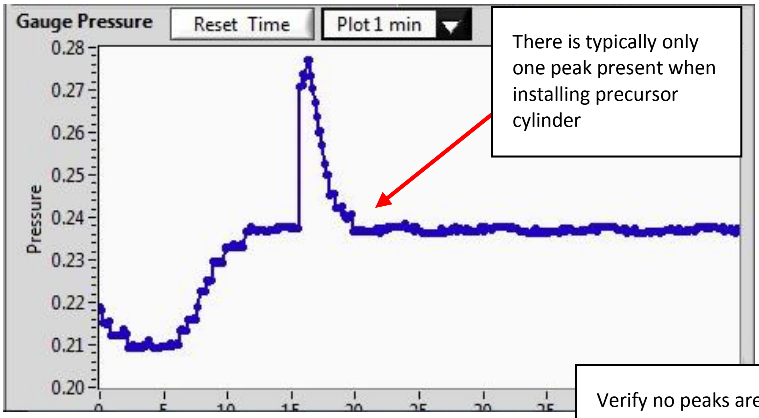


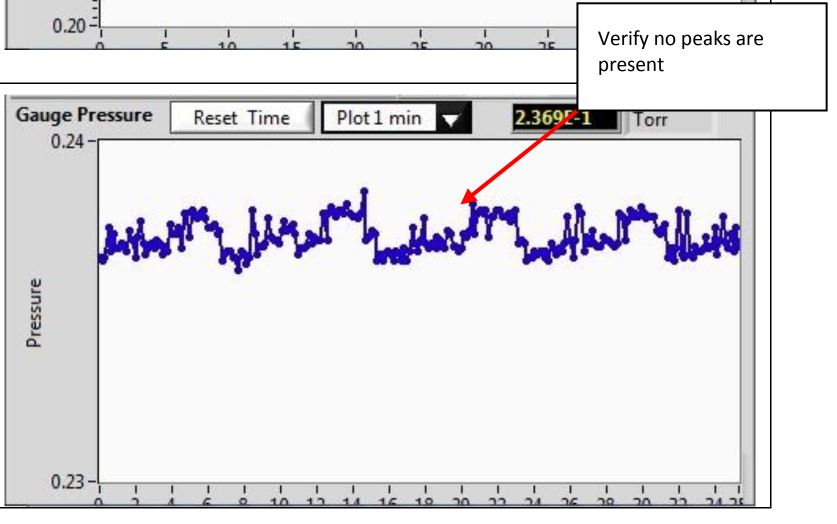
Sample water cylinder degassing recipe:

<table>
<tr><th>Step</th><th>Instruction</th><th>#</th><th>Value</th><th>Purpose</th></tr>
<tr><td>0</td><td>flow</td><td>0</td><td>60</td><td>Flow carrier gas at 60 sccm.</td></tr>
<tr><td>1</td><td>flow</td><td>1</td><td>200</td><td>Flow plasma gas at 200 sccm.</td></tr>
<tr><td>2</td><td>wait</td><td></td><td>10</td><td>Wait 10 seconds.</td></tr>
<tr><td>3</td><td>pulse</td><td>X</td><td>0.06</td><td>Open the ALD valve for the water cylinder "X" for 0.06 seconds.</td></tr>
<tr><td>4</td><td>wait</td><td></td><td>10</td><td>Wait 10 seconds.</td></tr>
<tr><td>5</td><td>goto</td><td>3</td><td>5</td><td>Go to step 3 (pulse) and repeat the pulse/wait sequence 10 times.</td></tr>
<tr><td>6</td><td>flow</td><td>0</td><td>20</td><td>Reduce carrier flow to idle</td></tr>
<tr><td>7</td><td>flow</td><td>1</td><td>40</td><td>Reduce plasma flow to idle</td></tr>
</table>
</td></tr>
</table>

<table>
<tr>
<td>4.</td>
<td>Evacuate the CHEMICAL precursor cylinder headspace:</td>
<td>
When installing a precursor cylinder, atmosphere is introduced to the ‘head-space’ between precursor cylinder manual valve and the inlet of the ALD valve.
An evacuation of the precursor ‘head-space’ MUST be performed <u>every time</u> a precursor cylinder is changed.
DO NOT OPEN THE MANUAL VALVE AT THIS TIME.

Load (or create) and run a purge recipe to purge the gas line. Ensure the pressure plot does not have any peaks with the exception of the first few pulses. If not, repeat the program to ensure the space is evacuated.
Wait at least 10 minutes then repeat the Headspace Evacuation to verify no pressure peaks are present during the pulse of the ALD valve. Any peak in the pressure plot indicates a leak in the VCR seal made during install.

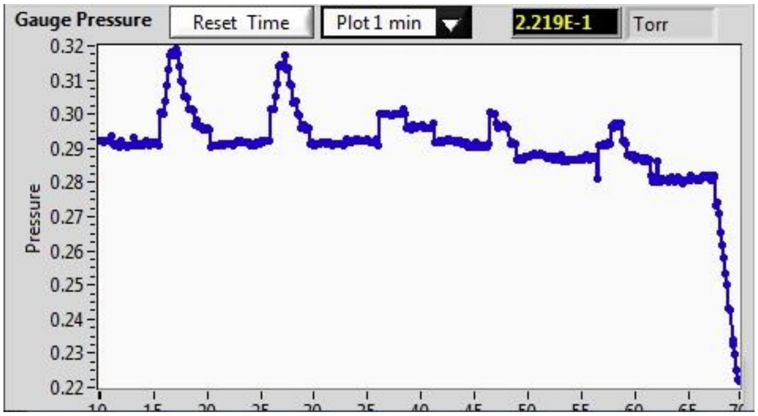
<table>
<tr><th>Step</th><th>Instruction</th><th>#</th><th>Value</th><th>Purpose</th></tr>
<tr><td>0</td><td>flow</td><td>0</td><td>20</td><td>Flow Ar carrier gas at 20 sccm.</td></tr>
<tr><td>1</td><td>flow</td><td>1</td><td>40</td><td>Flow Ar plasma gas at 40 sccm.</td></tr>
<tr><td>2</td><td>wait</td><td></td><td>10</td><td>Wait 10 seconds.</td></tr>
<tr><td>3</td><td>pulse</td><td>X</td><td>1</td><td>Open the ALD valve for the CHEMICAL cylinder “X” for 1 second.</td></tr>
<tr><td>4</td><td>wait</td><td></td><td>5</td><td>Wait 5 seconds.</td></tr>
<tr><td>5</td><td>goto</td><td>3</td><td>20</td><td>Go to step 3 (pulse) and repeat the pulse/wait cycle 20 times.</td></tr>
</table>


</td>
</tr>
<tr>
<td>5.</td>
<td>Repeat Headspace Evacuation after > 10 min.</td>
<td>


</td>
</tr>
</table>

<table>
<tr><td>6.</td><td>Perform system rate of rise</td><td>It is best practice to perform a system rate of rise test (see Maintenance manual) both pre- and post-precursor installation to verify the vacuum integrity of the system.</td></tr>
<tr><td>7.</td><td>AFTER evacuating a CHEMICAL cylinder precursor ‘head-space’, open the cylinder’s manual outlet valve.</td><td></td></tr>
<tr><td>8.</td><td>Perform initial pulses for each CHEMICAL precursor cylinder.</td><td>When initially pulsing newly installed precursors, it is recommended that the duration of pulse and process gas flow be similar to that required in the process recipe. Allow the pulse pressure peaks to stabilize to a magnitude exhibited under a steady state process condition.

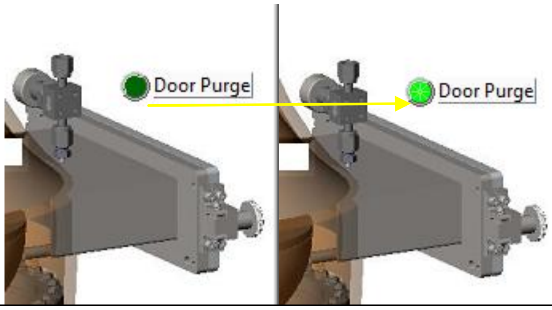
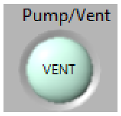
Sample TMA cylinder pulsing recipe to stabilize pressure peak height:

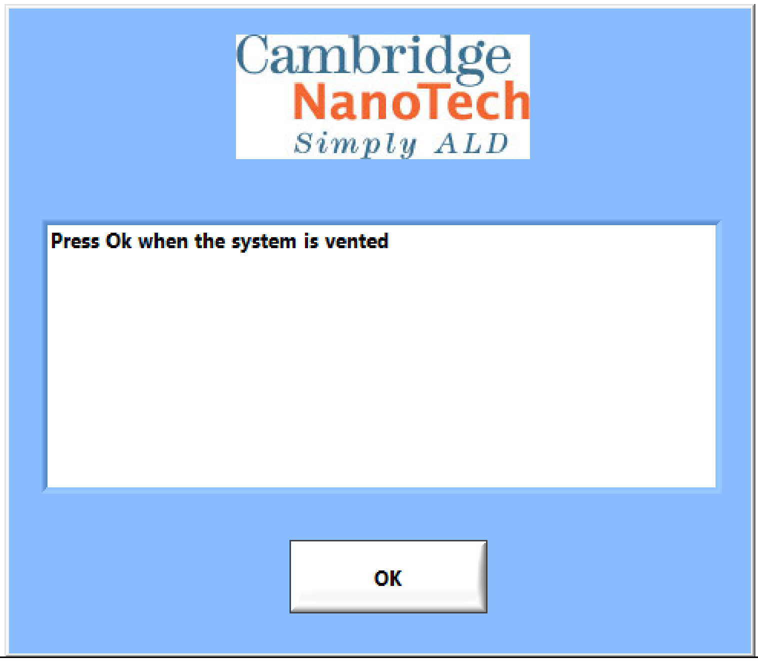
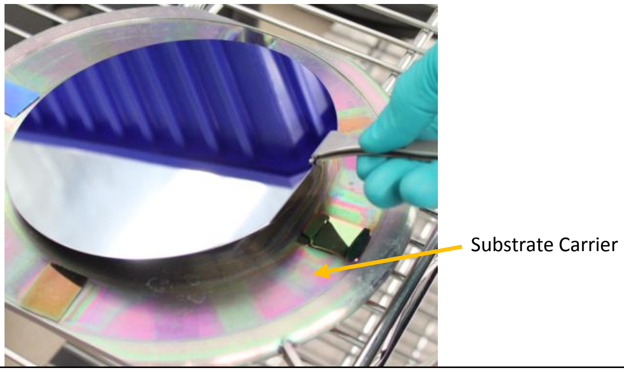
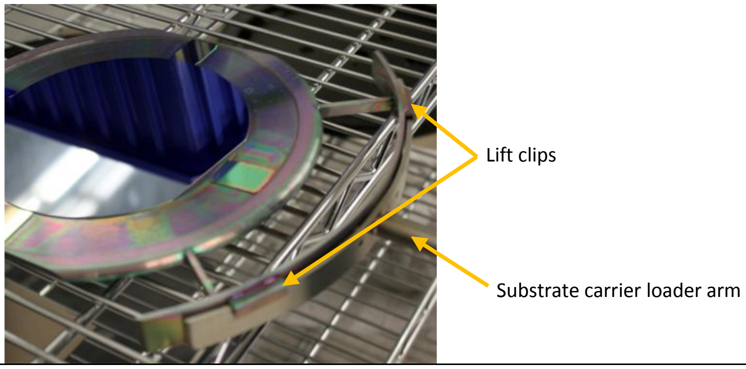
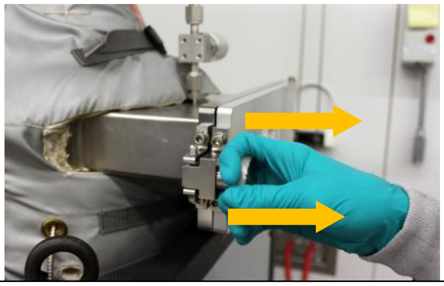
<table>
<tr><th>Step</th><th>Instruction</th><th>#</th><th>Value</th><th>Purpose</th></tr>
<tr><td>0</td><td>flow</td><td>0</td><td>60</td><td>Flow carrier gas at 60 sccm.</td></tr>
<tr><td>1</td><td>flow</td><td>1</td><td>200</td><td>Flow plasma gas at 200 sccm.</td></tr>
<tr><td>2</td><td>wait</td><td></td><td>10</td><td>Wait 10 seconds.</td></tr>
<tr><td>3</td><td>pulse</td><td>X</td><td>0.06</td><td>Open the ALD valve for the water cylinder “X” for 0.06 seconds.</td></tr>
<tr><td>4</td><td>wait</td><td></td><td>10</td><td>Wait 10 seconds.</td></tr>
<tr><td>5</td><td>goto</td><td>3</td><td>5</td><td>Go to step 3 (pulse) and repeat the pulse/wait sequence 10 times.</td></tr>
<tr><td>6</td><td>flow</td><td>0</td><td>20</td><td>Reduce carrier flow to idle</td></tr>
<tr><td>7</td><td>flow</td><td>1</td><td>40</td><td>Reduce plasma flow to idle</td></tr>
</table>


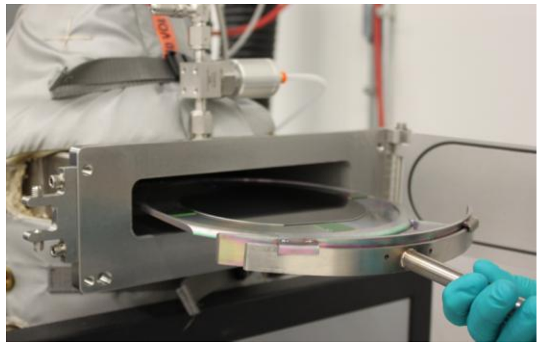
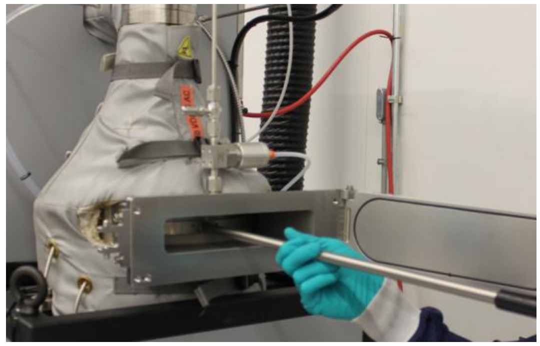
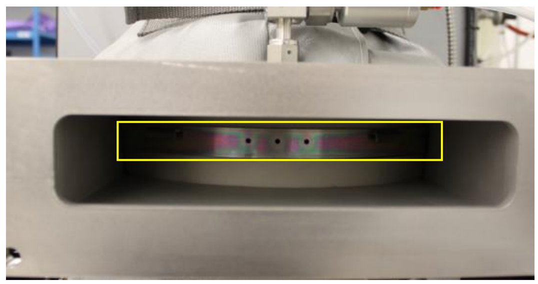
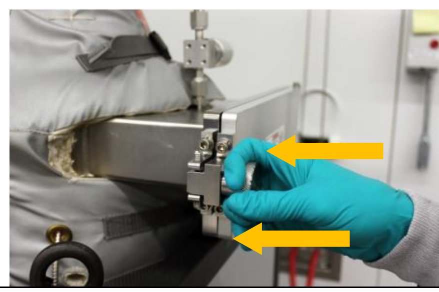
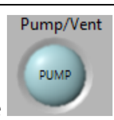
</td></tr>
<tr><td>9.</td><td>Check precursor temperatures. If started from cold, wait at least half an hour after having reached set temperatures before attempting a deposition.</td><td></td></tr>
</table>

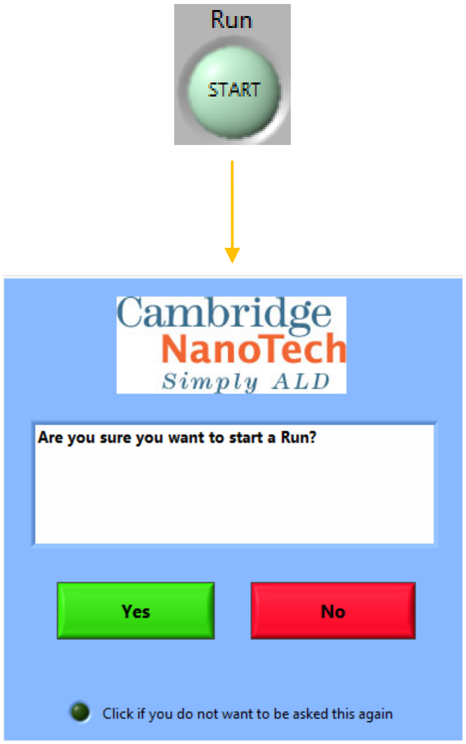
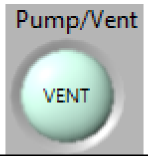
Processing a Substrate with a Manual Load Door System

Use this procedure AFTER completing the System Start-Up procedure (previous pages).

Step	Action	Details
1.	Complete the system startup procedure to ensure that the main process chamber is pumped down, the system is at temperature, and the precursors have been properly installed.	
2.	Click on the door purge icon to turn on the Door Purge.	Door purge is calibrated to 50 sccm argon. Recalibrate flow rate if necessary (refer to the Maintenance Manual). A flow of argon gas is delivered through the door purge valve in order to negate the effect of the dead space created by the rectangular volume of the door. The door purge maintains a higher pressure differential in the volume which is enough to influence the gas flow dynamic to counteract the non-symmetry of the chamber in this section and provide uniform deposition thickness. The flow rate of the door purge may require further optimization depending on the process to improve uniformity, especially if the thickness at the edge near the door is high. 
3.	Press the  button to vent the main chamber.	The main chamber is vented up to atmospheric pressure-to allow the main chamber door to be opened manually. The system can take up to 2 minutes to reach atmospheric pressure.

4.	Press **OK** on the software popup screen to turn off the main chamber vent valve.	
5.	Carefully place a substrate on the carrier plate. **Note**: It is best to have a stainless steel table available that is located near the system in order to set down the substrate carrier to load/unload samples.	
6.	Carefully lift the substrate and substrate carrier with the loader arm. The arm engages clips on the rear of the carrier plate.	
7.	Open the system door. **Note**: The door has a hinge that can be configured to open to the right or left and latches closed with a ball-bearing set screws.	
8.	Load a substrate onto the chuck, then close the door.	

		 Insert substrate carrier with loader arm  Carefully align substrate carrier on heated chuck  Carrier back-plane acts as a ‘seal’ of the process chamber.
9.	Close the system door. **Note**: The door will appear slightly loose. During the following steps, the door will be vacuum-sealed.	
10.	Press the  button to pump down the process chamber.	
11.	Wait for the system to pump down and for the heaters to stabilize at setpoint temperature.	Wait for the system to stabilize and for the system heaters to stabilize at setpoint.
12.	Create/load a recipe. Refer to the Software Reference section of this manual for details on process steps.	Load or create your process recipe as necessary for your run. Refer to the software reference section of this manual for details.
13.	From the **Process** tab, press the run	

	Start button to begin processing.	
14.	After the process run has completed, from the **Process** tab, select **Vent** and follow the system prompts to unload the sample from the system.	

Idle Conditions

It is recommended to keep the system powered on at all times under vacuum with idle gas flows and at temperature.

IMPORTANT! Minimizing temperature cycling can help ensure cleanliness of the chamber components (prevent flaking of any ALD residual material).

Step	Action	Details
1.	Leave the heaters on	
2.	Set MFC 0 Ar Carrier flow to 20 sccm. Set MFC 1 Ar Plasma flow to 40 sccm.	
3.	Allow the system to remain under vacuum	

SECTION 6: Fiji Recipe and Applications Guide

Fiji Recipe Development Overview

The Fiji software provides a very flexible platform for ALD recipe development. Effective recipe development has several key aspects.

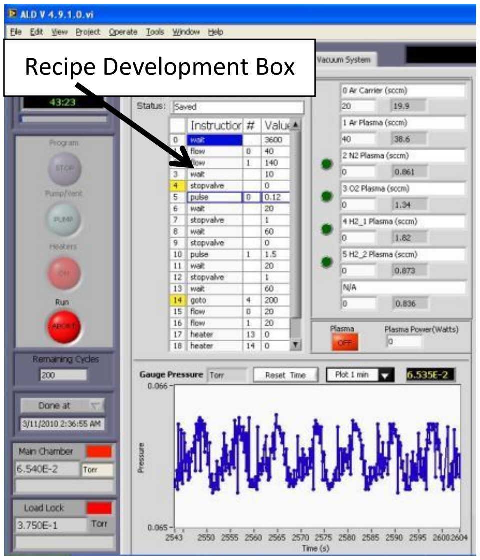
- Recipe commands –
  The user will be introduced to all of the recipe commands available in the Fiji software and their usage.
- Recipe structure –
  The logic of the overall recipe structure will be demonstrated in the context of using the Fiji to deposit various ALD films.
- Recipe development and results interpretation –
  Developing good recipes requires understanding of the underlying ALD chemistry and interpretation of deposition results. Basic concepts for interpreting the results of ALD processes are discussed. Only through an iterative process where deposition results are optimized through a systematic modification of the process recipe details can robust Fiji recipes be developed.

ALD is typically accomplished with two precursors which are alternatively dosed into a heated vacuum system in which is placed the target substrate. The precursor pulses are separated in time by a purging step, during which excess precursor and reaction by-products are purged from the reactor volume. ALD recipe development primarily concerns itself with three things: process temperature, precursor dosing, and precursor purging.

To successfully develop recipes on the Fiji, the user must understand the available recipe commands, the recipe programming structure, and be able to properly interpret results from test depositions such that the recipe specifics can be appropriately adjusted to produce high quality ALD films. If the user understands the recipe commands and programming methods and always keeps in mind the basic concepts introduced in the discussion of the ALD window and saturation curves on the following pages, they will be well on their way to developing their own optimized Fiji ALD recipes for thermal continuous, Exposure Mode™, and plasma enhanced ALD processes.

Recipe Development Box

On the left side of the process tab is the recipe development box which looks similar to the box shown below. This box will contain the instructions the Fiji will use to deposit the ALD film.



	Instruction	#	value

The recipe development box consists of four columns. The leftmost column is for recipe line numbers. The lines of Fiji recipe code are numbered sequentially starting at 0. The recipe developer never needs to enter line numbers, the software automatically numbers the lines of the recipe. The instruction column contains the recipe commands which will be discussed in detail in the subsequent sections. The recipe commands can take one or two arguments. These arguments are entered in the “#” and “value” columns.

To enter information into the recipe development box, place the mouse pointer over the cell to edit and left click. A cursor will blink in the activated cell. Information can then be entered into the recipe using the keyboard. Right-clicking on the instruction column will bring up a very useful menu that includes recipe file saving and loading, recipe command shortcuts, and recipe line insertion and deletion commands. Typing a command in the Instruction column has the same affect as inserting the command from the right-click menu.

For illustrative purposes, the process for depositing Al_2O_3 via trimethylaluminum (TMA) and water (H_2O) will be considered. At this point, only the precursor dosing and purge steps will be considered. Other process parameters, such as purge gas flow rate and reactor temperature, are also important. The pulsing and purging parameters will be considered set at appropriate values for the initial discussion.

Pulse Command

Consider a substrate which has been inserted into a heated process reactor through which a precursor carrier gas is flowing at reduced pressures. The first step of the Al_2O_3 deposition process is the introduction of the TMA pulse. The "pulse" command is used to generate precursor pulses and is shown below in the context of the recipe window of the Fiji control software. The pulse instruction has two arguments. The # argument is the number of the ALD valve to pulse. In this case it is the number of the ALD valve on which the TMA is installed. ALD valves are numbered left to right starting at 0. The value argument is the duration the ALD valve is opened in seconds.

	Instruction	#	value
line #	pulse	ALD valve number	pulse time in seconds

The pulse command example below pulses the second ALD valve from the left open for 0.06 seconds or 60 milliseconds. The shortest usable pulse duration is 0.015s.

	Instruction	#	value
0	pulse	1	0.06

Wait Command

After the TMA pulse, the recipe is paused momentarily to give any excess TMA and reaction by-products a chance to be purged out of the system with the flowing precursor carrier gas. The "wait" command is provided to give the user precise control over the length of the purge step. The wait command has only one argument. The value argument is the duration of the wait step in seconds. The wait command does not take an argument in the # column. The software will generate a warning if a value is put in this column for a wait command. The example shows a ten second purge step following the TMA pulse.

	Instruction	#	value
line #	Wait		time in seconds

	Instruction	#	value
0	Pulse	1	0.06
1	Wait		10

The first half of the Al_2O_3 cycle is now finished. Now the second half of the ALD process, H_2O pulse and purge, must be included.

	Instruction	#	value
0	Pulse	1	0.06
1	Wait		10
2	Pulse	0	0.06
3	Wait		10

Similar pulse and purge durations are used for the water pulse. The recipe now contains one cycle of the Al_2O_3 process. Single ALD cycles tend to put down very small amounts of material, typically sub-monolayer growth is observed as precursor ligand steric hindrances impede the ability to react with every active site on every ALD cycle. Thus, the single ALD cycle must typically be repeated many times to build up films of the desired thickness.

Goto Command

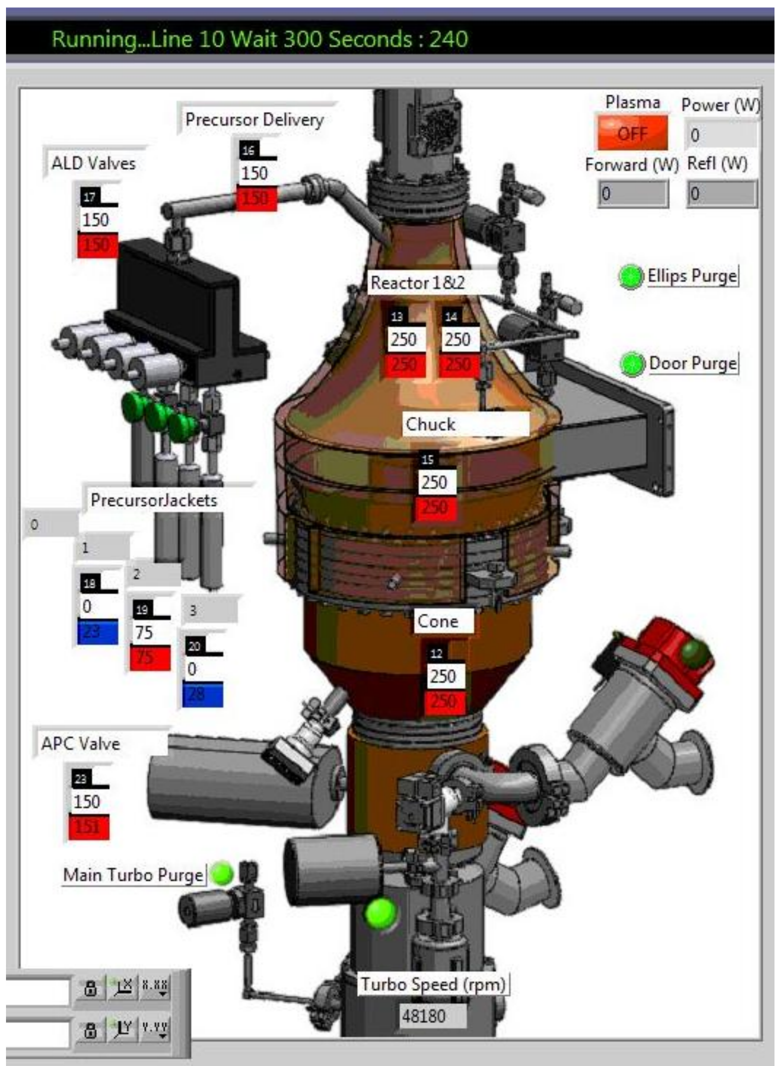
Systematic repetition of sections of a recipe is accomplished with the “goto” command. The “goto” command takes two arguments. The # argument is the line number of the beginning of the loop. The line number is the number in the far left column. The value argument is the number of times to repeat the loop.

	Instruction	#	value
line #	Goto	line number of loop start	times to repeat loop

	Instruction	#	value
0	Pulse	1	0.06
1	wait		10
2	pulse	0	0.06
3	wait		10
4	goto	0	300

The Fiji software automatically highlights the line number cell of the beginning and ending rows of a goto loop with the same color. This makes it very easy to see which section of the recipe is going to be repeated in the loop. The above example shows the TMA/purge/H_2O/purge repeated in a loop 300 times. As will be discussed later, multiple loops can exist in a recipe and each will have its own unique color.

Heater Command



On the right hand side of the process tab is a Fiji schematic similar to the one pictured below which depicts the reactor heaters. Each heater has a name and a number. In the example, the heaters 12-17, 23 are associated with sections of the Fiji reactor. Heaters 18-20 are for the precursor jackets. Depending on the configuration of your system, the numbering may be different and you may have additional heaters not shown or you may not have some heaters that are shown. For each heater there is a small box with two numbers. The number with the white background is the setpoint for that heater. Below the setpoint is the current temperature on either a blue or red background. All temperatures are in °C. Blue indicates the heater is off. Red indicates the heater is on and actively attempting to control the temperature at the setpoint. The heater is off if it is set to zero. The heater is on if it is set to greater than zero.

Heater setpoints can be set by typing the desired temperature directly into the setpoint box for the given heater. Alternatively, heater setpoints can be set by recipe commands. The heater command takes two arguments. The # argument corresponds to the heater number as shown on the process screen. The value argument is the heater setpoint temperature in °C.

	Instruction	#	value
line #	Heater	heater number	heater setpoint in °C

The Al_2O_3 recipe developed above will run at whatever temperature the system is currently operating. Adding heater commands at the beginning of the recipe will ensure the recipe is run at the desired temperature. To insert new commands at the beginning of the recipe, blank recipe lines must be inserted into the recipe. Right clicking on the recipe line number zero brings up the pop-up menu. The menu will have an option for inserting a new line above. Doing this twice creates two blank recipe lines at the beginning of the recipe.

	Instruction	#	value
0			
1			
2	pulse	1	0.06
3	wait		10
4	pulse	0	0.06
5	wait		10
6	goto	2	300

Goto command # arguments get automatically updates when recipe lines are deleted or inserted

Notice that the # argument for the goto command automatically changed from 0 to 2 as the new lines are inserted at the beginning of the recipe. Now the first two lines can be edited for the heater commands. The reactor walls (heater 13) and the chuck (heater 14) are set to 250°C as shown below.

	Instruction	#	value
0	heater	13	250
1	heater	14	250
2	pulse	1	0.06
3	wait		10
4	pulse	0	0.06
5	wait		10
6	goto	2	300

The problem with this recipe is that it takes time for the equipment to stabilize at a new temperature setpoint. However, the recipe will proceed with the precursor pulsing and purging right after the temperature setpoints are established. A certain amount of time must pass between the heater commands and the pulse commands. A long “wait” command would be one way of making sure temperatures had stabilized before the pulsing began. But there is uncertainty in how long to wait because time to stabilization will depend on the reactor conditions when the recipe is started.

The better option is to use the “stabilize” command.

Stabilize command

The stabilize command takes one argument. The # argument is a heater number. The stabilize command pauses the execution of a recipe until the heater specified in the # argument achieves its setpoint.

	Instruction	#	value
line #	Stabilize	heater number	

	Instruction	#	value
0	heater	13	250
1	heater	14	250
2	stabilize	13	
3	stabilize	14	
4	pulse	1	0.06

5	wait		10
6	pulse	0	0.06
7	wait		10
8	goto	4	300

Adding in the stabilize commands forces the recipe to pause until the reactor walls and chuck have achieved their 250°C setpoints. The stabilize command ensures that the recipe is paused only as long as it needs to be.

Flow Command

The Fiji in its standard configuration has five mass flow controllers (MFCs): precursor carrier Ar, plasma Ar, plasma N_2, plasma O_2, and plasma H_2. These are shown on the process tab of the software next to the recipe development box. The MFCs are numbered sequentially 0-4. The MFCs on the process tab are labeled with the MFC # and the gas description. Below each MFC description is two boxes. The MFC setpoint can be entered into the white box similarly to how the heater setpoints are set. The flow reported back from the MFC is shown in the grey box.

The MFC setpoints can also be set programmatically with the “flow” recipe command. The flow command takes two arguments. The # argument refers to the MFC number. The value argument is the desired flowrate in sccm.

	Instruction	#	value
line #	Flow	MFC number	flow setpoint in sccm

For thermal ALD processes on the Fiji, argon flow is controlled through the precursor manifold (MFC 0) and plasma source (MFC 1).

	Instruction	#	value
0	Heater	13	250
1	Heater	14	250
2	stabilize	13	
3	stabilize	14	
4	flow	0	60
5	flow	1	200
6	wait		10
7	pulse	1	0.06
8	wait		10
9	pulse	0	0.06
10	wait		10
11	goto	7	300
12	flow	0	20
13	flow	1	40

Due to the internal feedback mechanism of MFCs, setpoint changes are never instantaneous. Adding a short wait command after a flow command is a good idea to allow the MFC to equilibrate. Flow commands can also be used at the end of the recipe to establish lower, standby flow rates to conserve argon.

Recipe Duration

Now is a good time to point out a useful feature on the front panel of the Fiji software. Along the left side of the window below the main program buttons are the remaining cycles display and the recipe timing dropdown box. The recipe timing dropdown box allows one of three pieces of timing information to be displayed in the box below it. As it is shown, the box indicates when the current recipe would finish if the recipe is running or if it was started now. Alternatively, the box can be set up to display the total run time or the time to completion.

As a recipe is modified, the software continuously updates the output of the box. The recipe developed above will last about 1:40:00. Experiment with different purge times and loop counts to see how they will affect the calculated recipe run time.

The estimated run time does not include everything such as variable time stabilize commands. But it will give you a good idea of how long a new recipe will take or when the current recipe will finish.

Thermal ALD Recipe Development

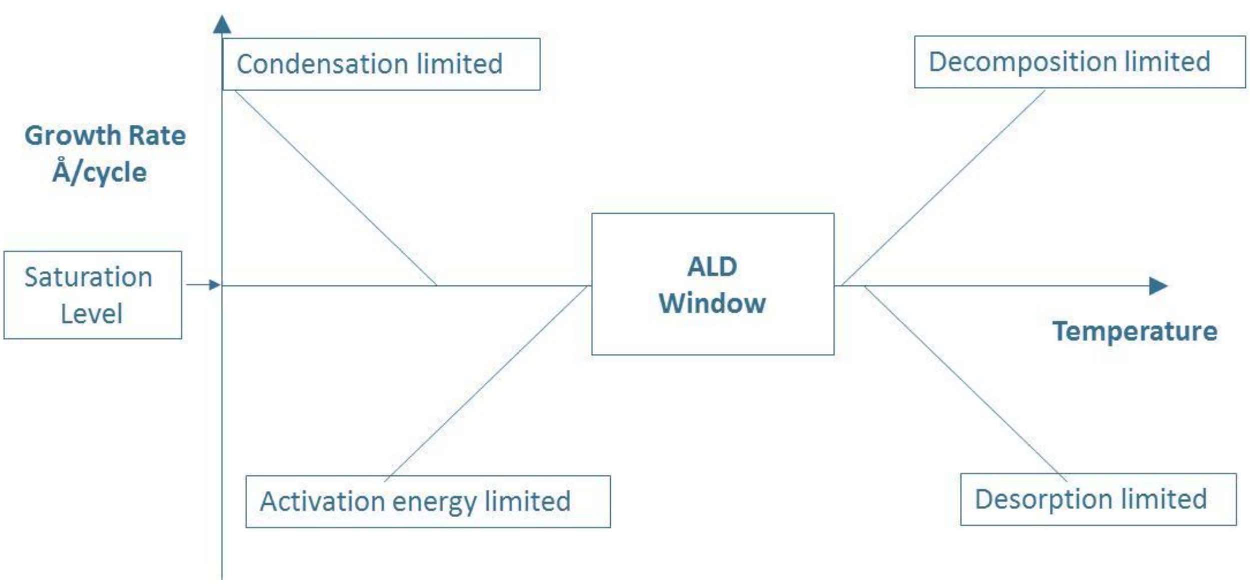
This is a good point to start considering some of the quantitative aspects of thermal ALD process development. If the recipe that has been developed up to now is analyzed, the structure of the recipe makes sense given the understanding of how ALD works. Precursors are alternately pulsed into the reactor separated by a purge steps. The energy to generate the chemical reaction is supplied by the heaters which maintain the temperature of the reactor and substrate holder. Qualitatively the recipe makes sense, but where do the exact values for gas flows, precursor doses, and temperatures come from? These numbers come from experimentation. When a new ALD process is being considered initial experimentation must be conducted to ascertain the appropriate process conditions and recipe parameters.

The ALD Window

A very useful concept for understanding the ALD recipe development process is called the ALD window which is depicted below. The 2-D chart has temperature on the x-axis and deposition rate on the y-axis. In the middle of the chart is a box representing the ALD window. The window indicates that over a given temperature range, the ALD process will be well behaved with a well-defined deposition rate. As temperature goes above or below the ALD window, different things can happen, depending on the nature of the particular chemistry being investigated.

At temperatures lower than the ALD window, one may observe deposition rates greater or lower than the anticipated ALD deposition rate. At lower temperatures, there may be insufficient energy to drive the chemical reaction between the two ALD precursors. This will lead to a lower than expected observed deposition rate. Another possibility is that rather than the monolayer of chemisorbed precursor, a thicker layer of precursor chemical condenses on the substrate surface. This will likely lead to a higher than expected observed deposition rate.

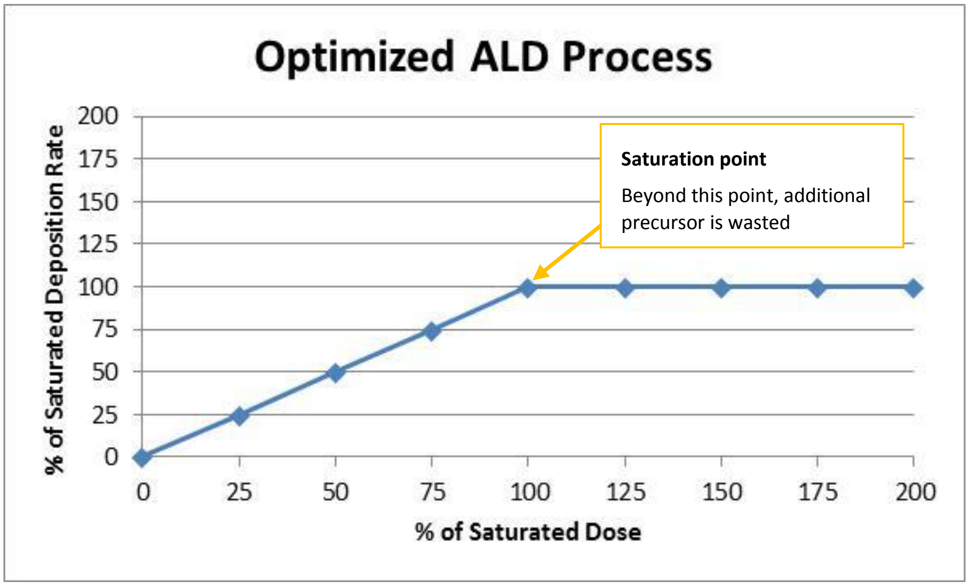
At temperatures above the ALD temperature window, observed deposition rates can also be higher or lower than expected. If the precursor decomposes on the substrate at the high temperatures, the observed deposition rate can be much higher than expected. Alternatively, the precursor may not stay chemisorbed to the substrate at the higher temperatures. With the precursor desorbing from the substrate prior to introduction of the other precursor, less or no film ends up being deposited on the substrate.



Precursor saturation curves

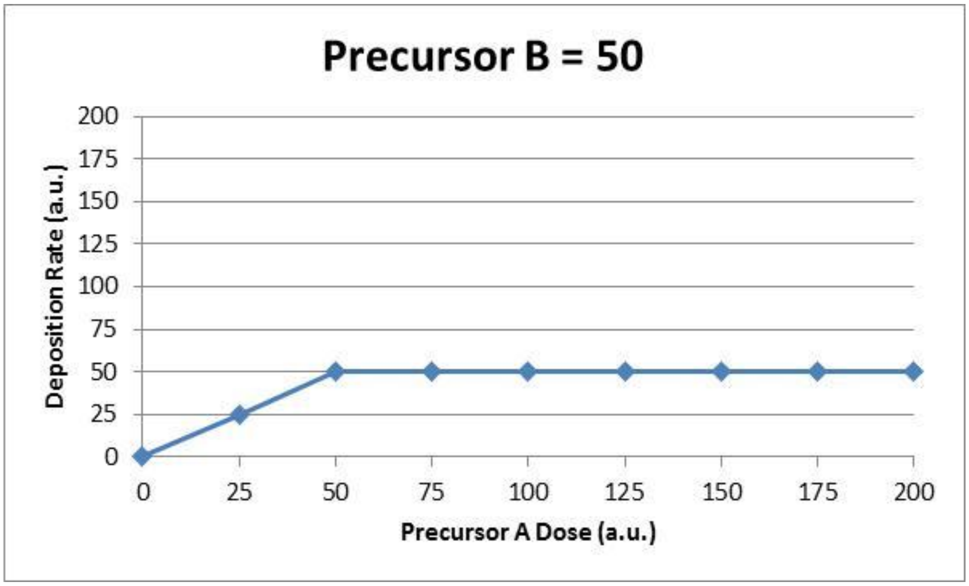
When precursor is dosed into the ALD system, it reacts with the surface of the substrate to create the desired film. Ideally, the amount of material that is dosed into the reactor is just enough to saturate all the available sites on the substrate surface. Operating at the bare minimum in precursor dosing is not a good idea. A slight excess of material accommodates any process or equipment fluctuations. How big a dose is required is determined by generating what are referred to as saturation curves.

In order to generate a saturation curve, the system temperatures are set at a point that previous experience suggests would be close to the ALD window. If no such insights are available, it is recommend to start at lower temperatures and increase temperature until deposited films are observed. Below is an idealized saturation curve for an ALD process at a temperature in the ALD window. This plot shows percentage of saturated deposition rate as a function of the percentage of the saturated precursor dose. The saturated precursor dose delivers sufficient precursor chemical to the reactor to react with all of the available sites on the substrate surface. By reacting with all the available sites on the substrate, the highest available ALD deposition rate is achieved. The highest available ALD deposition rate is not to be confused with higher deposition rates that can be produced when there is precursor condensation or decomposition as discussed above with respect to the ALD window.

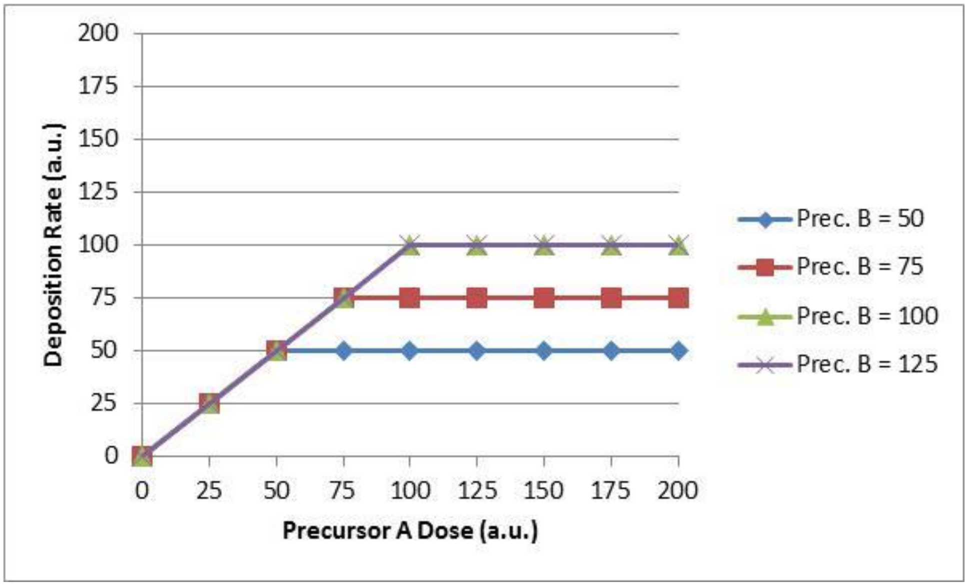


As the precursor dose is increased, the deposition rate increases until it saturates. Once at saturation, any additional precursor introduced into the reactor is wasted. The optimized process is the goal of the recipe development process. When the recipe development process is started, the saturated precursor dose and the saturated deposition rate are probably unknown.

Consider a plot very similar to:



Remember that ALD is a two step process. Both precursors, call them precursor A and precursor B, must both be optimized to determine the ALD window. It appears that the process is nicely saturated at a precursor A dose of 50. It is important that we do not let a nice plot like this fool us into thinking we have everything figured out. The deposition rate for various precursor A doses must be compared at various precursor B doses. If the precursor A dose scans are repeated at various precursor B doses, a plot like this may be generated:



When precursor B was increased from 50 to 75 and from 75 to 100, the apparent saturated deposition rate increased. The curves for the 100 and 125 precursor B doses overlap indicating that the precursor B dose = 100 was a saturated condition. This example serves to emphasize that precursor dosing must be optimized for both precursors. Failure to do so generates misleading results.

Precursor (Vapor) Depletion

There is another consideration when increasing the precursor dose when generating saturation curves. Increasing the precursor dose is typically achieved by increasing the length of time the ALD valve is open with the pulse command. The headspace is the portion of the precursor cylinder between the top of the liquid or solid precursor and the ALD valve which becomes filled with the precursor vapor. If the ALD pulse is long enough, the vapor in this space can be completely depleted. Longer ALD pulses would result in the same amount of precursor being delivered to the reactor.

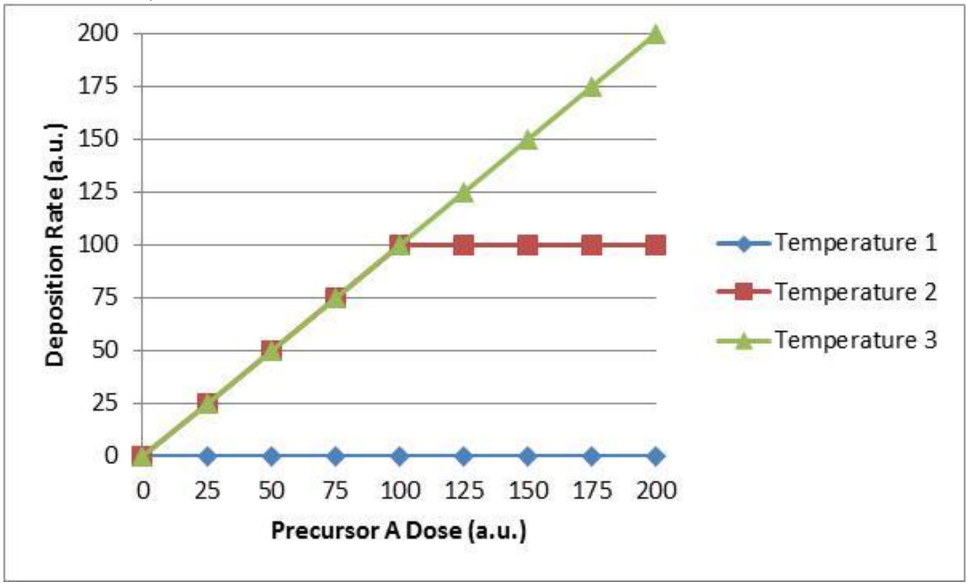
This could generate a false impression that saturation has been achieve when actually the process is still underdosed, but the system cannot deliver any addition material by lengthening the pulse duration.

There are a couple techniques that can be used to determine if the precursor cylinder vapor is being depleted on each pulse:

- If the size of the pressure pulse does not change, that is one indicator.
- Slightly increasing the temperature of the precursor will increase the vapor pressure in the cylinder which will lead to a larger dose for the same pulse length. Care must be taken when increasing the precursor temperature if operating near the temperature at which the precursor will decompose.
- A final technique to check for vapor depletion is to double pulse the precursor. By pulsing once, then giving sufficient time to build the vapor pressure back up, and pulsing a second time, essentially a double dose of precursor can be delivered to the system to quickly check if the observed deposition saturation is actually a precursor depletion issue.

Temperature Considerations

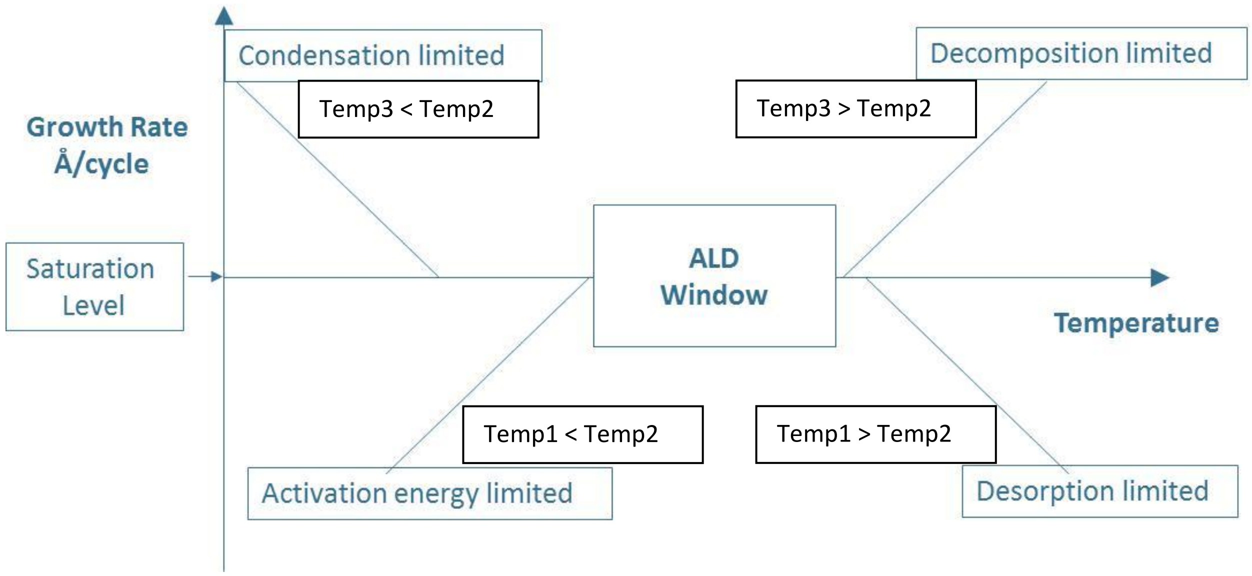
Understanding the potential impact on the saturation curves when operating outside the ALD window can help decipher other observations when developing ALD recipes. Consider the plot below with saturation curves obtained at three different temperatures.



The Temperature 2 saturation curve has the characteristic shape of a well-behaved ALD process. The Temperature 1 data shows no deposition while Temperature 3 shows a lack of saturation. Depending on how Temperatures 1 and 3 compare to Temperature 2, some insight into the process chemistry can be made if the previous discussion regarding the ALD window is taken into account.

If Temperature 1 is less than Temperature 2, the ALD window discussion would suggest that the temperature is too low to provide the energy required to generate the chemical reaction. If Temperature 1 is greater than Temperature 2, the high temperature of the substrate is likely leading to precursor desorption before the next precursor pulse is introduced into the system.

Likewise, if Temperature 3 is less than Temperature 2, the ALD window discussion would suggest that the precursor condensation is leading to enhanced deposition rates. If Temperature 3 is greater than Temperature 2, the high temperature of the substrate is likely leading to precursor decomposition which also leads to enhanced deposition rates.

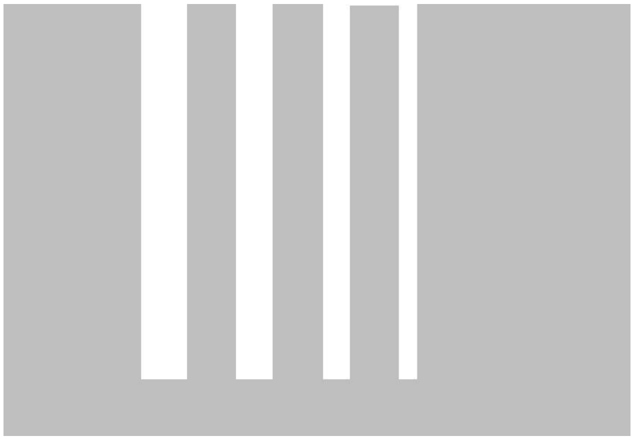


Obviously the plots in this section are idealized and data that is generated in the process of optimizing real ALD recipes is rarely as neat and clean as the plots shown here. It is hoped that the trends and general observations discussed here will enable you to run the appropriate experiments and interpret the resulting data to enable you to produce optimized ALD recipes of your own.

The discussions here have focused on continuous, thermal, ALD processes. The Fiji is also capable of depositing films in Exposure Mode™ and plasma enhanced mode. All of the discussions up until now apply, but there are additional considerations and recipe commands to discuss to enable you to successfully develop optimized recipes for these operating modes.

Exposure Mode™

Consider the magnified detail of a substrate cross-section shown below.

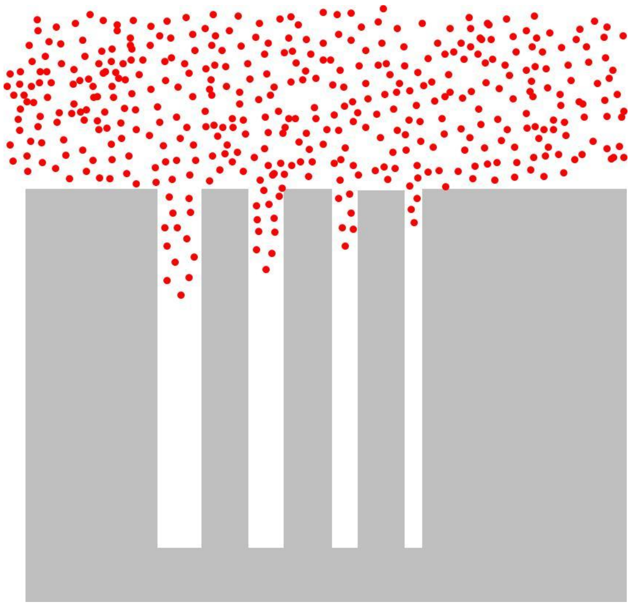


This substrate has some high aspect ratio features that the ALD user wants to conformally coat. Defining the aspect ratio will have to take into some account details of the substrate to be coated, but it is typically calculated as the ratio of the depth to width of the features of interest.

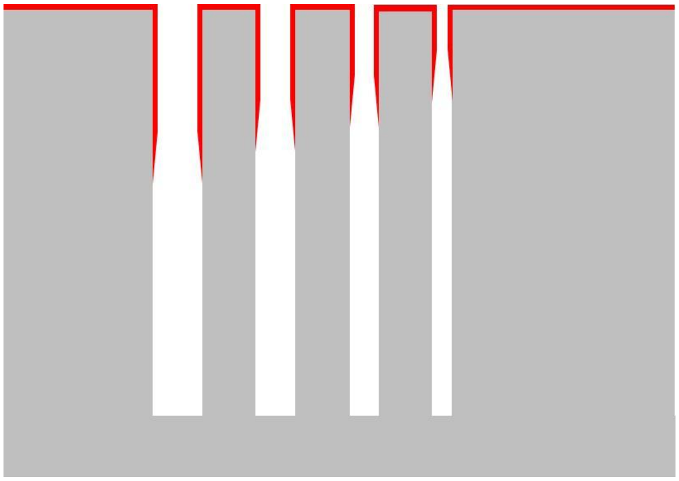
$$Aspect\ Ratio = \frac{Depth}{Width}$$

A hole that is 1µm deep and 10nm in diameter will have an aspect ratio of 100. If instead of a hole, the high aspect ratio feature is a trench with a depth of 1µm and a width of 10nm, the aspect ratio is not 100 but actually 50 for this discussion. This factor of 2 difference is due to the extra degree of freedom for precursor diffusion in the trench as compared to the hole.

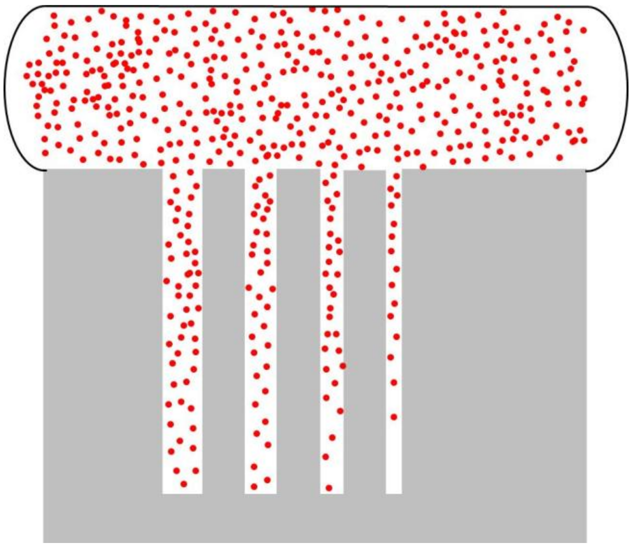
Below is a schematic of what may happen if an ALD recipe developed for a planar substrate is utilized to coat a substrate with high aspect ratio features. The precursor (represented by red dots) is dosed into the processing chamber. The precursor will diffuse into the high aspect ratio features of the substrate, but may not diffuse to the bottom before the purge cycle of the recipe pumps away the remaining precursor.



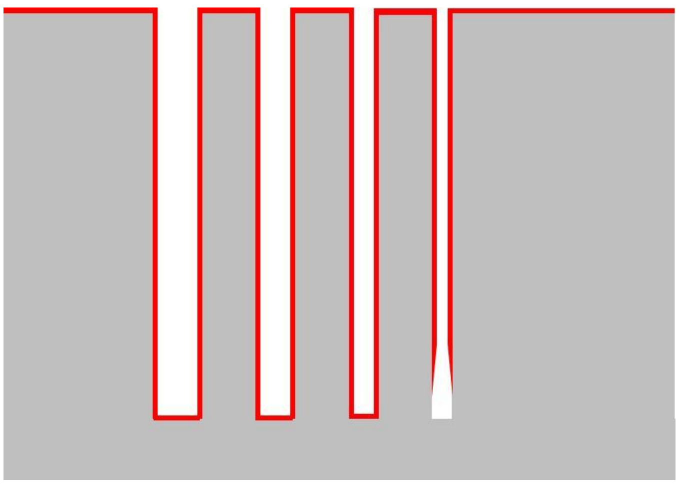
The result would be that the surface of the substrate as well as the portions of the high aspect ratio features near the substrate surface are coated. But the high aspect ratio features are not conformally coated all the way to the bottom. Lower aspect ratio features are more coated than higher aspect ratio features.



Consider the situation where following the pulse step instead of immediately purging the system, the ALD reactor is isolated from the system pump. The substrate is exposed to the precursor for a period of time, giving the precursor time to diffuse down into the high aspect ratio features. Then the pumping is reactivated and sufficient purge time is provided to allow excess precursor and reaction by-products to diffuse back out of the high aspect ratio features. By following this type of precursor exposure procedure for both of the ALD precursors, uniform, conformal films can be deposited on high aspect ratio features.



In the picture below, the leftmost three features are conformally coated. Insufficient time was allowed for full precursor diffusion into the rightmost feature with the highest aspect ratio. Exposure times will have to be extended to conformally coat the highest aspect ratio feature.



Technical Information for High Aspect Ratio Depositions

For the interested reader, below is a discussion of the some technical aspects of coating high aspect ratio features utilizing ALD. When beginning a development process for coating new high aspect ratio features, the equations below can provide some guidance regarding precursor dosing and exposure times. This discussion follows from the following reference,

Gordon, R. G.; Hausmann, D.; Kim, E; Shepard, J. "A kinetic model for step coverage by atomic layer deposition in narrow holes or trenches" Chemical Vapor Deposition 2003, 9, 73.

For a hole of length L, diameter d, and aspect ratio a, the exposure $(P \cdot t)$ required for coating the sidewalls of the hole is given by:

$$(P \cdot t)_{sidewalls} = S \cdot \sqrt{2\pi mkT} \cdot \left[4a + \frac{3}{2}a^2\right]$$

$$Let\ k' = S \cdot \sqrt{2\pi mkT}$$

$$(P \cdot t)_{sidewalls} = k' \cdot \left[4a + \frac{3}{2}a^2\right]$$

P = Reactant partial pressure, and t = time needed to coat the entire hole length
T= Temperature
k = Boltzmann Constant

m = molecular mass of the reactant
S = saturated surface coverage per cycle (no. of molecules/ square meter)

Coating of the bottom of the hole is given by the following expression:

$$(P \cdot t)_{bottom} = k' \cdot \left[1 + \frac{3}{4}a\right]$$

Combining equations gives the total exposure needed to cover both the sidewalls and bottom of the hole.

$$(P \cdot t)_{total} = k' \cdot \left[1 + \frac{19}{4}a + \frac{3}{2}a^2\right]$$

Scientific References Pertaining to High-Aspect Ratio ALD Coatings

Kucheyev, S. O.; Biener, J.; Baumann, T. F.; Wang, Y. M.; Hamza, A. V.; Li, Z.; Lee, D. K., Gordon, R. G. "Mechanisms of atomic layer deposition on substrates with ultkahigh aspect ratios" Langmuir 2008, 24, 943

C. Detavernier, J. Dendooven, D. Deduytsche, and J. Musschoot, "Thermal Versus Plasma-Enhanced ALD: Growth Kinetics and Conformality" ECS Transactions 2008, 16, 239.

Gordon, R. G.; Hausmann, D.; Kim, E; Shepard, J. "A kinetic model for step coverage by atomic layer deposition in narrow holes or trenches" Chemical Vapor Deposition 2003, 9, 73.

Sundaram, G. M.; Deguns, E.W.; Bhatia, R.; Dalberth, M. J.; Sowa, M. J.; Becker, J. S. Solid State Technology, June 2009.

Exposure Mode™ Recipe Development

The general technique for accomplishing Exposure Mode™ depositions on the Fiji is to:

1. Isolate the reactor from the vacuum pumping
2. Pulse in precursor A
3. Allow time, t_{A1}, for precursor A to diffuse into high aspect ratio features
4. Restablish vacuum pumping and pump/purge system for $t_{A2} > t_{A1}$
5. Isolate the reactor from the vacuum pumping
6. Pulse in precursor B
7. Allow time, t_{B1}, for precursor B to diffuse into high aspect ratio features
8. Restablish vacuum pumping and pump/purge system for $t_{B2} > t_{B1}$
9. Repeat until desired film thickness is achieved

Exposure Mode Steps:

1. Reactor isolation – This is accomplished one of two ways depending on whether the Fiji being used is configured with a turbo pump/throttle valve option. If there is no turbo pump/throttle valve option, the stopvalve is closed with the stopvalve command discussed below. If there is a turbo pump/throttle valve, the throttle valve is closed with the APC command discussed below.

2. Precursor pulsing is accomplished with the pulse command just as in a continuous mode ALD recipe, however, it should be noted that the precursor dose will be larger than that used in continuous mode. The required dose will depend on the chemistry, but using 5x the continuous mode dose is a good starting point.

At this point gas flows may be adjusted as well. During the exposure step, the gas flows from the precursor manifold and the plasma source should not be completely turned off. Keeping a small positive gas flow through the manifold and the plasma source into the reactor minimizes precursor backstreaming into these parts of the reactor. The recommended minimum gas flow rates during the exposure step are 20sccm for the precursor manifold and 75sccm for the plasma source.

3. t_{A1} exposure – The exposure time needs to be sufficiently long to allow for full diffusion of precursor into the high aspect ratio features. This may require some experimentation to determine the appropriate length of time for the exposure. The time is constrained by the fact that there is a positive gas flow into the reactor and the reactor pressure will climb continuously throughout the exposure step. A maximum pressure of 76Torr is recommended for the exposure step. For the 19L reactor with 20sccm from the precursor manifold, 75sccm from the plasma source, and 50sccm from the door purge, the maximum exposure time is 13 minutes.

4. t_{A2} vacuum/purge – The time for pumping excess precursor and reaction by-products from the high aspect ratio features needs to be slightly longer than the time allowed for precursor diffusion into the high aspect ratio features. It is very important that any excess precursor A is pumped from the system before introducing precursor B so there are no CVD-like chemical reactions inside the high aspect ratio structures. If thicker films are observed inside the high aspect ratio features compared to the substrate surface, CVD due to insufficient pumping is the likely cause. Care must also be made when opening the throttle valve after a long exposure so as to not expose the turbo pump to a sudden high pressure. This can be avoided by opening the throttle valve slightly enabling the bulk of the reactor contents to pump out slowly before completely opening the throttle valve to fully pump out the reactor before precursor B.

5-8. Precursor B – In general, the precursor B exposure will proceed similarly to that of A. Depending on the specifics of the precursor molecule diffusion properties, precursor B may need different times for diffusion in and out of the high aspect ratio features.

High Aspect Ratio Features with Temperature Sensitive Precursors

In continuous mode ALD at higher temperatures, the precursors tend to only be exposed to high temperatures for a few seconds before either being incorporated into the film through the ALD reaction or being pumped away. During Exposure Mode™ processing, the precursor molecules are intentionally kept in contact with the substrate for extended periods of time. Temperature sensitive precursors may be fine in the continuous mode ALD but may exhibit extensive thermal decomposition if utilized in Exposure Mode™ processes at the same temperatures. A good technique for identifying this problem is to insert a silicon wafer coupon and expose it to a couple 100 precursor exposures with the desired exposure time and processing temperature. If the silicon sample comes out discolored, this is a strong indicator that the precursor will thermally decompose with the current exposure time/processing temperature conditions. Tests should be conducted to determine what temperature range the proposed Exposure Mode™ process will work with.

High Aspect Ratio Features with Plasma

Plasma enhanced ALD films are limited to a maximum aspect ratio of 15-25 for holes, depending on the process chemistry. The reason for the limitation is the high radical reactivity which leads to radical recombination on the sidewalls of the high aspect ratio features. Within just a couple wall collisions, all radicals will be lost due to recombination. Once the radicals are recombined, they are no longer available to participate in the Plasma-Enhanced Atomic Layer Deposition (PEALD) reaction process. No special recipe or equipment design considerations are going to enable higher aspect ratios to be coated with plasma processes. If higher aspect ratios are claimed with PEALD, check the details of the features. If the features are not holes, it is the extra degree of freedom for radical diffusion that is enabling the higher aspect ratio to be coated, not anything particularly unique regarding the process or equipment.

Vacuum Pump Isolation

As mentioned previously, the method of vacuum pump isolation depends on the system configuration. Systems with a turbo pump/throttle valve will use the APC command while those without will use the stopvalve command.

Stopvalve command

The stopvalve command allows recipe open/close control of the heated pneumatic valve situated at the base of the Fiji between the ALD reactor and the vacuum pump line.

	Instruction	#	value
line #	Stopvalve	empty	0 = closed 1 = open

The stopvalve command only takes a value argument: 0 to close and 1 to open. Below is an example Exposure Mode™ recipe utilizing the stopvalve command.

	Instruction	#	value
0	heater	13	250
1	heater	14	250
2	stabilize	13	
3	stabilize	14	
4	flow	0	60
5	flow	1	200

6	wait		5
7	stopvalve		0
8	pulse	1	0.2
9	flow	0	20
10	flow	1	75
11	wait		120
12	stopvalve		1
13	wait		150
14	flow	0	60
15	flow	1	200
16	wait		5
17	stopvalve		0
18	pulse	0	0.2
19	flow	0	20
20	flow	1	75
21	wait		120
22	stopvalve		1
23	wait		150
24	goto	4	200
25	flow	0	20
26	flow	1	40

APC command

The APC command allows recipe control of the heated butterfly valve situated between the Fiji reactor and the system turbo pump. The butterfly valve can be controlled from 0-100% open with 0.1% granularity.

	Instruction	#	value
line #	APC	empty	0.0 – 100.0

The APC command only takes a value argument: the throttle valve percentage open setpoint. After this command is issued during execution of the recipe, the throttle valve takes up to a second to respond, with longer times required for larger percentage changes. Below is an example Exposure Mode™ recipe utilizing the APC command. Note the extra step to allow most of the gas to be pumped from the reactor before fully opening the throttle valve. This protects the turbo pump from repeated exposures to high gas flows and pressures. The exact percentage open value for the initial pump out varies slightly from system to system. Experimentation should be conducted to determine the throttle valve setting which pumps the system down from 76Torr to 1Torr in 10seconds.

	Instruction	#	value
0	heater	13	250
1	heater	14	250
2	stabilize	13	
3	stabilize	14	
4	flow	0	60
5	flow	1	200
6	wait		5
7	APC		0
8	pulse	1	0.2
9	flow	0	20
10	flow	1	75
11	wait		120
12	APC		5

13	wait		10
14	APC		100
15	wait		140
16	flow	0	60
17	flow	1	200
18	wait		5
19	APC		0
20	pulse	0	0.2
21	flow	0	20
22	flow	1	75
23	wait		120
24	APC		5
25	wait		10
26	APC		100
27	wait		140
28	goto	4	200
29	flow	0	20
30	flow	1	40

Plasma Mode

Plasma mode is where the Fiji excels. A typical use of plasma mode is to replace the co-reactant used in thermal ALD processes with atomic radicals generated using a remote plasma source. In this manner oxides are deposited with an O_2 plasma rather than H_2O or O_3. Nitrides are deposited with N_2 and/or H_2 plasmas rather than NH_3. Depending on the precursor and process conditions, O_2, N_2, and H_2 can play a role in depositing metals.

The procedure for plasma mode processing is as follows:

1. Establish system temperatures
2. Open required MFC pneumatic valves
3. Establish precursor pulsing gas flows and pumping conditions
4. Pulse precursor A
5. Purge precursor A
6. Establish plasma gas flows and pumping conditions
7. Turn on remote plasma source
8. Expose substrate to reactive radicals from plasma source for set time
9. Turn off remote plasma source
10. Turn off and purge plasma gas
11. Repeat 3 – 10 until desired film thickness is achieved
12. Establish standby gas flows and pumping conditions
13. Establish standby temperatures
14. Close open MFC pneumatic valves

1. Temperatures – The reactor walls and substrate heater temperatures are important process parameters. ALD processes typically benefit from higher processing temperatures but must be compatible with the substrate limitations and not lead to precursor decomposition on the time scale of an ALD cycle. The reactor walls and substrate holder temperature setpoints are typically fairly close. If the substrate heater temperature needs to be set low, the reactor walls cannot remain significantly hotter because heat transfer will occur between the walls and the substrate heater, preventing the substrate from getting as cool as required. It can take over 10 minutes for a substrate to achieve a steady state temperature after being inserted into the reactor. To minimize this time, set the reactor walls 10-20°C above the temperature of the substrate holder. If you set the reactor walls temperature too high relative the substrate holder, the

substrate holder heater duty cycle will go to zero and you will no longer be controlling the substrate holder temperature.

2. Open MFC pneumatic valves – Each of the reactive plasma gas MFCs has a downstream pneumatic shutoff valve. This valve must be opened in order to deliver a controlled gas flow from the reactor through the MFC. The reasoning for the valve and the recipe command are described in detail below.

3.&6. Precursor pulse/plasma gas flow and pumping – The optimal gas flow/pressure/residence time conditions are not necessarily the same for the precursor pulsing and plasma steps. Precursor pulsing is more effective with low flow/high pressure/long residence time to give the precursor sufficient time to interact with the substrate surface. The plasma step benefits from high flow/low pressure/short residence time because of the short lifetime of the radicals generated in the plasma source. In systems equipped with a turbo pump/throttle valve, the vacuum pumping speed can be rapidly changed between the two regimes providing an extra knob for process optimization.

4.&5. Precursor pulse and purge – The previous discussions for precursor pulsing and purging apply here.

7. Turn on the plasma – Once the gas flows are established, the plasma source is turned on and the characteristic plasma glow can be seen in the ICP source. Radicals generated in the plasma source flow down to the substrate surface and react with the chemisorbed precursor A, volatilizing the precursor ligand constituents and becoming incorporated into the resulting PEALD film. The plasma source is turned on with the plasma command which is described below.

8. Plasma exposure time – The plasma step has a duration which differentiates it from the precursor A pulsing. The flux of radicals from the plasma source continuously reacts with the growing film. The longer the plasma step, the more completely the precursor A ligands are removed from the surface (less impurities). Typical plasma times on the Fiji are 20seconds. The plasma exposure time is accomplished with a wait command between the plasma on and plasma off commands. Just as in thermal ALD processing, a saturation curve should be developed for the plasma step with the plasma duration being varied.

9. Turn off the plasma – The plasma is turned off with the same plasma command as described below.

10. Turn off and purge plasma gas and reaction by-products – Some precursors/plasma gas combinations are reactive and the plasma gas must be turned off for the precursor pulsing step. N_2 will not be reactive with precursors and can be left on. Also, a brief purge following the plasma step clears the system of any reaction by-products. A clear advantage to PEALD processing is the short required purge following the plasma step. When doing low temperature oxides with H_2O coreactant, purge times in excess of 60s can be required to fully purge the excess H_2O from the system. O_2 is purged quickly from the system, even at low temperatures, and the long purge time is not needed.

11. Repeat – The precursor pulse/purge/plasma/purge cycle is repeated many times to produce the desired PEALD film thickness.

12.-14 Standby – When the deposition is complete, the recipe can perform several actions to put the Fiji in a standby state until the operator can return to remove their substrate. Reducing the gas flows can save argon and fully opening the throttle valve on turbo systems can maximize pumping out of any residual precursors in the system. It is not a good idea to completely turn off the gas flows. It is good to keep the reactor hot. Thermal cycling of the reactor can generate particles due to mismatch of thermal coefficients of expansion of the reactor materials and the adhered ALD films on the reactor walls. MFC pneumatic valves can also be closed at this time.

MFCvalve Command

MFCs are not positive shutoff devices. This means that even when zero flow is requested from the MFC, a small amount may trickle past the device. For the MFCs used on the Fiji, the specification for flow past a closed valve is <1% full scale. The N_2, O_2, and H_2 MFCs on the Fiji are 200sccm full scale. This means that up to 2sccm of gas can flow through these MFCs when they are set to zero. This could lead to some undesirable conditions. For example, if trace amounts of O_2 are present in the plasma gas flow when nitrides are being deposited, the film will be left with considerably higher levels of O-impurity. This will most likely negatively impact the desired film properties. To combat this, each of the MFCs for the reactive plasma gases have downstream pneumatic positive shut-off valves.

Looking at the partial screenshot of the MFC readouts, there can be seen three green buttons to the left of the N_2, O_2, and H_2 indicators. These buttons both indicate the status of the pneumatic valves and allow front panel control of the valves. The screenshot shows that all of the valves are closed. Clicking on the button opens the valve and the button changes to bright green. Clicking again closes the valve and the button returns to dark green. Before the reactive plasma gases are utilized in a deposition recipe, the MFCvalve must be opened. This can be done by clicking the appropriate button before starting the recipe or programmatically in the recipe with the MFCvalve command.

The MFCvalve command takes two arguments. The # argument is the MFC number and value is either 0 for closed or 1 for open.

	Instruction	#	value
line #	MFCvalve	MFC number	0 = closed 1 = open

The Fiji system has hardware and software interlocks that prevents the O_2 and H_2 MFC pneumatic valves from being open at the same time. Additionally, whenever an O_2 and H_2 MFC pneumatic valve is closed, the interlock causes a large argon flow to flush any remaining reactive plasma gases from the system for 5 seconds before allowing either the O_2 or H_2 MFC pneumatic valve to be opened. Some processes (such as low temperature Pt) require switching between O_2 and H_2 during each ALD cycle. A wait step should be inserted into the recipe following the command closing the O_2 and H_2 MFC pneumatic valve to accommodate the 5 second purge.

Plasma command

The plasma command controls the operation of the plasma source. The plasma command takes only one argument in the value column. A value greater than 0 turns on the rf output and the rf generator attempts to put out the requested wattage. A value of 0 puts the rf setpoint at 0W and turns off the rf output.

	Instruction	#	value
line #	plasma	empty	0 = off 1-300 = on, requested forward rf power (W)

For the standard Fiji configuration, the more power the better. The PEALD recipes provided from Cambridge NanoTech will typically utilize 300W for all plasma processes.

Below is an example TiN recipe that utilizes most of the commands and concepts that have been discussed above. This recipe includes commentary that explains the purpose of the recipe commands.

	Instruction	#	Value	Comments
0	APC		100	Open throttle valve
1	flow	0	20	Standby flows during thermal equilibrium
2	flow	1	40	
3	heater	12	250	Set trap temperature
4	heater	13	250	Set reactor zone 1 temperature
5	heater	14	250	Set reactor zone 2 temperature
6	heater	15	250	Set chuck temperature
7	stabilize	12		Wait for temperatures to stabilize
8	stabilize	13		
9	stabilize	14		
10	stabilize	15		
11	wait		1800	Time to pump away any residual H2O or O2 from sample introduction
12	MFCvalve	2	1	Open N2 pneumatic valve
13	MFCvalve	4	1	Open H2 pneumatic valve
14	flow	0	60	Set Ar carrier process flow
15	flow	1	200	Set Ar plasma process flow
16	flow	2	50	Set N2 plasma process flow
17	APC		22.4	Increase residence time for precursor pulse
18	wait		10	Give MFCs time to stabilize
19	pulse	75C TDMAT	0.2	TDMAT pulse. Put ALD valve position in # column.
20	wait		6	TDMAT purge
21	flow	1	400	Increase plasma Ar flow
22	APC		100	Reduce residence time for plasma step
23	plasma	300		N2/Ar plasma on
24	wait		10	10s of N2/Ar plasma
25	flow	4	20	Add in some H2
26	wait		5	for 5s
27	flow	4	0	Remove H2
28	wait		5	5s more Ar/N2 plasma
29	plasma		0	Plasma off
30	flow	1	200	Return plasma Ar to precursor pulse flow rate
31	APC		22.4	Increase residence time for precursor pulse
32	wait		5	Purge reaction products
33	goto	19	y	Set # of cycles. ~0.5A/cycle
34	flow	0	20	Set flows to standby levels.
35	flow	1	40	
36	flow	2	0	
37	MFCvalve	2	0	Close N2 pneumatic valve
38	MFCvalve	4	0	Close H2 pneumatic valve
39	APC		100	Open throttle valve

Plasma Source Operation

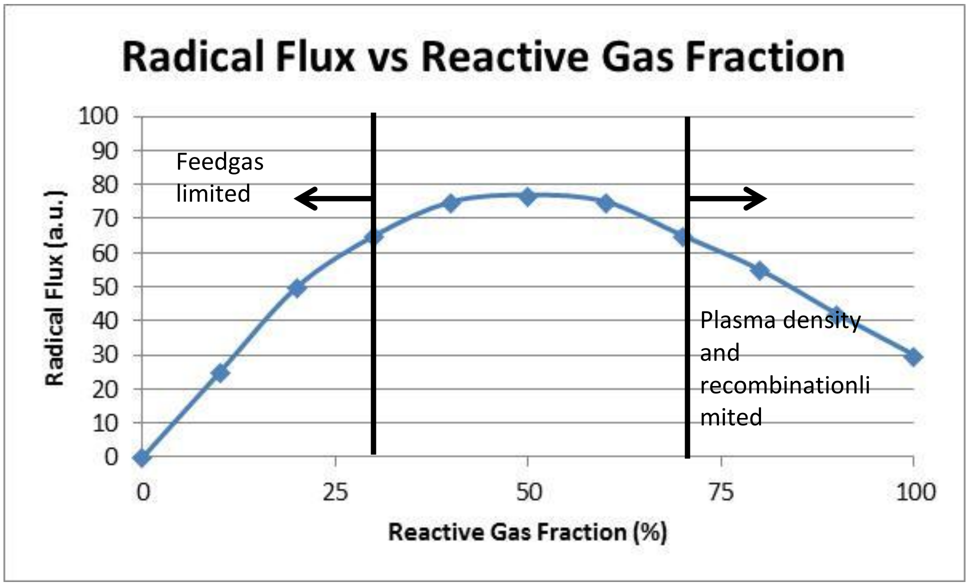
The plasma source can generate a plasma with just about any mixture of gases and pressures that can be produced on the Fiji. It makes sense that the best way to deposit a PEALD film is to produce the highest flux of radicals possible during the plasma step. One may assume that to generate the largest, for example, oxygen radical flux to the surface, they would turn the O_2 MFC to its maximum flow rate and start the plasma. This is, however, rarely the case due to the nonlinear behavior of plasmas.

Plasmas work best with gases that are easily ionized so that a large concentration of free electrons can be generated. These electrons can be accelerated to sufficiently high energies to dissociate the reactive plasma gases into reactive radicals. The noble gases are good examples of easily ionized gases. As one goes down the noble gas column of the periodic table (He, Ne, Ar, Kr,…) the gases become easier to ionize. Because of their chemical inertness, the noble gases also make for a good carrier gas for PEALD activities. N_2 is the preferred carrier gas in thermal ALD systems, but if it was used as the carrier gas for PEALD activities, one would certainly get nitrogen incorporated into their films when it was not desired. Argon is used for Fiji activities because it strikes a balance between inertness, ionizability, and price.

Oxygen and nitrogen are fairly electronegative. In a plasma, oxygen and nitrogen will have a tendency to remove free electrons from the plasma through electron attachment. Because of this phenomenon, plasmas with high oxygen and nitrogen fractions will have lower densities of free electrons. Less electrons means fewer radical dissociation events. This can lead to the counter-intuitive result of lower radical fluxes at higher reactive gas fractions.

The radicals produced in the plasma stream out into the reactor, carried along with the overall gas flow. The radicals are very reactive and will react quickly with the chemisorbed precursor on the substrate and reactor walls or recombine on the walls or in the gas phase. Radical recombination events will be reduced by operating at low pressure/high flow rate/short residence time. This is the primary reason that the turbo pump/throttle vale option benefits the PEALD process.

It turns out there will be a maximum radical flux at intermediate reactive gas fractions. At low reactive gas fractions the radical flux will be limited by the availability of the feed gas. At high reactive gas fractions, the radical flux will be limited by reduced plasma density and radical recombination.

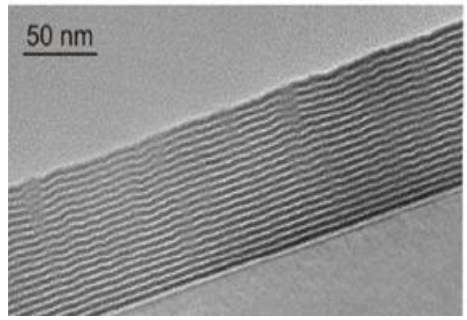


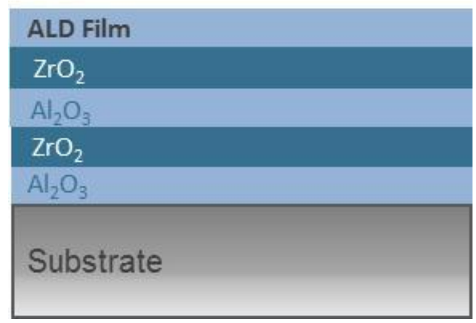
Nanolaminates and Doping

Certain applications do not rely on just one set of precursors to deposit a continuous, uniform film. Mixing of thin film materials as nanolaminates or through doping can produce novel results. Below these topics are discussed briefly along with examples of recipes to deposit example films.

Nanolaminates

Nanolaminates are alternating stacks of multiple discreet materials. Shown here is an SEM image of a stack of alternating 5nm layers of Al_2O_3 and ZrO_2 deposited via thermal ALD for the purpose of establishing a water permeation barrier. (Meyer, J., et al., Adv. Matls 2009, 21, 1845-1849; Meyer, J., et al., Appl. Phys. Lett. 2009, 94 233305-233303.)





To deposit such a structure on the Fiji is straightforward. By nesting several loops together, the recipe is set up to automatically generate the nanolaminate structure.

	Instruction	#	value
0	wait		5
1	pulse	1	0.06
2	wait		10
3	pulse	0	0.06
4	wait		10
5	goto	1	45
6	pulse	2	0.25
7	wait		10
8	pulse	0	0.06
9	wait		10
10	goto	6	45
11	goto	0	10

5nm Al_2O_3

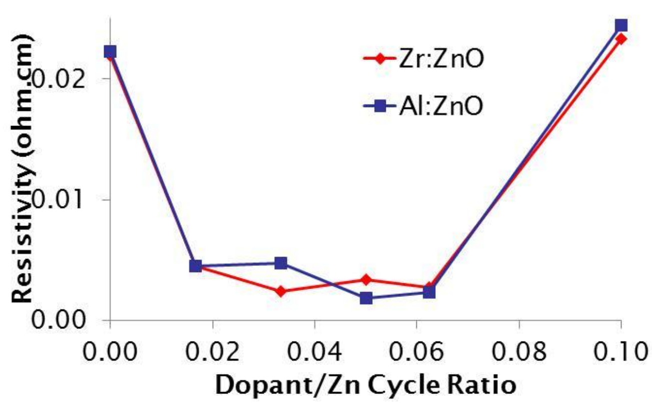
10 super cycles

5nm ZrO_2

The example has three loops. The first loop deposits 5nm of Al_2O_3. Then a second loop deposits 5nm of ZrO_2. Both of these loops are nested inside a larger loop which controls the number nanolaminates to deposit. Notice how the loops are all color coded to make it easier to see the recipe structure. The wait command in line #0 is just a placeholder for the outer nanolaminate loop. This could have been omitted and the outer nanolaminate loop could have repeated back to the pulse command on line #1 with no real difference in how the recipe operates. But then the loop color coding would not be as obvious as line numbers 1, 5, and 11 would all be yellow.

Doping

Doping is the process of inserting very small amounts of a different material into a bulk film to change the bulk film properties in a useful way. An example of this is to dope ZnO with low levels of Al to improve the conductivity of the transparent conductor. The graph shows how low levels of dopant in an ALD ZnO film can drastically reduce the film resistivity.(Bhatia, R., et al. ALD 2009, Monterey, CA, USA) ZnO is deposited with DiEthylZinc (DEZ) and H_2O. Doping the ZnO with Al is accomplished by periodically replacing one of the DEZ pulses with a TMA pulse. By replacing as little as every 50^{th} DEZ pulse with a pulse of TMA, the film resistivity is reduced by nearly an order of magnitude.



A sample recipe to achieve this type of doping is provided below. The doping recipe and the nanolaminate recipe only differ in that the doping recipe runs through the second sub-loop only once per supercycle. If the goto command in line #10 in the nanolaminate recipe had a 1 in the value column, it would have the same functionality as the example doping recipe.

	Instruction	#	value
0	wait		5
1	pulse	3	0.06
2	wait		10
3	pulse	0	0.06
4	wait		10
5	goto	1	49
6	pulse	1	0.06
7	wait		10
8	pulse	0	0.06
9	wait		10
10	goto	0	10

49 cycles ZnO

10 super cycles of Al:ZnO

1 cycle Al_2O_3

.

SECTION 7: Facility Requirements and Installation

Facility Requirements

Contact Cambridge NanoTech (support@cambridgenanotech.com) with any site-specific questions.

1. System Dimensions

<table>
<tr><th>Item</th><th>Details</th><th>Verified</th></tr>
<tr><td>System Dimensions and Service Space Requirements</td><td>
See the System Dimension drawings in the Appendix for specific dimensions, foot loading, seismic, and facility location details.

Fiji System Dimensions:
<table>
<tr><th>System</th><th>Length</th><th>Width*</th><th>Height</th><th>Service Area Footprint**</th></tr>
<tr><td>Fiji F200 System with Manual Load Door</td><td>114 cm
(45”)</td><td rowspan="3">89 cm
(35”)</td><td rowspan="3">216 cm
(85”)</td><td>239 x 285 cm
(94 x 112”)</td></tr>
<tr><td>Fiji F200 System with VAT Loadlock with Manual Transfer</td><td>234 cm
(92”)</td><td rowspan="2">239 x 354 cm
(94 x 140”)</td></tr>
<tr><td>Fiji F200 System with Hine Loadlock with Auto-Transfer</td><td>186 cm
(73”)</td></tr>
<tr><td colspan="5">*With temporary installation wheels installed on system. System frame is 22” wide. With ozone generator option, frame extends to 29” wide.
**Overall system service footprint includes required service space around the system which typically can be shared with other equipment. Refer the following dimension schematics and consult Cambridge NanoTech for any specific area and usage concerns.

Minimum System Service Clearance Space
<table>
<tr><th>Side</th><th>Minimum Clearance Space*</th></tr>
<tr><td>TOP</td><td>Sufficient space to make facility connections</td></tr>
<tr><td>FRONT
(controls side of system)</td><td>36” (91.5 cm)</td></tr>
<tr><td>RIGHT
(loading side of system)</td><td>36” (91.5 cm), use of manual loading recommended 6’ (180 cm)</td></tr>
<tr><td>LEFT
(gas box side of system)</td><td>36” (91.5 cm)</td></tr>
<tr><td>REAR:</td><td>36” (91.5 cm)</td></tr>
</table>
*Clearance space can be shared with other equipment.</td></tr>
</table>

Mechanical Pump Dimensions:
The standard dry pump used on the Fiji system is the Edwards iGX100N dry pumping system.
</td><td></td></tr>
</table>

Pump Type	Length	Width*	Height
***Edwards* iGX100N dry pumping system**	72 cm (28.0”)	29 cm (11.5)	41 cm (16.0”)

The pump fits under the frame of the system. It can be placed in a chase, in a utility closet, alongside the system, or, with some models, placed inside the base of the system with panel modifications (at time of order).

Note: One 12” (with main chamber turbo) or 18” (without main chamber turbo) section of flexible bellows is provided to connect the pump to the system. These lengths are sufficiently only if housing the pump within the Fiji frame. Additional lengths are required to house the pump outside the system.

2. Exhaust Requirements

Item	Details	Verified

WARNING

HAZARDOUS GAS EXHAUST POTENTIAL

All system exhaust lines must be properly connected to an appropriate facility exhaust to handle the chemical hazards present in the system supply gases and precursor chemicals, as well as any thermal exhaust loads.

Component	Exhaust Requirements
Fiji Cabinet Exhaust	☐ A 6” diameter exhaust duct port is provided at the top of the system. This port must be connected to an appropriate facility exhaust to handle the chemical hazards present in the system supply gases. ☐ Exhaust draw should be 150 CFM at 0.5” W.C.
Pump Exhaust	☐ Connection: NW40 at silencer outlet ☐ Exhaust should be capable of handling any toxic gases and related effluents from your system. All processes are run through the system pump. Each user’s environmental requirements are different due to the chemical processes being employed. Consult the MSDS sheets of the precursors and contact your local safety office for appropriate venting precautions.
Ozone Generator (Option) Exhaust	The ozone generator requires an appropriate exhaust system which is capable of safe handling of the exhaust gases. Use of a non-rigid exhaust connect will aid in performing service to the unit (to remove the ozone kit enclosure) ☐ Ozone exhaust port is 2” diameter, with a required flow rate of 30 CFM and 0.5” WC.  **DANGER** **TOXIC OZONE EXHAUST POTENTIAL** Typical exhaust gas is oxygen. In the event of a leak, the exhaust stream could contain ozone.

3. Power Requirements

<table>
<tr><th>Item</th><th>Details</th><th>Verified</th></tr>
<tr><td>Fiji System Power</td><td>
Power supplied from (35A US / 32 A EU) circuit using 6-8 AWG stranded cable (supplied by customer) according to chart below:
<table>
<tr><th rowspan="2">Supply</th><th colspan="5">PD Box Terminal</th><th rowspan="2">Outlets</th></tr>
<tr><th>L1</th><th>L2</th><th>N</th><th>G</th><th>Jumper</th></tr>
<tr><td>208V, 3ϕ
withou Neural</td><td>L1</td><td>L2</td><td>**</td><td>G</td><td>NONE</td><td>208V</td></tr>
<tr><td>220-240V, 1ϕ</td><td>L1</td><td>L2*</td><td>**</td><td>G</td><td>NONE</td><td>220-240V</td></tr>
<tr><td colspan="7">Notes: *For locations where Neutral is named L2. **Not connected</td></tr>
</table>
Consult with a qualified electrician to prepare for proper installation at your site.
<table>
<tr><th>Unied States:</th><th>Europe:</th></tr>
<tr><td>
☐ 208 VAC , 60 Hz
☐ 35 Amps
☐ 3 conductor, 6-8 AWG stranded
Wiring Color Codes (Typical):
<table>
<tr><th>Line</th><th>Function</th><th>Wire Color in Use</th></tr>
<tr><td>L1</td><td>HOT</td><td>Black</td></tr>
<tr><td>L2</td><td>HOT</td><td>Red</td></tr>
<tr><td>N</td><td>Neutral</td><td>White</td></tr>
<tr><td>G</td><td>Ground</td><td>Green or Green with Yellow stripes</td></tr>
</table>
</td><td>
☐ 230 VAC, 50 Hz
☐ 32 Amps
☐ 3 conductor, 6-8 AWG stranded
Wiring Color Codes:
<table>
<tr><th>Line</th><th>Function</th><th>Wire Color in Use</th></tr>
<tr><td>L1</td><td>HOT</td><td>Brown</td></tr>
<tr><td>L2</td><td>Neutral</td><td>Blue</td></tr>
<tr><td>G</td><td>Ground</td><td>Green with Yellow stripes</td></tr>
</table>
[color scheme by IEC (International Electrotechnical Commission)]
</td></tr>
</table>
The final disconnect device is the main circuit breaker CB1 on the power distribution box (PD Box).
</td><td></td></tr>
</table>

<table>
<tr><th>Item</th><th>Details</th><th>Verified</th></tr>
<tr><td>Edwards iGX100N Dry Pump Power</td><td>
☐ Power supplied by separate 15A circuit, 200-230Vac or 380-420Vac (model dependent – see section 2.7 of pump manual for wiring instructions)
☐ 4 or 3 conductor (model dependent) 6mm^2 (10 AWG) stranded (supplied by customer)
</td><td></td></tr>
</table>

4. Facility Gas Requirements

Item	Details	Verified
Facility Gases	The system has been configured for use with the following gases, however, order changes in the production cycle may have resulted in customized configurations for your system. Refer to your system for verification. Follow all standard practices for handling and connection of appropriate high-purity components, tubing, and metal gaskets to make all connections.	

Pneumatic Actuation Gas

For actuation of pneumatic valves

Gas	Supply Pressure, Regulated	Connection	
		Fitting Size	Type
CDA or N_2	80 PSIG	¼" Swagelok®	PFA Tubing

Process (Carrier and Purge) Gas*

Recommended research grade (99.9995%)

Gas	Supply Pressure, Regulated	Max Flow/ Consumption	Connection	
			Fitting Size	Type
Argon	25 PSIG	3 SLM	¼" Butt weld tube	Stainless Steel

Plasma Gas

Recommended research grade (99.9995%)

Supply lines: stainless steel delivery lines to be welded by customer to provided bulkhead fittings terminating in ¼" tube

Optional: An inline gas purifier is recommended for each gas feed.
Recommended: Use of a 1 slpm Entegris Gatekeeper Part # CE35KFN4R, hydride gas purifier is strongly recommended for use with NH3.

Gas	Supply Pressure, Regulated	Max Flow/ Consumption	Connection	
			Fitting Size	Type
N_2	30 PSIG	0.2 SLM	¼" Butt weld tube	Stainless Steel
O_2	30 PSIG	1.2 SLM	¼" Butt weld tube	Stainless Steel
H_2	30 PSIG	0.2 SLM	¼" Butt weld tube	Stainless Steel
NH_3[1]	30 PSIG	0.2 SLM	¼" Butt weld tube	Stainless Steel
CF_4[2]	30 PSIG	0.2 SLM	¼" Butt weld tube	Stainless Steel

[1] Optional gases may vary per system configuration.

Nitrogen Purge of Edwards iGX100N Dry Pump

Recommended research grade (99.9995%)

Gas	Flow/ Consumption	Connection	
		Fitting Size	Type
N_2	5 SLM	¼" Swagelok compression	Stainless Steel

5. Cooling Requirements

Item	Details	Verified
Water	**Plasma System Cooling Water**	

Requirement	Specification
Specific Resistivity*	Minimum water Specific Resistivity is 500,000 Ohms per centimeter at 25°C.
Temperature Range	5 – 25°C
Supply Pressure, Regulated	0.3 MPa
Flow/Consumption	1 lpm for base system with plasma 3 lpm for a system with main chamber turbo option and plasma source
Connection Type	½” Swagelok compression fittings with quick-disconnect fittings

IMPORTANT: For Water-Cooled Matching Networks:

Proper water resistivity is crucial for heat extraction and system performance. If the system water resistivity is too low, the water may conduct RF energy from the reactor to ground. This RF energy “leak” is an additional load to the RF delivery system and makes the matching network appear less efficient, resulting in an apparent power loss and is nominally identified by Low DC Developed Bias Voltage.

Pump Cooling Water

Requirement	Specification
Temperature Range	10 – 30°C
Supply Pressure	36 – 100 psi
Water Quality	Maximum particle size: 0.03 mm2 Acidity: 6.5 to 8.0 pH Hardness: < 100 ppm Resistivity: > 1 k cm Solids (turbidity): < 100 ppm Materials in contact with cooling water: stainless stell, PTFE, copper, brass, and fluoroelstomer
Flow	1 slm
Connection Type	1/4” BSPT male (use of quick-disconnect fittings is recommended; see installation instructions)

6. Required Parts – Customer Supplied

The customer is required to supply the following parts for system installation:

Category	Description	Vendor/Part Number	QTY
Mechanical	Seismic anchor bolts for Fiji System and Pump		8
Water	Inlet/Outlet tubing	Recommended: Tubing, PUSH-LOK Plus Parker Part # 801-9 [WP 2.1 MPa (300 PSI) MSHA IC-40/22 12.5 mm (1/2")] (tubing shown with supplied fittings and with optional customer-supplied push-on barbed hose fittings) 	2
	Inlet/Outlet tubing hose barbs, recommended for use with supplied water inlet/outlet fittings	Push On Hose Fittings: Swagelok Part # SS-PB8-TA8 	2
	Loctite 577 for water line male thread		

	connectors and (qty. 2) 3/8" male BSPP adapter for supply and return cooling lines connection to provided quick connectors with the Edwards iGX100N rough pump		

Category	Description	Vendor/Part Number	QTY
Electrical	Fiji Input wiring	6-8 AWG	Lengths as required by facility location
	Wire ferrules	Use properly-sized, industry-standard ferrules such as Altech® ferrules with an appropriately sized crimper to attached ferrules to the end of each power wire 	10*
	Ferrule crimper	As required for ferrule type and size	1
	Pump Input wiring	10 AWG	Lengths as required by facility location
Gas	Welding equipment and supplies, as required for butt-tube welding of gases to system inlets		As needed
	STANDARD SYSTEMS: ¼" Silver-plated stainless steel VCR® gaskets	SS-4-VCR-2, or SS-4 VCR-2-GR (with retaining clip)	1 per cylinder (additional gaskets should be available at all times)
	OZONE SYSTEMS: UNCOATED ¼" stainless steel VCR gaskets	SS-4-VCR-2-VS, or SS-4 VCR-2-GR-VS (with retaining clip)	

WARNING

HAZARDOUS GAS LEAK POTENTIAL

Never use silver coated or nickel-coated gaskets on systems with ozone as deterioration of the seals will occur. See installation and use instructions provided with the ozone generator option.

Tubing and Fittings

All internal gas connections use standard VCR or Swagelok® fittings. External fittings for process gases are ¼” Butt Weld tubing. Use standard fitting equipment and techniques to make high-purity, leak-tight fittings.

WARNING

HAZARDOUS GAS LEAK POTENTIAL

All plasma gas lines must be helium leak tested to ensure they are leak-tight. Secondary containment and hazard gas detectors and other hazardous gas handling and detection equipment is solely the responsibility of the end user. See installation steps.

CAUTION

PROCESS/MOISTURE/PARTICLE ISSUE

DO NOT USE plastic tubing for Argon line.

The argon purge-gas line must be stainless steel. Plastic or Teflon® tubing should NOT be used due to the ability to attract and retain moisture and other impurities which will affect the ALD process.

Required Tools

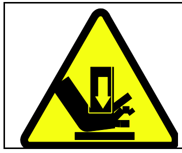
- level
- metal tubing tools/fixtures: welding equipment and supplies, tubing cutter, tubing bender and related tools, if applicable
- helium leak checking equipment (for facility gas line installation)
- standard electrical and mechanical tool kits
- 1/2”, 5/8”, 9/16”, and 3/4” open end wrenches
- 5/16” 12-point box end wrench
  (additional Open end and box wrench sets should be available, English and Metric)
- socket wrench and ratchet driver, English and Metric
- crimpers for 6-8AWG stranded wire (as necessary to attach ferrules)
- wire cutters, various sizes
- small screwdrivers, flat and Phillips
- set of Allen wrenches, English and Metric
- tie wraps (various sizes)
- cleanroom wipes

Additional Safety Cautions

WARNING

HEAVY OBJECT

Two to four people are required to perform the following procedures due to the weight and location (height) of the top frame assembly.



WARNING

PINCH HAZARD

Protect yourself from any pinch or crush hazard.

Recommended Precursors – Customer Supplied

Item	Details	Verified
Precursors/ Chemicals	- Distilled water - Chemical precursors loaded into cylinders Fiji systems ship with one empty water cylinder (no valve) and with empty valved precursor cylinders populating the remainder of the precursor lines. Common chemical precursors can be found, for example from Strem or Sigma-Aldrich. http://www.sigmaaldrich.com http://www.strem.com Trimethylaluminum (TMA) is a good precursor to have in order to test the operation of the system. It can be purchased from Sigma-Aldrich prepackaged in an appropriate cylinder, P/N # 66301, or Strem Chemicals # 98-4003. Cambridge Nanotech recommends using distilled water as a precursor.  **WARNING** **FIRE HAZARD** Trimethylaluminum (TMA) is a liquid at room temperature and is pyrophoric. This means that it burns upon exposure to air. TMA reacts with water vapor in the air. For this reason, the TMA bottle may only be opened in a glove box with inert atmosphere by experienced professionals such as at the chemical supply companies (Strem, Sigma-Aldrich etc).	

Installation

Step 1: Uncrate and Locate System

Step	Action	Details
1.	Note: Please consult professional movers. Casters are provided on the system to aid in installation. Unpack the crates carefully and inspect the system for damage that may have occurred during shipping. IMPORTANT: Verify the integrity of the shock tab on the crate upon receiving the equipment. Inform the shipper and Cambridge NanoTech immediately if a shock tab has been activated. Remove all wood, strapping, cardboard, and outer protective wrappings prior to bring the system into a clean environment. DO NOT open the inner clean bags at this time.	The system is typically shipped in 3 or more crates or boxes, similar to those shown below:  **CAUTION:** Avoid Particulate Contamination. If the unit is to be used in a cleanroom environment, DO NOT remove the inner clean bags on any item until immediately before installation. Notify the carrier immediately if any damage is found. Retain the shipping cartons and packing material for the carrier's inspection and for repackaging should reshipment become necessary.
2.	Drive the Main system crate into an appropriate uncrating location	

3.	Remove the screws from the top panel of the crate	
4.	Remove top braces (seen in picture above)	
5.	Then remove side panels	

6.	With the use of a forklift, carefully and slowly lift the Fiji system until cleared from the bottom pallet	
7.	Slide bottom pallet away so that the system may be lowered in place and resting on the 4 caster wheels installed	.
8.	Plastic wrap covering wheels will have to be partially removed to drive the Fiji system to a wipdeown area/final location.	
9.	Move the system into position with great care to prevent damage.	Remove the casters and store them in a safe place for future use, if necessary.
10.	Level the system and remove casters.	The system is equipped with multiple leveling legs. Adjust each leg carefully to level the system, front and back, side to side. Use of a precision bubble level on multiple surfaces is recommended.
11.	Secure seismic brackets to system and floor using hardened bolts, if applicable	Refer to installation drawing.

Step 2: Install Exhaust Connections

1.	Connect the cabinet exhaust connection to an appropriate facility exhaust. The exhaust connection is located at the top of the system. The connection is a 4" diameter duct. Install an air flow meter into the exhaust draw and regulate the air flow (with panels on) to a flow of 150 CFM and a draw of .5" W.C. The approximate heat load generated by the system is <3kW.	 **WARNING** **HAZARDOUS GAS EXHAUST POTENTIAL** All system exhaust lines must be properly connected to an appropriate facility exhaust to handle the chemical hazards present in the system supply gases and precursor chemicals, as well as any thermal exhaust loads. While the cabinet exhaust is primarily for thermal exhaust of the heat generated by the system, unanticipated release of supply gases and/or chamber gases may present hazards.  **WARNING** **FIRE HAZARD** Connect the system only to an exhaust system that has been approved for your process effluents and your process gases.
2.	If the system is equipped with an ozone generator (as shown), connect the unit to an appropriate exhaust system which is capable of safe handling of the exhaust gases. Use of a non-rigid exhaust connect will aid in performing service to the unit (to remove the ozone kit enclosure)	Ozone exhaust port is 2" diameter, with a required flow rate of 30 CFM and 0.5" WC. 

		 **DANGER** **TOXIC OZONE EXHAUST POTENTIAL** Typical exhaust gas is oxygen. In the event of a leak, the exhaust stream could contain ozone.

Step 3: Connect Input Power

Step	Action	Details
1.	Connect Input Power to the System.	See details below

Action:

Connect Input Power to the System.

Wire must be 6-8 AWG stranded. Current <35 Amps in continuous operation.

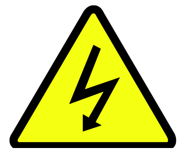
Use properly-sized, industry-standard ferrules (such as Altech® ferrules) with an appropriately sized crimper to attached ferrules to the end of each power wire, as shown below:

Ferrule

Ferrule crimped on stranded wire

IMPORTANT: Ferrules ensure reliable electrical connections when terminating stranded flexible wire in terminal blocks. Insulated ferrules prevent conductor breakage due to bending, wire stress or vibration while facilitating wire insertion into the terminal clamp.

Details:



DANGER

HIGH VOLTAGE! SHOCK HAZARD!

A trained electrician should perform this installation in accordance with all applicable local wiring codes including any required conduit installation.

Refer to the wiring specifications below for your installation site. The final disconnect device is the main circuit breaker CB1 in the power distribution box (PD Box). A wall-mount lockable device should also be installed to isolate all power from the system.

Power supplied from (35A US / 32 A EU) circuit using 6-8 AWG stranded cable (supplied by customer) according to chart below:

Supply	PD Box Terminal					Outlets
	L1	L2	N	G	Jumper	
208V, 3ϕ *without Neutral*	L1	L2	**	G	NONE	208V
220-240V, 1ϕ	L1	L2*	**	G	NONE	220-240V

Notes: *For locations where Neutral is named L2. **No connection required

United States:

208 VAC , 60 Hz
35 Amps
3 conductor wire, 6-8 AWG stranded

Wiring Color Codes (Typical):

Line	Function	Wire Color in Use
L1	HOT	Black
L2	HOT	Red
N	Neutral	White
G	Ground	Green or Green with Yellow stripes

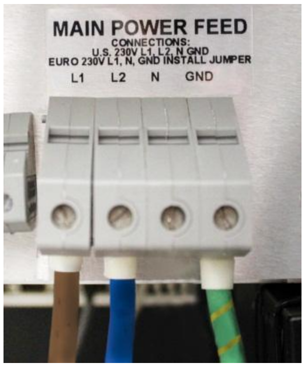
Europe:

230 VAC, 50 Hz
32 Amps
3 conductor wire, 6-8 AWG stranded

Wiring Color Codes:

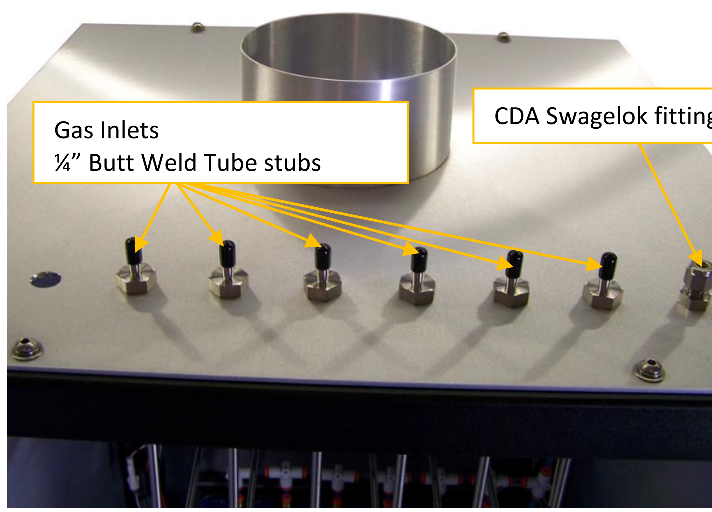
Line	Function	Wire Color in Use
L1	HOT	Brown
L2	Neutral	Blue
G	Ground	Green with Yellow stripes

[color scheme by IEC (International Electrotechnical Commission)]

			MAIN POWER FEED CONNECTIONS: U.S. 230V L1, L2, N GND EURO 230V L1, N, GND INSTALL JUMPER L1 L2 N GND	MAIN POWER FEED CONNECTIONS: U.S. 230V L1, L2, N GND EURO 230V L1, N, GND INSTALL JUMPER L1 L2 N GND

Step 4: Connect Facility Gases

<table>
<tr><th>Step</th><th>Action</th><th>Details</th></tr>
<tr><td>1.</td><td>Connect Facility Gases</td><td>
1. Connect all facility gases as required. Open the rear panel door and verify the labeling on each gas input.

Follow all standard practices for handling and connection of appropriate high-purity components and tubing to make connections.
<table>
<tr><th>Gas Inlet</th><th>Fitting Size/Type</th><th>Inlet Pressure</th></tr>
<tr><td>CDA</td><td>¼” Swagelok Compression</td><td>80 PSIG</td></tr>
<tr><td>Argon</td><td>¼” Butt Weld Tube Stub</td><td>25 PSIG</td></tr>
<tr><td>Nitrogen</td><td>¼” Butt Weld Tube Stub</td><td>30 PSIG</td></tr>
<tr><td>Oxygen</td><td>¼” Butt Weld Tube Stub</td><td>30 PSIG</td></tr>
<tr><td>Hydrogen</td><td>¼” Butt Weld Tube Stub</td><td>30 PSIG</td></tr>
<tr><td>Ammonia*</td><td>¼” Butt Weld Tube Stub</td><td>30 PSIG</td></tr>
<tr><td>Methane*</td><td>¼” Butt Weld Tube Stub</td><td>30 PSIG</td></tr>
</table>
*Optional


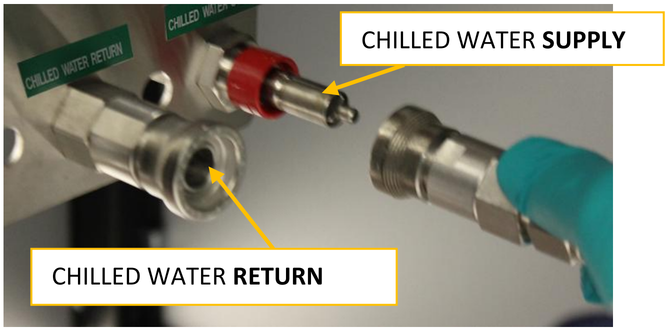
Leak check each line using standard Helium leak checking procedures. Consult with an experienced gas installation engineer.
Typically, each line should be purged with inert gas prior to the introduction of a potentially reactive gas such as Oxygen or Hydrogen, etc. Consult Cambridge NanoTech or your gas welder/installer or gas supplier with any questions.

DANGER
LEAK HAZARD
All gas connections should be performed by properly licensed and trained plumbers for the specific gas types used on the system. All connections and lines must be leak-checked to ensure safety from fire, explosion, and/or release of toxic or other gas hazards.
-
</td></tr>
</table>

2.	Check all fittings, lines, and wire connectors to ensure that all components are secured properly.	
3.	Any facility and/or external sensors should be certified to be working properly before proceeding.	

Step 5: Install Facility Cooling Water Lines

Step	Action	Details
1.	Use the supplied quick-disconnect fittingswhich terminate in ½” Swageko compression fitting to make inlet and outlet hoses for the required chilled water supply and return lines.	The system is shipped with the following quick-disconnect fittings: Fitting: Male Water (Return) Fitting Part #: Swagelok # SS-QC8-B-810 Item:  Fitting: Female Water (Supply) Fitting Part #: Swagelok # SS-QC8-B-810 Item: 
2.	Use of hose barbed fittings and appropriate hose material is recommended. See Required Parts for details.	Inlet/Outlet tubing hose barbs, recommended for use with supplied water inlet/outlet fittings: customer-supplied Push On Hose Fittings: Swagelok Part # SS-PB8-TA8

		
3.	NOTE: Verify plasma cooling connections are complete before making chilled water connections or turning on flow to the Fiji system The connections for chilled supply and returns lines to the Fiji system are located below the process chamber, mounted on the system frame, as shown below.	

Step 6: Install the Vacuum Pump

The following instructions are provided for installation of the Edwards iGX100N vacuum pump. Refer to the manufacturer's manual for additional details and important notices.

Required Equipment

- ☐ Water coupling fittings
  An adapter (customer supplied) is required to connect the coolant line to the provided quick-connects terminating in 3/8" BSPP female fittings

Required Tools

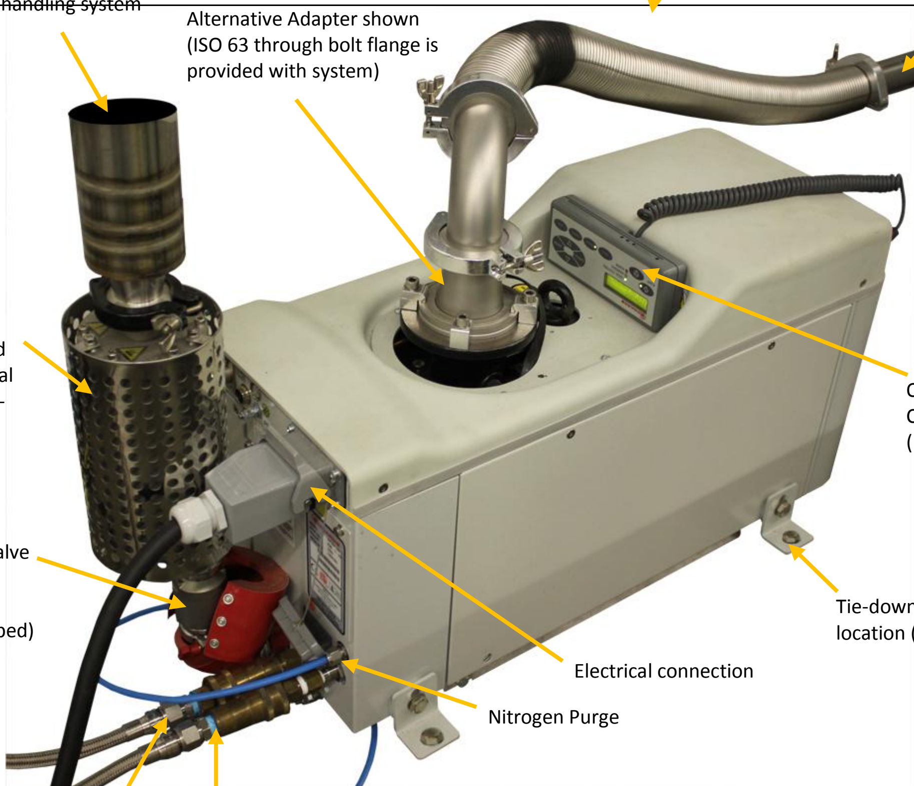
- ☐ Loctite 577 for water line male thread connectors
- ☐ ½" wrench, ¾" wrench, adjustable wrench
- ☐ Metric and Standard Allen wrench sets
- ☐ Small flat screwdriver

Pump Kit Contents

- ☐ Pump
- ☐ Operation Control Pad (Pendant)
- ☐ Pump exhaust flange connection, mounting bolts and washers
- ☐ Pump 3/8" water fittings with quick disconnects (male and female)

Exhaust Kit Contents

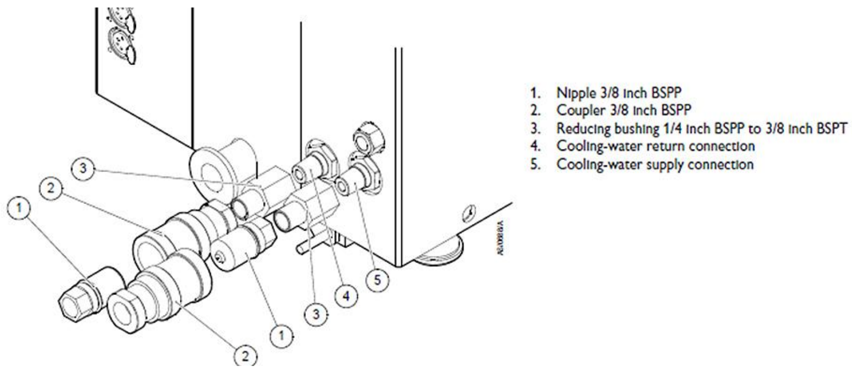
The pump can be placed in a chase, in a utility closet, alongside the system, or, with some models, placed inside the base of the Fiji system, depending on system configuration. Pump is shown connected below:



Step	Action	Details
1.	Position the vacuum pump as close as practical to the Fiji system, on inside the Fiji system (if applicable).	Adjust the leveling feet to ensure the system is level and not supported by any castors. The pump weighs approximately 120 Kg **Vibration Transmission:** If vibration transmission to the floor is a concern, install suitable vibration isolators (not supplied) between the mounting angles and a bolt or stud to secure the pump to the floor. Removal the leveling feet is required when vibration isolators are installed. **Seismic Tiedowns:** The system can be secured to the floor using suitable bolts or studs (not supplied) through the 17.5 mm hole in the seismic brackets. If vibration transmission to the floor is a concern, suitable vibration isolators (not supplied) should be fitted between the seismic brackets and the bolt or stud.

4.	Used supplied vacuum tubing and/or customer-supplied vacuum tubing, o-rings, and clamps to connect the pump to the Fiji system.	**Notes:** • To get the best pumping speed, ensure that the pipeline which connects the Fiji system to the iGX system is the minimum length possible and has an internal diameter not less than the iGX system inlet-port. • Ensure that all components in the vacuum pipeline have a maximum pressure rating which is greater than the highest pressure that can be generated in your system. • Incorporate flexible pipelines in the vacuum pipeline to reduce the transmission of vibration and to prevent loading of coupling-joints. We recommend that you use Edwards braided flexible pipelines. The pipelines should be suitable for 110 °C. • Adequately support vacuum/exhaust pipelines to prevent the transmission of stress to pipeline coupling joints.
5.	Connect the nitrogen supply to the pump using the ¼” compression fitting.	
6.	Connect the electrical supply to the pump.	**Refer to the pump manual for details on the electrical wiring.** **This work must be performed by a trained electrician.**

<table>
<tr>
<td></td>
<td>Connect the water supply (IN) and return (OUT) using supplied connectors.</td>
<td>
Use of leak-free quick-disconnect connectors is recommended be used to reduce the risk of water spillage during connection/disconnection. Several options are available for use. The instructions below detail the use fittings and couplings which are supplied unassembled with the system:

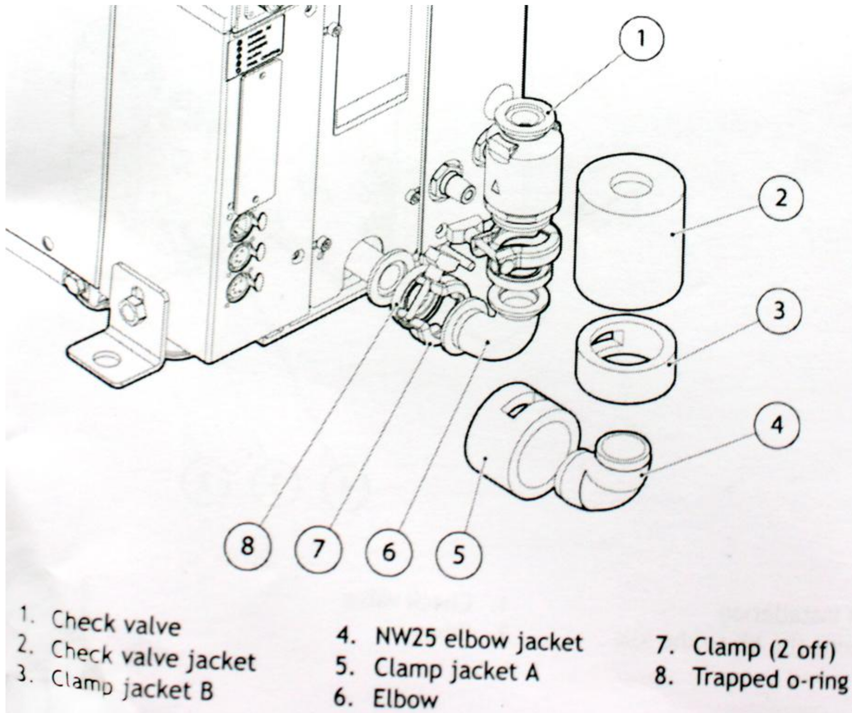


1. Remove the dust-caps from the cooling-water inlet and outlet
2. If not pre-assembled, apply Loctite® 577 (not supplied) to all male threads prior to installation.
3. Connect the reducing bushing (3) to the threaded end of the coupler (2).
4. Connect this sub-assembly to the water return port on the pumping system (4).
5. Connect the threaded end of the nipple (1) to the customer water return line.
6. Connect the reducing bushing (3) to the threaded end of the nipple (1).
7. Connect this sub-assembly to the water supply port on the pumping system (5).
8. Connect the threaded end of the coupler (2) to the customer water supply line.
9. Connect the customer supply and return hoses to the pump.
10. Turn on the cooling-water supply.
11. Inspect the water hoses, pipelines and connections and check that there are no leaks.
12. Turn off the water supply while you complete the remainder of the installation procedures.

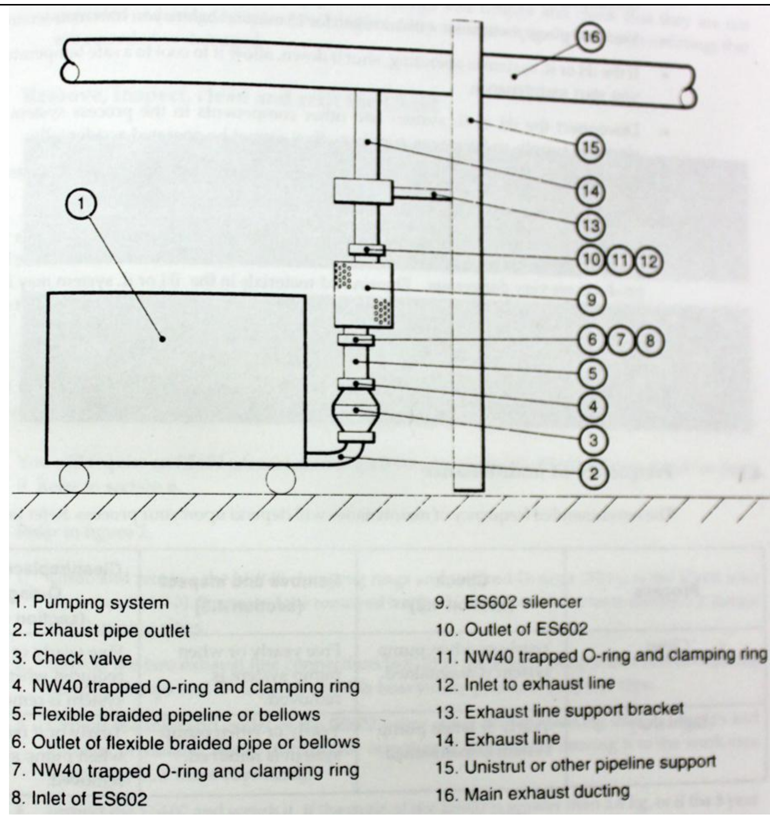
Note: An adapter (customer supplied) is required to connect the coolant line to the provided quick connects terminating in 3/8” BSPP female fittings


</td>
</tr>
</table>

<table>
<tr>
<td>7.</td>
<td>Connect the exhaust elbow, check valve, and silencer to the pump exhaust fitting.</td>
<td>
1. Connect the supplied elbow to the rear of the pump.
2. Connect the check valve to the elbow. Verify that the arrow on the check valve is pointing up, away from the pump.
3. Connect the silencer to the check valve.
4. Fully support the exhaust line immediately above the ES602 silencer using pipeline brackets that are strong enough to support the ES602.

Ideally, a short piece of flexible braided stainless steel pipe or bellows can be installed between the check valve and the silencer. This prevents vibration from being transmitted from the pump system to the exhaust line, allows for thermal expansion and contraction, and avoids loading of coupling joints.



WARNING
GAS LEAK POTENTIAL
The ES602 exhaust silencer MUST be supported by an external bracket. The pump is not designed to support external loads, including the silencer and tubings.
</td>
</tr>
</table>

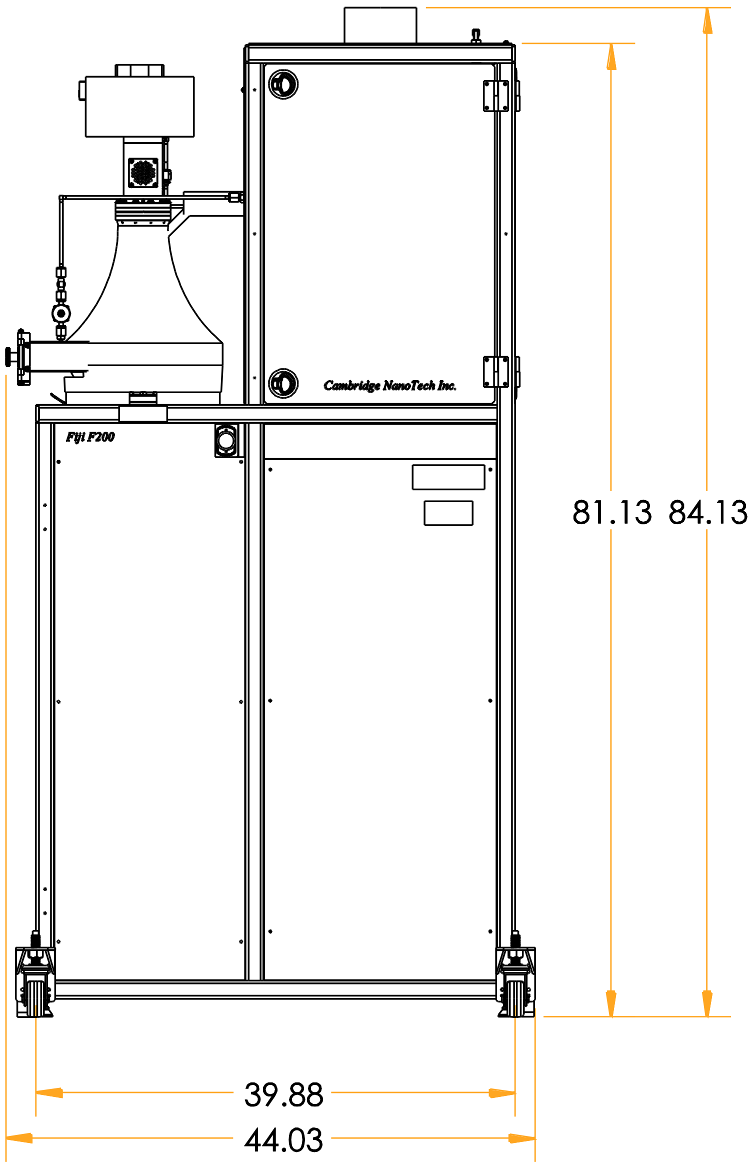
		
2.	Install insulation blankets on each of the exhaust components, as detailed.	Install the blankets in the following order: 1. Large blanket strip: on the fitting/clamp closest to the pump. 2. Elbow blanket 3. Small blanket strip on the clamp between the elbow and the check valve 4. Check valve blanket This order of assembly will allow proper fitting and easier access for maintenance of the check valve.
3.	Connect the exhaust line terminating in an NW40 fitting from the outlet of the silencer to an appropriate facility system exhaust that is capable of properly handling all effluents from the process chamber.	 **DANGER** **HAZARDOUS GAS EFFLUENT** All gas connections should be performed by properly licensed and trained fitters. The system exhaust must be connected to an appropriate facility exhaust which is capable of handling the gases and chemicals which are present or which can be created as part of the system operation. Consult your local facility safety engineers to ensure you are in compliance with all local, regional, national, and industry-standard safety guidelines. for the specific gas types used on the system. All connections and lines must be leak-checked to ensure safety from fire, explosion, and/or release of toxic or other gas hazards.

Appendix

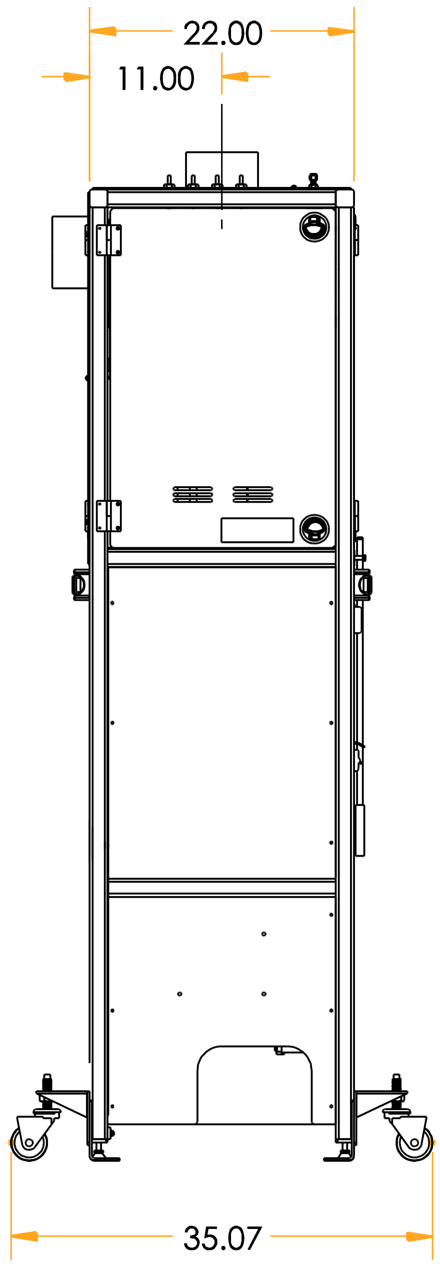
System Dimension Drawings

All dimensions in inches unless otherwise noted

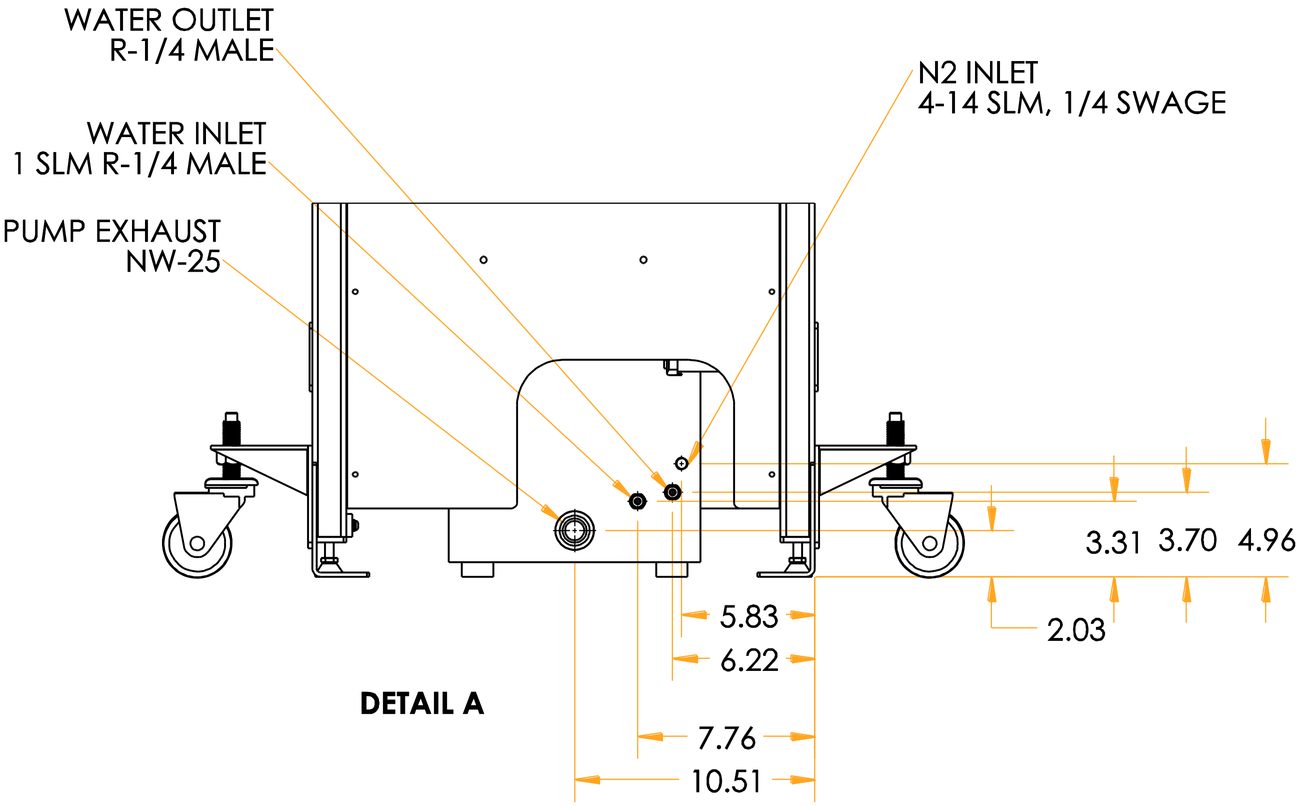
1. Fiji F200 System with Manual Load Door



Fiji F200 Base System: REAR VIEW (non-controls side)

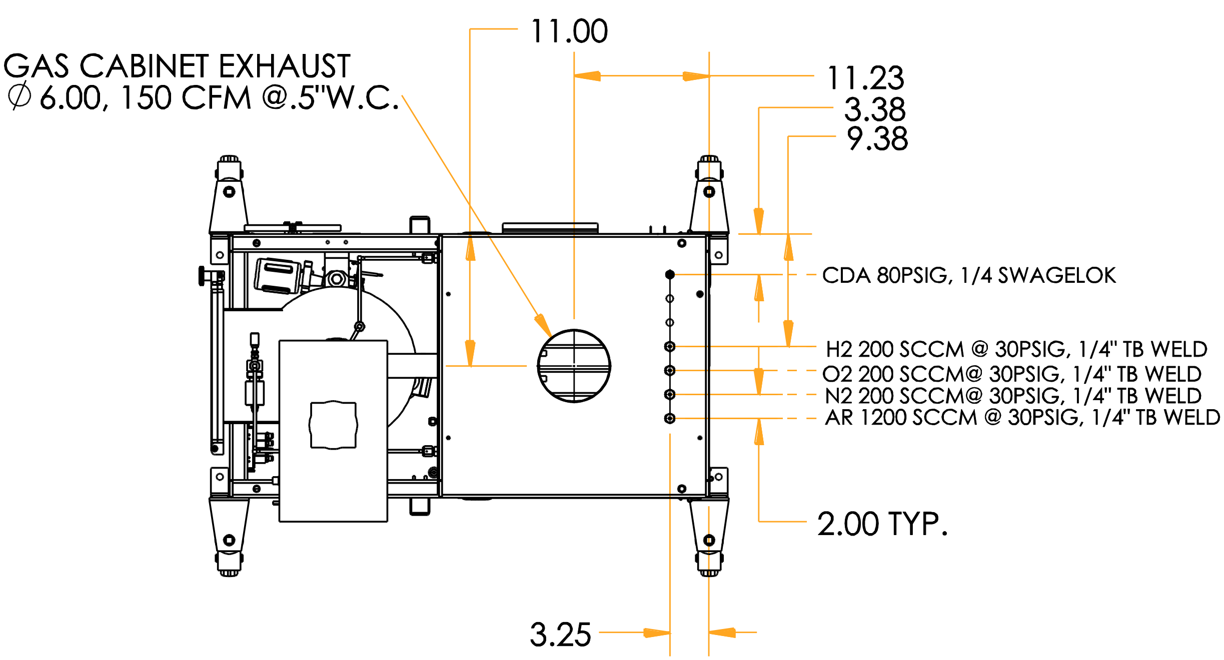


Fiji F200 Base System: LEFT SIDE (PRECURSOR) VIEW

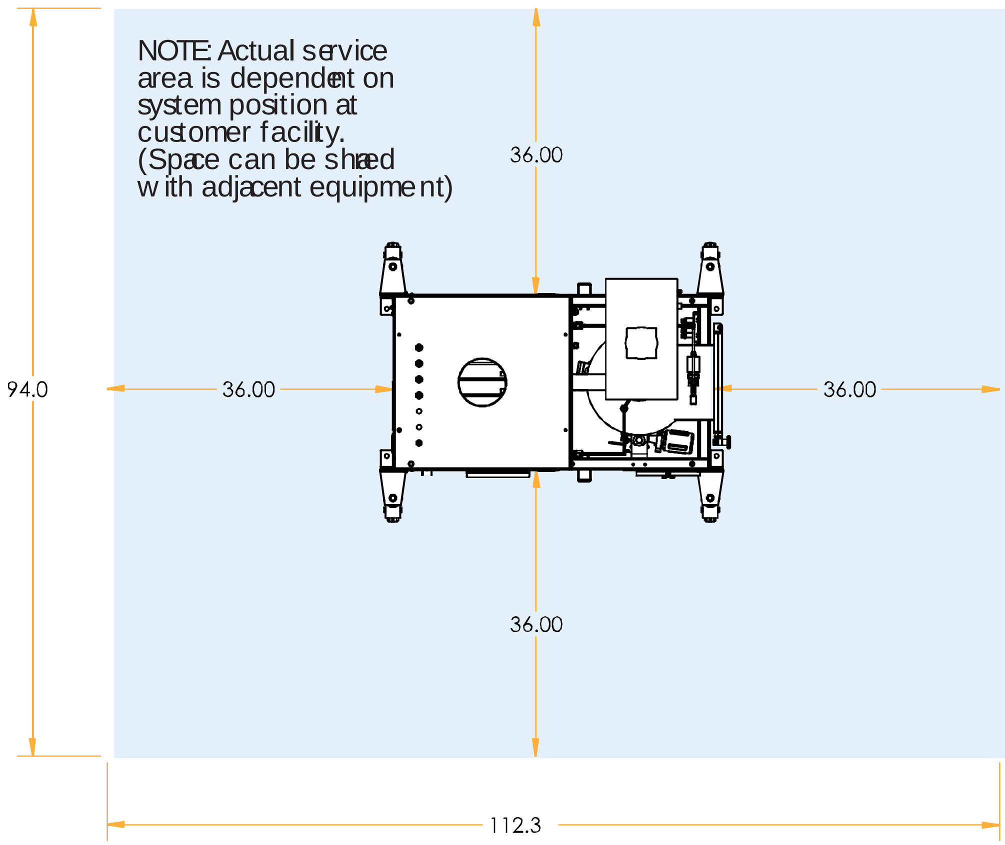


(shown with temporary machine installation wheels in place)

Fiji F200 - Detail A: Approx. Dimensions/Locations for Vacuum Pump Facility Connections

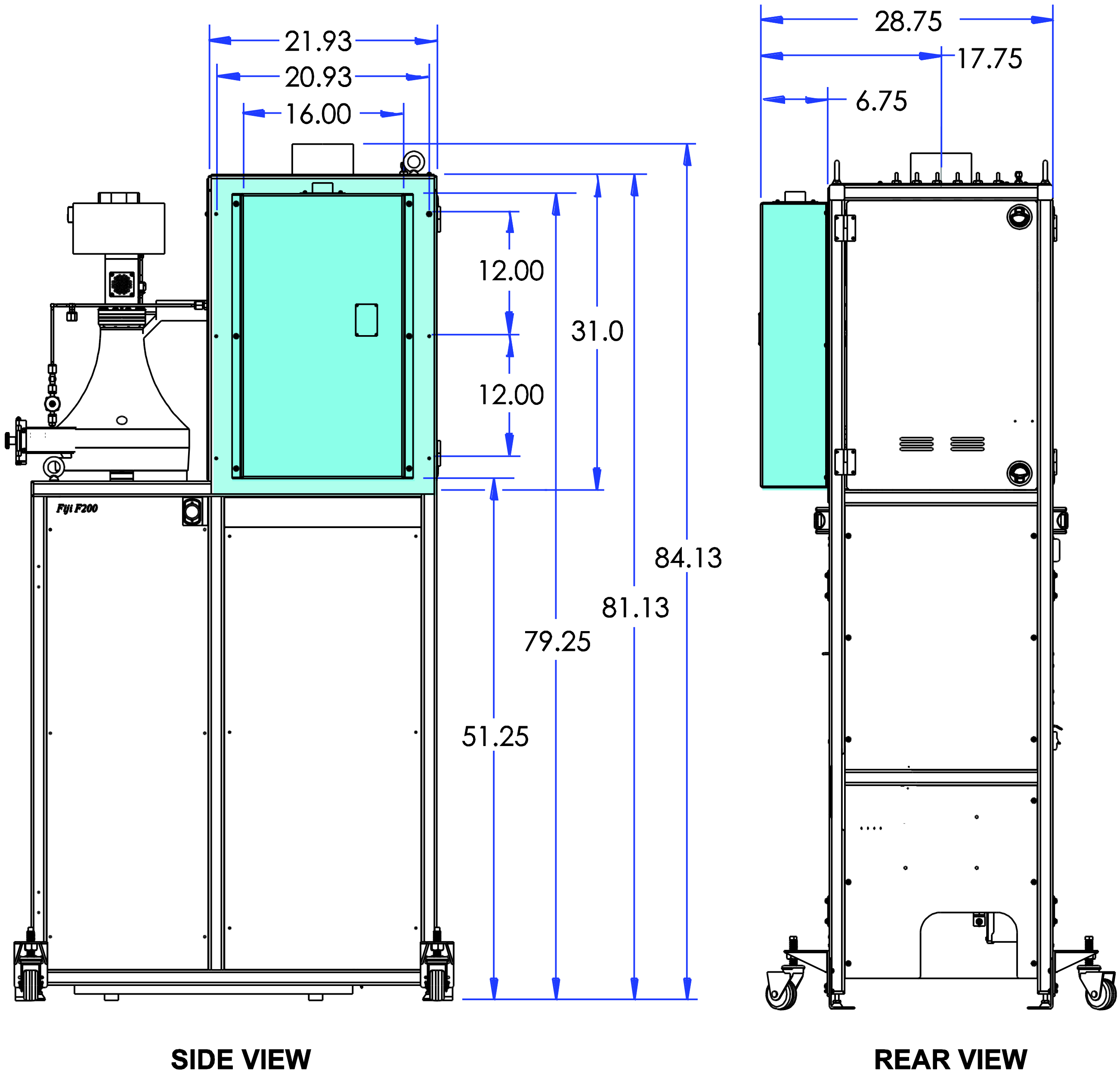


Fiji F200 Base System: TOP VIEW

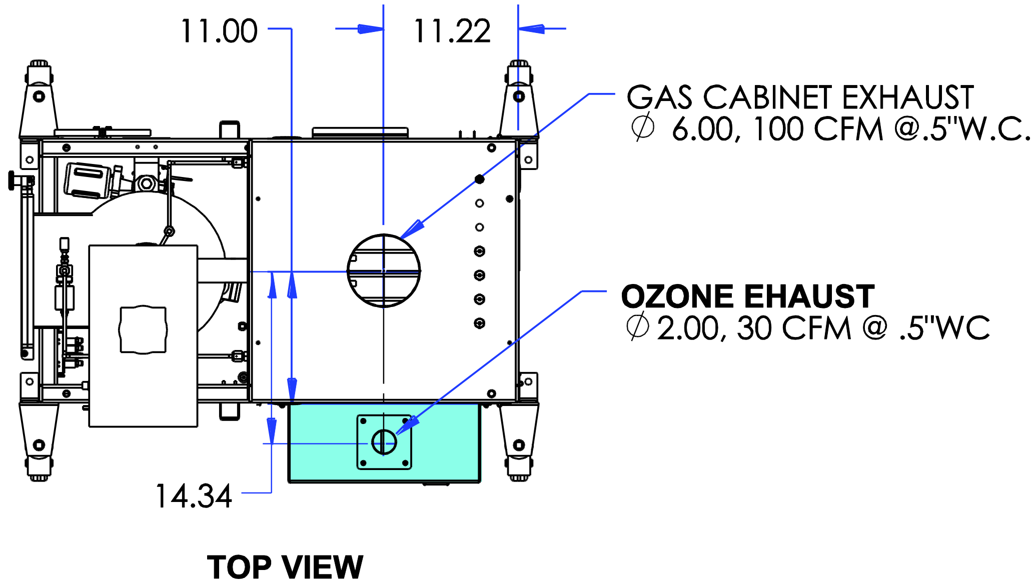


Fiji F200 Base System: TYPICAL SERVICE SPACE

Ozone Generator on Base System Frame:

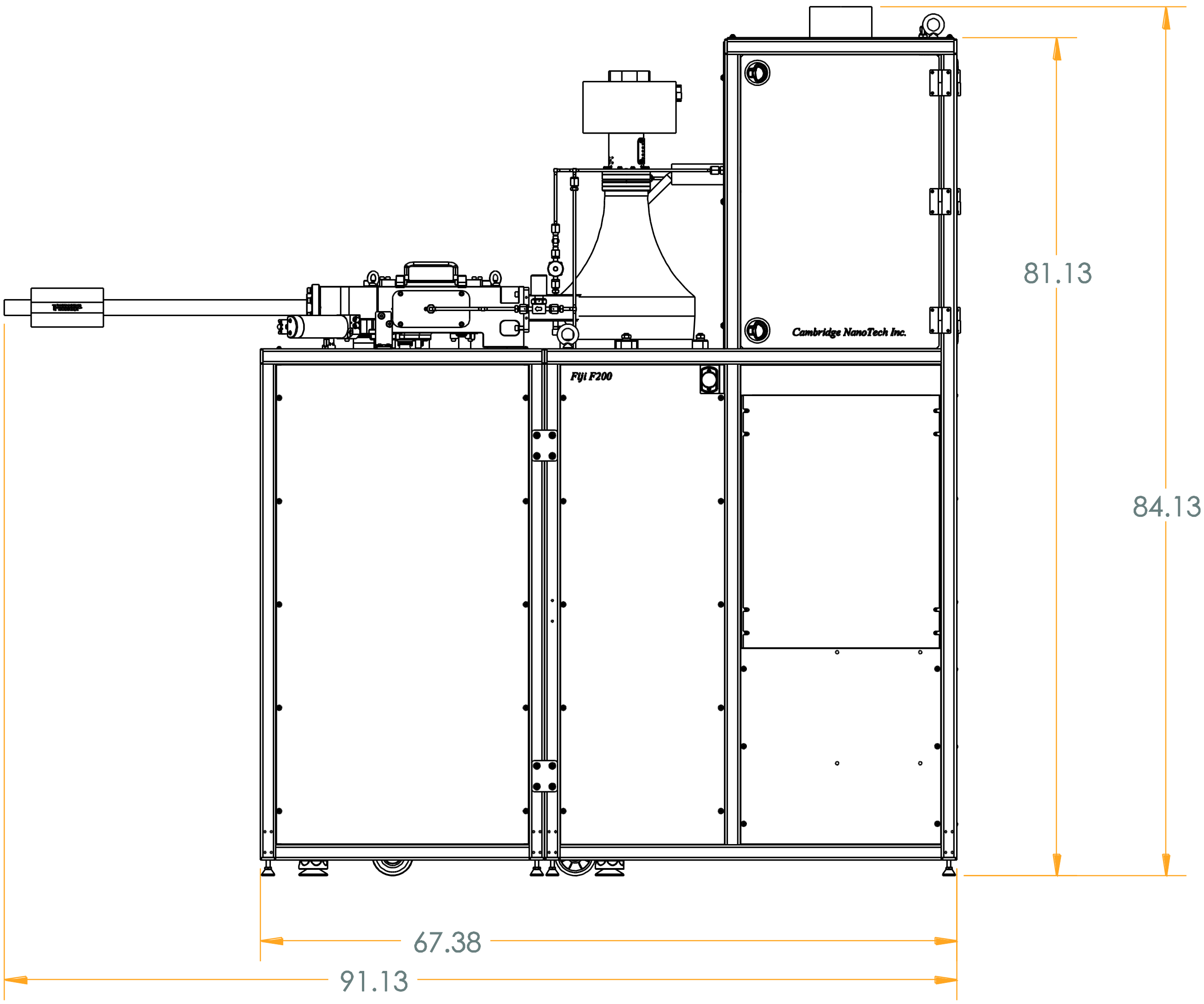


Side and Rear Views– Ozone System on Fiji F200
Note: All dimensions in inches

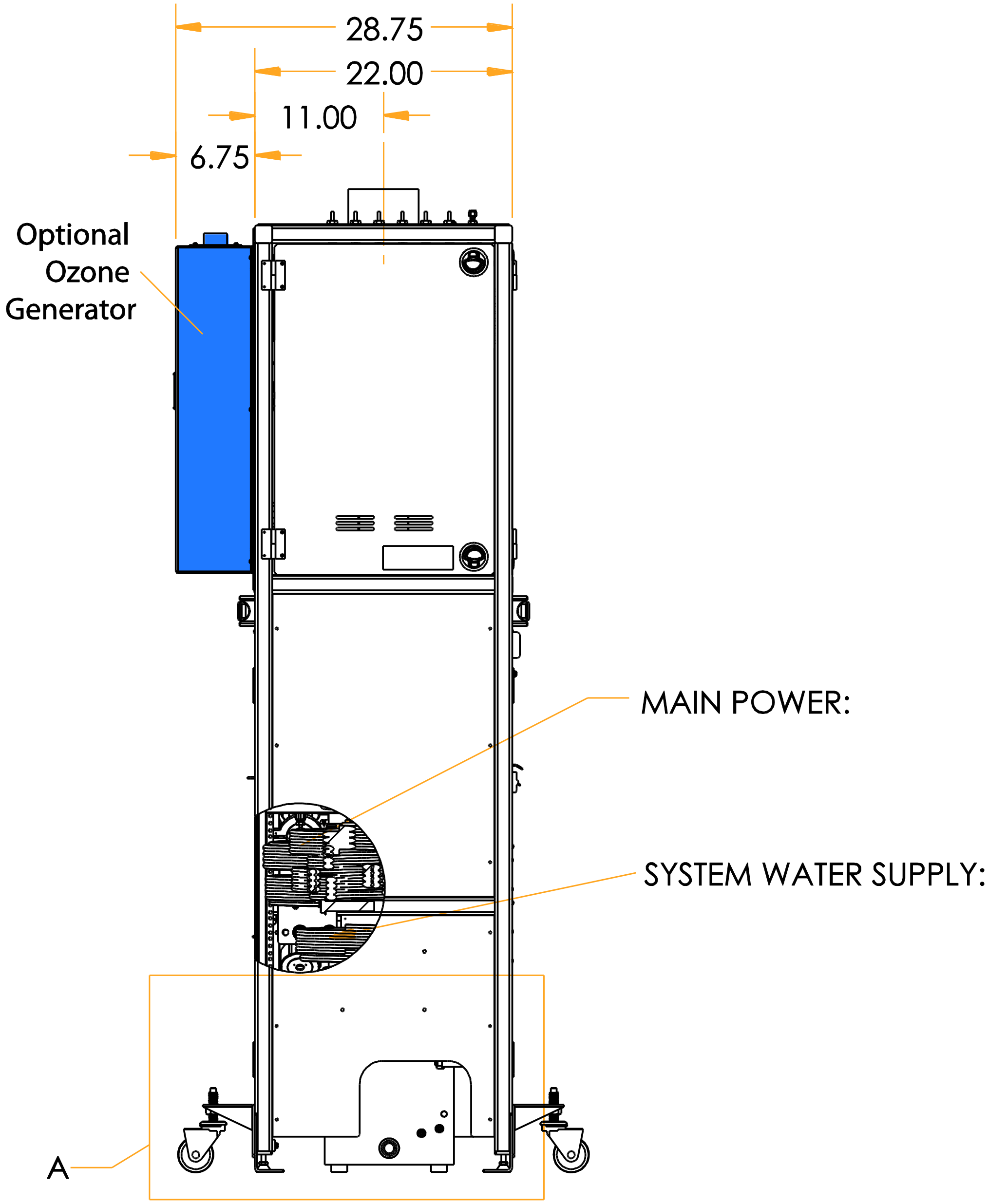


Top View – Ozone System on Fiji F200
Note: All dimensions in inches

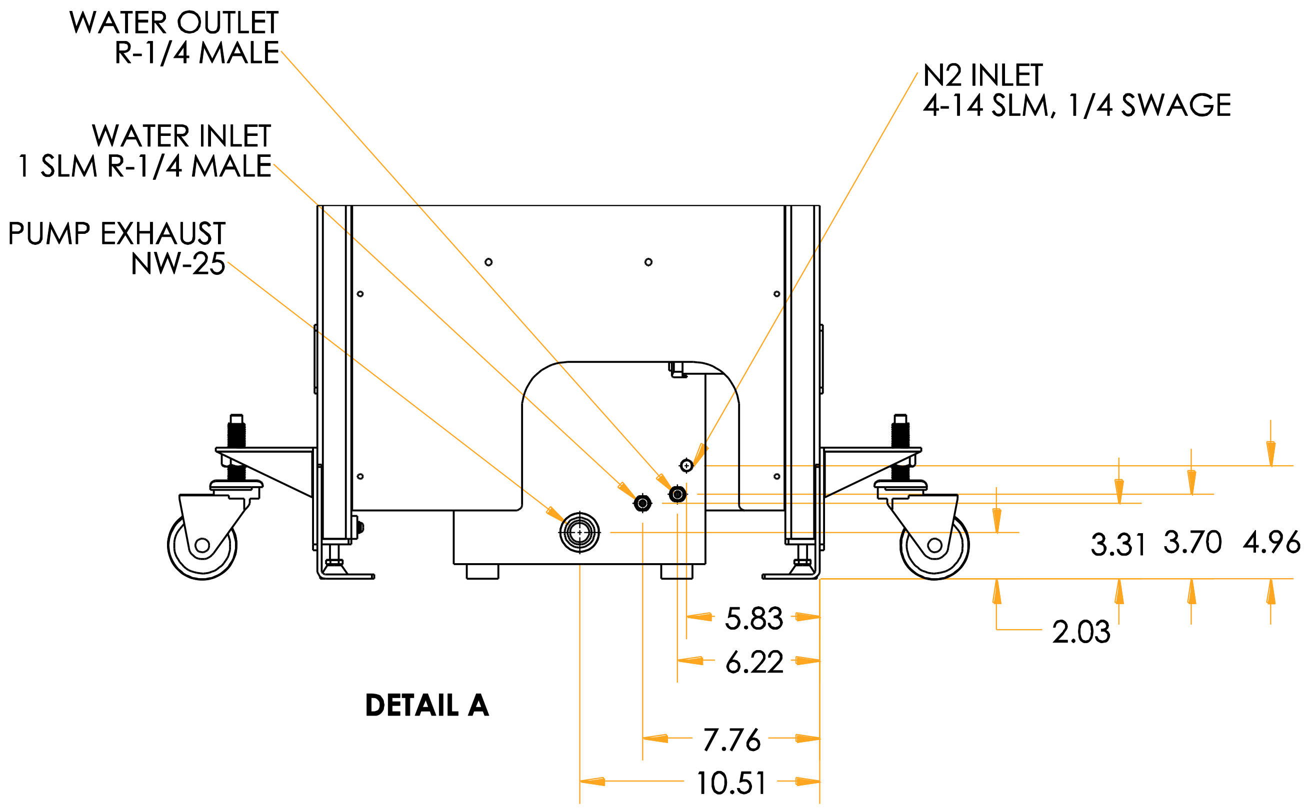
2. Fiji F200 System with VAT Loader



Fiji F200 System with VAT Load/Lock Push Loader: REAR VIEW (non-controls side)

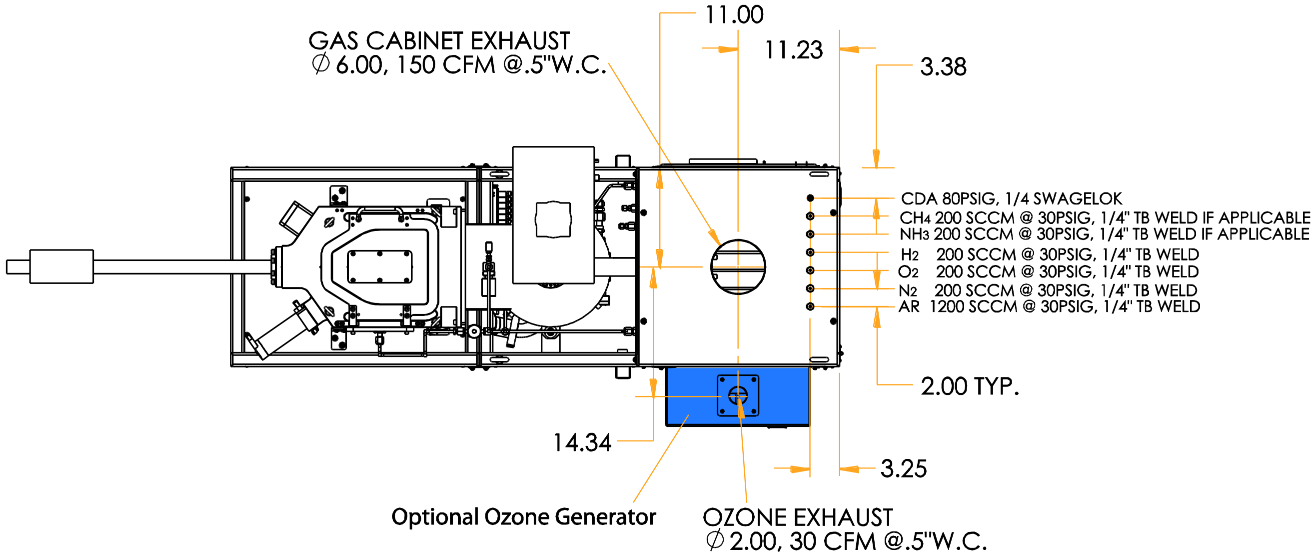


Fiji F200 System with VAT Load/Lock Push Loader: LEFT SIDE (PRECURSOR) VIEW

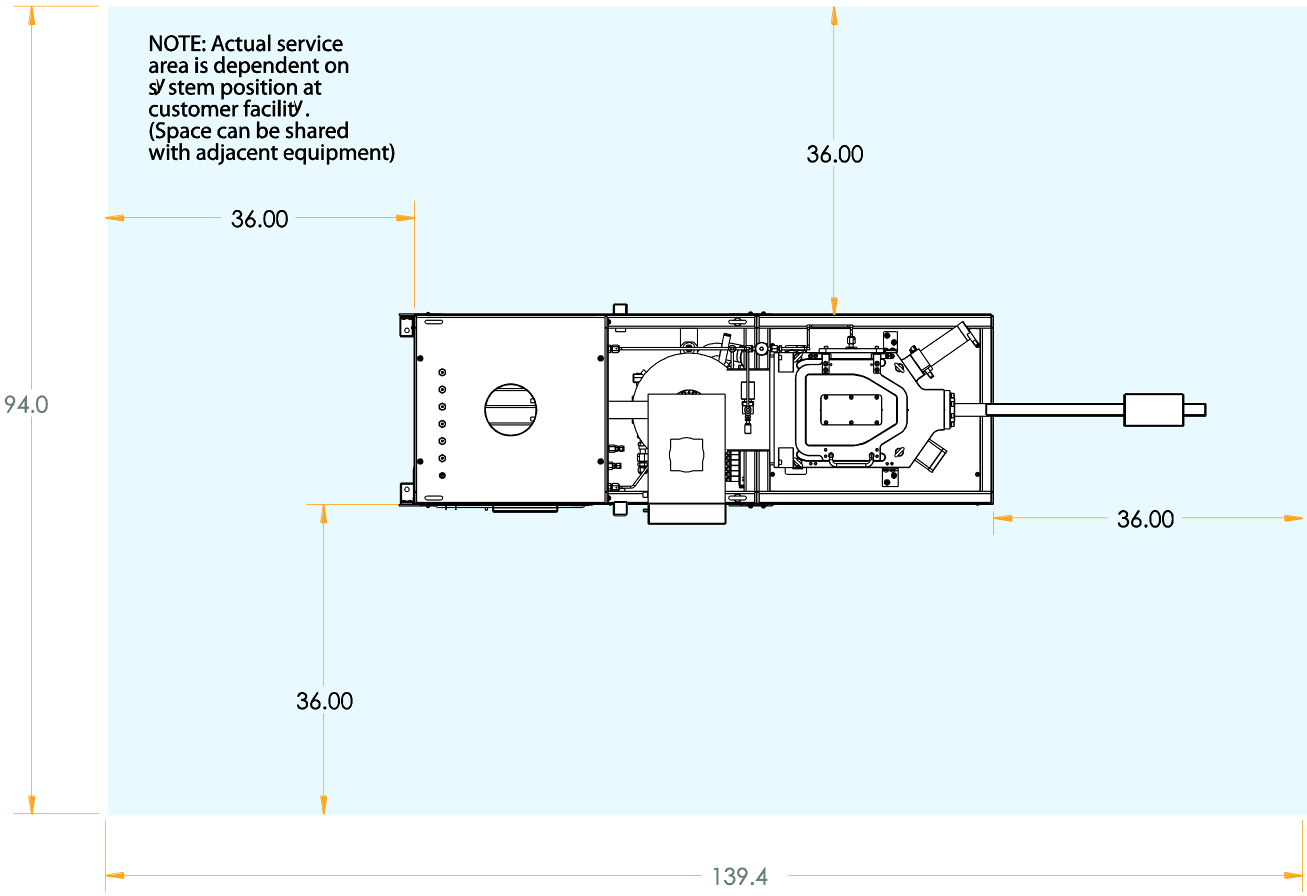


(shown with temporary machine installation wheels in place)

Fiji F200 - Detail A: Approx. Dimensions/Locations for Vacuum Pump Facility Connections

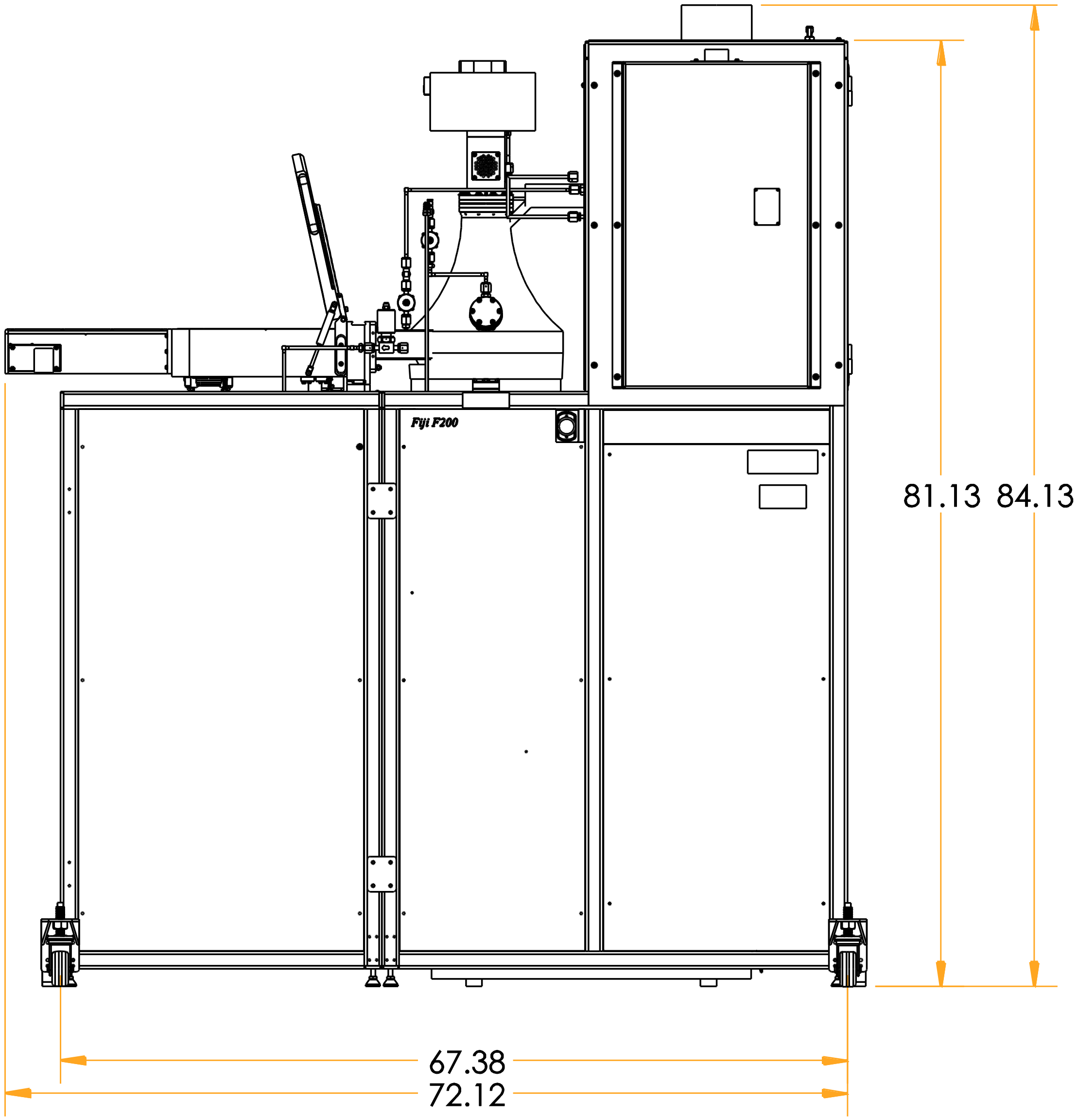


Fiji F200 System with VAT Load/Lock Push Loader: TOP VIEW

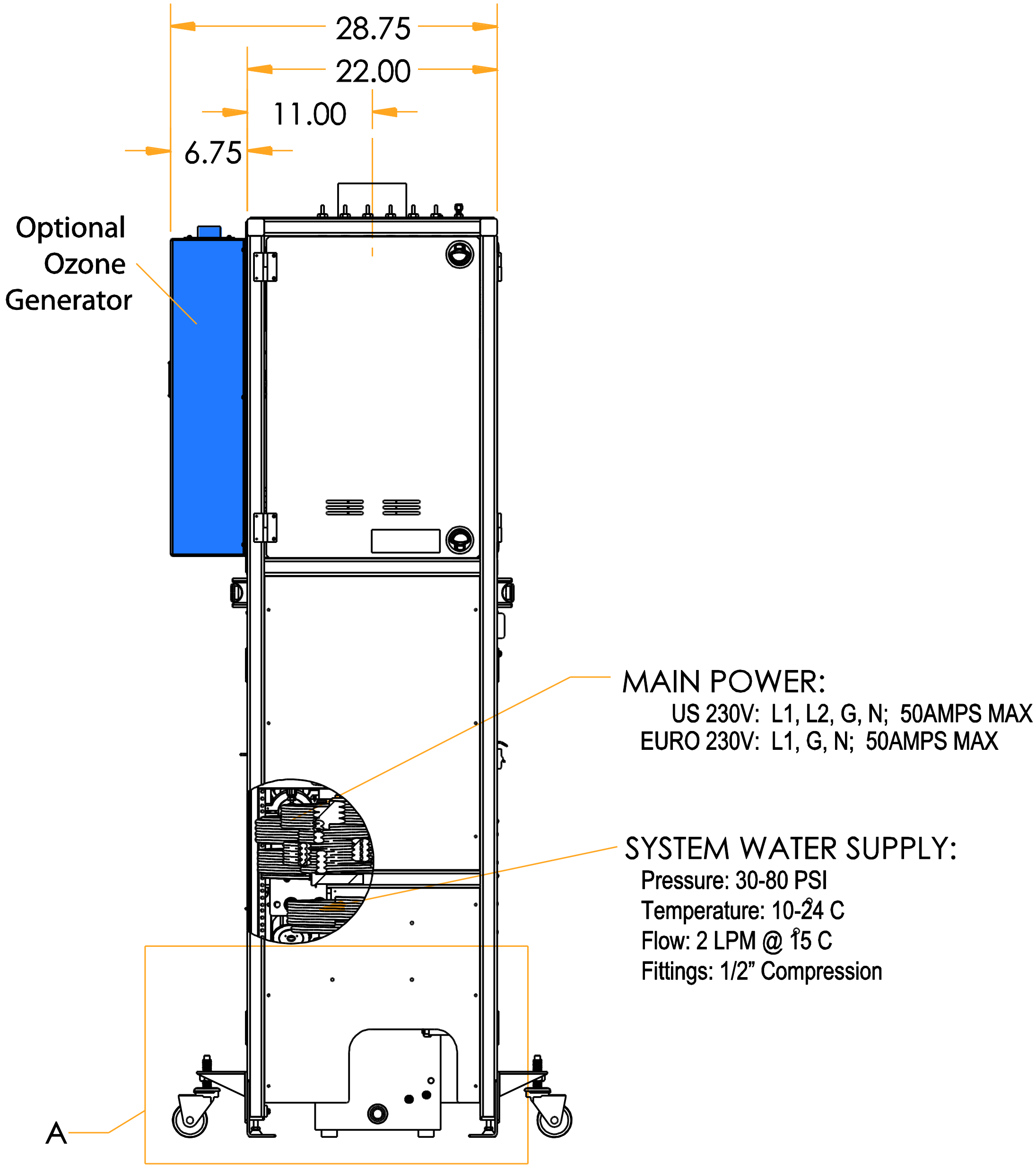


Fiji F200 System with VAT Load/Lock Push Loader: TYPICAL SERVICE SPACE

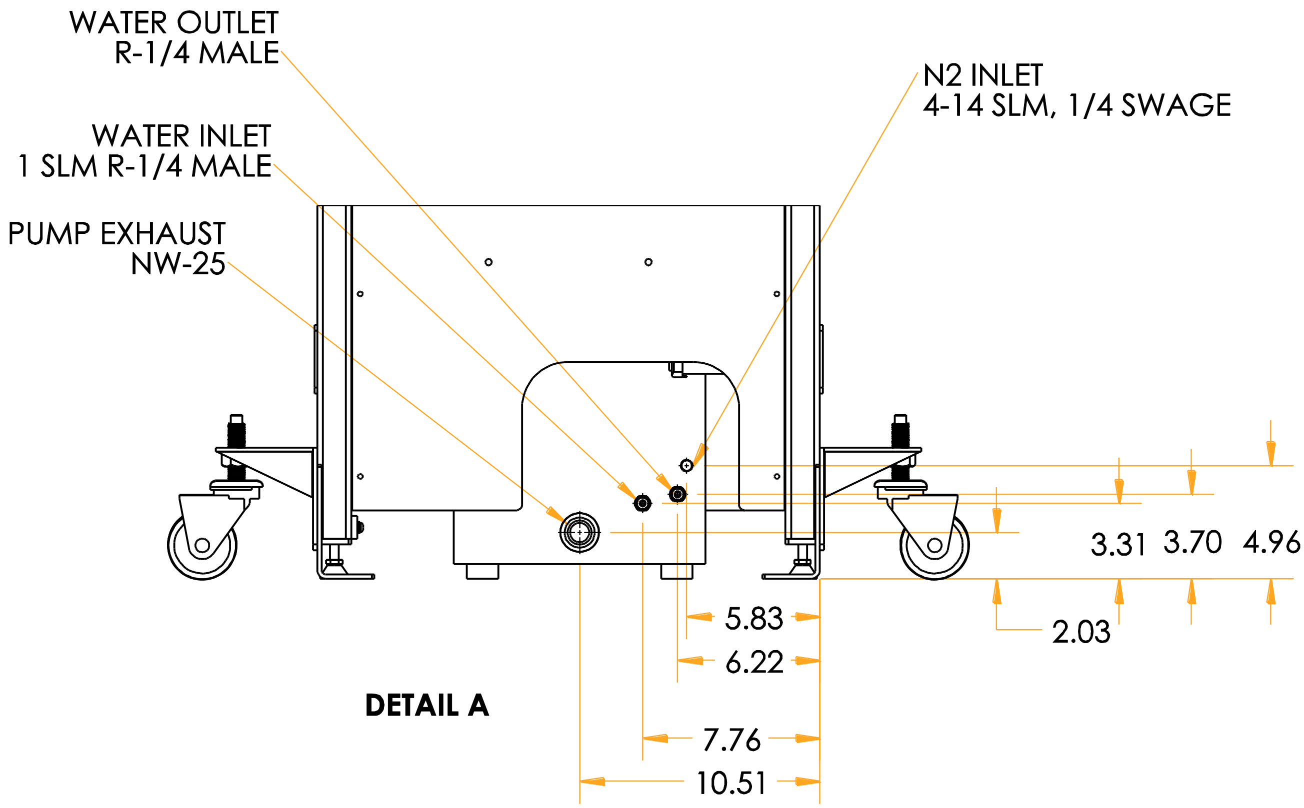
3. Fiji F200 System with Hine Loadlock



Fiji F200 System with Hine Load/Lock Auto-Loader: REAR VIEW (non-controls side)

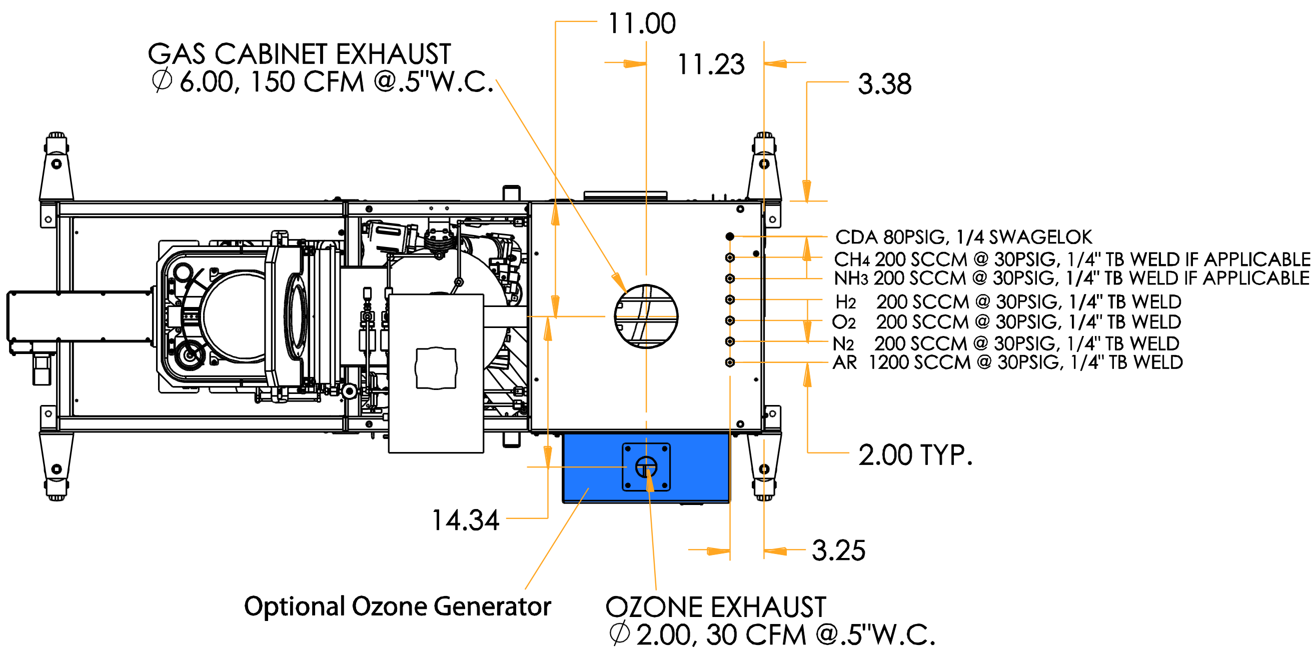


Fiji F200 System with Hine Load/Lock Auto-Loader: LEFT SIDE (PRECURSOR) VIEW

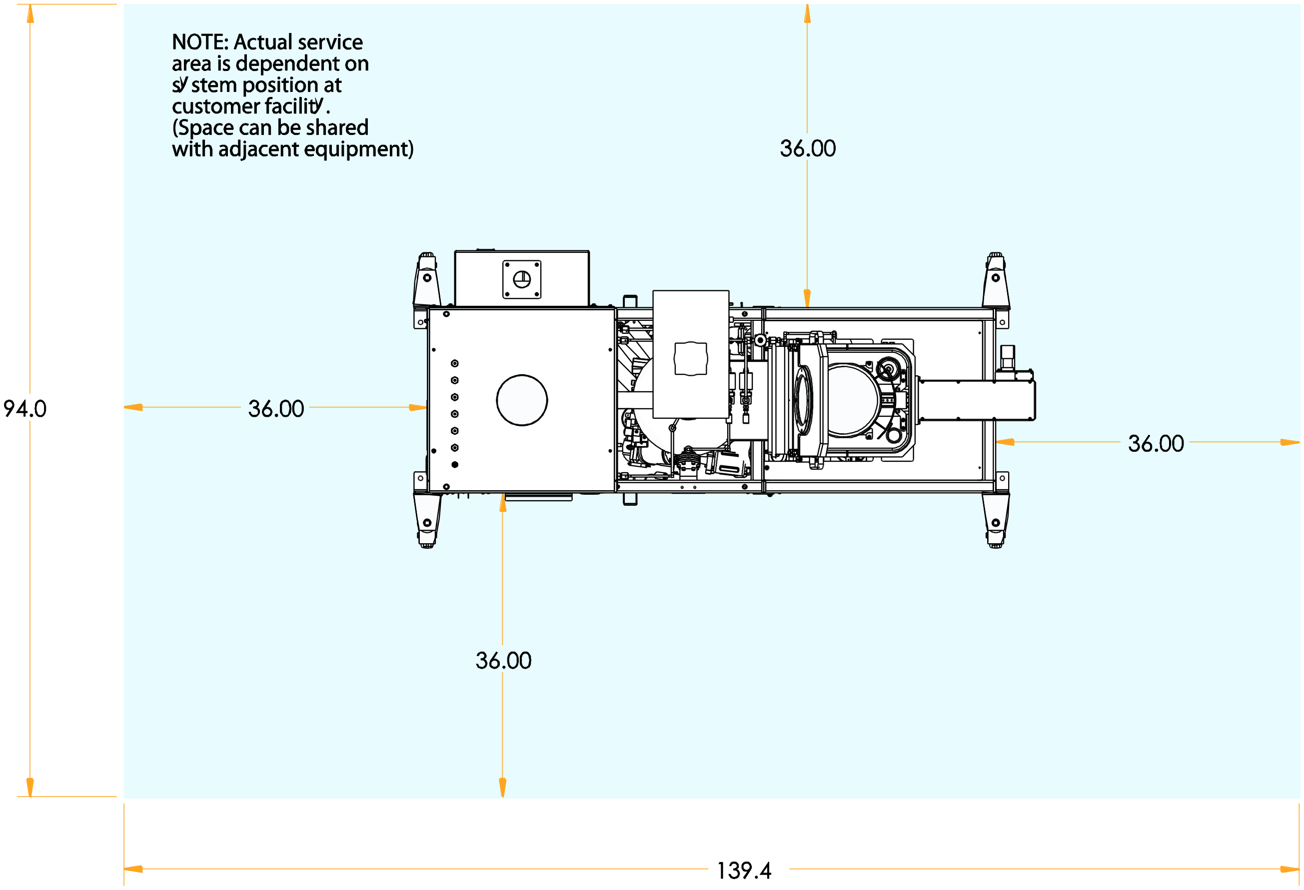


(shown with temporary machine installation wheels in place)

Fiji F200 - Detail A: Approx. Dimensions/Locations for Vacuum Pump Facility Connections



Fiji F200 System with Hine Load/Lock Auto-Loader: TOP VIEW



Fiji F200 System with Hine Load/Lock Auto-Loader: TYPICAL SERVICE SPACE

Safety Symbols

Symbol	Meaning
	**READ ALL INSTRUCTIONS BEFORE BEGINNING WORK!** Read all instructions and prepare all parts, tools, and safety equipment well in advance of performing a task. Contact Cambridge NanoTech with any questions.
	**SHOCK HAZARD** Voltage present. Take appropriate measures to protect yourself from electrical shock. The "lightning bolt within a triangle" symbol is used in and/or on the equipment to alert the user, operator, or service personnel to the presence of un-insulated voltage within the enclosure of sufficient magnitude to constitute a risk of electric shock. **Only authorized service personnel with a thorough knowledge of the voltages existing within the equipment shall remove covers or panels from the product bearing this symbol.** This symbol is also used within the product manual to identify important operating and/or maintenance instructions, which, if not followed carefully, could result in personal injury or death.
	**TOXIC MATERIAL HAZARD** This symbol is used in the product manual to identify sources of toxic gas materials. While the system is NOT shipped with any precursors or other gases, the customer and end-user must be aware of on-site gas usage and its resulting hazards.
	**RISK OF FIRE** The "flame within a triangle" symbol (reference IEC Publication 417, and ISO Publication 3864) is used in and or on the equipment to **alert the user, operator, or service personnel to the potential of fire hazard, including that caused by gases which may ignite upon contact with air (pyrophoric gases). Only authorized service personnel with a thorough knowledge of the gases existing within the equipment shall remove covers or panels from the product bearing this symbol.** This symbol is also used within the product manual itself to identify important operating and/or maintenance instructions, which, if not followed carefully, could result in personal injury or even death.
	**PINCH HAZARD** This symbol is used in the product manual to identify a pinch hazard such as a door, panel, fixture, or overall system handling which could cause a pinch or crushing hazard.
	**TOXIC MATERIAL HAZARD** This symbol is used in the product manual to identify sources of toxic gas materials. While the system is NOT shipped with any precursors or other gases, the customer and end-user must be aware of on-site gas usage and its resulting hazards.
	**CHEMICAL MATERIAL HAZARD** This symbol is used in the product manual to identify sources of chemical materials. While the system is NOT shipped with any precursors or other chemicals, chemicals are installed at the customer site and residual chemicals may exist in the system or system components. Always use care and wear appropriate personal protective clothing and equipment for the chemicals in use.

	**BURN HAZARD** This symbol is used in the product manual to identify sources of burn hazards. Do not touch hot surfaces! Allow the system components to properly cool before performing maintenance tasks or touching hot parts.
	**HEAVY/AWKWARD OBJECT LIFT HAZARD!** This symbol is used in the product manual to identify procedures where a minimum of two people are required to lift a heavy or unbalanced/awkward object.