OPERATION INSTRUCTION
TFS 200

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1 Operating instructions

1.1 General notes

1.1.1 Scope of this manual

The TFS 200 is designed to be a flexible ALD tool for research. It gives high freedom for the process engineer to adapt it to daily needs. The flow system is easy to change and it is possible to run many different types of recipes with TFS 200 system. The high freedom of using and modifying the TFS 200 system makes it possible to run this reactor even in undesirable mode. Thus, when changing the precursor tubing and recipe, the process engineer has to fully understand the operation of the system. This manual is built to be a handy set of information for the advanced user for getting a good understanding of the reactor operation and for getting the most out of TFS 200 features. Simple daily operations are described in the chapter "Brief operator instructions" of this manual.

1.2 Startup and shut down procedures/Emergency stop

1.2.1 Cold startup / Recovery from emergency stop

The cold startup procedure is the following:
-Check the overall condition of the system.
-Open any shutoff hand valves in the carrier gas, instrument gas, and process gas inlets if closed.
-Turn on the tool main switch located in the electric cabinet.
-Wait approximately 1-2 min, PLC starts.
-Start TFS 200 HMI on the computer, log in to TFS 200 HMI using the valid username and password.
-Acknowledge pop-up windows related to cold start. E-stop must be acknowledged by pressing **Ack Estop** button from HMI top header.

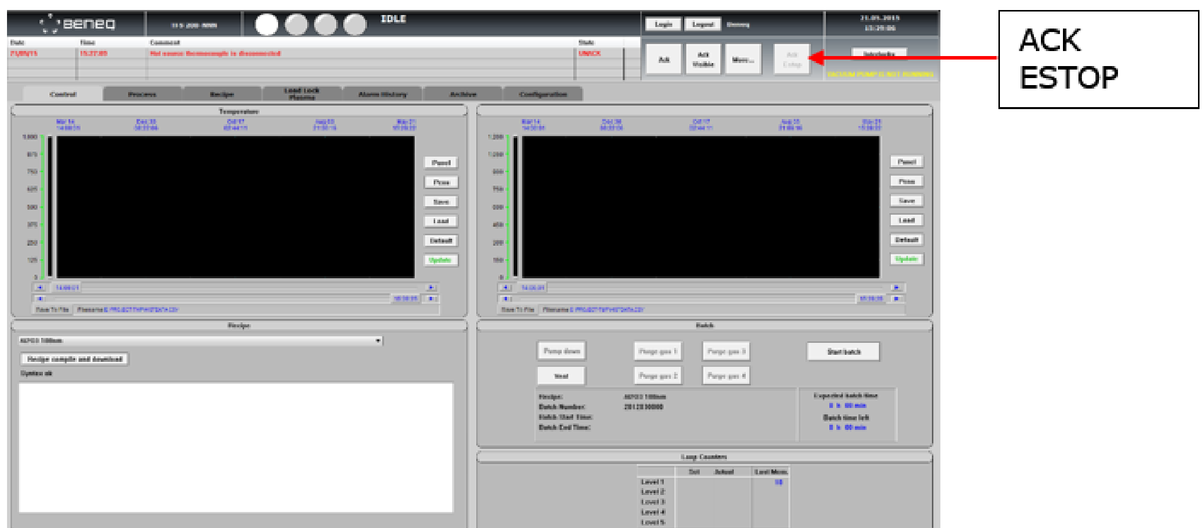

Figure: Control page of TFS 200 HMI

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-Open cooling water shutoff Hand valves if closed.
-When the emergency routine is performed and acknowledged, the system runs the startup routine automatically. The system runs the startup routine also when powered up.
-The system is on idle state and ready to run. Alarms can be cleared from the alarm window.

1.2.2 Shut down for a longer period of time

ALL PRECURSOR HAND VALVES SHOULD BE CLOSED AND CONTAINERS SHOULD BE REMOVED! RISK OF PRECURSOR LEAKAGE!

Shut down for a longer period of time can be done when the tool is left unattended for weeks.

Shut down procedure for a longer period of time, when the reactor is left in atmospheric pressure.
-Pump down the reactor using the pump down button in the control window.
-Remove all precursor containers based on the unloading procedure.
-Vent the reactor using the vent button in the control window.
-Close user interface quit any other programs and shut down the computer.
-If the system is equipped with other than a rotary vane vacuum pump, shut down the pump according to the pump user manual.
-Turn the power off from the main switch (all valves are closed, vacuum pump stops).
-Turn water and gas inlets off.

Shut down procedure for a longer period of time, when the reactor is left under the vacuum.
-Pump down the reactor using the pump down button in the control window.
-Remove all precursor containers based on the unloading procedure.
-Set all MFC flows to 0 sccm.
-Close nitrogen main valve and vacuum valves. Keep the reactor under vacuum condition.
-Close user interface quit any other programs and shut down the computer.
-If the system is equipped with other than a rotary vane vacuum pump, shut down the pump according to the pump user manual.
-Turn the power off from the main switch (all valves are closed, vacuum pump stops).
-Turn water and gas inlets off.

1.3 Brief operator instructions (manual operations, HMI)

REACTION CHAMBER AND VACUUM CHAMBER PARTS MIGHT BE HOT WHEN UNLOADING SUBSTRATES WITH TOP-LOADED REACTION CHAMBER! RISK OF BURN INJURIES!

DO NOT TOUCH ANY PARTS OF THE MACHINE THAT ARE >60 °C! RISK OF BURN INJURIES!

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For daily operation use the following procedures:

Preparation:
-Check the overall condition of the system.
-Check that the precursors are in the right positions.

Pumping down with top-loaded reaction chamber:
-Close the reaction chamber lid.
-Close the vacuum chamber lid.
-Run the pump down routine (by pressing the "Pump down" button in the control window).
-Check that the machine status is in the IDLE state after the pump down routine completed.

Pumping down with load lock:
With the load lock chamber installed, you can pump down either the load lock chamber (in normal operation) or the vacuum chamber (after maintenance) when the gate valve between the two chambers is closed. If the gate valve is open, both chambers will be in the same pressure; pumping down or venting one chamber affects the other chamber too. To pump down the vacuum chamber, follow the instructions of "Pumping down with top-loaded reaction chamber".

To pump down the load lock chamber:
-Close the load lock chamber lid.
-Make sure the substrate loader is pulled all the way back to home position.
-Make sure the gate valve is closed.
-Run the load lock pump down routine in the load lock window.
-Check that the machine status is in the IDLE state after the pump down routine completed.

HANDLE THE VACUUM AND LOAD LOCK CHAMBER LIDS WITH CARE WHEN OPENING AND CLOSING! RISK OF FINGER INJURY!

Loading/unloading the substrate (with the top-loaded reaction chamber):
-Run the vent routine if the reactor is under vacuum (by pressing the "Vent" button in the control window).
-Open the vacuum chamber lid.
-Open the reaction chamber lid.
-Unload and/or load the substrate in the reaction chamber.
-Close the reaction chamber lid.
-Close the vacuum chamber lid (and HS 500 hot source lid if present).
-Run the pump down routine (by pressing the "Pump down" button in the control window).

Loading the substrate through the load lock:
-Make sure that the vacuum chamber is in vacuum.
-The substrate carrier must be in the home position.

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-Vent the load lock from the load lock window.
-Open the load lock chamber lid.
-Load the substrate on the substrate carrier.
-Close the load lock chamber lid.
-Pump down the load lock chamber from the load lock window.
-Open the gate valve from the load lock window.
-Push the substrate carrier into the reaction chamber until it is in the front position.
-Lift substrate up by pressing the substrate lifter button. The button is lit when active.
-Pull back substrate carrier to home position.
-Lower substrate by pressing the substrate lifter button. The indication light of the button goes off.
-Close the reaction chamber for the process by pressing the substrate holder button. The button is lit when active.
-Close gate valve from the load lock window.

Unloading the substrate through the load lock
-Open the reaction chamber after the process by pressing the substrate holder button. The indication light of the button goes off.
-Check the loadlock is in vacuum condition.
-Open gate valve from the load lock window.
-Lift substrate up by pressing the substrate lifter button. The button is lit when active.
-Push the substrate carrier into the reaction chamber until it is in front position
-Lower substrate to the carrier by pressing the substrate lifter button. The indication light of the button goes off.
-Pull back substrate carrier to home position.
-Close gate valve from the load lock window.
-Vent the load lock from the load lock window.
-Open the load lock chamber lid.
-Unload the substrate.

Processing/Run recipe:
-Select and load the right recipe.
-Start the run (by pressing the "Start batch" button in the control window).
-Check that the temperature set values are right.
-Check that the pressure values are at the right level. To avoid precursor leaking from the reaction chamber to the vacuum chamber, the pressure of vacuum chamber should always be higher than the reaction chamber.
-Follow the instructions given by pop-up windows which are defined in the recipe, i.e. the substrate and precursor temperatures reach to setting points, hand valves of precursor containers are opened and etc.

1.4 Precursor delivery

RISK OF INJURY DUE TO HIGH PRESSURE FLUIDS AND GASES IN THE PRECURSOR LINES! SAFETY GOGGLES IS RECOMMENED DURING THE OPERATION.

In general, the precursor delivery can be described in several different ways, while the three most common ways are the following:

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- **Own vapor pressure**
  The precursor material is actually boiling when the pressure in the container is dropping during the pulse. This method is most common for materials with the vapor pressure of at least 10 mbar at source temperature.

- **Carrier gas assisted delivery**
  The carrier gas and pulse valves are opened simultaneously. The carrier gas flows through the precursor container making the flow of lower vapor pressure precursor more efficient.

- **Carrier gas assisted booster delivery**
  The carrier gas is first loaded into the container to increase the pressure inside the container. Then the pulse valve is opened to release the mixture of carrier gas and precursor vapor from the container. This is the most efficient way of delivering a low vapor pressure material from the container. This method should not be used for high vapor pressure materials since there is a risk of precursor flowing to the carrier gas feeding line.

1.5 Source loading and unloading procedures

PRECURSOR RESIDUALS MIGHT BE STILL PRESENT IN THE LINES! EXTRA PRECAUTIONS SHOULD BE TAKEN WHEN OPENING ANY CHEMISTRY LINES OF THE SYSTEM! PROPER PURGING OF THE LINES IS NEEDED!

RISK OF PRECURSOR LEAK DUE TO WRONG ASSEMBLY OF PRECURSOR CONTAINERS OR DURING INSTALLATION CONTAINER MIGHT FALL OVER CAUSING LEAK TO THE ATMOSPHERE!

1.5.1 Liquid source

Liquid precursor materials are packed into metal containers. Liquid precursor containers can be called “Liquid container with a single line” and “Liquid container with dual lines”. “Liquid container with a single line” has only one connection with ¼" VCR type metal fitting while the “Liquid container with dual lines” has two connections with ¼" VCR type metal fittings. For all liquid containers, the material filling is a ½” VCR fitting and the recommended maximum filling is 50% of the container capacity.

Liquid container with a single line
One hand valve is connected to the precursor outlet of the container.

PRECURSOR MATERIALS CAN BE DANGEROUS. PLEASE FOLLOW THE CHEMICAL RELATED MSDS (MATERIAL SAFEY DATA SHEET).

HANDLE THE CONTAINERS WITH CARE DURING THE LOADING AND UNLOADING PROCEDURES. ENSURE THE CONTAINER HAND VALVES ARE CLOSED!

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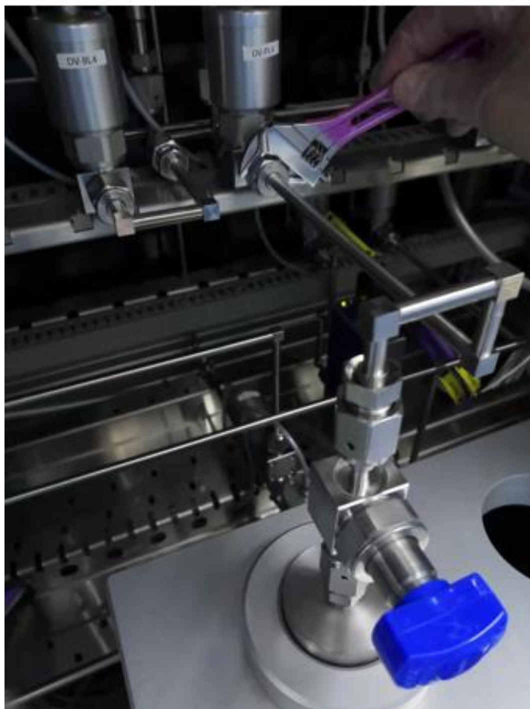
Single line container for H_2O	Single line container for TMA, DEZ, $TiCl_4$ etc.
	

Figure: Liquid container with a single line

<u>Container loading</u>

-Make sure that the container hand valve is closed.
-Remove the blind VCR caps from the container connectors and the TFS 200 feeding line. (It is recommended to have caps plugged on the TFS 200 feeding lines when source container is not in place.)
-Remove the used VCR gaskets.
-Place new VCR gaskets.
-Put the filled liquid source container to the right position in the aluminum support.
-Tighten the VCR fittings.
-Pump down the reactor into vacuum if not done already.
-Check that the machine is in an IDLE state.
-Leakage test VCR connections.
-Make sure the reaction chamber sealed well (there is the pressure difference between reaction and vacuum chambers).
-Run container loading routine from either “control page” or “precursor page” of TFS 200 HMI based on the position of the liquid container.

NOTE: if the container is already under the vacuum, it is not necessary to have Micropulsing in routine.

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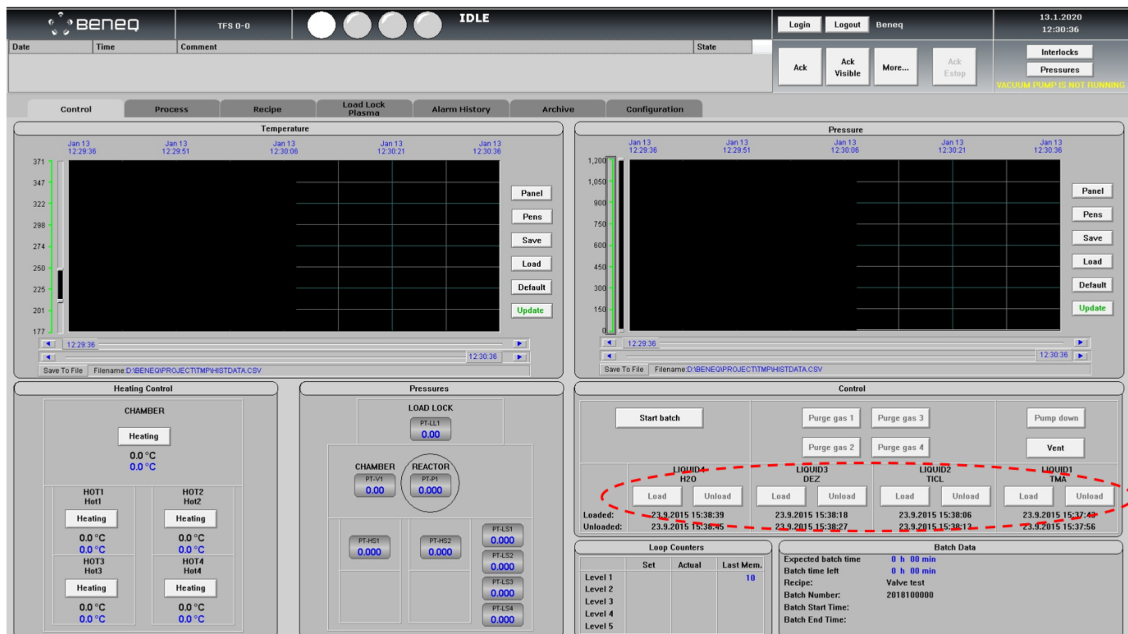

Figure: Control page of TFS 200 HMI

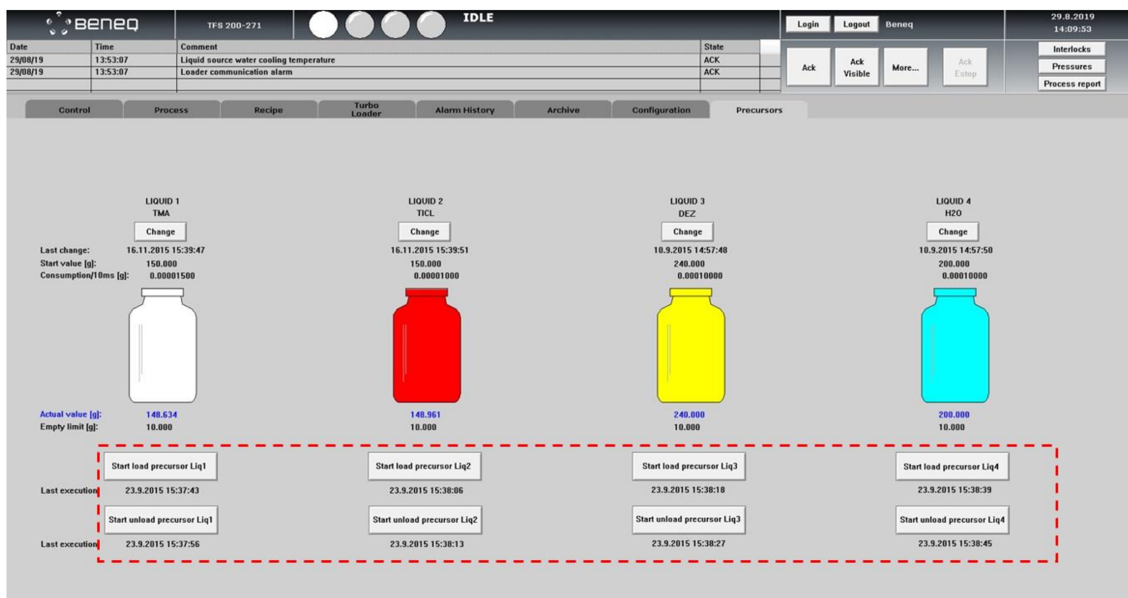

Figure: Precursor page of TFS 200 HMI

<u>Container unloading</u>

-Make sure that the container hand valve is closed.
-Pump down the reactor to vacuum if not done beforehand.
-Make sure the reaction chamber sealed well (there is the pressure difference between reaction and vacuum chambers).
-Run container unloading routine from either “control page” or “precursor page” of TFS 200 HMI based on the position of the liquid container.
-Open the VCR fitting between machine and container.
-Remove the container.
-Plug the open fittings on both machine and container with blind VCR caps.

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Liquid container with dual lines
Two hand valves are connected to the container, one to gas inlet and one to precursor outlet. Hand valves are connected to each other by a purge flow valve HV-SLx which is used only when the container is removed/installed.

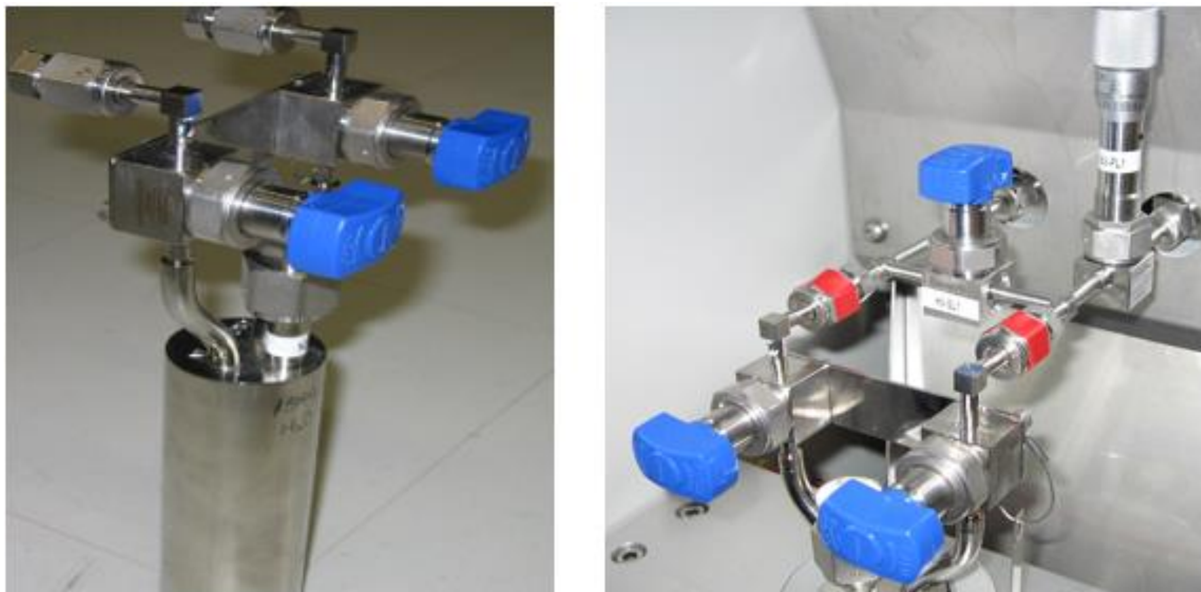

Figure: Liquid source precursor container (Left) and the connections to TFS 200 (Right). Red marks show the fittings that are opened and fastened when the container is removed and installed. The purge valve is in the middle.

<u>Container loading</u>
-Make sure that container hand valves are closed.
-Make sure that purge valve HV-SLx is in purge position (valve handle is in position open).
-Remove the blind VCR caps from the container connectors and the TFS 200 feeding line. (It is recommended to have caps plugged on the TFS 200 feeding lines when source container is not in place.)
-Remove the used VCR gaskets.
-Place new VCR gaskets.
-Put the filled liquid source container to the right position in the aluminum support.
-Tighten the VCR fittings.
-Pump down the reactor into vacuum if not done already.
-Fully open the needle valve (NV-PLx, where x is the liquid source number).
-Check that the machine is in an IDLE state.
-Leakage test VCR connections.
-Make sure the reaction chamber sealed well (there is the pressure difference between reaction and vacuum chambers).
-Run container loading routine from either "control page" or "precursor page" of TFS 200 HMI based on the position of the liquid container.
-Close the purge valve HV-SLx.
-Adjust back the needle valve setting.

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NOTE: if the container is already under the vacuum, it is not necessary to have Micropulsing in routine.

Container unloading
-Make sure that the container hand valve is closed.
-Pump down the reactor to vacuum if not done beforehand.
-Fully Open the needle valve (NV-PLx).
-Turn purge valve HV-SLx to purge position (valve handle position open).
-Make sure the reaction chamber sealed well (there is the pressure difference between reaction and vacuum chambers).
-Run container unloading routine from either “control page” or “precursor page” of TFS 200 HMI based on the position of the liquid container.
-Open the VCR fittings between machine and container.
-Remove the container.
-Plug the open fittings on both machine and container with blind VCR caps.

1.5.2 Hot source, HS 500

HOT SURFACES AT HOT SOURCE PARTS WHEN HEATING THEM UP ABOVE 100°C. RISK OF BURN INJURY!

PRECURSOR MATERIALS CAN BE DANGEROUS. PLEASE FOLLOW THE CHEMICAL RELATED MSDS (MATERIAL SAFEY DATA SHEET).

HANDLE THE CONTAINERS WITH CARE! DO NOT OVERHEAT PRECURSOR MATERIALS RISK OF UNCONTROLLED OVERPRESSURE BUILD UP IN THE CONTAINER!

Semi-inert hot source (solid source) HS 500 has the capability to operate at temperatures up to 500°C. This is possible because the pulsing is made by inert gas valving. On the other hand, it is not possible to load/unload this type of hot source without breaking the vacuum in the reactor.

This source type is designed to be used for very low vapor pressure materials. The precursor delivery method is always carrier gas assisted pulsing mode.

HS 500 source cartridge loading
-Run vent routine from TFS 200 HMI to increase the pressure in the vacuum chamber and HS 500 to atmospheric pressure.
-Fill the source cartridge (under glove box if needed).
-Open the source back flange and push the cartridge into the source tube.
-Close the back flange as far it goes without pressing the spring loaded hot source cartridge.
-Set MFC-NOP and MFC-NOV flow to 1000 sccm for purging the HS 500.
-Wait 1 minute.
-Set MFC-NOP and MFC-NOV flow to 300 sccm.

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-Push the back flange completely closed and lock it by pressing the handle gently.
-Pump down the reactor to vacuum

HS 500 source cartridge unloading
-Ensure that HS 500 is cooled down
-Run the vent routine from TFS 200 HMI to increase the pressure in the vacuum chamber and HS 500 to atmospheric pressure.
-Open the source back flange and pull out the used cartridge.

1.5.3 Hot source, HS 300

HOT SURFACES AT HOT SOURCE PARTS WHEN HEATING THEM UP ABOVE 100°C. RISK OF BURN INJURIES!

PRECURSOR MATERIALS CAN BE DANGEROUS. PLEASE FOLLOW THE CHEMICAL RELATED MSDS (MATERIAL SAFEY DATA SHEET).

HANDLE THE CONTAINERS WITH CARE! DO NOT OVERHEAT PRECURSOR MATERIALS RISK OF UNCONTROLLED OVERPRESSURE BUILD UP IN THE CONTAINER!

The HS 300 can be heated up to 300°C and is designed for liquid and solid precursor materials that need heating to reach sufficient vapor pressure. Precursor pulsing can be done using either material's own vapor pressure or different ways of carrier gas assisted pulsing. These methods are described in more detail in **Chapter 1.4**.

The recommended maximum filling of the precursor container is 150 ml. After precursor filling, the container pressure can be different compared to normal process pressure. As an example: if the precursor filling has been done at atmospheric pressure and the deposition process will be done at vacuum, the higher pressure from the container will cause higher flow into the reactor during the first pulses. This may cause reactor contamination.
To avoid this, please follow the procedure:
HS 300 container loading
-Make sure that container hand valves are closed.
-Remove the blind VCR caps from the container connectors and the TFS 200 feeding lines. (It is recommended to have caps plugged on the TFS 200 feeding lines when source container is not in place.)
-Remove the used VCR gaskets.
-Place new VCR gaskets.
-Put the filled HS 300 container to the right position.
-Tighten the VCR fittings.
-Pump down the reactor into vacuum if not done already.
-Check that machine is in IDLE state
-Leakage test VCR connection.
-Make sure the reaction chamber sealed well (there is the pressure difference between reaction and vacuum chambers).

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-Run source loading recipe of the HS 300 container. If it can not be found in the recipe list, please contact Beneq. An example is shown below,

----

```
*Recipe Loading Hot source 1 Precursor
*Recipe for purging hot source 1 line after attaching the container to the machine
*Based on flow chart N502400
*Program start
        SPROG
*Open the N2 main valve and chamber flow valve and make sure filling valve is closed
        OPEN DV-SN1,DV-NV2
        CLOSE DV-NV1
*Check the vacuum level
        WUNTIL PT-P1<10 10s
*Open main vacuum valve
        OPEN DV-VP1
*Set flows
        FLOW MFC-NOVS=300
        FLOW MFC-NOPS=600
*Close pulse valves
        CLOSE DV-PL1,DV-BL1
        CLOSE DV-PL2,DV-BL2
        CLOSE DV-PL3,DV-BL3
        CLOSE DV-PL4,DV-BL4
        CLOSE DV-PH1,DV-BH1,DV-BHA1
        CLOSE DV-PH2,DV-BH2,DV-BHA2
        CLOSE DV-PH3,DV-BH3,DV-BHA3
*Close process gas valves
        CLOSE DV-PN1,DV-PN2
        CLOSE DV-PG1,DV-PG2
        CLOSE DV-PG6,DV-PG7,DV-PG8
        CLOSE DV-PG1C,DV-SG02,DV-PG6C,DV-PG7C
*close precursor hand valves
        WRITE M7
        WUSER YES
*confirm that all precursor hand valves are closed
        WRITE M22
        WUSER YES
*Purge hot source 1 line
        OPEN DV-PH1,DV-BH1
        WTIME 1min
        REPEAT 8
                PULSE DV-BHA1 10s
                WTIME 2min
        REND
        CLOSE DV-PH1,DV-BH1
*Prepare for processing
        WRITE M6
        WUSER YES
*mircopulsing to evacuate canister
        REPEAT 80
                PULSE DV-PH1 50ms
                WTIME 1s
        REND
        REPEAT 100
                PULSE DV-PH1 100ms
                WTIME 1s
        REND
*close precursor hand valves
        WRITE M7
```


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WUSER YES
**Purge hot source 1 line again*
OPEN DV-PH1,DV-BH1
WTIME 1min
CLOSE DV-PH1,DV-BH1
**end program*
EPROG

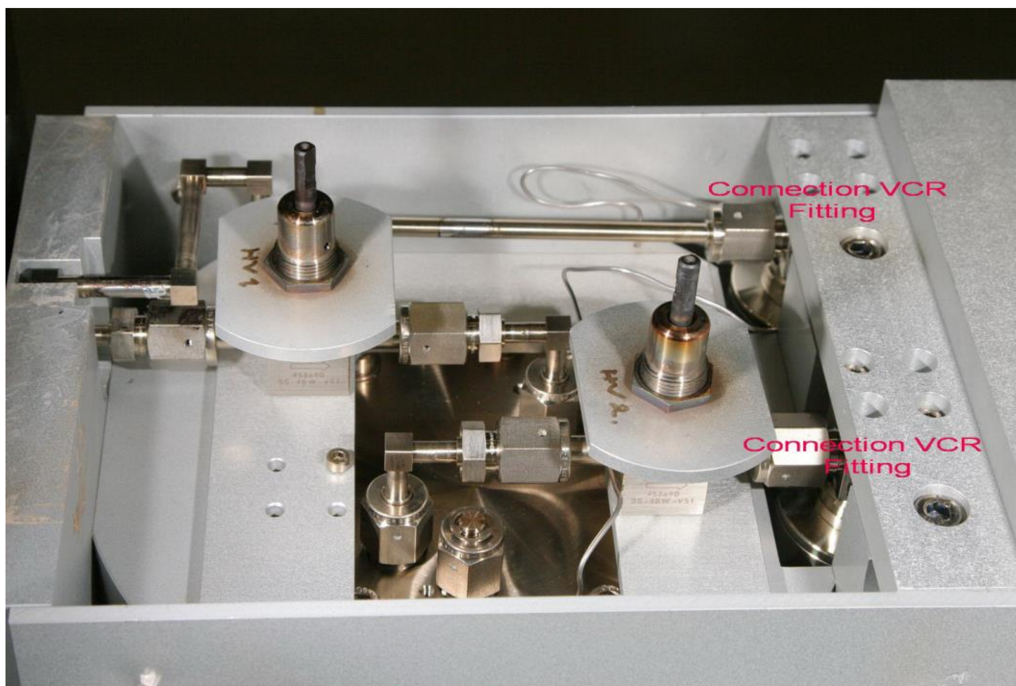

Figure: HS 300 container with the feeling lines. Red marks show the fittings that are opened and fastened when the container is removed and installed.

NOTE: Preferably use metal (copper) seals in the top flange. If using polymer seals, make sure seal material is compatible with the chemical and the temperature used. A new container is always filled with Air. Please open the container before transferring it into the glove box for chemical filling.

HS 300 container unloading
-Ensure that HS 300 is cooled down.
-Make sure that the container hand valve is closed.
-Pump down the reactor into vacuum if not done beforehand.
-Make sure the reaction chamber sealed well (there is the pressure difference between reaction and vacuum chambers).
-Run source unloading recipe of the HS 300 container. If it can not be found in the recipe list, please contact Beneq. An example is shown below,

---

**Recipe Unloading Hot source 1 Precursor*
**Recipe for purging hot source 1 line after detaching container from the machine*
**Based on flow chart N502400*
**Program start*
SPROG
**Open the N2 main valve and chamber flow valve and make sure filling valve is closed*
OPEN DV-SN1,DV-NV2

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```
          CLOSE DV-NV1
*Check the vacuum level
          WUNTIL PT-P1<10 10s
*Open main vacuum valve
          OPEN DV-VP1
*Set flows
          FLOW MFC-NOVS=300
          FLOW MFC-NOPS=600
*Close pulse valves
          CLOSE DV-PL1,DV-BL1
          CLOSE DV-PL2,DV-BL2
          CLOSE DV-PL3,DV-BL3
          CLOSE DV-PL4,DV-BL4
          CLOSE DV-PH1,DV-BH1,DV-BHA1
          CLOSE DV-PH2,DV-BH2,DV-BHA2
          CLOSE DV-PH3,DV-BH3,DV-BHA3
*Close process gas valves
          CLOSE DV-PN1,DV-PN2
          CLOSE DV-PG1,DV-PG2
          CLOSE DV-PG6,DV-PG7,DV-PG8
          CLOSE DV-PG1C,DV-SG02,DV-PG6C,DV-PG7C
*close precursor hand valves
          WRITE M7
          WUSER YES
*confirm that all precursor hand valves are closed
          WRITE M22
          WUSER YES
*Purge hot source 1 line
          OPEN DV-PH1,DV-BH1
          WTIME 1min
          REPEAT 8
                    PULSE DV-BHA1 10s
                    WTIME 2min
          REND
          CLOSE DV-PH1,DV-BH1
*end program
          EPROG
```

-Open the two VCR fittings between machine and container.
-Remove the container.
-Plug the open fittings on both machine and container with blind VCR caps.

NOTE: Always make sure you are not overheating the precursor in the container. Some precursors may contain for example water or other volatile components that may be released during heating. This kind of precursors may generate overpressure in the container when it is heated. Use pure chemicals and monitor the pressure build-up during the first heating. The risk of uncontrolled pressure builds up in the container! Risk of damaging the source and uncontrolled precursor release!

1.6 Source adjustments

The TFS 200 ALD system has three main types of sources; gas, liquid (cold) and hot sources. For hot sources, there are two different source constructions, HS 300 and HS 500.

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1.6.1 The gas lines

RISK OF TOXIC AND FLAMMABLE GAS LEAK TO THE ROOM ATHMOSPERE! EXTRA PRECONSCIOUS STEPS SHOULD BE TAKEN ACCORDING TO MSDS, LOCAL LAW, HEALTH AND SAFETY REGULATIONS!

RISK OF NON-COMPATIBLE REACTIVE GASES TO BE SWITCHED ON SIMULTANEOUSLY DURING PROCESS!

The TFS 200 is equipt with gas lines for both thermal and plasma ALD operation as shown in the figure below. For thermal ALD operation, the gas lines are not equipped with mass flow controllers (MFC) for each gas line and usually the MFC controlled gas lines are used for plasma gases that are not pulsed during the deposition. Plasma gas lines are equipped with a pressure switch which prevents the pulsing valves to be operated in case that the plasma gas feeding line is not under vacuum.

The precursors from the gas sources are delivered to the reactor by all-welded ¼" SS tubes. The VCR type connection point is inside the machine frame.There is a pulsing valve in the gas line, which leads the gas into the feeding line. The gas flow is restricted with a flow orifice, which is located in the inlet connector of the pulsing valve. The feeding lines of gas lines can be grouped in different ways. Plasma gases are mixed to a common feeding line which goes to the plasma electrode through the top lid of the vacuum chamber. Gas lines for thermal ALD are grouped into up to 3 separate feeding lines, which all have separate inlet connectors at the bottom of the vacuum chamber.

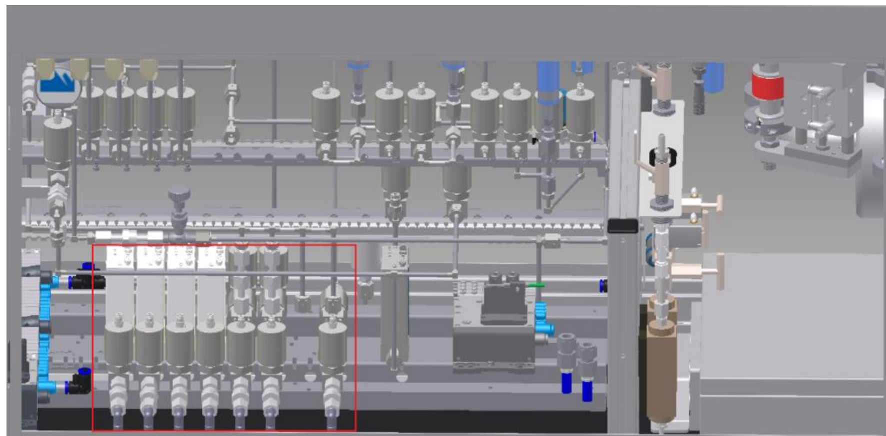

Figure: The area marked with red, starting from the left side it shows four Plasma lines equipped with MFCs, two flammable/toxic gas lines and a normal gas line.

Both thermal and plasma gas lines can be further separated into two types: a) Normal gas line and b) Flammable/toxic gas line. The normal gas line is usually used for gasses such as N_2, O_2, H_2 and the flammable/toxic line is used for gasses such as NH_3, H_2S, WF_6 and more. For both types, software interlocks are used in cases of non-combatible gasses which doesn’t allow the operation of the pulsing valves at the same time. Both types of gas lines include line filters, inlet check valves for

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preventing flow from the TFS 200 to the facility system in a fault situation, pusling vavles and orifices for flow adjustment. The flammable/toxic gas line is equipted with more safety features such as double interlock valves on the gas supply, double interlock pressure switches on the vacuum chamber for vacuum level monitoring and interlocked to material feeding valves, check vavles on the purging line for preventing the gas flowing back to the nitrogen line.

1.6.2 The Ozone source

RISK OF OZONE LEAK TO THE ROOM ATMOSPHERE DUE TO LEAKING FEEDING TUBES, OZONE DESTRUCTOR DOES NOT WORK PROPERLY!

RISK OF OZONE RESIDUALS PRESENT IN THE VENTILATION LINE! EXTRA PRECONSCIOUS STEPS SHOULD BE TAKEN ACCORDING TO MSDS, LOCAL LAW, HEALTH AND SAFETY REGULATIONS!

The ozone source is enclosed within a ventilation cabinet as shown in the figure below. Oxygen is fed into the ozone generator which generates the ozone to be used for the ALD process. Due to the short limiting lifetime of ozone, there are both inlet and outlet connections for the ozone line. This allows ozone to circulate through the source tubes. During pulsing, the pulse valve will take enough material from the circulation.

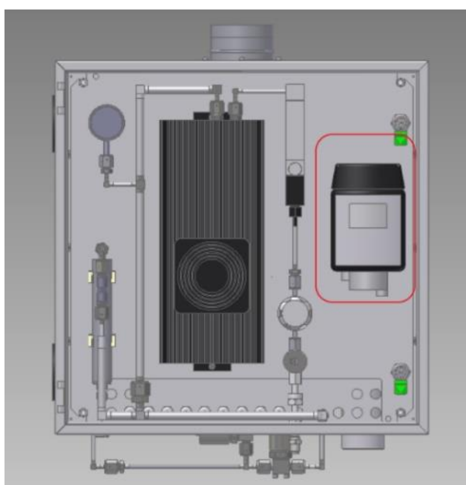

Figure: Ozone source cabinet

An ozone destructor is included in the source tube for destroying the bypass flow of ozone and sending the residual O_2 by-product to the facilitie's ventilation line. In addition, the ozone cabinet is equipt with an ozone detector which is used to trigger an alarm in case of ozone leakage caused within the ozone cabinet. A fatal alarm would be triggered if the level detected by the ozone sensor is above a preset value which will automatically close all process valves.

After the chemical reactions within the Reaction Chamber, excess gasess flow through the exhaust line to the pump and then to the facilitie's ventilation line. There

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is a possible risk that ozone residuals may enter the ventilation line and in this case an ozone destroyer should be installed in the ventilation line of factory to eliminate this risk.

1.6.3 The liquid sources

RISK OF PRECURSOR LEAK TO THE ATMOSPHERE DUE TO VERY HIGH PRESSURE OF N2 CARRIER GAS! FEEDING N2 WITH HIGH PRESSURE IN THE CONTAINER MIGHT CAUSE LEAKING OF THE PRECURSOR!

The liquid sources are designed for precursor materials that have enough vapor pressure at room temperature for vacuum processing. The source containers are located in a temperature-stabilized aluminum block. Normally the temperature is adjusted to about 19-20°C for ensuring that the vapor pressure does not change according to room temperature changes. Furthermore, the lower source temperature minimizes the risk of condensation in the tubing between the source material container and the reactor. The temperature is kept constant either by a separate chiller (option) or other sources of cold water. The cooling liquid is circulating inside the aluminum block.

The most common way to use this kind of high vapor pressure source is "pulsing by own vapor pressure". In this case, the precursor vapor pressure is higher than the pressure in the reaction chamber feeding tube. By opening the pulsing valve of the liquid source (DV-PLx, x is the number of sources), the precursor vapor flows into the reaction chamber. The needle valve (NV-PLx) or orifice is used to adjust the flow to the right dosage level. The dose is also affected by pulse time and source temperature.

If the precursor vapor pressure is not significantly greater than the feeding tube pressure, it is possible to run this source in the "carrier gas assisted delivery" mode. In this case, both container valves of DV-PLx and DV-BLx are opened simultaneously, and thus the carrier gas is mixed with the precursor material. The dose is dependent on the precursor vapor pressure, the total pressure of the container, reaction chamber feeding tube pressure and the carrier gas flow rate. Precursor vapor pressure is a physical value depending on source temperature. Flow is adjusted by the mass flow controller and the overall pressure of the container can be adjusted by the needle valve. Reaction chamber feeding tube pressure is dependent on all MFC flow rates. This means that the dosing can be increased by opening the needle valve or increasing the MFC flow rate. The dose is also affected by pulse time and source temperature.

If the precursor vapor pressure is significantly lower than system pressure, the “Carrier gas assisted booster delivery” mode can be used. This delivery type is based on two steps: a) increasing the container pressure by pulsing nitrogen through the DV-BLx valve and b) pulsing the mixture of carrier gas and precursor into the chamber by opening the DV-PLx valve.

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1.6.4 The hot sources

RISK OF BURN INJURIES! HOT SOURCES AND SARROUNDING PARTS MIGHT BE HOT! USE PROTECTIVE HEAT SHIELD WHEN OPERATING!

RISK OF UNCONTROLLED PRECURSOR FLOW DUE TO OVERHEAT OF PRECURSOR MATERIAL TO THE TEMPERATURES WHERE ITS VAPOR PRESSURE EXCEEDS REACTOR PRESSURE!

RISK OF PRECURSOR LEAK TO THE ATMOSPHERE DUE TO VERY HIGH PRESSURE OF N2 CARRIER GAS! FEEDING N2 WITH HIGH PRESSURE IN THE CONTAINER MIGHT CAUSE LEAKING OF THE PRECURSOR!

There are two types of hot sources: HS 300 and HS 500.

Hot source HS 500
This hot source type utilizes the most commonly used and robust technology for reaching high source temperature. This is mainly needed for materials with low vapor pressure (most of them are solid). The flow system is always the "purge assisted" type. The inert carrier gas flows are used to prevent leakage from hot source volume to the reaction chamber volume (and vice versa) between pulses. The dosing can be adjusted by changing precursor vapor pressure (Source temperature change), by changing the carrier gas flow rate and by changing the pulse time.

Hot source HS 300
When the precursor material needs moderate heating, it is possible to use this hot source type. The flow system is very similar to the liquid source and the delivery methods can be found in **Chapter 1.4**. The source can be heated up to 300°C. It is designed for both liquid and solid precursor materials.

When using this source type in "own vapor pressure” mode, the temperature should be high enough to get precursor vapor pressure above the system pressure. There are no adjustable needle valves integrated into the hot source. This means that the pressure should be only slightly above the system pressure for minimizing the overdose of precursors. The dose can be adjusted by pulse time and source temperature.

Using “carrier gas assisted booster delivery” mode, the chemical decomposition of the low vapor pressure precursors can be avoided. This type of delivery mode can be done by pulsing the carrier gas valve to increase the container pressure and then by opening the pulsing valve to release the carrier gas and precursor mixture to the reaction chamber. The dose of the precursor can be adjusted by changing the precursor temperature or by changing the length of the carrier gas/precursor pulse. Typically, the carrier gas/precursor pulse ratio is kept constant. The relatively long time is often needed to generate enough pressure in the container.

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For example:
100 sccm carrier gas flowing into a hot source container with the free volume of 500cc needs 3 seconds to create an additional 10 mbar pressure in the container.
*100sccm*3s/500cc = 100bar*cc/60s*3s/500cc=0.01bar=10mbar*

NOTE: The dosing depends on the system pressure (pressure in tubes leading the precursor to the reaction chamber). Any changes in this will affect the precursor flow from all sources. In most of the cases, small system pressure changes are acceptable. However, if the system pressure and precursor vapor pressure are close to each other, even a small change in either system pressure or precursor pressure has a dramatic influence on the dose.

1.7 Description of the flow system

RISK OF SUFFICATION CAUSED BY LEAKING OF THE INERT GAS TO THE ROOM ATMOSPHERE! THIS COULD BE DUE TO CONSTANT LEAKING FROM THE N2 SUPPLY LINE OR VACUUM CHAMBER LID IS OPEN AND N2 VAVLE IS KEPT OPEN!

NOTE: As part of the TFS 200 delivery, a PI-diagram has been provided to you. See PI-diagram of your system configuration follow the description of the flow system.

TFS 200 is designed to use nitrogen or argon as the carrier gas, inert gas valving gas and purge gas. The instrumentation (pneumatic valves) and pump gas ballast are using nitrogen or dry compressed air. The process and instrumentation gases have separate inlets. This allows using higher purity gas as a process gas and less pure (less expensive) gas for instrumentation. It is also possible to use the same gas for both purposes. Liquid sources and vacuum chamber are cooled by the cooling system.

1.7.1 The process gas flows

INERT GAS LEAK MAY CAUSE OXYGEN REMOVAL FROM THE ROOM ATMOSPERE! EXTRA PRECONSCIOUS STEPS SHOULD BE TAKEN ACCORDING TO MSDS, LOCAL LAW, HEALTH AND SAFETY REGULATIONS!

In the process gas line, there is a filter prior to the main gas valve DV-SN1 followed by a pressure gauge for visual inspection and monitoring of proper inlet pressure. Then gas is divided into two separate lines by two Mass Flow Controllers (MFC's) and both lines are separated by check valves.

MFC-NOV controls the flow, which is used for filling the vacuum chamber. The purpose of this flow is to keep the pressure in the vacuum chamber higher than the pressure in the reaction chamber. This prevents the precursor escaping from the reaction chamber to the vacuum chamber. There is also a by-pass line equipped with DV-NV1, which is used to fill the vacuum chamber faster than MFC would allow during venting. Filling gas for an optional load lock is also taken from the carrier gas line

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by-passing the MFC. This flow is controlled by a diaphragm valve DV-NLL, a needle valve and an orifice CA-NLL.

MFC-NOP controls the flow, which is used as the carrier gas and inert gas valving gas for each source. Each liquid source and hot source have their own carrier gas feeding lines after the MFC-NOP. The gas lines are grouped with up to 3 different feeding lines, each with its own connection for carrier gas after MFC-NOP. Flows are divided by orifices (CA-XX in the PI-diagram) after the MFC. Inert gas valving flow for gas and liquid sources are also separated from the carrier gas line by an orifice (CA-I). Hot sources also have their own inert gas feeding lines separated from the carrier gas line by orifices.

Liquid/gas source

Pulsing precursor from gas or liquid source with "own vapor pressure" mode can be done by opening the valve DV-PGx/DV-PLx. The flow can be adjusted by the relevant needle valve or orifice. The carrier/purge gas is controlled by DV-BLx and DV-PNx valves for liquid and gas sources, respectively. The inert gas valving system is built in the gas mixing unit inside the vacuum chamber and controlled by the orifices CA-Ix and CA-Dx. During the purge stage, the purge gas flows through CA-Ix and it divides into two flows. One goes through the reaction chamber to the pump line. The other flow goes through the path with CA-Dx to the drain. These flows will create inert gas valving between the reaction chamber and precursor inlet. During the pulse stage, the fraction of the precursor flow is wasted via orifice CA-Dx, but the main flow goes through the reaction chamber. A minor part of the purge gas flow is still going through CA-Ix for preventing precursors from going into that line.

Hot sources

In the hot source HS 300/500, the inert gas valving system is controlled by the orifices CA-IHx and CA-DHx. During the purge stage, the purge gas flows through CA-IHx and it divides into two flows. One goes through the reaction chamber to the pump line. The other flow goes through the path with CA-Dx to the drain. These flows will create inert gas valving between the reaction chamber and precursor inlet. During pulsing, the fraction of the flow is wasted to the drain through capillary CA-DHx, but the main flow goes through the reaction chamber. Some of the nitrogen/argon flow is still going through CA-IHx to prevent precursors from going into that line.

NOTE: The hot sources have their own inert gas valving separate to the inert gas valving of liquid/gas sources. When dual versions of HS 300 are used, two HS 300 containers will share a common feeding line, the material compatibility has to be checked.

Gas mixing

NON-COMPATIBLE PRECURSOR MIXTURE SHOULD BE AVOIDED! READ CAREFULLY MSDS BEFORE MATERIAL USE!

Gases from all precursor sources are mixed together before entering the reaction chamber. It is often called the "Gas Mixing Unit" or "Gas Delivery Unit". The flows

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from gas and liquid sources are mixed together at a lower level of the unit. The flows from hot sources are mixed into the upper level of the unit.

Vacuum chamber flow
The mass flow controller MFC-NOV is used for carrier gas flow straight to the vacuum chamber. This flow is used for adjusting the pressure in the vacuum chamber and for vacuum chamber filling (venting).

In the vacuum chamber, the fittings and connections of the process tubing and reaction chamber are not fully sealed mechanically. For preventing the precursor leakage, the controlled flow in intermediate volume (volume between the vacuum chamber and the reaction chamber and process tubing) has to be taken into account. The MFC-NOV has been designed for this purpose. The sealing tightness can be done by building up a pressure difference between vacuum and reaction chambers. To monitor this pressure difference, the pressure gage of PT-P1 (monitoring the pressure of the vacuum chamber) and PT-P1 (monitoring the pressure of the reaction chamber outlet) are needed.

1.7.2 Gas flows for the instrumentation

The instrumentation flow can be switched on by hand valve HV-N2. This flow goes to the pneumatic block operating the pneumatic valves.
One of the ports in the block is connected to the vacuum pump gas ballast connection through a rotameter NV-NP1 and check valve CV-P01.

1.7.3 The vacuum system

RISK OF INJURY DUE TO SUCTION FROM THE VACUUM PUMP! IF VACUUM CONNECTIONS MUST BE OPENED, THE TOOL MUST BE IN ATMOSPHERIC PRESSURE AND WITH THE VACUUM VALVE CLOSED.

For the vacuum chamber, there are two valves related to the pump system. DV-VP1 is the main valve for pumping during processing. DV-VP2 is a soft start valve for a smooth pump down. The system is equipped with a minimum of two pressure transducers which are PT-P1 for the reaction chamber outlet and PT-V1 for the vacuum chamber.

For the load lock chamber, the soft-start valve DV-VLL2 and the main valve DV-VLL1 are used during the pump down. The pressure transducer PT-LL1 is used to monitor the pressure of the load lock chamber.

There is a gate valve (GV-V1) between the load lock and the vacuum chamber. It is possible to load and unload the substrates through the gate valve without breaking the vacuum in the vacuum chamber.

1.8 Flow chart symbols

1.8.1 Key components names

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The PI diagram component code format is XXX-YZZ.

First 1-3 digits (XXX) describe the component type:
Valves
- Diaphragm valves (DV)
- Solenoid valve (SV)
- Needle valves (NV)
- Hand valves (HV)
- Axial valves (AV)
- Gate valves (GV)
- Relief valves (RV)
- Check valves (CV)

Mass flow controllers (MFC)
Flow indicators (FI)
Orifices / Capillaries (CA)
Thermoelements (TE)
Heaters (H)
Pressure transducers (PT)
Switches (S)
Filters (FI)

The letter Y describes the component "function":
P=Pulsing flow
B=Bubbler flow
N=Nitrogen/argon flow
W=Water flow
V=Vacuum flow
I=Inert gas valving
D=Drain for inert gas flow
M=Maintenance
E=Exhaust
S=Supply

The letters ZZ describe the component location
G=Gas source
L=Liquid source
H=Hot source
V=Vacuum chamber
LL=Load lock
P=Pump
R=Reaction chamber

1.8.2 Diaphragm valves (DV)

Gas sources (G1...8)

DV-PG1	Pulsing valve for gas line 1
DV-PG2	Pulsing valve for gas line 2
DV-PG3	Pulsing valve for gas line 3
DV-PG4	Pulsing valve for gas line 4
DV-PG5	Pulsing valve for gas line 5

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DV-PG6 Pulsing valve for gas line 6
DV-PG7 Pulsing valve for gas line 7
DV-PG8 Pulsing valve for gas line 8

Liquid sources (L1...4)
DV-PL1 Pulsing valve for liquid source 1
DV-BL1 Bubbler tube valve for liquid source 1
DV-PL2 Pulsing valve for liquid source 2
DV-BL2 Bubbler tube valve for liquid source 2
DV-PL3 Pulsing valve for liquid source 3
DV-BL3 Bubbler tube valve for liquid source 3
DV-PL4 Pulsing valve for liquid source 4
DV-BL4 Bubbler tube valve for liquid source 4
Hot sources (HS1...4)
DV-BH1 Bubbler valve for hot source 1
DV-BHA1 Carrier/purge gas valve for hot source 1
DV-PH1 Pulsing valve for hot source 1
DV-BH2 Bubbler valve for hot source 2
DV-BHA2 Carrier/purge gas valve for hot source 2
DV-PH2 Pulsing valve for hot source 2
DV-BH3 Bubbler valve for hot source 3
DV-BHA3 Carrier/purge gas valve for hot source 3
DV-PH3 Pulsing valve for hot source 3
DV-BH4 Bubbler valve for hot source 4
DV-BHA4 Carrier/purge gas valve for hot source 4
DV-PH4 Pulsing valve for hot source 4

Nitrogen system for process
DV-SN1 N2 inlet main valve
DV-NV1 Vacuum chamber flow valve for process
DV-NV2 Vacuum chamber fast flow valve for venting
DV-NLL Load lock chamber flow valve

Vacuum system
DV-VP1 Vacuum pump main valve
DV-VP2 Vacuum pump soft-start valve
DV-VLL1 Load lock pump down valve
DV-VLL2 Load lock pump down soft-start valve

1.8.3 Solenoid valves (SV)

SV-NP1 Pump gas ballast valve

1.8.4 Axial valves (AV)

Water circulations
AV-WV Water inlet valve for vacuum chamber and HS 500 cooling
AV-WL Water inlet valve for liquid source cooling

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1.8.5 Needle valves (NV)

Needle valves for pulse flows

NV-PL1	Pulse flow adjusting valve for liquid source 1
NV-PL2	Pulse flow adjusting valve for liquid source 2
NV-PL3	Pulse flow adjusting valve for liquid source 3
NV-PL4	Pulse flow adjusting valve for liquid source 4

Needle valves for other purposes

NV-NP1	Vacuum pump gas ballast adjusting valve
NV-NV1	Rotameter for vacuum chamber venting flow
NV-WV	Rotameter for Vacuum chamber cooling water flow adjustment
NV-WL	Rotameter for liquid source cooling water flow adjustment

1.8.6 Hand valves (HV)

Hand valves for liquid source bottle operation and purging (L1..3)

HV-BL1	Hand valve for carrier gas inlet to liquid source 1
HV-PL1	Hand valve for pulsing of liquid source 1
HV-BL2	Hand valve for carrier gas inlet to liquid source 2
HV-PL2	Hand valve for pulsing of liquid source 2
HV-BL3	Hand valve for carrier gas inlet to liquid source 3
HV-PL3	Hand valve for pulsing of liquid source 3
HV-BL4	Hand valve for carrier gas inlet to liquid source 4
HV-PL4	Hand valve for pulsing of liquid source 4

Hand valves for water connections

HV-W01	Hand valve for water inlet
HV-W02	Hand valve for water outlet

Hand valves for other purposes

HV-N02	Hand valve for pneumatic valve actuator inlet

1.8.7 Check valves (CV)

Check valves in nitrogen lines

CV-NOV	Check valve for vacuum chamber
CV-NOP	Check valve for carrier gas line
CV-P01	Check valve for pump N2 ballast

1.8.8 Gate valves (GV)

Gate valves

GV-V1	Gate valve for load lock

1.8.9 Relief valves (RV)

Relief valves

RV-WV	Overpressure relief valve for vacuum chamber water cooling jacket

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1.8.10 Mass flow controllers (MFC)

Mass flow controllers

MFC-NOP	Mass flow controller for carrier gas and inert gas valving
MFC-NOV	Mass flow controller for vacuum chamber flow

1.8.11 Flow indicators (FT)

Flow indicators

FI-WV	Flow indicator with metering scale for vacuum chamber cooling water output
FI-WL	Flow indicator with metering scale for liquid source cooling water output

1.8.12 Orifices and Capillaries (CA)

Orifices for source flows

CA-BL1	Flow distributor orifice for liquid source 1
CA-BL2	Flow distributor orifice for liquid source 2
CA-BL3	Flow distributor orifice for liquid source 3
CA-BL4	Flow distributor orifice for liquid source 4
CA-PH1	Flow distributor orifice for hot source 1
CA-PH2	Flow distributor orifice for hot source 2
CA-PH3	Flow distributor orifice for hot source 3
CA-PH4	Flow distributor orifice for hot source 4

Orifices for inert gas valving flows

CA-I	Inert gas valving flow orifice for gas and liquid sources
CA-IA	Inert gas valving flow orifice for gas/liquid source
CA-IB	Inert gas valving flow orifice for gas/liquid source
CA-IC	Inert gas valving flow orifice for gas/liquid source
CA-ID	Inert gas valving flow orifice for gas/liquid source
CA-IE	Inert gas valving flow orifice for gas/liquid source
CA-IF	Inert gas valving flow orifice for gas/liquid source
CA-IH1	Inert gas valving flow orifice for hot source 1/3
CA-IH2	Inert gas valving flow orifice for hot source 2/4

Capillaries for inert gas drain flows (H)

CA-DA	Inert gas valving drain orifice for gas/liquid source
CA-DB	Inert gas valving drain orifice for gas/liquid source
CA-DC	Inert gas valving drain orifice for gas/liquid source
CA-DD	Inert gas valving drain orifice for gas/liquid source
CA-DE	Inert gas valving drain orifice for gas/liquid source
CA-DF	Inert gas valving drain orifice for gas/liquid source
CA-DH1	Inert gas valving drain orifice for hot source 1/3
CA-DH2	Inert gas valving drain orifice for hot source 2/4

1.8.13 Temperature sensors (TE)

Temperature sensors for process temperature monitoring and control

TE-R1	Sensor for reaction chamber temperature control

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TE-R2	Sensor for reaction chamber temperature monitoring
TE-HS1	Sensor for hot source 1 container temperature control
TE-HH1.1	Sensor for hot source 1 body temperature control
TE-HH1.2	Sensor for hot source 1 feeding line heater temperature control
TE-HS2	Sensor for hot source 2 container temperature control
TE-HH2.1	Sensor for hot source 2 body temperature control
TE-HH2.2	Sensor for hot source 2 feeding line heater temperature control
TE-HS3	Sensor for hot source 3 container temperature control
TE-HH3.1	Sensor for hot source 3 body temperature control
TE-HS4	Sensor for hot source 4 container temperature control
TE-HH4.1	Sensor for hot source 4 body temperature control
TE-L	Sensor for temperature control of liquid sources

Temperature sensors for heaters

TE-HV1	Sensor for vacuum chamber heater 1 temperature control
TE-HV2	Sensor for vacuum chamber heater 2 temperature control

Other temperature sensors

TE-V	Sensor for vacuum chamber wall temperature monitoring

1.8.14 Heaters (H)

Heaters

H-V1	Heater 1 in the vacuum chamber
H-V2	Heater 2 in the vacuum chamber
HH1.11	Heater for hot source 1 body
HH1.12	Heater for hot source 1 body
HH1.13	Heater for hot source 1 feeding tube
HH2.11	Heater for hot source 2 body
HH2.12	Heater for hot source 2 body
HH2.13	Heater for hot source 2 feeding tube
HH3.11	Heater for hot source 3 body
HH3.12	Heater for hot source 3 body
HH3.13	Heater for hot source 3 feeding tube
HH4.11	Heater for hot source 4 body
HH4.12	Heater for hot source 4 body
HH4.13	Heater for hot source 4 feeding tube

1.8.15 Pressure transducers and indicators (PT,PIA)

Pressure transducers for process monitoring

PT-V1	Pressure transducer for vacuum chamber monitoring
PT-P1	Pressure transducer for reaction chamber pressure monitoring
PT-HSx	Pressure transducer for hot source feeding tube monitoring
PT-LSx	Pressure transducer for liquid source feeding tube monitoring
PT-LL1	Pressure transducer for load lock pressure monitoring

Pressure indicators

PIA-N2	Pressure indicator for process nitrogen inlet pressure visual monitoring

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1.8.16 Filters

Filters (FI)
FI-N01 Filter for process nitrogen inlet
FI-V01 Particle filter / condense trap for in for pump line flow

1.9 Factory settings for flow components

Flow tuning is made by adjusting the gas feeding (2 x MFC), adjusting the needle valves, changing the VCR orifices or changing the flow system components.

Beneq has defined good settings for orifices and needle valves. These are valid at MFC-NOV and MFC-NOP set values between 100-1000 sccm. Here are presented the recommended starting values for the flow components (factory settings made during startup).

1.9.1 Orifices

The system has orifices for dividing the flows in the right manner inside the system. They are critical components affecting the reactor overall performance. It is extremely important to ensure that the right orifices are in place in the right locations.

Orifice	Size (mm)	Location
CA-PGx	0.2	Gas precursor line x
CA-BLx	0.2	Liquid source x
CA-PHx	0.6	Hot source x
CA-AHx	0.2	Hot source x
CA-I	0.6	Under reactor inert gas flow line
CA-Ix	0.4	Inside vacuum chamber, gas mixing tube
CA-IHx	0.4	Inside vacuum chamber, gas mixing tube
CA-Dx	1	Inside vacuum chamber, gas mixing tube
CA-DHx	1	Inside vacuum chamber, gas mixing tube
CA-NLL	1	Load lock

1.9.2 Needle valves

The needle valves are the main tuning instruments of the reactor flow system in normal process development.

Needle valves for liquid precursor	Maximum Cv value	Maximum turns open	Recommended turns open
NV-PL1	0.15	11	1
NV-PL2	0.15	11	1
NV-PL3	0.15	11	1
NV-PL4	0.15	11	1

Needle valves for cooling water	Maximum flow l/min	Recommended flow l/min
NV-WV	10	2-5
NV-WL	10	2
NV-WS	10	2

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1.9.3 Gas inlet adjustments

N2 1.5-2.5 bar (abs.) for carrier gas N2 line (can alternatively be Argon)
5-8 bar for instrument N2 line
Gas lines without MFC: 0.5-1 bar (abs.)
with MFC: 0.5-1 bar (abs.)
Ozone 1.5-2 bar (abs.) for O2 inlet

1.10 Basic of process tuning

1.10.1 Process tests

The basic rule for good processing: "Ensure that the reactor is clean and vacuum-tight. The precursors have to be fresh and pure".

-Check that the flow components are in "factory settings" unless otherwise wanted.
-Check that the recipe is valid for the current physical flow system configuration.
-Do the following adjustments:

Material:
Water (Liquid source 4)
TMA (Liquid source 1)

Needle valves (if included):
Pulsing by own vapor pressure:
NV-PL4; L-series, Cv 0.045 = 0.5 turns open (max 11)
NV-PL1; L-series, Cv 0.045 = 1 turns open (max 11)

Reaction chamber:
200 mm silicon wafer (standard reaction chamber)

Flows:
MFC-NOP=600 sccm
MFC-NOV=250 sccm

Temperature:
Reactor 200°C
Liquid Sources 20°C

Pulse times:
TMA 100ms
Water 100ms

Purge times:
TMA 750ms
Water 1s

Cycles:
1000 cycles for 100 nm target thickness

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-Depending on the results adjust:
- Prolong the precursor pulse time if underdosing occurs.
- Increase the source temperature if underdosing occurs.
- Adjust the precursor needle valve opening or orifice size to optimize the dose.
- Increase purge time if CVD like growth occurs.
- Increase MFC-NOP flow if minor CVD like growth occurs.
- Increase the MFC-NOV flow if the joints are leaking to the vacuum chamber (film growth in the vacuum chamber)

1.10.2 Underdosing test

The underdosing test is a very useful method for optimizing the precursor dosing parameters. The basic idea is to deposit ALD film from precursor materials "A" and "B" so that with each process cycle there is enough material A (saturation or overdosing) and with each cycle, there is a lack of material B (underdosing). Depositing the film in this manner you should produce good ALD film on the front part of the substrate and have no film on the end part of the substrate (in flow direction).

From the film you can analyze:
- Your reactor and reaction is working in ALD mode
- Your reaction chamber optimization level for that process (shape of the deposited region)
- Reactivity of the precursor material in the process (short end-profile=high reactivity)
- Estimation for needed dosing (valve and flow adjustments)

This underdosing test should be made individually for both precursor materials (A and B). The underdosing test is the instrument for optimizing combinations of flows, needle valve settings, temperatures and pulse times. Indeed, many things, like pulse times, purge times, material consumption etc., can be optimized. In most cases, it is enough to ensure a reasonable overdosing situation without too much wasting of precursor material. Typically the underdosing tests are done when new chemical/process is being studied.

Reactor adjustments in underdosing stage:
- Increase the feeding opening if there is a lack of material on the centerline of the substrate (centerline = straight line from reaction chamber inlet connection to output connection to pump line).
- Decrease the feeding opening if there is a lack of material at sides of the substrate
- If this does not help adjust the feeding angle. Making the feeding sector smaller more material is being deposited to the centerline of the substrate. Making the feeding sector wider improves the growth on the sides of the substrate.
- Lower pressure improves the gas distribution, lower flows will give better uniformity.
- The flow speed effects can be studied by changing MFC-NOP flow.

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1.10.3 Process time optimization:

-Optimize precursor pulse times based on underdosing tests
-Optimize purge times:

- First by decreasing the purge time until CVD like growth occurs (film thickness increases rapidly)
- Then increasing the MFC-NOP flow to reach higher gas speeds in the tubes.
- Then minimizing the MFC-NOV flow (without precursor leak to vacuum chamber).

NOTE: Further optimization can be done with the following procedure but is very rarely necessary.

- Further optimization can only be done by mechanical changes to the system:
  - Replace the larger orifices to the inert gas drain to get faster inert gas valving
  - Eliminate dead-end pocket constructions (volumes with no flow).
  - Decrease the pressure with a higher capacity pump.
  - Feeding tube heating will reduce diffusion from the tube after the pulse.

1.11 Heating and cooling system

RISK OF LEAKING WATER! DUE TO OVERPRESSURE IN VACUUM VESSEL WATER JACKET. THE WATER OUTLET HAND VALVE MUST BE ALWAYS BE OPENED BEFORE OPENING THE WATER INLET HAND VALVE.

DO NOT TOUCH ANY PARTS OF THE MACHINE THAT ARE >60 °C! RISK OF BURN INJURIES! DIFFERENT PARTS OF VACUUM CHAMBER COULD BE ABOVE 60°C DURING HEATING UP!

RISK OF INJURIES CAUSED BY PRESSURIZED STEAM ESCAPING FROM THE SYSTEM DUE TO FAILURE OF COOLING WATER LINES AND COOLING SYSTEMS SUCH AS CHILLER!

The water flows can be adjusted by needle valves (NV-WV for vacuum vessel and NV-WL for liquid sources). They are located inside the frame under the vacuum chamber. The right flow level can be monitored by flow indicators (FI-WV and FI-WL). Water circulation is automatically controlled, except in maintenance state.

The right flow for the vacuum vessel can be adjusted by heating the reactor to 500°C and adjusting the flow level so that the reactor wall temperature (TE-V) will be about 30°C.

The right flow for hot source HS 500 can be adjusted by heating the source to 500°C and adjusting the flow level so that the source wall temperature will be about 30°C.

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1.12 Residual risks

The residual risks associated with the TFS 200 machine are described in the table below.

RISK	PRESENT	SUMMARY
Mechanical	YES	**Vacuum chamber hatch:** Use handle for opening/closing for finger protection. **Cover doors:** Use handle for opening/closing for finger protection.
Electrical	NO	
Thermal	YES	**Chamber hot surface:** Use protective gloves or wait for temperature to cool down. See hot surface signs on machine.
Material (Liquid, Gas)	YES	**Liquid, Gas:** Material safety data sheets (MSDS) must be available, read and understood. Use LOTO –procedure for maintenance. Container change should be carried out according operating instructions and training. Local fire department need to be informed (MSDS). Use personal safety equipment according MSDS.
Noise	NO	
Vibration	NO	
Radiation	NO	

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