

# UNDERGRADUATE REPORT

REU Report: The Essentials of a Vacuum System

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# The Essentials of a Vacuum System

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## Abstract

The parts of a Chemical Vapor Deposition (CVD) Reactor were examined extensively to create a procedure for placing a metal wafer into the loading chamber, transferring it into the reaction chamber, returning it to the loading chamber, then taking it back out. The instructions were created to learn about vacuum technology.

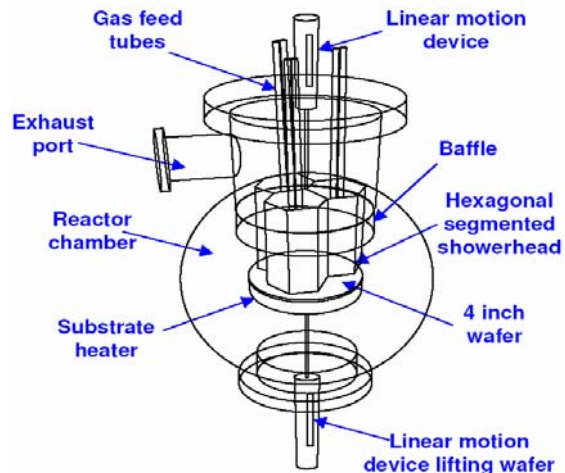
## Introduction

A CVD Reactor is used to deposit thin layers of film on a metal substrate called a *wafer*. The reactor relies heavily on being a vacuum system. Ideally, there is no pressure, and there are no large atoms (of air) floating about in such a system. This enables the gases to flow directly onto the wafer after being pumped through the feed tubes in the reaction chamber. The controllability of uniformity or non-uniformity is the ultimate goal of LAMP's CVD Reactor. This will be useful in the semiconductor industry, where thin pieces of film are needed.

Diagram of Reactor Chamber Area

No vacuum system, however, can reach a pressure of zero. The lowest pressure attainable is the *base pressure*. This is measured at the *inlet* of the mechanical pump. A *mechanical pump* is vital to any vacuum system. One of its jobs is to **reduce** the exhaust pressure so that the *turbomolecular pump* can be started. The mechanical pump used is a "roughing pump" because it works in the rough (low) vacuum range. The different ranges for vacuums are:

Rough (low) Vacuum =  $1 \times 10^{-3}$  torr  
Medium Vacuum =  $10^{-3} - 10^{-5}$  torr  
High Vacuum (HU) =  $10^{-6} - 10^{-8}$  torr  
Ultra High Vacuum (UHV) =  $<10^{-9}$  torr.



The turbomolecular pump, or *turbo* for short, comprises a turbine that spins rapidly, sending gas from the inlet of the pump toward the exhaust. This causes the pressure in the vacuum to decrease. There are three turbos in the CVD system. They get destroyed if exposed to atmospheric pressure.

The pressure inside the *scrubber* also needs to be negative relative to atmospheric pressure. The scrubber is responsible for cleaning the gases. It is a large box with an inlet and outlet and it is shared by many devices of the CVD Reactor.

In addition to the inability of the vacuum to attain a pressure of zero, the “vacuum” is further inaccurately named due to the existence of spaces between the atoms of the metals composing the vacuum chambers. These spaces hold water and air, preventing the vacuum from being completely pure.

The CVD Reactor comprises two six-way crosses. The first one is part of the *loading chamber* (or “load lock”). The loading chamber is the place where the wafer is first placed. The wafer cannot be placed directly into the reaction chamber because the reaction chamber needs to be very clean. If the reaction chamber were exposed to atmospheric pressure each time a wafer needed to be loaded, it would undoubtedly lead to contamination. Such a chamber would result in depositing film with aberrant electrical properties. Therefore the wafer is first placed into the loading chamber and then transferred to the reaction chamber.

On one “cross,” the *flanges* or metal ribs on the load lock are connected to a door. Another pipe on the six-way cross connects the loading chamber to the mechanical pump and a turbomolecular pump.

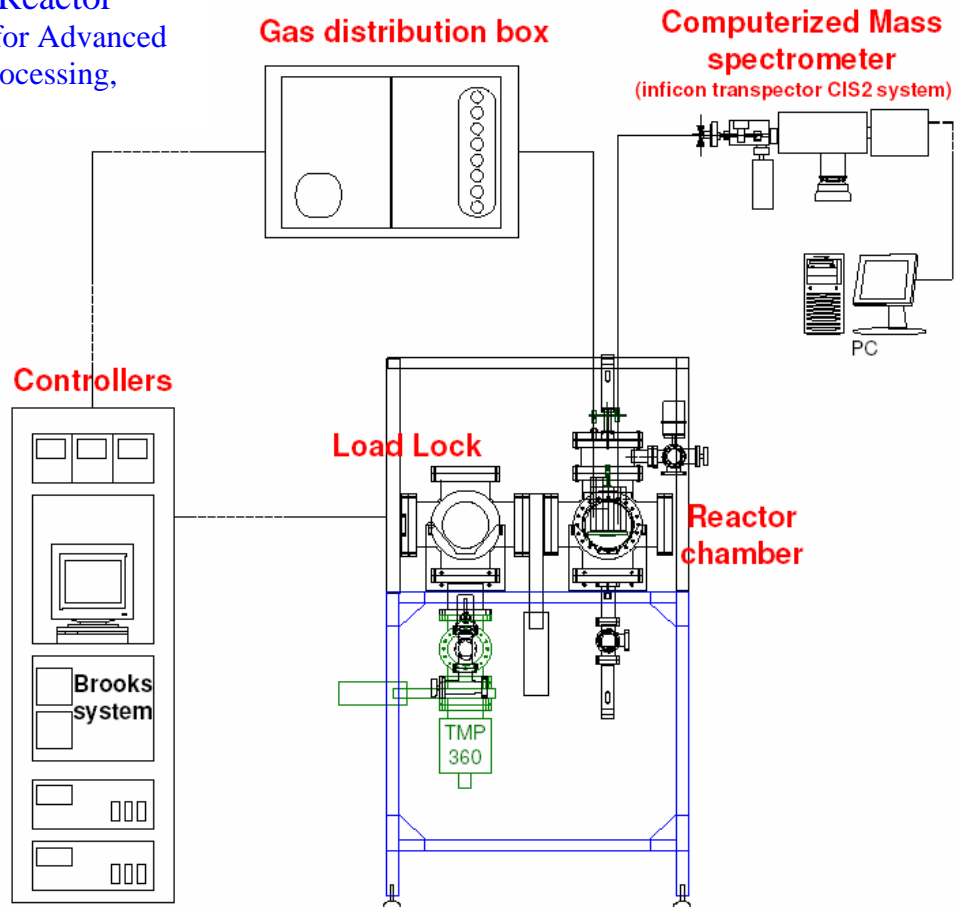
The pipe directly below the load lock is connected to another turbo. Each is separated by a gate valve that is computer-operated, meaning it receives electrical signals from the Central Processing Unit making it open or close. Directly behind the loading chamber is a pipe connected to a vent lever. **Venting** is vital to a vacuum system since it allows the vacuum system to interact with the outside world. When the vent lever is pulled laterally, air rushes from outside the loading chamber to the inside since air flows from regions of high pressure to regions of low pressure.

The second six-way cross contains the *reaction chamber* at its center. This chamber is connected to the loading chamber via another computer-operated gate valve. A turbo is also connected to this chamber. Directly below the chamber is the knob of a *linear motion device* which is used to move a thin metal T-shaped rod up and down. When a wafer is inside the reaction chamber, this device allows the experimenter to handle the wafer without physically touching the wafer or the inside of the reaction chamber. The linear motion device moves through the center of the heating unit inside the reaction chamber. This heating device is aptly named, since it provides heat to the wafer, enabling gases to be deposited thereon.

There are several gauges on the system that are used to measure pressure. Each belongs to either a *convection* class of gauges or an *ion* class. The convection gauge is a small metal cylindrical device that is always horizontal. Alternately, the ion gauge can be horizontal or vertical. The latter is used to accurately measure pressures of  $10^{-3}$  to  $10^{-9}$  torr. The former will give accurate readings of pressures above  $1 \times 10^{-3}$  torr but will not give accurate readings for pressures below this value.

The vacuum system is constantly in *cleaning mode* when not in use. In this mode, gases are always pumped to clean the vacuum. The *process mode* was examined in this lab.

The CVD Reactor  
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## Procedure

First, microchip fabrication, semiconductor processing, and vacuum technology were researched to get an idea of the purpose of such a system. To distinguish between necessary actions and dangerous ones, each part of the system was then researched.

Afterward, a drawing was created, illustrating where the parts are relative to the loading chamber and the reaction chamber. Most importantly, the drawing depicted the connections between the parts.

Ramaswamy Sreenivasan helped go through the process of transferring the wafer from the loading chamber to the reaction chamber by asking questions about what the next step should be, and more importantly, why that step had to be taken. Precautionary steps were stressed.

After explaining each step, the wafer was lifted from a counter with special tweezers. Then there was an attempt to open the loading chamber door but it was impossible. To overcome this, the pressure within the chamber was brought up to atmospheric pressure. Then the door was opened, and the wafer was placed onto a tray inside this chamber. The one flat end of the wafer sat facing the chamber door.

The door of the loading chamber was then closed and the pressure was brought down. When the pressure inside the chamber was low enough, the valve connecting the loading chamber to the reaction chamber was opened.

With the robotic arm, the tray was transferred into the reaction chamber. Then a linear motion device lifted the wafer up, enabling the tray to be taken back to a pipe outside of the reaction chamber. The valve connecting the loading chamber to the reaction chamber was closed after the wafer was placed onto the heater.

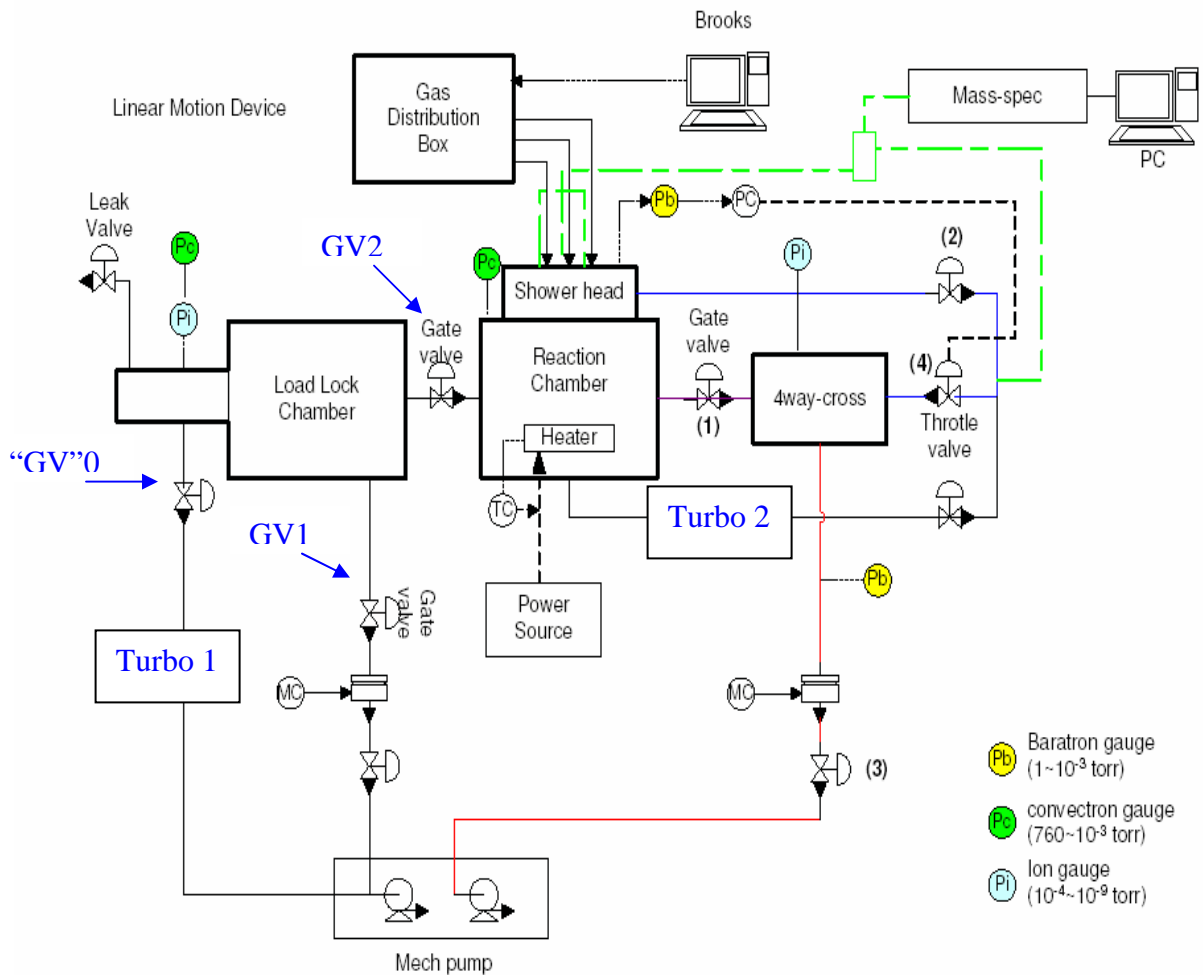
After the tray was transferred back into the reaction chamber, the wafer was again lifted up and placed onto the tray. The wafer finally returned to the loading chamber. After closing the valve that connected the loading and reaction chambers, the pressure was brought back up to atmospheric pressure (760 torr).

Last, the door of the loading chamber was opened and the tweezers were used to take out the wafer.

## Results

### Diagram of System

(gas flow control system, pumps, chambers, gas distribution box, mass-spectrometer, and controllers, turbomolecular pumps)



## I. Opening the Loading Chamber

At-Risk Units	Ways to Avoid Destruction
Turbo 1	Close GV0.
The reaction chamber	Close GV2, which connects the load lock to the reaction chamber.

### Procedure:

- 1) Use the computer to close “Gate Valve” 0 (GV0), GV1 and GV2 by using the arrow keys and the Enter button on the keyboard.
- 2) Allow air to come into the load lock by pulling the horizontal, black vent lever (behind the loading chamber) laterally.
- 3) Examine the pressure level (in torr) above the computer monitor; when the pressure reads 760, return the vent lever to its original position, thereby closing it.
- 4) Turn the black knob on the loading chamber door, move it laterally, then open the door to the chamber by pulling the thin metal nearest the stationary black knob.
- 5) With the tweezers, place the wafer into the chamber, making sure that the flat part is facing the load lock door. Look from the window on top of the chamber, to make sure that the wafer is balanced on the tray and positioned correctly, with the flat part of the tray next to the flat part on the wafer

## II. Placing the Wafer into the Reaction Chamber

At-Risk Units	Ways to Avoid Destruction
The reaction chamber	Close GV2
The 2 turbos	Obstruct the passageway of each turbo to the mechanical pump; close gate valves

### Procedure:

- 1) Close the door of the load lock.
- 2) Keep GV1 shut since there is too much pressure in the load lock (it would damage the turbomolecular pump). Keep GV2 shut, too, so that the reaction chamber (it is a vacuum set to 1000 mtorr pressure) stays clean.
- 3) Manually close the pipes connecting the turbos to the mechanical pump by turning the two blue levers (by the pump) perpendicular as opposed to their open state (parallel to the pipes). This ensures that the gas from the mechanical pump will go to the load lock and not to the turbos.
- 4) Make sure that the vent lever is also closed to prevent leakage of atmospheric air into the vacuum.
- 5) Open GV0, which connects the mechanical pump to the loading chamber. Then, watching the numbers on top of the computer monitor, wait until the pressure is at  $1 \times 10^{-2}$  torr. When it reaches this pressure, close GV0.
- 6) Open GV1 which connects a turbo to the loading chamber. It will bring down the pressure farther. To check the pressure, press the “Ion” button to the right of the screen giving the pressure value.

- 7) Once the pressure reaches  $1 \times 10^{-5}$  torr (or a lower pressure), close the gate valves connecting the turbos to the loading chamber, again making sure the monitor has “Off” underneath the gate valve names.

Note: GV1 should be left open. This allows the turbo to help clean the load lock.

### III. Placing the Wafer onto the Heating Device then Back onto the Tray

<b>At Risk Units</b>
None

#### Procedure:

- 1) Open GV2, which connects the reaction chamber to the loading chamber and turn the black knob on the robotic arm (left of the loading chamber) counterclockwise to move the tray into the reaction chamber. The tray is holding the wafer.
- 2) Look on top of the reaction chamber, through the window, to make sure that the wafer is directly above the heating device.
- 3) Turn the black knob of the linear motion device counterclockwise to raise the wafer. After the wafer is 2 mm or more above the tray, slightly move the tray left of the heater to catch the wafer should it fall.
- 4) Turn the knob of the linear motion device clockwise until the wafer rests on the heater.
- 5) Use the robotic arm to return the tray into the pipe connecting the reaction chamber to the load lock.
- 6) Close GV2. Note: GV3 connects the 2<sup>nd</sup> turbomolecular pump to the reaction chamber. It should be left open so that the turbo can help keep the vacuum clean.
- 7) (Optional) Manually adjust the distance between the wafer and the showerhead by placing 1 mm pieces of metal along the neck of the showerhead’s linear motion device. Raise and lower the showerhead (using the computer’s Up and Down commands).

### IV. Taking the Tray Back to the Loading Chamber

At-Risk Units	Ways to Avoid Destruction
The reaction chamber	Make sure the pressure in the loading chamber is well below atmospheric pressure.

#### Procedure:

- 1) Open the gate valve connecting the two chambers (GV2), and turn the black knob on the robotic arm, once more bringing the tray into the reaction chamber.
- 2) Turn the knob on the linear motion device to raise the wafer, again about 2 mm above the level of the tray’s upper surface.
- 3) Bring the tray (which has a whole along the side/in the middle) directly below the wafer using the robotic arm. Look through the window on top of the reaction chamber to make sure it is correctly placed.
- 4) Turn the knob on the linear motion device clockwise, placing the wafer on top of the tray.

- 5) Bring back the tray into the loading chamber by turning the knob on the robotic arm.
- 6) Close GV2.

## V. Taking the Wafer Out of the Vacuum System

At-Risk Units	Ways to Avoid Destruction
The 2 turbos	Close GV0 and GV1.
The reaction chamber	Make sure GV2 is closed.

### Procedure:

- 1) Close GV0 and GV1 so that the turbos are protected since the pressure is about to be raised.
- 2) Turn the vent lever (behind the loading chamber) laterally, exposing the chamber to atmospheric air and thereby causing the pressure to rise.
- 3) When the number above the monitor reads 760 (torr), open the door of the loading chamber.
- 4) Using the tweezers, carefully take the wafer off of the tray and into the room. Close the door of the loading chamber.
- 5) Repeat the process of bringing down the pressure in the loading chamber (see part II).

## Discussion

After the wafer is placed onto the heating device (Part III, number 4), the heating device would have been turned on and the computer would have been used to send an electrical signal to the system, enabling the gas to flow onto the wafer. This did not happen in this lab whose purpose was to become familiar with the process of loading a wafer. Hence, it did not deal with an actual chemical vapor deposition.

The most important thing to do when figuring out what steps must be taken in order to load the wafer is to think about the ramifications of every action. To simplify this vital process, each part should be looked at separately. For instance, when figuring out how to open the loading chamber to load a wafer, all the units connected to the loading chamber's six-way cross needed to be noted. Is the turbo connected to the loading chamber? If so, would it be okay if it were exposed to atmospheric pressure? Why? How can it be protected in order to be able to increase the pressure of the chamber without destroying the turbo? Questions like these are necessary to ensure safety, as well. It would prove futile to try to open the load lock door when the pressure outside is much higher than the pressure inside. Trying to do so could seriously bruise the hand.

Although the vacuum seems overwhelmingly complex at first, when the system is broken into its constituent units, its overall functioning at each stage of the loading, transferring and unloading processes becomes very clear. Processes like opening and closing gate valves were simple as they involved using the keyboard on the computer that is connected to the system. By selecting which gate valve needed to be opened or closed, and pressing Enter, choosing "On" or "Off" and then pressing Enter again, the valve responded instantly.



A computer programmer was in charge of creating the program used to control the vacuum system. Given the intrinsic qualities of the gases being pumped through the three tubes, different computer programs are also needed to accurately predict the outcomes of depositions (thickness, uniformity, etc.).

Overall the Reactor was very easy to use. It mainly utilized electrical signaling to open the valves, although it used manual methods as well (like lifting the vent lever or turning the blue levers near the mechanical pump). Although not examined closely in this lab, the chemistry of the gases and the metal of the chambers was very important. The physics involved in determining the values of the pressure via the pressure gauges and the mass flow rate were important as well.

The Chemical Vapor Deposition Reactor is truly an amazing vacuum system where so many different fields of science and engineering work in harmony in order to achieve its purpose of depositing film onto a substrate.

## Observations

When the valves are opened, there is a sound resembling a small explosion. It is caused by letting air flow from one area to another and is normal.

## Note

All diagrams were created by Dr. Raymond Adomaitis's Research Team (which includes L. Henn-Lecordier, J. O. Choo and others), with slight modifications (in blue) by H. Jamal.