Introduction to Angstrom Evaporator

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Physical Vapor Deposition (PVD)

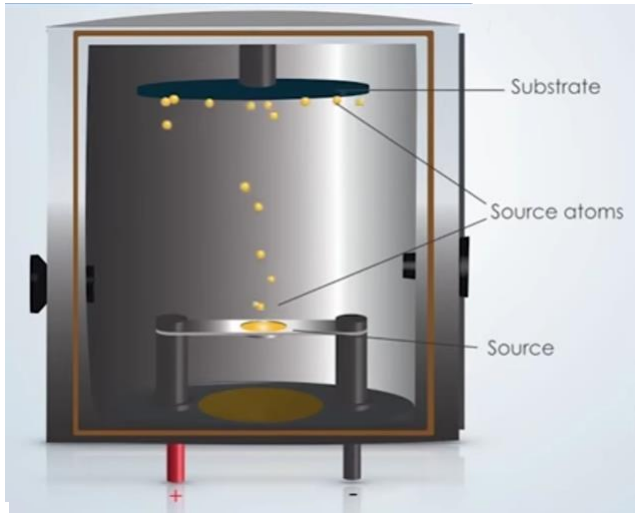
PVD is a technique using a high vacuum system to deposit thin layers of materials such as metals and insulators on a substrate.

The thickness of these deposited layers is on the order of 5-250nm.

The three most common PVD techniques are:

- Electron beam evaporation
- Thermal evaporation
- Sputtering

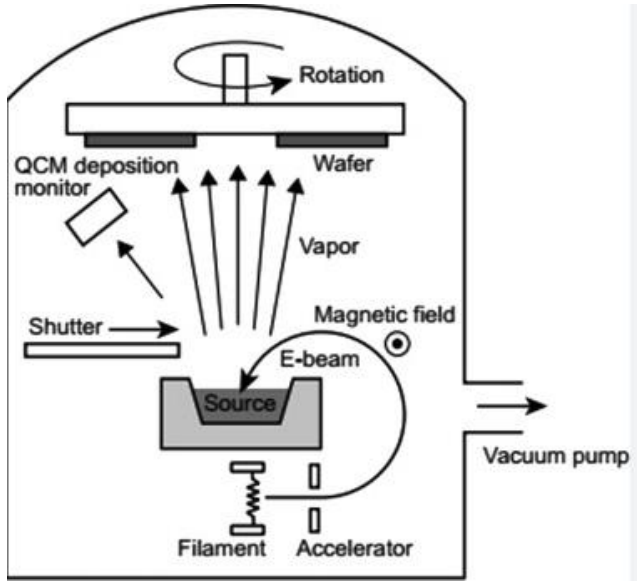
In evaporation process, the atoms origin is an ultra-high purity material (source), and atoms from this source travels through the vacuum chamber and are deposited onto the surface of our substrate.



Electron Beam Evaporation (e-beam)

In electron beam evaporation, a stream of electrons is directed toward high-purity source material that we want to evaporate.

The beam hits the material to its melting point and then evaporates the source material. The electron beam is well confined thus enabling deposition of multiple layers sequentially without breaking the chamber vacuum.

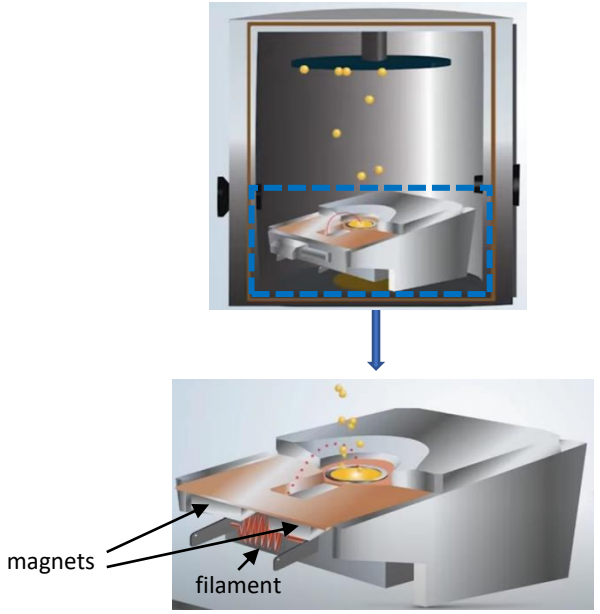


Electron Beam Evaporation (e-beam)

Ebeam evaporator consist of two main components:

▪ Electron gun – produces the beam of electrons. The gun contains a tungsten filament (the source of the electrons) and magnets (focusing the electron beam and directing it toward the crucible). The electron beam is generated by heating the filament to the point that it glows bright (~2500°C), where electrons have enough energy to leave the surface of the filament, accelerated toward the source (using a high voltage electrode), and focused on source material to be evaporated. The power level can be controlled by adjusting the filament current (different material requires different power to melt).

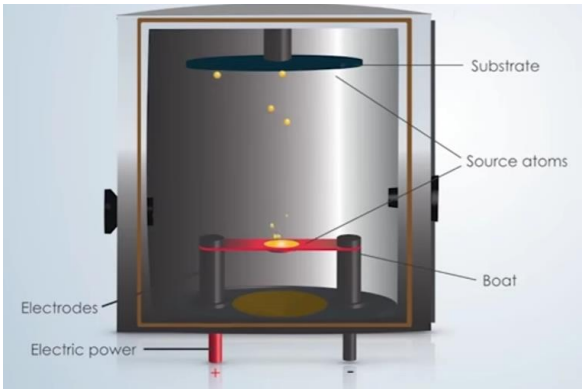
▪ Crucible – where the source material is contained. Since the beam is well confined, only a small area of the source material is heated. ODEM contains 6 pockets hearth (6 crucibles). The hearth is a rotating holder of copper which is water-cooled. The water cooling prevents the crucible material from melting and mixing with the source material or with the hearth itself.

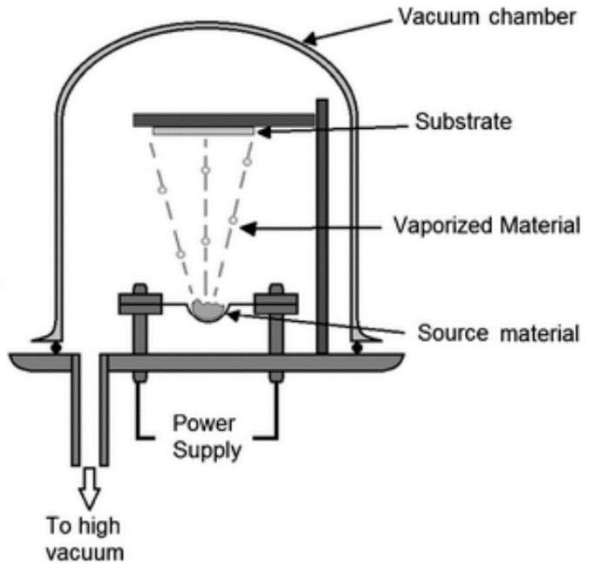


Thermal Evaporation

In thermal evaporation, we use electrical current to heat a boat so that the source material in the boat melts and evaporates. The ultra-high purity source goes from solid → liquid → gas. The gas atoms travel through the vacuum in the chamber, and when these atoms hit the substrate, they condense and form a thin film on the substrate surface. Both metals and dialectics can be used in thermal evaporation. Metals are more suitable since their melting temperature is lower thus producing steady deposition rates. In this process, a small amount of our source material is placed in a boat, the boat is heated by passing a large electrical current through it to heat it up in a process called resistive heating.

The boat is usually made of tungsten or ceramics, since melting temperature should be higher than the source.

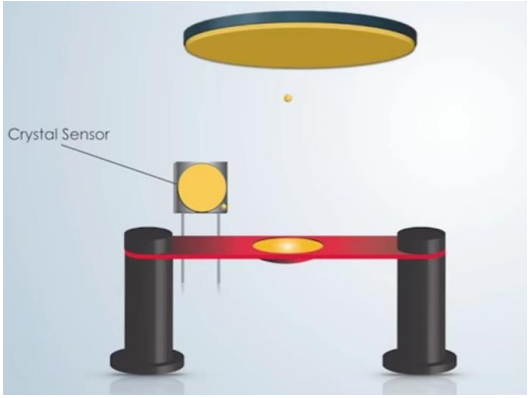




Quartz Crystal Monitor (QCM)

The QCM enables us to monitor the layer thickness in real time during the deposition. To monitor the thickness, we place a crystal sensor in the chamber near the sample holder, so that the source material is deposited onto the sensor at the same rate as onto the substrate. The crystal sensor vibrates, and the vibration frequency changes as the film is deposited onto the crystal, enabling us to sense the change of vibration and calculate the thickness in situ. When the desired thickness is reached, we stop the flow of electrons, the heating of the source stops and deposition stops.

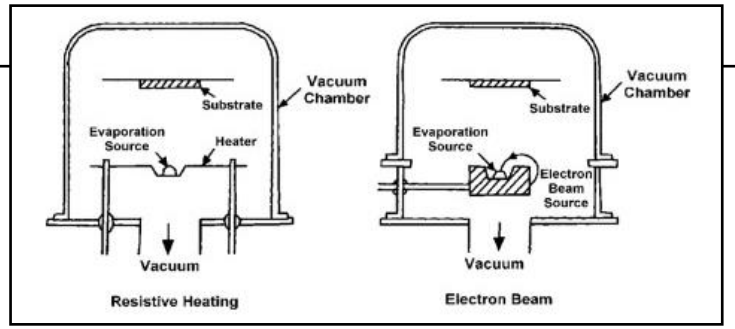
QCM has a lifetime, at a certain point the QCM is coated so the vibration frequency is no longer correlated to layer thickness.
In ODEM, we aim to work at values below 20%.



Crystal life < 20%

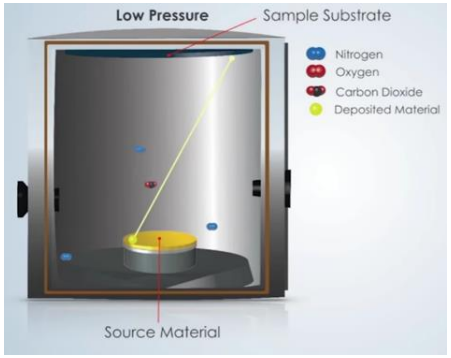
Ebeam vs Thermal Evaporation

	advantages	disadvantages
ebeam	▪ Electron beam deposition heats materials to higher temperatures than most other methods of PVD, enabling high deposition rates. ▪ It produces thinner films than thermal evaporation. ▪ Electron beam evaporation gives rise to products of high purity. ▪ The coating is more easily controlled with electron beam evaporation. ▪ It is ideal for metals with a high melting point. ▪ Film quality has a higher density than in the thermal evaporation method.	▪ This method can not coat complex geometries completely. This is because it is a line-of-sight deposition process. ▪ When the tungsten filament degrades, the evaporation rate becomes non-uniform. ▪ It is more expensive than the thermal evaporation method. ▪ Not suitable for samples that are radiation sensitive (electrons, X-rays etc).
thermal	▪ It can be easily used for both metals and nonmetals. ▪ It is ideal for materials that have a low melting point. These materials include alloys containing mercury. ▪ This physical vapor deposition process is easy to understand and implement. ▪ It is more affordable than most other methods of physical vapor deposition.	▪ Its products have less purity than products from the electron beam evaporation method (due to resistive heating). ▪ Film quality is relatively low density.



Vacuum Pumps

In order to achieve high purity thin films, a clean environment is required. This can be done by using high vacuum systems, by removing air molecules from the vacuum chamber.



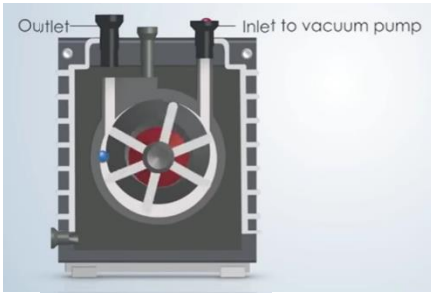
The type of pumps used on evaporators:

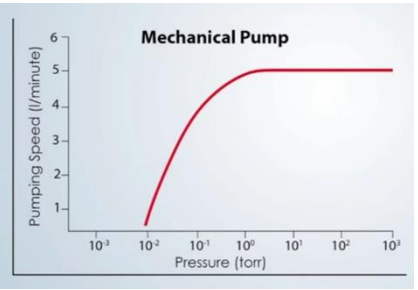
Mechanical pump (<10^{-2}Torr)

When pushing air out of the vacuum chamber, there is less air near the pump.

The rotor of the pump pushes small volume of air to an outlet pipe with every rotation, then air molecules diffused from the rest of the toward the pump.

When the pressure evens, reaching rough vacuum, the pump becomes less effective.

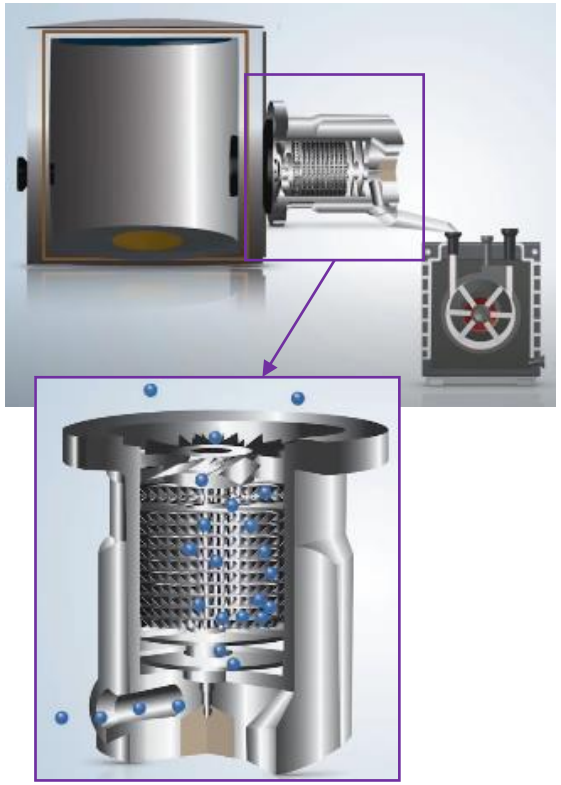




Vacuum Pumps

Turbomolecular pump (<10^{-6}Torr)

After mechanical pump reaches the pressure of 10^{-2}Torr, we need to use a second high vacuum pump. The design consists of several turbines spinning at high speed (50K rpm), air molecules are hit by the angle turbine blades and are bounced out of the chamber into the turbo pump. The rest of the air molecules in the chamber diffuses toward the turbo pump where there is less air, out of the turbo pump, which then pumped by the mechanical pump (backing the turbo pump).



Vacuum Pumps

Cryogenic pump (<10^{-8}Torr)

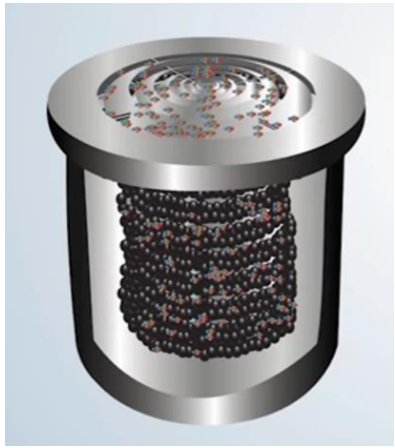
- Using helium coolant
- Typically cooled to 15K (-258˚C)

The cooled region of the cryo pump has large surface areas (more trapped air molecules). Arrays of helium cooled metal films provide the frozen surface area.

Some areas in the pump are covered with activated puros carbon (extremely large surface area) to trap even more air molecules.

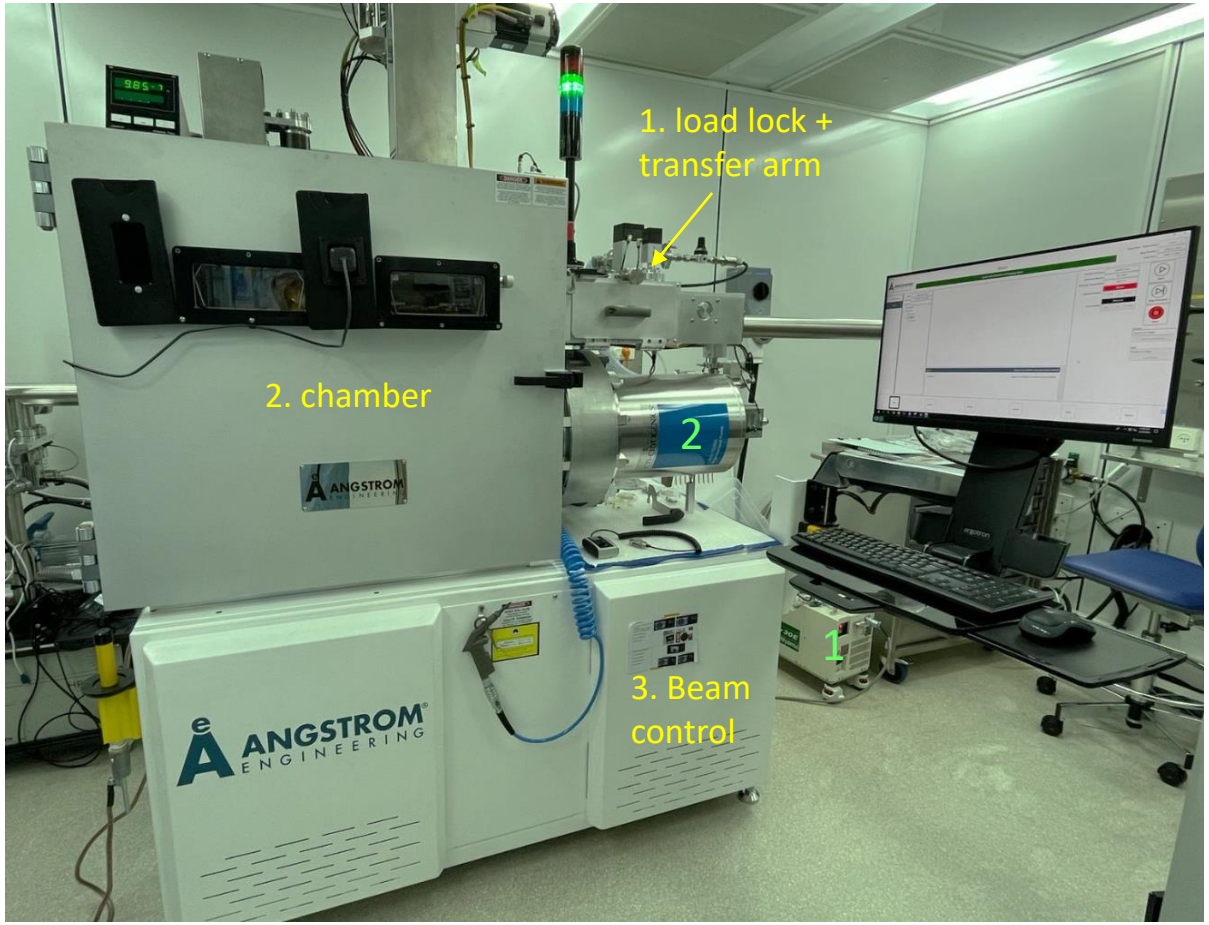
The cryo pump has no outlet. The air molecules stay frozen and trapped in that pump, until at some point, all of the surface area on the metal fins, and all of the porous on the carbon become filled with trapped air molecules, then the pump is saturated (cryo temperature begins to rise).

When the pump is saturated, regeneration process is required. The pump is filled with ultra high purity N_2 gas, slightly heated, and the pump is slowly warm up to room temperature. The trapped air molecules are evaporated and then pumped out of the system with the mechanical pump.



saturated cryo pump

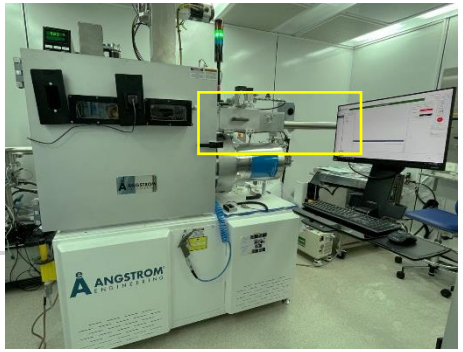
Angstrom Design



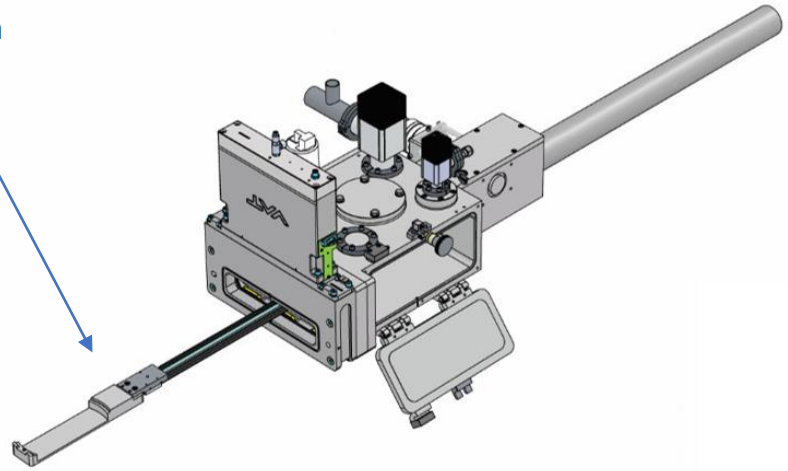
Machine contains 2 pumps:

- Mechanical pump (1)
- Cryogenic pump (2)

1. Load Lock + Transfer Arm

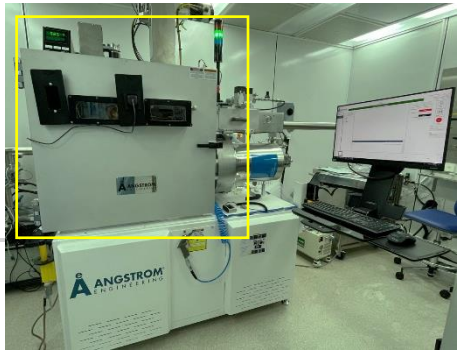


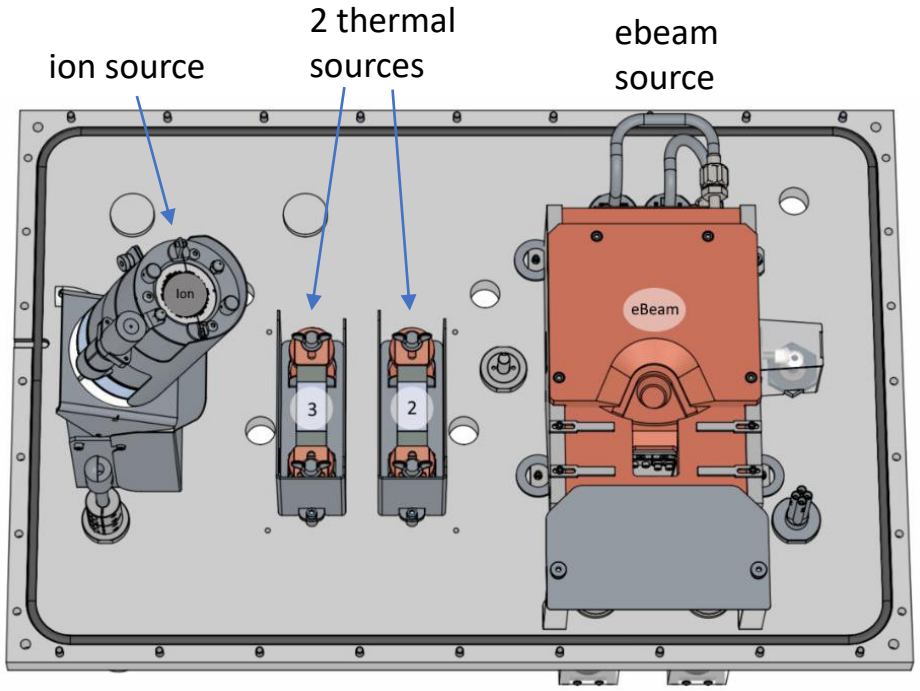
Transfer arm

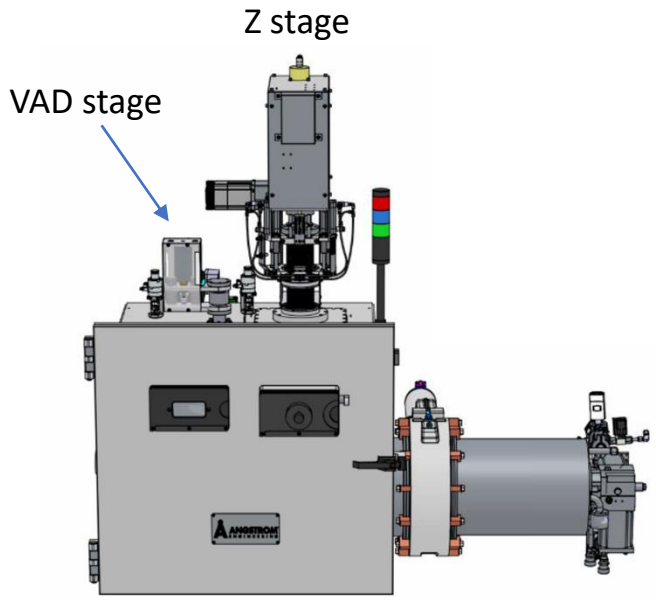


Mechanical pump pumps the load lock to vacuum of $3.5X10^{-2}$ Torr, then gate valve is opened, and sample holder is transferred to the chamber.

2. Chamber







Machine contains 2 stages:

- Z stage (above ebeam source).
  Capabilities:
  * rotation
  * change heights (500, 400, 300mm)

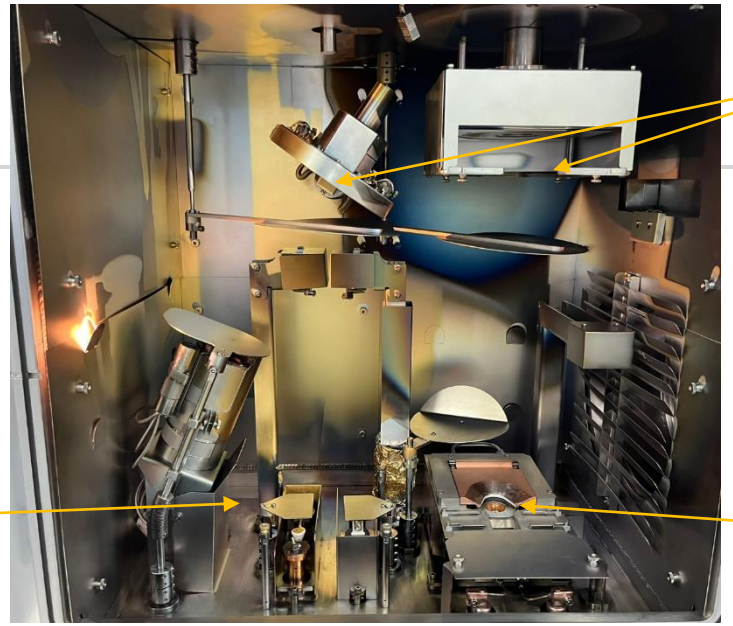
- VAD stage (above thermal source).
  Capabilities:
  * rotation
  * substrate angle (up to 45deg)
  * substrate temperature (LN2-800°C)

There is the option of cross depositing:
ebeam on VAD stage or thermal on Z stage.

Alumina basket thermal boat for Au

8 pockets hearth

2. Chamber



Source to substrate distance

3 process heights (source to substrate):

500mm, 400mm, 300mm.

If your sample is sensitive (resist etc), we suggest using 500mm. Disadvantage: more material is wasted.

If not sensitive, we suggest working at 400mm.

Beam centering

It is essential to center the electron beam in the center of the source, otherwise, you might evaporate part of the crucible and have difficulties controlling the rate and power.

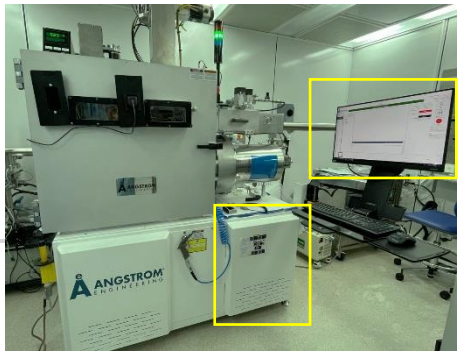
Example for non-centered ebeam, source material is shifted

Deposition rate

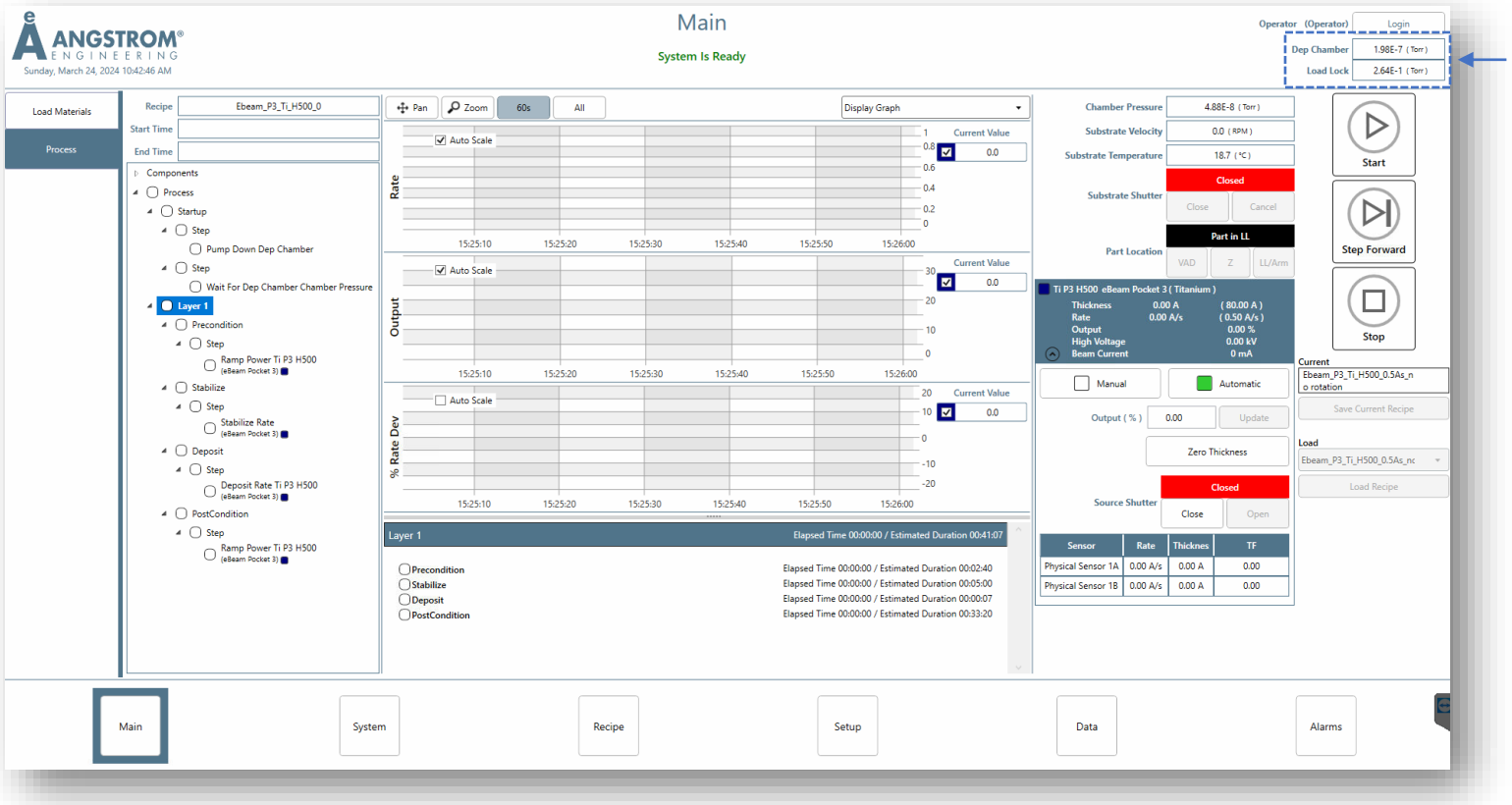
If you wish for smooth low roughness layer, try deposition using high rates (> 1.5 Å/s).

For thin layers (< 10 nm) use low rates (< 0.5 Å/s).

3. Process Control



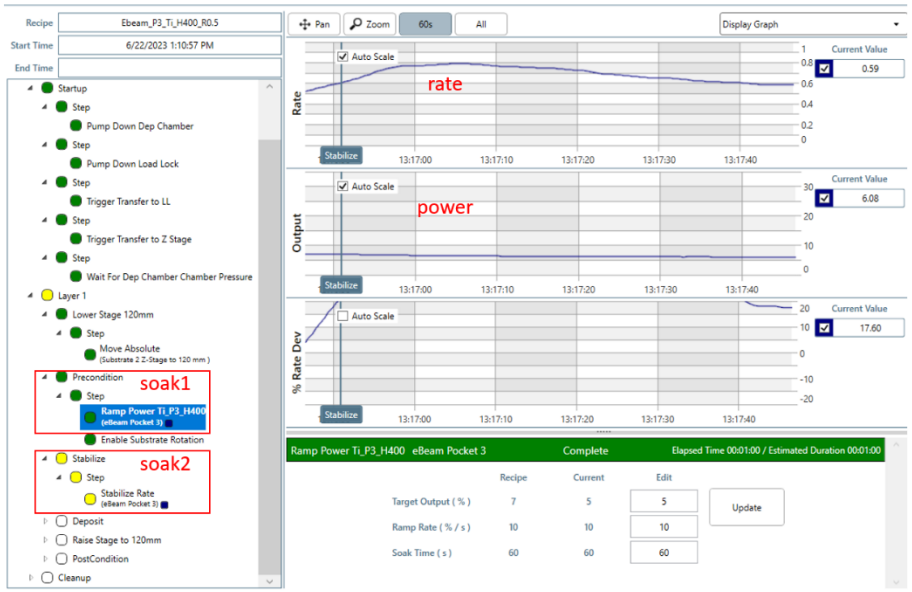
Process control is achieved from main screen:

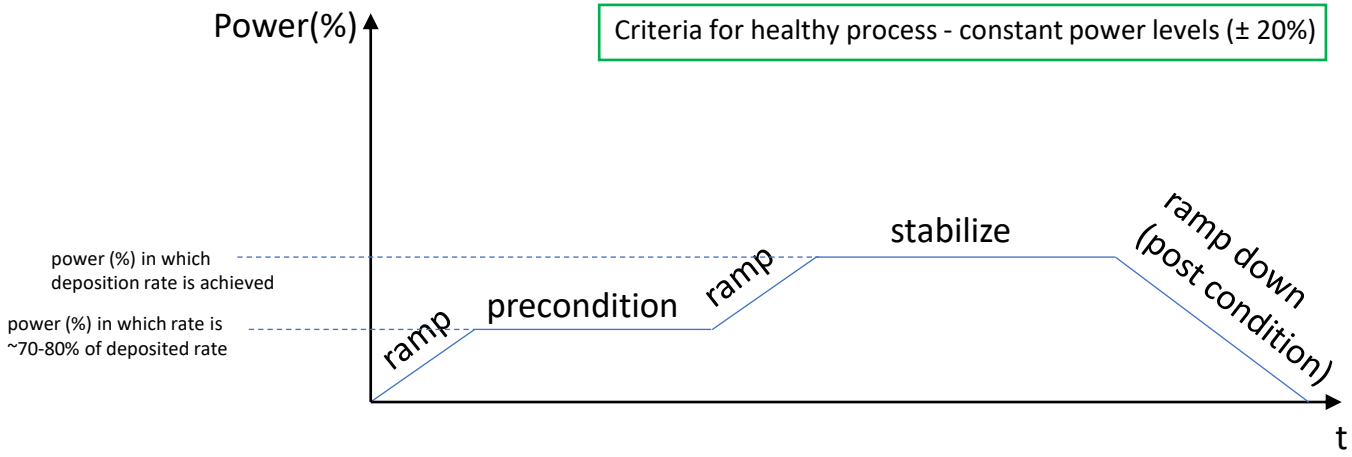


Chamber/LL vacuum

Beam alignment is controlled from here:

3. Process Control





Recommendations:

- Precondition (soak 1): the only step where you control the power. Set the power so the rate is ~70-80% of final rate (for 0.5 Å/s, set precondition rate to 0.35 Å/s).
- As a new user, you should increase soak time (1) so you have enough time to adjust your process and align the beam.
- Post condition: for power <20%: 2 minutes, >20%: 3 minutes, >30%: 4 minutes

Power levels are controlled by:

- Source to substrate distance The larger the distance, the higher the power you will need to reach the desired thickness.
- Deposition rate The higher the rate, the higher the power required.
- Crucible fill The less material in the crucible, the higher the power required to evaporate atoms from the source material.
- Carousel cooling if cooling is not effective, the source material will reach high temperature, power for evaporation will be lower.
- Chamber vacuum - the higher the vacuum the lower power you will need (beam is less interfered).