Microscope alignment

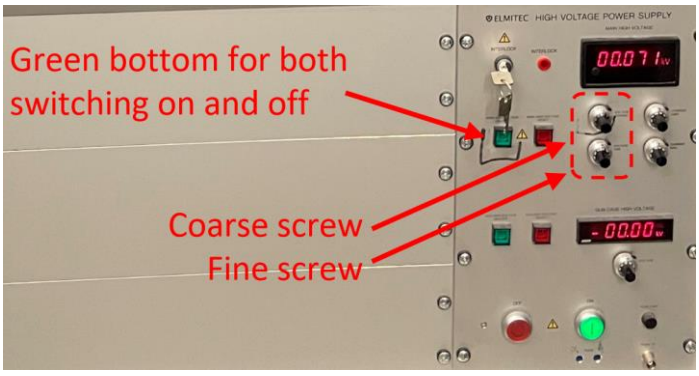
For detailed alignment, one can start with UV-PEEM for aligning intermediate column and image column with field of view typically > 50 µm, without influence from illumination column.
For simple alignment, one can directly start with LEEM or XPEEM with a smaller field of view.
The setup inherited from the previous week is normally well-aligned, allowing for a simple alignment check first. During alignment, one can always use 'undo' to return to previous setting of lens, but not manipulator motors.

Prepare the setup

1. **Position the Manipulator Head (3mm to objective lens)**
   i. Position the manipulator head approximately 1 mm further away from the stop ring. Use aluminum foil to temporarily fix the position of the head.
      * This creates a total gap of 3 mm between the sample surface and the nose of the objective lens. Observe via window when moving sample.
   ii. Set the objective lens current to be 1700-1800 mA if uncertain (e.g. 1950 mA for 3 mm distance).
      * Typical focusing current for 2 mm is about 2150 mA. For avoiding arc, objective lens might be 1700+ mA when measuring sample.
2. **Check the pressure of chambers (Main chamber < $2*10^{-9}$ torr), X-ray valve is closed, electron gun is off and the Start voltage is set to 0V. Camera can be at acquisition mode. Check the sample temperature if it has been heated.**
3. **Turn on high voltage rack with eyes on pressure !!!CAREFUL!!!**

*** Interlock will be activated once the pressure of Main chamber reaches $5*10^{-8}$ torr. !!!**

   i. Set the coarse screw to a lower value (5 or lower if necessary).
   ii. Switch on the HV rack by pressing the marked green bottom. If the coarse screw is at 5, it will rapidly go to ~ 10kV.
   iii. Use coarse and fine screws to slowly increase the high voltage to 20.001kV and use fine switch to decrease to 20.000 kV.
   iv. If the sample has experienced the high voltage, the initial coarse screw can be set with high value (maybe 7 or 8, since 9 or 10 is ~ 20 kV) and increasing of voltage can be faster.



High voltage rack.

----------UV-PEEM alignment ----------

UV-PEEM for adjusting the sample tilt and aligning the intermediate and imaging columns

(align with UV lamp when field of view > 50 µm with reasonable intensity)
All apertures and slit in the beam path should be removed for rough alignment.
Frequently used camera setting: exposure time = 0.1s, sliding averaging

Prepare the setup

1. **Switch Off the Electron Gun**
   i. Adjust the Wehnelt potential to the off-value (-290 V by default) to turn off the electron gun.
2. **Prepare the UV Lamp**
   i. Close the mechanical iris before the UV lamp.
   ii. Position the lamp in front of the quartz viewport.
   iii. Switch on the UV lamp (4.88 eV). Warm up might take around 2 minutes.
      * Be mindful of scattering and reflection.
3. **Monitor the Microscope Image and Main Chamber Pressure**
   i. Slowly and slightly open the iris. Normally, the aperture does not need to be fully opened.
   ii. Adjust the UV lamp position to see signals and maximize it until you see a clear image.

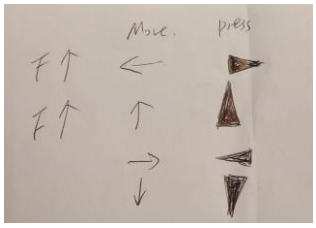
Alignment of intermediate column

① 1. **Find the Optical Axis and set marker**
   i. Wobble the **Mirror Transfer Lens 1 (MTL1)**.
   ii. Identify the "breathing" center (the point where the image moves least) and set a marker on it.
      * It may be helpful to use a noticeable feature for clearer judgment when finding the breathing center.
      * Feature can be moved to marker using sample manipulator (XY-movements).

② 2. **Adjust the Sample Tilt (based on marker)**

*** Start voltage is set to 0V when start aligning tilt.**

   i. Wobble the **Objective Lens** to find the breathing center again.
   ii. Align the breathing center to the previously set marker, minimizing image movement behind the marker.
      * The marker represents the optical axis. Keep in mind that image features may change while aligning the sample tilt.
   iii. Once the sample tilt is adjusted, bring a noticeable feature to the center of marker as reference point for future alignment.
      * Adjusting the sample tilt cannot be undone because motors are used to make this movement.
      * Motor can be locked for better motor performance in further alignment, although normally it is kept as partially unlocked.



A trick to align the tilt:
Observe the direction of feature movement with increasing value of objective lens and click on the corresponding bottom in the motor control panel.

3. **Move the Feature to the Optical Axis**
   i. After aligning the sample tilt, the marker can be removed from screen to avoid misleading.
   ii. Use the feature as your new reference for alignment.

③ 4. **Wobble Mirror Field Lens 1 (MFL1) and check**
   i. X direction: Outer sel; Y direction: MFL1 Align Y

④ 5. **Wobble Mirror Field Lens 2 (MFL2)**

⑤ 6. **Wobble Mirror Transfer Lens 2 (MTL2)**

Alignment of imaging column

6 1. **Wobble the Transfer Lens (TL)**
    i. **X-axis: Mouter Se; Y-axis: Sec2 Align**
7 2. **Wobble Minner Se and minimize the motion of reference point with FL value.**
    i. Then check the value of TL.
8 3. **Wobble the Field Lens (FL)**
    i. Align as needed and go back to check the breathing of TL.
    ii. Not moving towards the breath center but the opposite direction.
9 4. **Wobble the Intermediate Lens (IL)**
    i. Align X if wobble in Y direction and align Y if wobble in X direction.
10 5. **Wobble Projective Lens 1 (P1)**

Alignment in energy analyzer and projection system

Pass energy (bias): 1024.5 V; decrease for better energy resolution (at expense of intensity)

11 1. **Wobble the Inner Lens (instead of RL)**
    i. X and Y axes: RL Align
12 2. **Wobble the Acceleration Lens (AL)**
    i. Center it with Sel+/-
    ii. Can try adjusting AL Align A, B but it might not help alignment
13 3. **Wobble Sel +/- and minimize the motion with the Acc. Lens value**
    i. This step may not help alignment. The adjustment on Acc. Lens value might decrease the image sharpness.
14 4. **Wobble Projective Lenses 2**
15 5. **Wobble Projective Lenses 3**
    i. Breathing center should be centered in the image window.

* Go back and check the whole column, make corrections if required.
* During alignment, P3'x and y can be used for moving reference feature (optical axis) to center of view.

LEEM alignment with electron gun for smaller FOV

(typically use for alignment when field of view < 50 µm)
Frequently used camera setting: exposure time = 0.1s, slight averaging

Prepare the setup

1. **Check if START voltage is set to 0V to reflect electron beam from the sample**
2. **Slowly decrease Wehnelt potential and observe MEM image (from -265 to -240V)**
    * Do not set the Wehnelt voltage below -240V. !!!**CAREFUL!!!**
    * Electron gun off value is around -265V, even though the default value in software is -290V.

(16) Align Electron Gun Incidence Perpendicular to Sample

Using transition from MEM to LEEM:

1. **(Not necessary) Decrease the START voltage to negative values. A bright image should appear, indicating that MEM is taking place.**
2. **Slowly increase the START voltage to observe a uniform dark spot within the bright beam.**
3. Use the **ILUDX, Y deflectors** to center the dark spot in the bright beam area in both X and Y directions
    * In another word, maximize the black spot in view.
    * This confirms the beam is exactly perpendicular to the sample surface.

Repeat step 16:

1. Slowly decrease the START voltage but keep the dark spot in sight.
2. Check the MEM-LEEM transition and use ILUDX, Y deflectors to center the dark spot.
3. Further decrease the START voltage and repeat until START voltage reaches the lowest value (low enough value e.g., 0.5V).

Alignment of intermediate column

(1) **1. Find the Optical Axis and set marker**

i. Wobble the Mirror Transfer Lens 1 (MTL1).
ii. Identify the "breathing" center (the point where the image moves least) and set a marker on it.
    * It may be helpful to use a noticeable feature for clearer judgment when finding the breathing center.
    * Feature can be moved to marker using sample manipulator (XY-movements).

(2) **2. Adjust the Sample Tilt (based on marker)**

*** Start voltage is set to 0V when start aligning tilt.**

i. Wobble the Objective Lens to find the breathing center again.
ii. Align the breathing center to the previously set marker, or in another word, minimizing image movement behind the marker.
    * The marker represents the optical axis. Keep in mind that image features may change while aligning the sample tilt.
iii. Once the sample tilt is adjusted, bring a noticeable feature to the center of marker as reference point for future alignment.
    * Adjusting the sample tilt cannot be undone because motors are used to make this movement.
    * Motor can be locked for better motor performance in further alignment, although normally it is kept as partially unlocked.

3. Move the Feature to the Optical Axis

i. After aligning the sample tilt, the marker can be removed from screen to avoid misleading.
ii. Use the feature as your new reference for alignment.

(3)

4. **Wobble Mirror Field Lens 1 (MFL1) and check * A special lens for LEEM alignment (incidence angle will be affected by X-direct alignment)**
   i. **X direction: Outer sel; Y direction: MFL1 Align Y**
      * The separator is adjusted for X-direction alignment, and this might slightly change the incidence direction of the electron beam on the sample surface (not perpendicular anymore).
   ii. Recheck previous steps to confirm the normal incidence if needed.

Repeat step 16, 1, 2 and possibly 3 if needed:

Repeat the steps for perpendicular incidence, finding the optical axis, and adjusting the sample tilt until no further adjustments are needed.

Check and repeat the alignment of all lens until no further adjustments are needed.

----------Decrease FOV ----------

(1)→(16)

1. **Decrease the field of view and repeat over the checking and alignments if needed, until the desired field of view is reached.** FOV can be aligned as UVPEEM (100 µm, then 50 µm, sometimes can try 25 µm), then LEEM (50 µm, 25 µm, 10 µm). The setup inherited from previous week is normally well-aligned, and possibly standby with FOV as 10 µm. Most likely, due to the change of sample, the tilting is the most needed to be aligned.

(S1)

2. **Check the astigmatism of objective lens by adjusting Obj. stigm A, B to observe a sharper image.** One may need to adjust the objective lens to refocus. Since the Obj. stigm is to some extent coupled to illum. Defl, so check that too if using electron gun.
3. **P3 can be used to enlarge the field of view without changing lens alignment**
   i. Record the P3 value beforehand, so that later the value can be typed in to adjust back.

----------Slit and apertures ----------

IA

1. (Not necessary if align for XPEEM) Insertion of illumination aperture (LEEM, LEED)

Location: In the first beam separator, between electron gun and sample

i. Observe the mirror image and move the aperture mechanism
   * The first one is a large hole with diameter 400µm, the second one is 100µm. Move the aperture and try to put it close to the center of the observed image.
   * (Yellow) Allen key might be needed. Don't use too much force when adjusting.
   * This aperture decreases the beam size on the sample, so it improves the quality of LEED and LEEM images.

ii. Check if the aperture is in focus otherwise correct the objective lens a little bit.

iii. After both operations are finished check once more the image column and make corrections if required.

CA

2. Observe the PEEM/LEEM image on the screen and move the contrast aperture CA (LEEM, PEEM)

*** TL value and Diffraction Stigmator (S2) can be used for optimization.**

Tips: One can remember the TL value and increase the TL value for observing image before CA insertion, e.g. 550 to 720 or even up to 800 mA. One can also remember the P3 value (e.g. 2200) and decrease it to have a larger view (e.g. 1700+).

i. A marker can be used on the image to see if the image is moved.

ii. Try to find the image with **30 µm** aperture (or try it with70 µm first) and center it with two screws (**CA motion and CA correction**). To do that, one can try 100 in one direction (step=20), and change to the opposite direction if not found. Decrease the step size and correct it until step = 2.
   * This means that the TL value is set proper and the crossover is in aperture.
   * If the image is partial cut, try to see most of the image and let the shadow of object being uniform if sample surface is not flat.

iii. (Normally not needed) If you are now not able to see the full image without any dark regions regulate a little bit **TL value** and observe behavior of image.

S2

iv. (Normally not needed) During operation with the aperture you can also regulate a little bit the **diffraction stigmators DSTIGA, B**. This should also help if the previous regulation during the observation was not quite correct.

v. (Normally not needed) When this is finished, checks once more the column alignment (there are now new values on TL and perhaps also on DSTIGA, B). If any corrections are required repeat also the procedure with contrast aperture.

* Step iii-v only need to be done occasionally and don't need to do for every alignment. TL and diffraction stigmators are quite constant over time.

Slit

3. Insert the energy selection slit (must in LEEM mode)

* Can be done with UVPEEM but LEEM is easier.

i. You should see a uniformly illuminated image. If not, adjust position in the slit panel, from step=20 to fine step, e.g. step=2.

ii. (Normally not needed) If uniformly illuminated image cannot be achieved, one can try adjusting **P1 value**.

iii. (Normally not needed) Focus the image with FL value if needed.

iv. (Normally not needed) Slit can be inserted for adjusting P2 and P3 to observe a sharp edge in DP mode.

SAA

4. Insert the select area aperture SAA

* The image is enlarged 20 times, so that the real scale of observed sample image is (the size of SAA)/20.

Unlock SAA before changing, lock SAA after finding the good position with observing the image if needed, although normally it is kept as unlocked.

*** The CA is inserted before slit insertion, considering their positions in path.**

----------Modes ----------

Modes

1. Imaging mode (CA must be in, Slit if needed must be inserted in LEEM mode)

Contrast aperture in FL has to be used: reduce aberrations and create a reasonably small virtual entrance slit for the analyzer.

2. Dispersive plane mode (SAA and CA are in, Slit is removed)

Both the selected area and the contrast aperture are inserted to reduce aberrations and to form a virtual entrance slit.

3. μ-ARPES (PEEAD) mode (SAA and Slit are in, CA is removed)

A selected area aperture can be inserted in the sector field: enhances the sharpness of the pattern as well as defines a reasonably small virtual entrance slit for the analyzer.

4. LEED mode (IA and Slit are in, CA is removed)

Slit inserted or not are both fine. Illumination aperture is preferred than selected area aperture.

Modes	SAA	CA	Slit	
Imaging mode (LEEM, PEEM)		☑	☑	*Energy slit must be inserted in LEEM mode. * SAA is normally not inserted when observing full image.
Dispersive plane mode (XPS)	☑	☑		* Slit must be removed for spectrum acquisition.
μ-ARPES (PEEAD)	☑		☑	* CA is not needed when obtaining angular information.
LEED	IA		Y/N	* IA is preferred than SAA so that angular information is not partial cut out.

SAA = Select area aperture; CA = Contrast aperture; Slit = Energy slit; IA = Illumination aperture; Y/N = can remove the slit, PEEAD = photoelectron emission angular distribution.

Frequently used parameters:

Select area aperture = 100 / 50 μm (real image size = SAA/20), Contrast aperture = 30μm, Energy slit = 60 μm, Illumination aperture = 30 μm.

----------Switching modes----------

LEEM – XPEEM

check valve to X-ray, Wehnelt voltage (off), Start Voltage, Value of Objective lens, X-ray alignment, Value of Acc. Lens (normally not needed)

LEEM to LEED

1. **Save the LEEM setting** in case of changing back to imaging mode later, normally with FOV ~ 10 µm.
2. Insert illumination aperture **IA = 30 µm** or other value based on requirements.
3. **Set the Start Voltage to a higher value (e.g. 40 V).**
4. **Set to LEEDMOFF mode.**
5. **Remove Slit. Careful about setting start voltage!**
6. **Remove CA.**
7. **Decrease start voltage accordingly for measurement while observing LEED pattern.**
8. Use **P3'x and y deflectors** to centralize LEED pattern.
9. **Normal incidence might be changed and needs to be checked.**
10. Use the **diffraction stigmator** to make the pattern circle. One can use the marker generated by clicking three points to guide eyes. However, this step might make the (0, 0) being away from the center of LEED pattern.
11. **Alignments on lenses after Field Lens need to be checked.** Try to centralize the (0, 0) dot in pattern. If all the lenses are aligned well but the (0, 0) is still not in the center, one can use RI'x and y deflectors (without toggle Inner Lens) to manually centralize the (0, 0).

* The plot can be visualized with LEED(log) mode for clearer judgement.

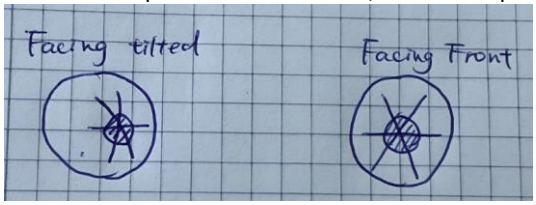
LEEM to ARPES

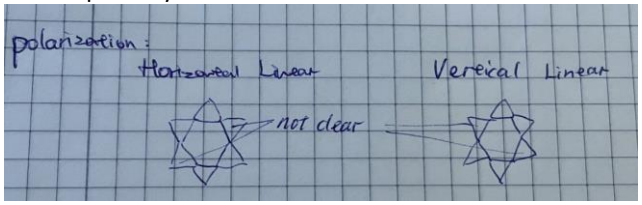
LEED = electron gun + LEEDMOFF mode; ARPES = X-ray + LEEDMOFF mode

* If coming from LEED mode, remember to remove illumination aperture.

1. **Save the LEEM setting** in case of changing back to imaging mode later, normally with FOV ~ 10 µm.
2. **Insert SAA (100/50 µm) in LEEM mode.**
3. **Set to LEEDMOFF mode.**
4. **Insert Slit (25 µm) in LEED mode.**
5. **Remember to turn off the electron gun and check the X-ray alignment.**
6. The patten should be like facing front instead of tilted. **Toggle IL** (which is most important for facing front) and **P1** for optimization. Adjustments on **P1's value**, **acc. Lens' value** might also be needed. Alignment on Ana. Stigmators is normally not needed.
7. **Toggle Acc. Lens and correct it with Sel+/-.**
8. Toggle Sel+/- and correct it with Acc. Lens when slit is not in the path, otherwise with very small amplitude for toggle or skip this step.
9. The start voltage can be adjusted accordingly for measurement.

* Due to the polarization of beam, the ARPES patten will be partially unclear.





LEEM to DP mode

1. **Save the LEEM setting** in case of changing back to imaging mode later, normally with FOV ~ 10 µm.
2. **Insert SAA (100/50 µm) in LEEM mode.**
3. **Set the Start Voltage to desired values if known**, e.g. (Pt4f) hv=250 eV with peaking at STV=174.6 and 171.6 V. **Or set the Start Voltage to a higher value if targeting at secondary electron**, e.g. (Au WF) hv=150 eV, STV = 40 V and later (after finishing rest of steps) decreases to 9 V for measuring work function.
4. **Set to D.P. mode.**
5. **Adjust P2 value and P3' x and y deflectors to observe the sharp edge of slit.**
6. **Remove Slit. Careful about setting start voltage!**
7. Remember to turn off the electron gun and check the X-ray alignment. X-ray alignment (M1_pitch) can be done with viewing DP signals if M4 alignment has been checked.

----------Changing sample ----------

* Turn off the high voltage rack before changing sample!!! **CAREFUL!!!**

One can change back to LEEM or XPEEM mode for checking if the beam or targeted area are still in position.

* Remove slit and apertures.
* Close valve to beam, turn off electron gun (-290 V) and iris of UV lamp accordingly.
* When inserting or removing sample from manipulator in main chamber, always remember to initialize the position (X, Y) and tilt of manipulator to 0. (X, Y, tilt = 0) Double check the value in software and manipulator head physically.
* Before moving transfer arm, remember to check the location of holder in prep chamber (not hit it), and open the valve between prep chamber and main chamber. Always be aware of the location of transfer arm and the objects in the path that it may pass through.
* If the microscope has been aligned, most likely the alignment is good enough for measurements after correcting the sample tilt.
* The standby mode generally is FOV = 10 µm and STV = 0V.

----------Other ----------

***Notes for motor in prep chamber:** The motor will not stop automatically. Always double check if the motor is safe to move so that transfer arm will not be bent. Always pay attention to the current location of holder: ~ 155 for Ar_2, ~ 286 for bottom location.

Notes for contrast aperture: If image is cut after insertion of contrast aperture, it means the aperture location deviates from BFP. Adjust TL value in PEEM mode, since illumination optics in LEEM mode can change BFP.

Notes for FOV: If the intermediate column, imaging column, energy analyzer and projection system have been aligned with XPEEM with small field of view and small apertures inserted, no further adjustment on those is needed. In another word, they have been aligned well and only the illumination optics need alignment with electron gun.
But if only UV-PEEM with large field of view have been used for alignment (field of view > 50 µm due to weak image intensity), intermediate column, imaging column, energy analyzer and projection system need to be realigned with electron gun (field of view < 50 µm). The detailed steps refer to UV-PEEM alignment.
If FOV is changed, most likely lens includes FL and afterwards need alignment.

Notes for electron gun setting: emission current as 0.11 µA is normally enough for measurements.

Notes for electron lens: If the current lens accidentally changes 20% higher or lower, the previous found current values of lens need to be double checked due to hysteresis.

Notes for objective lens: Value of objective lens is important for imaging mode, but not important for DP or diffraction mode.