Standard Operating Procedures

Small Sputtering Machine

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With revisions by:
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Important

- Gloves should be worn while handling anything going in vacuum to reduce contamination.
- You can only use CeNSE laboratories and equipment if you have been approved by Brian, reserved the tool on the calendar, and filled out a reservation form. No Exceptions!
- If the equipment is acting unusual STOP! Place the instrument in the normal standby mode. Leave a note on the machine. Then please discuss with Brian before proceeding.
- Any accidental damage must be reported immediately.
- All CeNSE laboratories are protected by video surveillance.

Machine Exterior

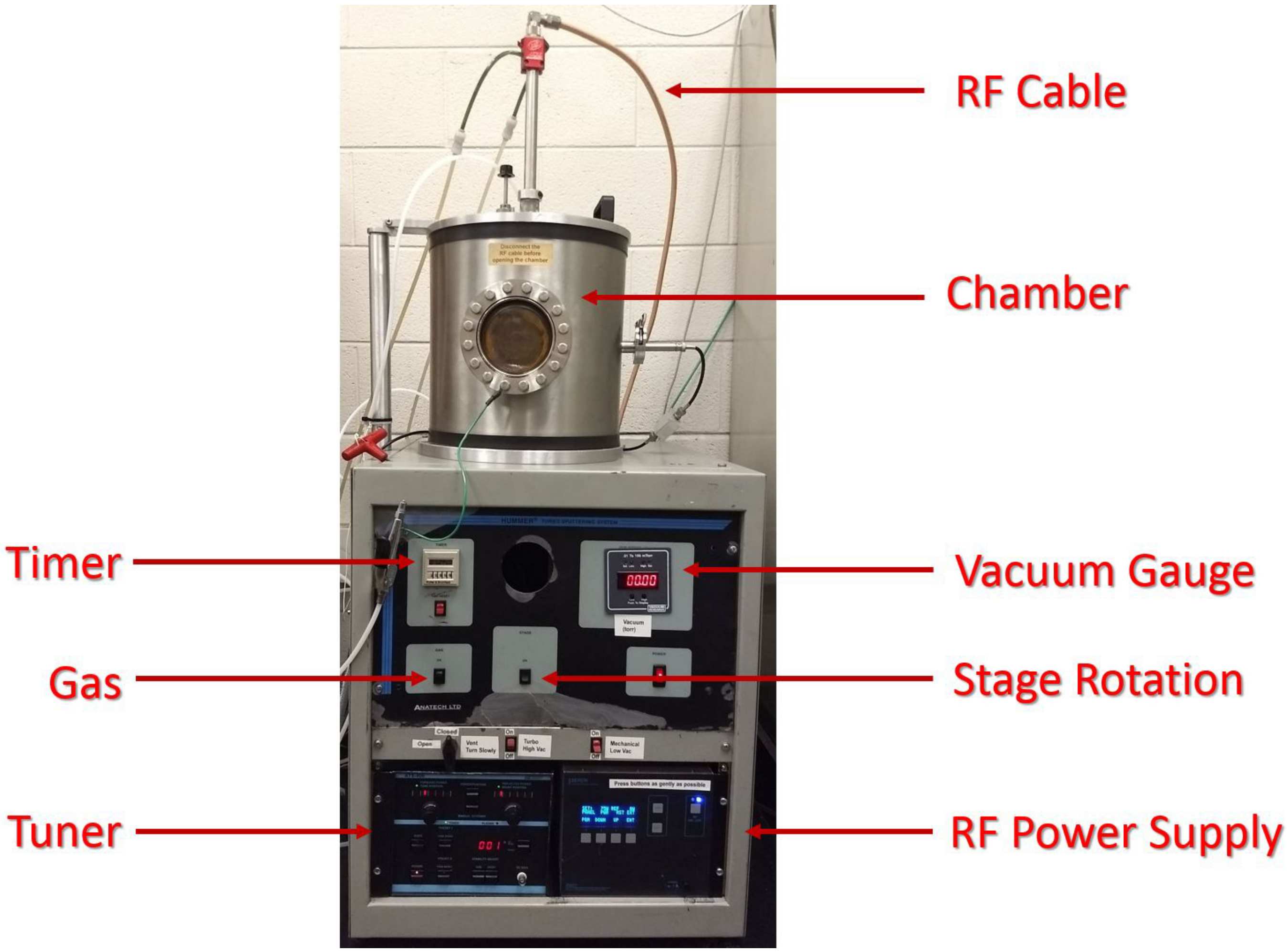


Figure 1 Machine exterior

Figure 1a Power and tuning controls

Figure 1b Gas control

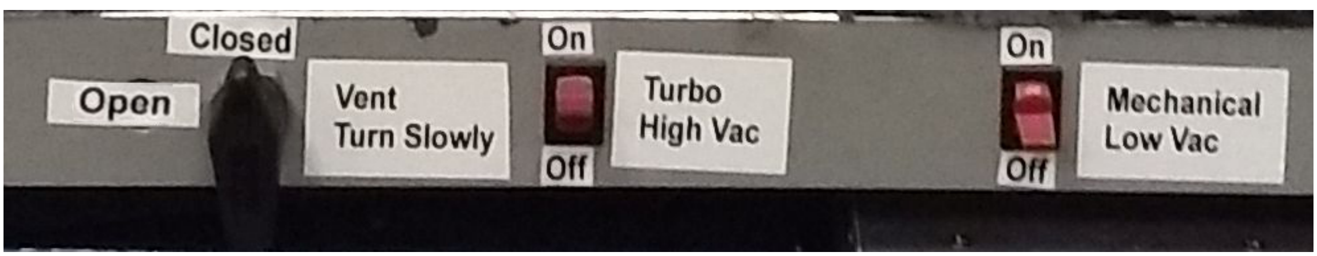


Figure 1c Vent and Pump panel

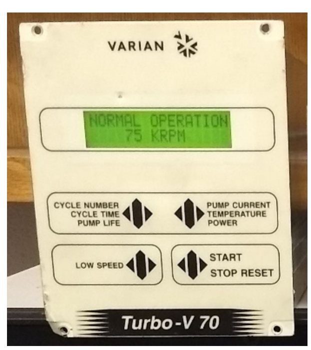


Figure 1d Turbo Pump controller

Other Parts of the Machine

Figure 2a Top of chamber

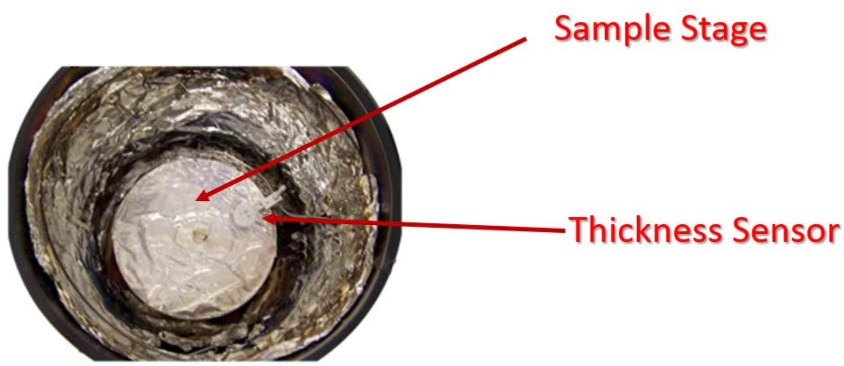


Figure 2b Inside of Chamber

Figure 2c Thickness Monitor

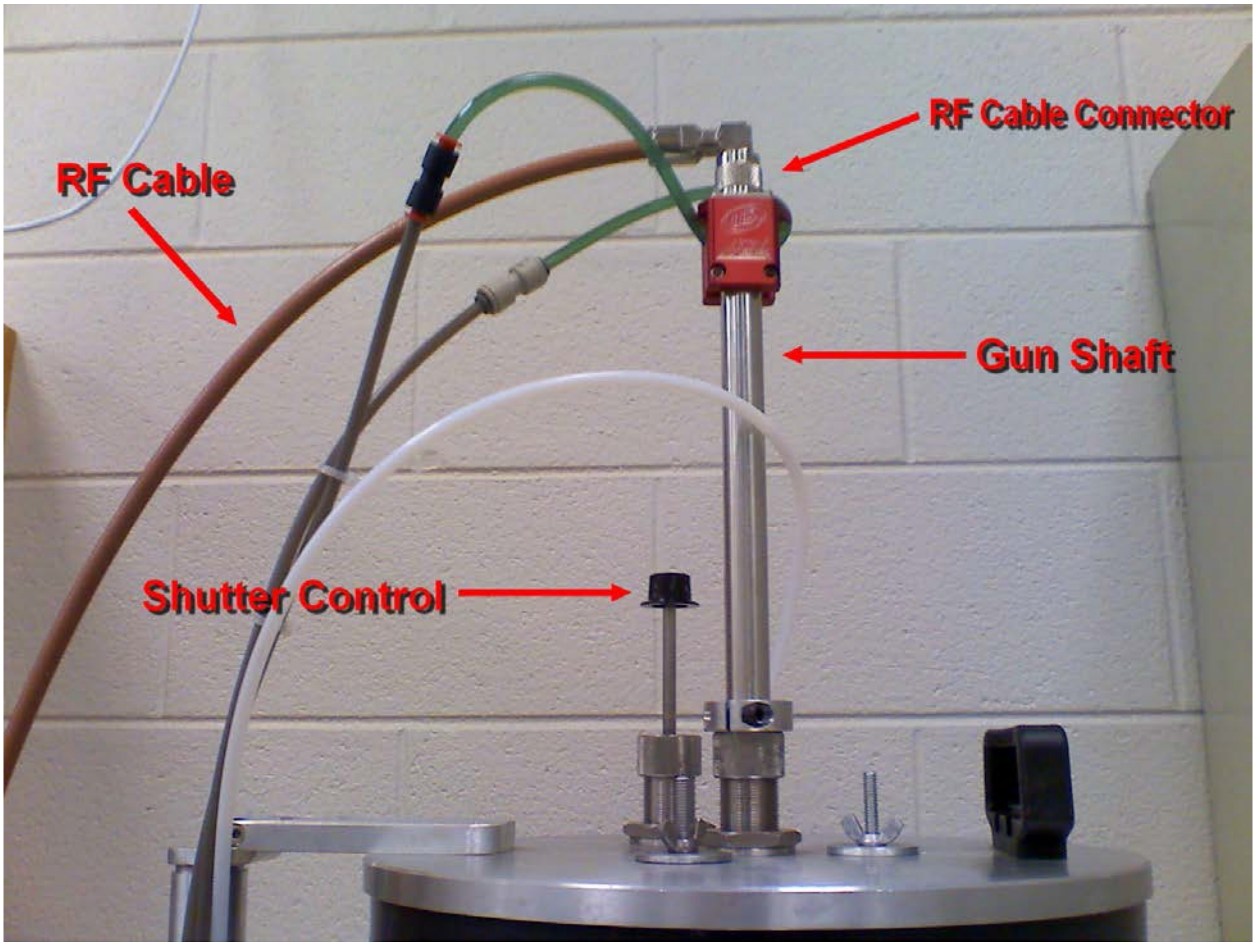


Figure 2d Chamber lid

Operating Procedure

1. Preparation

1.1. Before beginning, be sure to wear gloves to reduce contamination and to protect the hands.

2. Load the sample and target

2.1. Venting the System:

2.1.1. Disable the turbo pump by flipping the switch downward on the main panel (figure 1c). Wait about a minute before proceeding.

2.1.2. Open the vent valve (figure 1c)

2.1.3. Disable the rough pump by flipping the switch downward on the main panel (figure 1c).

2.1.4. Look through the chamber window and ensure that the shutter is directly below the gun; if it is not, the shutter will collide with the chamber wall when opening the lid.

2.1.5. Wait until the chamber is vented. There will be no obvious signs, but the chamber lid will not open if the chamber is not fully vented. Venting time is typically between 2-5 minutes.

2.1.6. Turn off the venting gas (Figure 1c)

2.1.7. Using a step ladder, unscrew the RF cable (Figure 2d). Place the cable out of the way.

2.1.8. Grab the chamber lid handle and open the chamber lid completely; it will sit upside-down on its own pole.

2.2. Load the sample and target

2.2.1. Place the sample on the stage inside the chamber (figure 2b). Ensure that the side on which the deposition will take place is facing upwards.

2.2.2. Before placing your target on the gun, check to make sure there is thermal paste on the copper cathode. The proper amount is thin enough to cover it completely but, it should not be completely opaque. You should still be able to see the copper color through the gray paste.

2.2.3. Place your target on the gun, with the magnetic keeper facing the gun (figure 2a).

2.3. Pumping down the chamber:

2.3.1. Close the chamber lid using the handle. The lid is centered over the chamber the lid sticks out all the way around the chamber rim.

2.3.2. Replace the RF cable (Figure 2d).

2.3.3. Turn on the rough pump by flipping the switch upward on the main panel (figure 1c).

2.3.4. Wait until the vacuum gauge turns on. The blinking of "0000" will stop and numbers will be present. Turn on the turbo pump by flipping the switch upward (figure 1c).

3. Configure the deposition (figure 2c)

3.1. Set the deposition thickness:

3.1.1. Press and hold the thickness button on the deposition monitor.

3.1.2. Use the increase and decrease buttons to set the desired thickness.

3.2. Set the material density:

3.2.1. Use the chart in Appendix A to find the density of the deposition material.

3.2.2. Press and hold the density button on the deposition monitor.

3.2.3. Use the increase and decrease buttons to set the density (figure 2c).

3.3. Set the material's acoustic impedance:

3.3.1. Use the chart in Appendix A to find the acoustic impedance of the deposition material.

3.3.2. Press and hold the acoustic impedance button on the deposition monitor (figure 2c).

3.3.3. Use the increase and decrease buttons to set the density (figure 2c).

3.4. Set the tooling factor:

3.4.1. Tooling factor must be found experimentally and varies by material. See Appendix B

3.4.2. Press and hold the tooling factor % button on the deposition monitor (figure 2c).

3.4.3. Use the increase and decrease buttons to set the tooling factor (figure 2c).

3.5. Press the start button on the deposition monitor. Note shutter open light should be on.

4. Set the RF output power (figure 1a)

4.1. Press the up arrow to increase or down arrow to decrease (figure 1a) the RF power wattage. If you aren't sure, 75watts is a good place to start.

5. Set the gas flow (figure 1b)

5.1. Edit the gas flow if necessary. 30sccm is default. Status of on is default. If no change is necessary, skip to step 6

5.1.1. Press the ←→ buttons on the gas controller to highlight the setpoint of Channel 5.

5.1.2. Use the ↓↑ buttons to adjust gas flow.

5.1.3. Press the ←→ buttons on the gas controller to highlight the status of Channel 5.

5.1.4. Use the ↓↑ buttons to change to on.

6. Start the sputtering process

6.1. Ensure that the valve is open on the argon tank. Open it by turning the grey knob at the top clockwise.

6.2. Turn on the "gas" switch. (figure 1)

6.3. Wait for the vacuum to stabilize inside the chamber.

6.4. Turn on the "stage" switch for an isotropic effect. This will to allow the stage to rotate creating better step coverage and be more conformal to the sample topography (default). When this isn't desired, such as in a lift-off process, this can be left off. (figure 1)

6.5. Check the RF source display for the letters "EXT" are not present to ensure the interlocks are open (Figure 1a).

6.6. Press the "RF" button (Figure 1a) to start the plasma.

6.7. Pre-sputter with the shutter closed to remove surface contaminants from the target. 1-2 minutes is usually a good amount of time. The vacuum level should be stable.

6.8. When you are ready to begin, turn the shutter fully clockwise open (figure 2d), and quickly press start again on the deposition monitor to re-zero the measurement. The thickness monitor will automatically turn off the RF power when the desired thickness is reached.

7. End the sputtering process (Figure 1)
   7.1. Turn off components, in this order:
   7.2. Turn off the gas:
      7.2.1. Turn off the “gas” switch.
      7.2.2. Turn off the gas flow (figure 1b)
      7.2.3. Close the valve on the argon tank.
   7.3. Turn off the “stage” switch
   7.4. Turn off the turbo pump and wait about a minute before proceeding to the next step.
   7.5. Slowly open the venting gas by rotating to the horizontal position.
   7.6. Turn off the rough pump.
   7.7. Move the shutter back over the gun.
   7.8. Wait for the chamber to pressurize.
   7.9. Rotate the vent knob to the vertical position. This will turn off the venting gas.
   7.10. Open the chamber lid. Look through the chamber window and ensure that the shutter is directly below the gun; if it is not, the shutter will collide with the chamber wall when opening the lid.
   7.11. Unload the sample if you are done with it (using gloves).
   7.12. If it is no longer needed, remove the target and put it back in its container. If necessary, carefully use the tool that is attached to the machine to pry it out. Be careful to not scratch the gun.
   7.13. Close the chamber lid using the handle. The lid is centered over the chamber the lid sticks out all the way around the chamber rim.
   7.14. Pump down the chamber as in step 2.3

Appendix A: Material Properties

Use the chart below[1] to find the properties of the deposition material for step 3 in the Operating Procedure.

Formula	Density	Z-Ratio	Acoustic Impedance	Material Name
Ag	10.5	0.529	16.69	Silver
AgBr	6.47	1.18	7.48	Silver Bromide
AgCl	5.56	1.32	6.69	Silver Chloride
Al	2.70	1.08	8.18	Aluminum
Al2O3	3.97	0.336	26.28	Aluminum Oxide
Al4C3	2.36	?		Aluminum Carbide
AlF3	3.07	?		Aluminum Fluoride
AlN	3.26	?		Aluminum Nitride
AlSb	4.36	0.743	11.88	Aluminum Antimonide
As	5.73	0.966	9.14	Arsenic
As2Se3	4.75	?		Arsenic Selenide
Au	19.3	0.381	23.18	Gold
B	2.37	0.389	22.70	Boron
B2O3	1.82	?		Boron Oxide
B4C	2.37	?		Boron Carbide
BN	1.86	?		Boron Nitride
Ba	3.5	2.1	4.20	Barium
BaF2	4.886	0.793	11.13	Barium Fluoride
BaN2O6	3.244	1.261	7.00	Barium Nitrate
BaO	5.72	?		Barium Oxide
BaTiO3	5.999	0.464	19.03	Barium Titanate (Tetr)
BaTiO3	6.035	0.412	21.43	Barium Titanate (Cubic)
Be	1.85	0.543	16.26	Beryllium
BeF2	1.99	?		Beryllium Fluoride
BeO	3.01	?		Beryllium Oxide
Bi	9.8	0.79	11.18	Bismuth
Bi2O3	8.9	?		Bismuth Oxide
Bi2S3	7.39	?		Bismuth Trisuiphide
Bi2Se3	6.82	?		Bismuth Selenide

[1] SQM-160 User's Guide, Version 4.06. Sigma Instruments, Inc. 2000-2008.

Formula	Density	Z-Ratio	Acoustic Impedance	Material Name
Bi2Te3	7.7	?		Bismuth Telluride
BiF3	5.32	?		Bismuth Fluoride
C	2.25	3.26	2.71	Carbon (Graphite)
C	3.52	0.22	40.14	Carbon (Diamond)
C8H8	1.1	?		Parlyene (Union Carbide)
Ca	1.55	2.62	3.37	Calcium
CaF2	3.18	0.775	11.39	Calcium Fluoride
CaO	3.35	?		Calcium Oxide
CaO-SiO2	2.9	?		Calcium Silicate (3)
CaSO4	2.962	0.955	9.25	Calcium Sulfate
CaTiO3	4.1	?		Calcium Titanate
CaWO4	6.06	?		Calcium Tungstate
Cd	8.64	0.682	12.95	Cadmium
CdF2	6.64	?		Cadmium Fluoride
CdO	8.15	?		Cadmium Oxide
CdS	4.83	1.02	8.66	Cadmium Sulfide
CdSe	5.81	?		Cadmium Selenide,
CdTe	6.2	0.98	9.01	Cadmium Telluride
Ce	6.78	?		Cerium
CeF3	6.16	?		Cerium (III) Fluoride
CeO2	7.13	?		Cerium (IV) Dioxide
Co	8.9	0.343	25.74	Cobalt
CoO	6.44	0.412	21.43	Cobalt Oxide
Cr	7.2	0.305	28.95	Chromium
Cr2O3	5.21	?		Chromium (III) Oxide
Cr3C2	6.68	?		Chromium Carbide
CrB	6.17	?		Chromium Boride
Cs	1.87	?		Cesium
Cs2SO4	4.243	1.212	7.29	Cesium Sulfate
CsBr	4.456	1.41	6.26	Cesium Bromide
CsCl	3.988	1.399	6.31	Cesium Chloride
CsI	4.516	1.542	5.73	Cesium Iodide
Cu	8.93	0.437	20.21	Copper
Cu2O	6	?		Copper Oxide
Cu2S	Cu2S	5.6	1.58	Copper (I) Sulfide (Alpha)
Cu2S	Cu2S	5.8	1.52	Copper (I) Sulfide (Beta)
CuS	CuS	4.6	1.92	Copper (II) Sulfide
Dy	Dy	8.55	1.03	Dysprosium
Dy2O3	Dy2O3	7.81	1.13	Dysprosium Oxide
Er	Er	9.05	0.98	Erbium

Formula	Density	Z-Ratio	Acoustic Impedance	Material Name
Er2O3	Er2O3	8.64	1.02	Erbium Oxide
Eu	Eu	5.26	1.68	Europium
EuF2	EuF2	6.5	1.36	Europium Fluoride
Fe	7.86	0.349	25.30	Iron
Fe2O3	5.24	?		Iron Oxide
FeO	5.7	?		Iron Oxide
FeS	4.84	?		Iron Sulphide
Ga	5.93	0.593	14.89	Gallium
Ga2O3	5.88	?		Gallium Oxide (B)
GaAs	5.31	1.59	5.55	Gallium Arsenide
GaN	6.1	?		Gallium Nitride
GaP	4.1	?		Gallium Phosphide
GaSb	5.6	?		Gallium Antimonide
Gd	7.89	0.67	13.18	Gadolinium
Gd2O3	7.41	?		Gadolinium Oxide
Ge	5.35	0.516	17.11	Germanium
Ge3N2	5.2	?		Germanium Nitride
GeO2	6.24	?		Germanium Oxide
GeTe	6.2	?		Germanium Telluride
Hf	13.09	0.36	24.53	Hafnium
HfB2	10.5	?		Hafnium Boride,
HfC	12.2	?		Hafnium Carbide
HfN	13.8	?		Hafnium Nitride
HfO2	9.68	?		Hafnium Oxide
HfSi2	7.2	?		Hafnium Silicide
Hg	13.46	0.74	11.93	Mercury
Ho	8.8	0.58	15.22	Holminum
Ho2O3	8.41	?		Holminum Oxide
In	7.3	0.841	10.50	Indium
In2O3	7.18	?		Indium Sesquioxide
In2Se3	5.7	?		Indium Selenide
In2Te3	5.8	?		Indium Telluride
InAs	5.7	?		Indium Arsenide
InP	4.8	?		Indium Phosphide
InSb	5.76	0.769	11.48	Indium Antimonide
Ir	22.4	0.129	68.45	Iridium
K	0.86	10.189	0.87	Potassium
KBr	2.75	1.893	4.66	Potassium Bromide
KCl	1.98	2.05	4.31	Potassium Chloride
KF	2.48	?		Potassium Fluoride

Formula	Density	Z-Ratio	Acoustic Impedance	Material Name
KI	3.128	2.077	4.25	Potassium Iodide
La	6.17	0.92	9.60	Lanthanum
La2O3	6.51	?		Lanthanum Oxide
LaB6	2.61	?		Lanthanum Boride
LaF3	5.94	?		Lanthanum Fluoride
Li	0.53	5.9	1.50	Lithium
LiBr	3.47	1.23	7.18	Lithium Bromide
LiF	2.638	0.778	11.35	Lithium Fluoride
LiNbO3	4.7	0.463	19.07	Lithium Niobate
Lu	9.84	?		Lutetium
Mg	1.74	1.61	5.48	Magnesium
MgAl2O4	3.6	?		Magnesium Aluminate
MgAl2O6	8	?		Spinel
MgF2	3.18	0.637	13.86	Magnesium Fluoride
MgO	3.58	0.411	21.48	Magnesium Oxide
Mn	7.2	0.377	23.42	Manganese
MnO	5.39	0.467	18.91	Manganese Oxide
MnS	3.99	0.94	9.39	Manganese (II) Sulfide
Mo	10.2	0.257	34.36	Molybdenum
Mo2C	9.18	?		Molybdenum Carbide
MoB2	7.12	?		Molybdenum Boride
MoO3	4.7	?		Molybdenum Trioxdide
MoS2	4.8	?		Molybdenum Disulfide
Na	0.97	4.8	1.84	Sodium
Na3AlF6	2.9	?		Cryolite
Na5AL3F14	2.9	?		Chiolite
NaBr	3.2	?		Sodium Bromide
NaCl	2.17	1.57	5.62	Sodium Chloride
NaClO3	2.164	1.565	5.64	Sodium Chlorate
NaF	2.558	0.949	9.30	Sodium Fluoride
NaNO3	2.27	1.194	7.40	Sodium Nitrate
Nb	8.578	0.492	17.95	Niobium (Columbium)
Nb2O3	7.5	?		Niobium Trioxide
Nb2O5	4.47	?		Niobium (V) Oxide
NbB2	6.97	?		Niobium Boride
NbC	7.82	?		Niobium Carbide
NbN	8.4	?		Niobium Nitride
Nd	7	?		Neodynium
Nd2O3	7.24	?		Neodynium Oxide
NdF3	6.506	?		Neodynium Fluoride

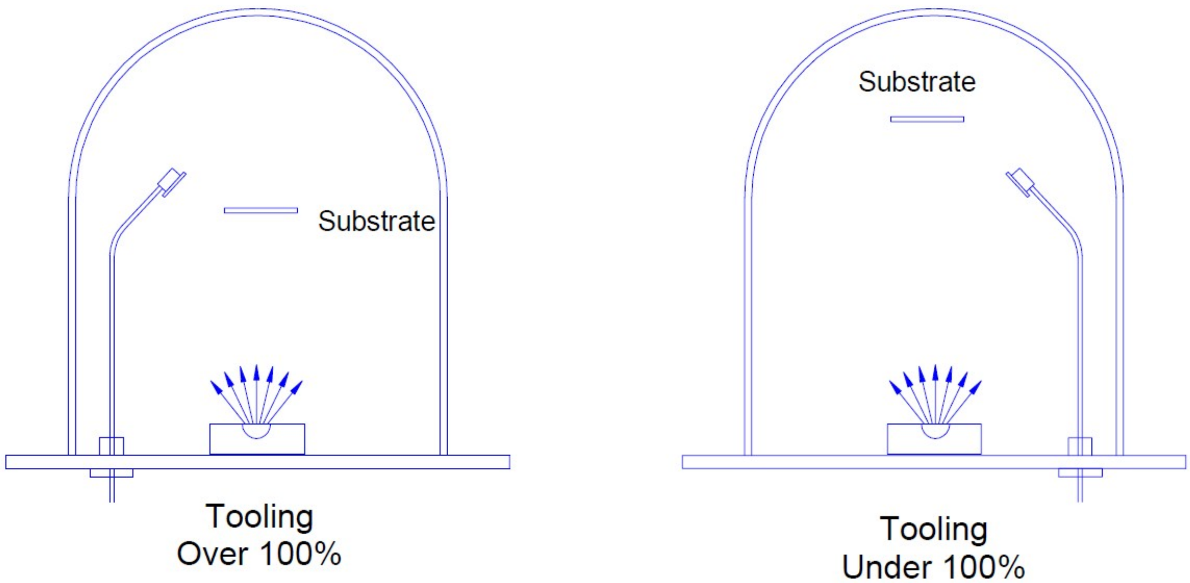
Formula	Density	Z-Ratio	Acoustic Impedance	Material Name
Ni	8.91	0.331	26.68	Nickel
NiCr	8.5	?		Nichrome
NiCrFe	8.5	?		Inconel
NiFe	8.7	?		Permalloy
NiFeMo	8.9	?		Supermalloy
NiO	7.45	?		Nickel Oxide
P3N5	2.51	?		Phosphorus Nitride
Pb	11.3	1.13	7.81	Lead
PbCl2	5.85	?		Lead Chloride
PbF2	8.24	0.661	13.36	Lead Fluoride
PbO	9.53	?		Lead Oxide
PbS	7.5	0.566	15.60	Lead Sulfide
PbSe	8.1	?		Lead Selenide
PbSnO3	8.1	?		Lead Stannate
PbTe	8.16	0.651	13.56	Lead Telluride
Pd	12.038	0.357	24.73	Palladium
PdO	8.31	?		Palladium Oxide
Po	9.4	?		Polonium
Pr	6.78	?		Praseodymium
Pr2O3	6.88	?		Praseodymium Oxide
Pt	21.4	0.245	36.04	Platinum
PtO2	10.2	?		Platinum Oxide
Ra	5	?		Radium
Rb	1.53	2.54	3.48	Rubidium
RbI	3.55	?		Rubidium Iodide
Re	21.04	0.15	58.87	Rhenium
Rh	12.41	0.21	42.05	Rhodium
Ru	12.362	0.182	48.52	Ruthenium
S8	2.07	2.29	3.86	Sulphur
Sb	6.62	0.768	11.50	Antimony
Sb2O3	5.2	?		Antimony Trioxide
Sb2S3	4.64	?		Antimony Trisulfide
Sc	3	0.91	9.70	Scandium
Sc2O3	3.86	?		Scandium Oxide
Se	4.81	0.864	10.22	Selenium
Si	2.32	0.712	12.40	Silicon
Si3N4	3.44	*1000		Silicon Nitride
SiC	3.22	?		Silicon Carbide
SiO	2.13	0.87	10.15	Silicon (II) Oxide
SiO2	2.648	1	8.83	Silicon Dioxide

Formula	Density	Z-Ratio	Acoustic Impedance	Material Name
Sm	7.54	0.89	9.92	Samarium
Sm2O3	7.43	?		Samarium Oxide
Sn	7.3	0.724	12.20	Tin
SnO2	6.95	?		Tin Oxide
SnS	5.08	?		Tin Sulfide
SnSe	6.18	?		Tin Selenide
SnTe	6.44	?		Tin Telluride
Sr	2.6	?		Strontium
SrF2	4.277	0.727	12.15	Strontium Fluroide
SrO	4.99	0.517	17.08	Strontium Oxide
Ta	16.6	0.262	33.70	Tantalum
Ta2O5	8.2	0.3	29.43	Tantalum (V) Oxide
TaB2	11.15	?		Tantalum Boride
TaC	13.9	?		Tantalum Carbide
TaN	16.3	?		Tantalum Nitride
Tb	8.27	0.66	13.38	Terbium
Tc	11.5	?		Technetium
Te	6.25	0.9	9.81	Tellurium
TeO2	5.99	0.862	10.24	Tellurium Oxide
Th	11.694	0.484	18.24	Thorium
ThF4	6.32	?		Thorium (IV) Fluoride
ThO2	9.86	0.284	31.09	Thorium Dioxide
ThOF2	9.1	?		Thorium Oxyfluoride
Ti	4.5	0.628	14.06	Titanium
Ti2O3	4.6	?		Titanium Sesquioxide
TiB2	4.5	?		Titanium Boride
TiC	4.93	?		Titanium Carbide
TiN	5.43	?		Titanium Nitride
TiO	4.9	?		Titanium Oxide
TiO2	4.26	0.4	22.08	Titanium (IV) Oxide
Tl	11.85	1.55	5.70	Thallium
TlBr	7.56	?		Thallium Bromide
TlCl	7	?		Thallium Chloride
TlI	7.09	?		Thallium Iodide (B)
U	19.05	0.238	37.10	Uranium
U3O8	8.3	?		Tri Uranium Octoxide
U4O9	10.969	0.348	25.37	Uranium Oxide
UO2	10.97	0.286	30.87	Uranium Dioxide
V	5.96	0.53	16.66	Vanadium
V2O5	3.36	?		Vanadium Pentoxide

Formula	Density	Z-Ratio	Acoustic Impedance	Material Name
VB2	5.1	?		Vanadium Boride
VC	5.77	?		Vanadium Carbide
VN	6.13	?		Vanadium Nitride
VO2	4.34	?		Vanadium Dioxide
W	19.3	0.163	54.17	Tungsten
WB2	10.77	?		Tungsten Boride
WC	15.6	0.151	58.48	Tungsten Carbide
WO3	7.16	?		Tungsten Trioxide
WS2	7.5	?		Tungsten Disulphide
WSi2	9.4	?		Tungsten Suicide
Y	4.34	0.835	10.57	Yttrium
Y2O3	5.01	?		Yttrium Oxide
Yb	6.98	1.13	7.81	Ytterbium
Yb2O3	9.17	?		Ytterbium Oxide
Zn	7.04	0.514	17.18	Zinc
Zn3Sb2	6.3	?		Zinc Antimonide
ZnF2	4.95	?		Zinc Fluoride
ZnO	5.61	0.556	15.88	Zinc Oxide
ZnS	4.09	0.775	11.39	Zinc Sulfide
ZnSe	5.26	0.722	12.23	Zinc Selenide
ZnTe	6.34	0.77	11.47	Zinc Telluride
Zr	6.49	0.6	14.72	Zirconium
ZrB2	6.08	?		Zirconium Boride
ZrC	6.73	0.264	33.45	Zirconium Carbide
ZrN	7.09	?		Zirconium Nitride
ZrO2	5.6	?		Zirconium Oxide

Appendix B: Tooling Factor

What is Tooling Factor? Tooling Factor is a correction for the difference in material deposited on the quartz sensor versus the substrate. Illustrated below is an example of how difference in distance between the sensor and substrate causes an incorrect reading as you would see in an electron or thermal evaporation system. It is impossible to place a sensor in exactly the same place as your substrate unless the sensor is your substrate.



How do I determine Tooling Factor?

1. Place your substrate and a sensor in their normal position. Mask part of the substrate with a thin material. Thinner is better (i.e. microscope cover glass).
2. Set Tooling to an approximate value or if unknown use 100. ($Tooling_{Approximate}$)
3. Set Density and Z-Factor for your material.
4. Deposit 1000Å or more of material. ($Thickness_{QCM}$)
5. Use a profilometer or AFM to measure the substrate's actual film thickness. ($Thickness_{Actual}$)
6. The Tooling Factor is calculated by:

$$Tooling_{Actual} = Tooling_{Approximate} \frac{Thickness_{Actual}}{Thickness_{QCM}}$$

7. Repeated this procedure a second or third time for increased accuracy.

For example

You want to deposit 250nm of Al. We have no idea what a good tooling factor is so we use 100 (which is equivalent to uncorrected) as the approximate tooling factor. We deposit what the thickness monitor tells us is 250nm, but measurement with a profilometer says you actually deposited 157nm. This gives us a tooling factor of 62.8

$$62.8 = 100 \times \frac{157}{250}$$

But we need our deposition to be even more precise therefore repeat the procedure. However we now know that the tooling factor is 62.8 so we use that as our approximate tooling factor and entered it on the thickness monitor. Again we deposit what the thickness monitor says is 250nm. This time the profiler tells us the actual deposition was 263nm. So to calculate an improved tooling factor we enter

$$71.7 = 68.2 \times \frac{263}{250}$$

This gives us a tooling factor of 71.7. You can continue to improve the tooling factor by repeating the process until a satisfactory accuracy is achieved.

When should I check the tooling factor?

1. When accuracy is critical.
2. When the target (source) material, substrate (sample), or detector placement has changed.
3. Large changes to chamber pressure, power, or material density from previous tooling correction.
    a. **I thought the purpose of the tooling factor is a correction for placement of the sensor vs. sample?**
        1. It is. Unfortunately other parameters can affect the deposition in other ways. For example while a plasma magnetron sputter system is considered fairly isotropic in nature. This often confuses users in to thinking the deposition thickness does not vary spatially with distance from the center. However the plasma is actually focused. Changes to power, pressure and material change the path of source atoms / molecules in their flight to the substrate.
        2. If a deposition source did act like a perfect point source, the entire sample stage would have to be hemispherically shaped to keep the distance from the source constant.

Appendix C: Pump / Vent sequence

There is danger of serious damage if pumping and venting of the system is done out of sequence. The good news it's very easy. High vacuum pumps can only work when there is a low vacuum pump on. The basic pump and vent schemes are below (RF cables, process gasses, etc. not included)

Pump down Sequence:

1. **Turn the Mechanical pump (low vac) on.**
2. **Wait for any reading on the vacuum gauge. A blinking "0000" means vacuum is to poor to read. It won't read until vacuum is 1000mtorrr or lower.**
3. **Turn on the Turbo (high vac) pump. Wait for a stable reading and proceed.**

Vent sequence:

1. **Turn off Turbo pump (high vac).**
2. **Slowly open the vent valve. You will hear a whining sound like a jet engine being turned off. Wait until you don't hear it any more.**
3. **Turn off the Mechanical pump (low vac)**
4. **Once you can open the lid, close the vent valve.**