The sputtering machine, shown in Fig. 1, consists of a stainless steel chamber with a full opening front door and three sputter (2 in.) flex magnetron guns suspended from the top of the chamber. The chamber is normally evacuated and then partially filled with nitrogen gas to about 1-2 torr (mm of Hg) so as to keep it clean. Maintaining cleanliness is very important—one should never touch the inside with bare hands because oils will be absorbed from one’s skin and it will take a long time to pump them back out.

Provisions are provided for holding three targets in the guns on the top. The targets are disks of pure metal (e.g., copper, silver, and iron) having a diameter of about 5 cm and a thickness of about 0.5 cm. The target of interest is held at high voltage and there is a large electric field in the chamber that strips electrons off of the argon atoms, which are provided from an adjoining argon gas tank. The resulting argon ions are accelerated; they bombard the target thereby releasing all their kinetic energy to the metal. That ends up sending target atoms into the chamber and onto the sample being coated (the substrate). So if the substrate is near the target, it will get coated with a spray of atoms. In this machine, the geometry is not very good as the guns are equally spaced around a circle on top of the chamber and the target is centrally spaced on the bottom of the chamber. Hence each gun sprays the substrate at an angle. To offset this effect, a provision has been made for continuously rotating the substrate.
Getting Started
The first thing to do is check that the building air inlet valve to the chamber is in the open position (handle parallel to outlet line), where it normally remains. It provides high-pressure air which operates the pneumatic valves that control the flow of gases into the chamber. Next turn on the electrical power to the entire unit using the toggle switch on the lower left (far) side of the main chassis. When the ion beam hits the target, it releases a lot of heat, something like between 100 to 1000 W (depending on the power supply settings), and that heat has to be removed. In this case, that goal is achieved through a combination of conduction and water cooling. One does not want building water flowing through the machine directly since mineral deposits will build up over time.

Hence this system, shown in Fig. 2, uses a self-contained, closed secondary system of distilled water that circulates through the machine and then through an external heat exchanger (bucket). A copper coil thereby is placed in a bucket and building water then circulates through the coil thereby carrying the heat away from the system. To get the circulation pump going you flip the switch on the wooden panel to the upper left of the pump. Turn on the building water by rotating the valve handle on the wall next to where the water pipe enters the room. Verify that the water is circulating at a pressure of 50 psi and 1.5 gpm of flow. Turn on the digital temperature gauge (Fluke meter and probe) which is provided for monitoring the water temperature during the deposition process. Should it suddenly start to rise, there may be a malfunction that could lead to a "melt down." When the deposition process is going on, the cooling water should stay well below room temperature (about 20°C); if it rises much above that, the procedure should be aborted.

Venting the Chamber to Atmospheric Pressure
Since the chamber is kept at partial vacuum when not in use, the first thing one needs to do is bring it up to atmospheric pressure. Consequently the chamber is brought up to full pressure using nitrogen gas (referred to as venting it). There are three large gas tanks connected to the chamber that are labeled N (nitrogen), A (argon), and O (oxygen). Make sure that the outlet valve (the one closest to the outlet end of the metal pipe, see Fig. 3 on next page) on the nitrogen tank is closed. Then open the valve on top of the tank; the tank pressure, which is not critical, can be read on the right hand meter (closest to that valve). Obviously, if the reading is very low, the tank will have to be replaced (see Max). The regulator valve (between the outlet and tank valves) is normally left alone so the gas flow, as read on the left-hand meter will be the same every time.
Check that the two clamps that can be used to hold the chamber door closed are actually in the open position. Once the system is pumped down you want to have these open because the system is not designed to take much of an over pressure, so one might blow out the glass, or something. The door is only clamped down when you first start to evacuate the chamber so that you get a good vacuum seal initially, but after it is partially evacuated, the clamps are opened.

Now we want to vent nitrogen gas into the system. On the VACUUM section of the top panel (see Fig. 4) switch the Vent toggle switch to the up position. This switch opens the pneumatic valve between the chamber and the nitrogen gas line. Then turn the outlet valve on the nitrogen tank a little and watch the sputter chamber pressure (left-most panel in Fig. 4) slowly increase. In this situation, venting can take place fairly quickly because the turbo pump is not running yet. Later on, when we are venting after having a low vacuum, we will want to be sure we do not vent too quickly since we could damage the turbo pump. Let nitrogen flow in until the chamber door pops open. In theory the pressure gauge should read 760 torr when that happens, but it might only read around 100 torr or so (the gauge is not very accurate at higher pressures as it is calibrated to be accurate down at $10^{-5}$ torr). Once the door is open, close off the nitrogen by flipping the Vent/VACUUM switch down and closing the outlet valve at the end of the nitrogen tank manifold. Be sure to put on gloves before handling any interior parts of the chamber.
**Inserting the Sample**

For practice, one can use a Superfrost microscope slide from the wall cabinet. These are new, clean slides which have a frosting on the end so you can write what was sputtered upon it. Place the slide on the holder in the middle of the table with the label side down and rotate the small clamps to hold it in place. The sample table is flimsy because the platform has lamps underneath it that allow one to heat the substrate if desired. They don’t really want to have a solid mechanical housing connecting this to the motor as that would conduct the heat away. The table can also be made to rotate when the sputtering is taking place. This action helps to compensate for the gun being at an angle relative to the substrate thereby making a more uniform coating.

Finally, check that the tin foil covering the two thickness monitors is still in place. The monitors are little piezoelectric transducers that vibrate and the frequency of vibration depends on how much mass is deposited upon them. In principle they provide a way of measuring the thickness but actually they have to be calibrated if one wants to deposit a film of a specified thickness.

**Pumping Down**

Next we want to pump the air out of the chamber. Visually check the O-ring seal on the door to make sure there is no contaminants upon it (which is unlikely if the system has been kept closed most of the time). Then close the door and engage its clamps. Make sure the switches connecting the chamber to the argon and oxygen gas tanks (on the GAS section, right side of Fig. 4) are in the closed (down) position and that the outlet valves on all of the gas tanks are closed. The nitrogen Vent switch should still be in the down position, i.e., the chamber is completely closed off.

Then just push the black Start button (on the VACUUM section in Fig. 4), which immediately starts both a roughing mechanical pump and the turbo pump. The rotation speed gauge for the turbo pump is on the far right side of the top panel. It shows the rotation speed of the blades in Hz. It also has some touch switches that allow one to change the set points of the turbo pump where it automatically changes speed depending upon pressure conditions (1000 Hz for good vacuum, 500 Hz for poor vacuum). One must be careful about suddenly increasing the chamber pressure when the turbo pump speed is high (above 500 Hz) as that creates a sudden, heavy load for the blades and could cause damage. However, when first pumping the chamber down from atmospheric pressure, the pump speed is just starting up from 0 Hz, so damage is less likely. After the door has been pulled in (1 torr on the pressure meter), open the two chamber clamps. When the pressure has dropped to about $10^{-1}$ torr, shut off the pumps by pushing the red Stop button on the VACUUM panel. The turbo pump will continue to operate on free rotation.

**Flushing with Nitrogen**

At this point, we must flush the chamber with nitrogen gas so as to remove the residual air and any associated water vapor as the latter would have a negative effect upon the ion discharge. Check that the outlet valve on the manifold of the nitrogen tank is still closed and that the regulator pressure is near the lower end of its range. Because the turbo pump may still rotating (note, it was shut off above), precautions are appropriate here as there may be an appreciable amount of nitrogen in the line coming from the nitrogen tank. So flip the nitrogen venting toggle switch up and down a few times while keeping an eye on the pressure gauge. If there is dramatic rise in pressure (to greater than $10^{-1}$ Torr) and the turbo pump has not stopped yet, it is probably best to leave the nitrogen switch in the down position until the pump has slowed down more. Then once again try flipping the nitrogen toggle switch. The key point is that we to not want the turbo pump to experience rapid changes in pressure when it is operating at high speeds.) Once the vent valve has been opened then slowly crack the output valve on the nitrogen tank so that the gas pressure in the chamber changes at no more than one Torr per second. Continue until the pressure gets up to about 100 Torr, thus giving a dilution of about 1 part in 100.
Preparing for Deposition

Close the nitrogen Vent valve on the front panel and the outlet valve on the nitrogen tank. The solenoid pneumatic valves are not very good and if there was a nitrogen over pressure, it probably would leak into the chamber a bit. Turn on the vacuum pump and open the clamps on the chamber door. Keep an eye on the speed of the turbo pump; ideally one does not want it over 300 Hz at the higher pressures. Eventually, when the pressure has dropped to $10^{-4}$, the pump speed will go up to its maximum of 1000 Hz.

If the sample heater is going to be used, the toggle switch on the HEATER panel (see Fig. 4) will need to be flipped upward. One should be able to see the lamps glowing through the chamber door. There may be considerable out gassing so the pressure may rise as high as $10^{-3}$ torr and then take a very long time to pump down to the desired $10^{-5}$ torr pressure. The platform temperature can be read on the GAS panel along with the preset maximum of 250 C. While this is the value normally used, it can be raised or lowered using the grey arrow buttons (left arrow to set condition, up and down arrows to increase or decrease set temperature, MO to lock it in.)

Meanwhile, one can connect the gun(s) that are going to be used to the voltage supplies. In this case, we will only use one gun. So on the center PROCESS panel (See Fig. 4, third panel from left), throw the right-hand toggle switch up to connect Gun 2 to DC voltage supply called DC2. Obviously, if more than one gun is going to be used, it will have to be connected to another supply; there is a one that uses rf as well, which is another type of sputtering. You have a choice of connecting the rf supply to the guns or you can apply it to the substrate in order to clean it (for now, keep it flipped down towards the PROCESS label). When the argon pressure gets to $5 \times 10^{-5}$ torr, one can start the argon ion bombardment.

The Bombardment

The argon regulator pressure is kept at about 15 psi. The argon tank outlet valve is still closed so, in principle, no argon is going in yet (the solenoid valve is also closed, it is rather leaky). When it is opened, then the argon gas goes through a mass flow controller (Fig. 5, below) on the white portion of the second panel from the top. It consists of a hot filament that the gas flows over and it measures the temperature of that filament. The temperature is a measure of the amount of gas flowing past it. This panel allows one to control the number of micrograms per second of argon flowing into the chamber. It has two channels, e.g., one for argon and the other for oxygen. For this example, we will control the argon flow with the left (1) side so flip the upper-most switch on
the right to the 1 position to connect the meter to that side. With the meter you can set the flow rate that you want using the rotary switch for that channel. The units of the flow meter are unknown, but one does not really need to know the actual number. The meter goes from 0 to 100 and we just arbitrarily set it at 50 as that has worked well in the past. It is just one of many parameters (voltage, current, etc.) that control the deposition. When recording deposition parameters in your notebook the key parameter to record is the system pressure as opposed to the flow rate. Different systems will require different flow rates to maintain a given pressure. It is the pressure which is universally quoted in sputtering literature.

Once the heater (if used) has stabilized at its set point (250 C in this case) and the chamber pressure has dropped to about $1 \times 10^{-5}$ torr, argon can be admitted into the chamber. The mass controller switch is set to the closed position so, in principle, no argon can flow there yet. However, when one opens the argon switch on the top panel (upper right side of Fig. 4), it will be observed that the pressure rises rapidly, which means that the valve associated with the flow meter leaks. Open the main valve and the outlet valve on the argon gas tank. Quickly flip the argon toggle switch back and forth several times allowing the pressure to rise slowly (while keeping an eye on the turbo pump speed and the vacuum gauge). After the argon switch is finally left open, the chamber pressure goes to about $10^{-4}$ torr. Finally to set flow of argon gas into the chamber, the switch on the flow panel is flipped up from the CLOSED to the 1 (middle) position. Now the pressure will rise to about $8.7 \times 10^{-3}$ torr. There is an interlock on the system so that whenever the pressure rises above $10^{-4}$ torr (determined by the set point discussed earlier), the turbo pump goes into standby. Standby just means it just slows down to 500 Hz, which is half of its maximum speed of 1000 Hz. When the speed has finally dropped to 500 Hz, one can do the deposition, at which point the pressure (set with the flow meter knob) will be about $10^{-2}$ Torr. That is the number that has been used for all the depositions at WWU.

One should keep an eye on the water temperature during the deposition process. It should be about 13 - 15 C at this point, and if it goes up above room temperature (20 - 25C) when the gun is running, there is something wrong, so the process should be stopped.

On the ROTATION pane (see Fig. 4), **flip the toggle switch up to start the table rotating**. You can adjust the rotation speed of the table, but normally we use the highest speed - there does not seem to be much use for lower speed. In principle, if only one gun is being used, a small platform could be constructed so that the gun being used points directly at the sample. This geometry with all three guns pointing at the center was meant for creating alloys using two or more guns.

The setting of the voltage and current (on the high voltage panel) depends upon the target metal. Iron is very problematic as the iron target interferes with the magnetic field of the magnetron gun thereby affecting the efficiency. Silver should be similar to copper. There are two identical voltage supplies, DC1 and DC2 (for running two guns at the same time), but today we are only using DC2, which is shown in Fig. 6. You can either set the maximum

![Figure 6](image_url)
the shutter on Gun 2 (middle toggle switch on the PROCESS panel of Fig. 4) to expose the target for bombarding (note that if you forget to do so, then when you turn the voltage knob, the voltage meter will not read anything since there apparently is an interlock between it and the shutter control). Turn on the POWER switch and then slowly turn up the voltage. When the current meter starts to read that indicates that a plasma has been struck, ions are hitting the target, and the bombardment has begun. One needs a power of about 100 W to get a significant rate of deposition. In this case, we will set the voltage to 0.350 kV which gives a current reading of 123 mA, i.e., 43 W of power is being delivered to the target. Looking through the chamber window, one should be able to see a nice bluish plasma glow at the target position. At this time, one should regularly check the cooling water temperature to make sure it is staying low (for this run, it was 14.4 C). For silver, a target bombardment of one minute gives a coating with a transmission of about 85-90% in the visible range. To stop the bombardment, just turn the voltage back to zero. Turn the HV power off. Close the shield on Gun 2. Turn off the vacuum pumps!

If the heater is being used, turn it off. It will take a long time for the sample to cool down even though some argon is still flowing into the chamber. To speed the process along, one may purge the chamber with argon gas (being a noble gas, it should not react with any substrate coating). Once the turbo pump speed has dropped to 500 Hz or lower, momentarily flip the toggle the switch on the flow meter to the PURGE position. If the pressure rises rapidly, close the switch and the outlet valve on the argon tank. Then toggle the PURGE switch back and forth a few times. When the turbo pump has slowed down to 100 Hz or so, you can leave it in the open position. Slowly open the argon tank outlet valve allowing the pressure to increase at about 1 torr per sec until it reaches 6.8 torr or more. Wait for the sample temperature of the substrate to drop to below 100 C.

In order to inspect the results, the chamber must be vented with nitrogen. Flip the argon toggle switch on the GAS panel down to close that valve. Close the outlet and main valves on the argon tank. Close the flow meter valve. Toggle the purge switch to the closed position. Make sure the clamps on the door are not engaged (they should be open at this point). Then flip the nitrogen toggle switch up and down quickly since, once again, you do not want the turbo pump speed to be high when the gas pressure is increased. Very gently crack the outlet valve on the nitrogen tank so that the chamber pressure is increasing at about 1 torr/sec (keep an eye on the pump speed). After about 5 minutes, the door will pop open. Close the outlet and main valves on the nitrogen tank. Toggle the Vent switch off to prevent possible damage from overheating the coil of the solenoid valve. Remove the sample and inspect it.

Shutting Down
Close the door and engage the clamps. Switch the vent switch to VACUUM and press the red Start button to begin evacuating the chamber. The turbo pump will come on at about 60 torr - watch the turbo pump speed (one wants it less than 500 Hz). When the pressure gets down to 1 torr or so, turn the pump off and open the door clamps. The chamber is left in this condition. Turn the power switch on the chamber chassis to the off position. Make sure the outlet and main valves on all of the gas tanks are closed (leave the regulator valves alone). Turn off the Fluke meter but do not turn off the air pressure. When the turbo pump speed has dropped to 100 Hz, shut off the pump on the secondary water circuit and then close the building input water valve. Toggle the main switch on the side of the sputter chamber to OFF. The building air valve should be left on as it also provides a constant pneumatic supply of air for the Newport suspension table.

Installing a new target (if necessary)
If the target material that you want to sputter is not already in the machine, you will have to install a new one. For the purposes of this discussion, we will assume that a copper target is being
replaced by a silver one. The normal targets are iron metal, copper and titanium. In this description, we will replace the copper target in gun 2 by a silver target. First open the target 2 chamber shutter by flipping the appropriate switch for gun 2 on the PROCESS section of the top panel (Fig. 4). Before doing anything use an insulated wire to short the target surface to the sputter chamber walls. (This is a safety precaution intended just in case the power supplies still have some residual charge left in their output capacitors.) There is a cylindrical shield surrounding the target gun which is removed by taking out the three small bolts around the edge of its housing using an allen wrench. Note that the back side of the shield has a slotted opening so that the screw need not come out all of the way in order to release the shield. Once the shield is off, the target is removed by taking out the six small bolts from around the edge of the ring that is holding it in place. There is quite a strong magnetic field there—a recent improvement in sputtering technology. The idea is to stream the ions in a helical path just to make sure that they primarily bombard the target.

The ring has a small lip into which the new target is inserted. When you put the new target in, the screws should be snuggled up fairly tight. You need a positive pressure on the target because you will be pumping a lot of heat into it and that heat has to be removed to prevent the target from actually melting. Once the ring and the shield have been reassembled, flip the toggle switch to place the cover back over the shield opening.

The target is cooled by water, which is circulating in the closed circuit. The water for each target comes down a tube (seen on top of the overall illustration), hits the target backing plate, cools it and then goes back out. So the whole assembly, the copper, the target, and associated mount is going to get raised up to three or four hundred volts. The voltage cable comes through the water line. The manufacturers caution that the water is not electrically isolated from the 300 volts so you do not want to grab the water leads on the outside of machine. They comment that you are not supposed to connect water to the machine with copper tubes so that means the tubes must be insulated. If one did not do so, substantial current would be conducted away from the voltage supply.