

# **Creation and Characterization of Gold Coated Slides with a Home Built Deposition Chamber**



**ALLEGHENY  
COLLEGE**

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# Creation and Characterization of Gold Coated Slides with a Home Built Deposition Chamber

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Senior Research Project

Submitted to the Allegheny College Department of Physics to partially fulfill the requirements for the degree of Bachelor of Science



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I hereby recognize and pledge to fulfill my responsibilities, as defined by the Honor Code, and to maintain the integrity of both myself and the College community as a whole.

Pledge:

Nate Rieders

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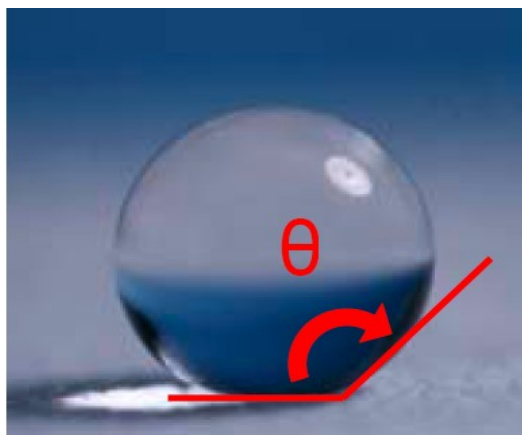
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**Abstract**

*An apparatus for the creation of gold slides was designed. Gold wire is placed in an evacuated chamber along with an array of glass slides. The gold wire is heated and evaporated onto the glass slides, leaving a thin deposition layer. The gold slides are created for the study of hydrophobic materials using surface plasmon resonance (SPR). The use of SPR as the experimental method requires the thickness of the gold layer to be precisely determined. Thus, the thickness of the gold slides are characterized using scanning tunneling microscopy. Further work must be done before the device is constructed and ready for deposition.*

## Introduction

Water is one of the most pervasive molecules on Earth. Liquid water is held together by a randomly changing hydrogen network. Hydrophobic surfaces are materials that have the tendency to disrupt these hydrogen bonds at the interface between the surface and water. This results from the inability of the material to form hydrogen bonds [1]. The contact angle,  $\theta$ , is the angle made by the line tangent to the drop and the surface at the point of contact (Figure 1). It is a measure of how hydrophobic a material is, its hydrophobicity. A surface is considered hydrophobic if its contact angle is greater than  $90^\circ$  [10].



*Figure 1: The contact angle, a measure of a material's hydrophobicity [1].*

There is disagreement in the literature as to what happens when water interacts with a hydrophobic surface. In the classical model of these materials, water forms a rigid cage around a hydrophobic particle in order to preserve its network of hydrogen bonds. Recently, it has been theoretically predicted that water in direct contact with a hydrophobic surface forms a thin film of water “vapor” [11]. This film is predicted to have a density that is significantly less than that of bulk water. Another theory of hydrophobic interactions has been proposed by Lum, Chandler, and Weeks, and is applicable to all fluids. They examine interactions at large and small length scales, and predict

that the depletion layer forms only at larger length scales. Furthermore, they are able to explain the observed phenomenon of two hydrophobic surfaces placed in water experiencing a net attraction over large length scales [8]. Experimental evidence of this depletion layer has been inconsistent.

Extreme sensitivity is required to study the small region of interaction between water and a hydrophobic surface. Surface Plasmon Resonance (SPR) is the experimental method this lab uses to investigate the properties of these materials. SPR allows for observations of the depletion layer without interfering with the bulk water, giving it a high surface specificity. This makes SPR an effective technique, as the depletion layer is thought to be on the order of an angstrom. Because gold has the appropriate dielectric coefficient, it is used to coat the glass slides needed for SPR. Many labs create their own gold coated slides, as they are not readily available. The purpose of this project is to create a device that would deposit thin layers of gold onto an array of glass slides. The gold slides could then be used by my colleagues to study hydrophobic surfaces using SPR. The thickness of the gold layers must be approximately 60 nm in order to be applicable for this experimental method. To determine the thickness of the gold we use a scanning tunneling microscope (STM).

The study of hydrophobic surfaces is widely applicable to many areas of science including: fluid flow, cell biology, and material science. Kristen Duthie, a member of my research group, looks at the relationship between changes in the coupling angle and protein concentrations. It is thought that the attraction between hydrophobic surfaces in water can lead to a better understanding of the complicated processes of protein folding and self-assembly [1].

## Theory

### SPR

When light is incident on an interface of two materials where the index of refraction of the incident medium,  $n_1$ , is greater than the index of refraction of the transmitted medium,  $n_2$ , the transmitted light tends to bend away from the normal [5], as shown in figure 2.

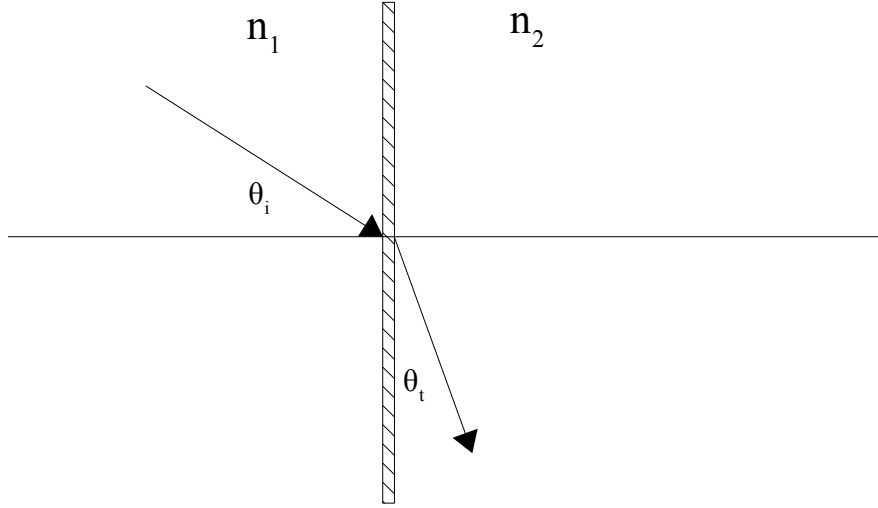


Figure 2: Light incident on two media of different optical densities,  $n_1 > n_2$ .  $\theta_i$  is the angle of incidence with respect to the normal,  $\theta_t$  is the angle of transmittance with respect to the normal. The transmitted light bends away from the normal.

Reflectivity is a ratio of the reflected intensity to the incident intensity, and is described by the Fresnel equations [5]

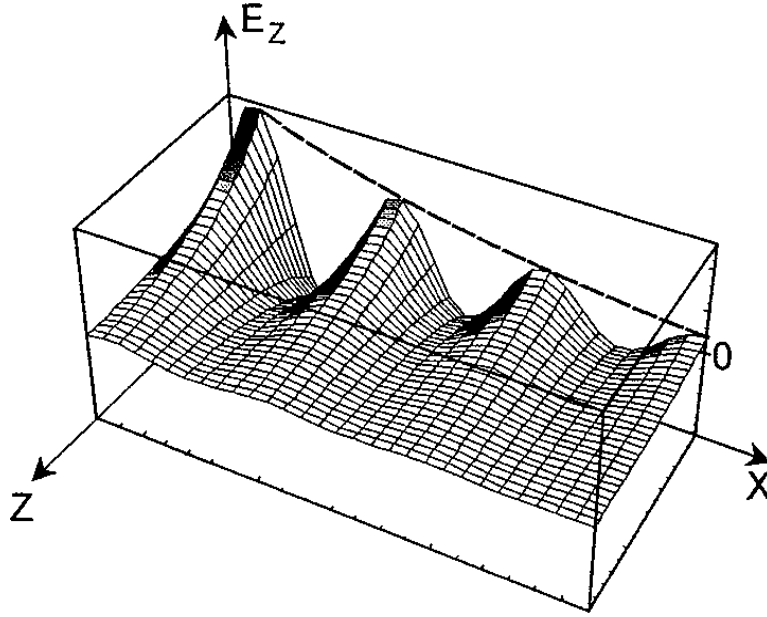
$$R_p = \left( \frac{n_2 \cos(\theta_i) - n_1 \cos(\theta_t)}{n_2 \cos(\theta_i) + n_1 \cos(\theta_t)} \right)^2 \quad (1)$$

$$R_s = \left( \frac{n_1 \cos(\theta_i) - n_2 \cos(\theta_t)}{n_1 \cos(\theta_i) + n_2 \cos(\theta_t)} \right)^2, \quad (2)$$

where  $R_s$  and  $R_p$  are the reflectivity of s and p polarized light respectively,  $\theta_i$  is the angle of incidence with respect to the normal,  $\theta_t$  is the angle of transmittance with respect to the normal. When the reflectivity of the light approaches unity, all of the incident light is reflected from the incident medium. This is known as total internal reflection, and occurs when  $\theta_i$  is equal to the critical angle,  $\theta_c$  given by,

$$\sin(\theta_c) = \frac{n_2}{n_1} \quad (3)$$

At an angle  $\theta > \theta_c$ , the intensity of the light in the transmitted medium is not zero, indeed an evanescent wave is created. These waves travel parallel to the surface of the reflective material, and decay exponentially in the normal direction [6], as shown in figure 3.



*Figure 3: An evanescent wave, created during internal reflection, oscillates in the x-direction, parallel to the reflective material, and decays exponentially in the z-direction, perpendicular to the material [7].*

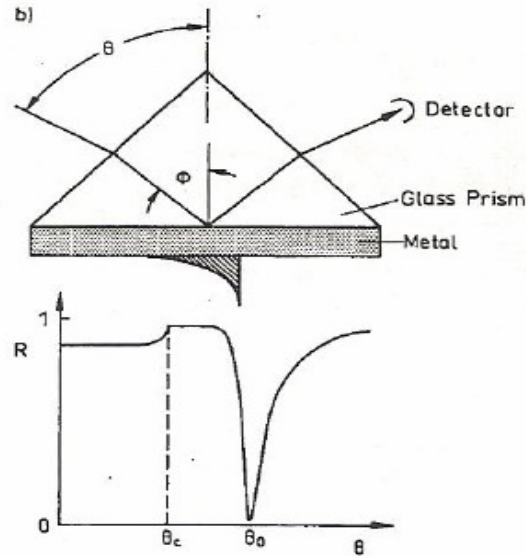
If the reflective material has free electrons, the evanescent waves can be used to drive oscillations in the free electrons at the surface of the material. These oscillations in surface charge density are known as surface plasmons. The amplitude of the surface plasmons is greatest at the

coupling angle,  $\theta_0$ . In order for coupling to occur, the propagation constant of the surface plasmons must be equal to the in-plane wave number of the incoming light given by [10]

$$\kappa_x^2 = \frac{\omega^2}{c^2} \frac{\epsilon_2(1 - \omega_p^2/\omega^2)}{(\epsilon_2 + 1 - \omega_p^2/\omega^2)}, \quad (4)$$

where  $\kappa_x^2$  is the propagation constant of the surface plasmons,  $\omega$  is the angular frequency of the incident light,  $\omega_p$  is the frequency of oscillation of the surface plasmons of the reflective material,  $\epsilon_2$  is the dielectric coefficient of the sample and surrounding media, and  $c$  is the speed of light.

If one looks at the relationship between reflectivity and incident angle (Figure 4), the creation of surface plasmons corresponds to a sharp dip in reflectivity. The minimum of the dip occurs at the coupling angle, corresponding to all of the light's momentum being transferred to the surface plasmons.



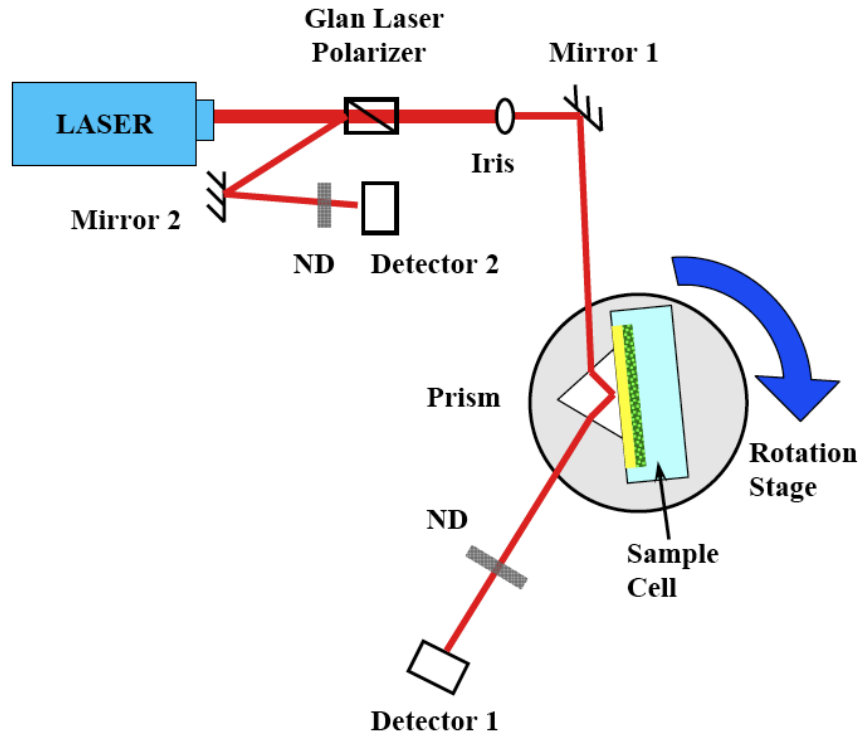
*Figure 4: A measure of the reflectivity as a function of incidence angle. The reflectivity approaches unity, as one approaches the critical angle,  $\theta_c$ . At the coupling angle,  $\theta_0$ , all of the incident light's momentum is transferred to the surface plasmons corresponding to the dip in reflectivity [6].*

The depth of the evanescent wave's penetration into the material,  $l$ , is of the order of magnitude of the wavelength of the incident light,  $\lambda$ , and is given by [6],

$$l = \frac{\lambda}{2\pi\sqrt{(n_1 \sin(\theta_i))^2 - 1}} \quad . \quad (5)$$

In order to induce changes in surface charge density, the incident light must have an electric field component normal to the surface. Thus, the incident light must be p-polarized. Additionally, the two materials at the interface must have dielectric constants whose real parts are opposite in sign [3]. Thus, gold constitutes a possible material for SPR.

Experimentally, my colleagues shine a He-Ne laser on a prism. The glass side of the gold slide is placed into contact with the base of a prism. The sample is then placed into contact with the gold portion of the slide. The prism and sample are placed on a turntable, allowing the incident angle of the laser to change. The reflectivity of the incident laser beam after interacting with the prism and sample is read and recorded as a function of incidence angle. Figure 5 shows a typical SPR apparatus.



*Figure 5: A typical SPR set-up. Laser light is p-polarized and reflected by a mirror onto a prism. The gold slide and slide containing sample are placed into contact with the prism at the base. The prism and sample are able to rotate, changing the angle of incidence. The reflected light is measured by a detector, and can be recorded as a function of incidence angle [10].*

## STM

Scanning Tunneling Microscopy is a method of imaging surfaces at the atomic level, and relies on the phenomenon of quantum tunneling. A small probe is placed at a small distance from the surface to be studied. The probe is sharpened to have a single atom at the tip. A bias voltage is then introduced between the probe and the surface, creating a potential barrier. There is a probability that an electron incident on the barrier will tunnel between the tip of the probe and the sample creating a current, known as the tunneling current. Because STM requires the electrons to be able to move between the

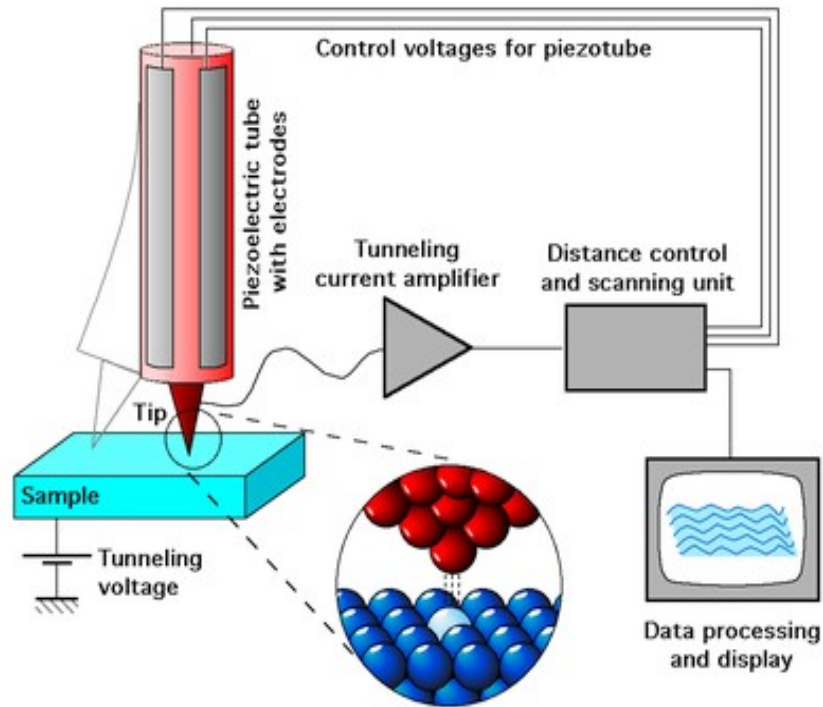
tip and the sample, both must be conducting materials. To create an image, the probe is moved along the surface, at a distance of about  $10\text{\AA}$  above the sample. A typical STM is shown in Figure 6. As the distance between the tip and surface changes, the tunneling current changes. The tunneling current decays exponentially with the distance between the tip and surface, and is given by

$$I \propto e^{-2\kappa z}, \quad (6)$$

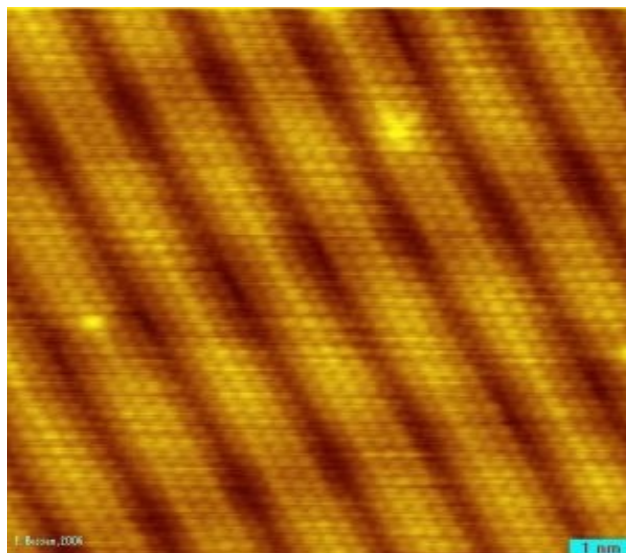
where  $z$  is the distance between the tip and the sample, and  $\kappa = \frac{\sqrt{2m(V-E)}}{\hbar}$

where  $m$  is the mass of an electron,  $V$  is the potential energy in the barrier,  $E$  is the energy of the electron, and  $\hbar$  is Planck's constant [1]. Thus, the probability that an electron tunnels decreases as the tip-sample distance increases. In our Burleigh STM, the probability of tunneling decreases an order of magnitude if the tip-sample distance increases by  $1\text{\AA}$  [9].

Many STM methods maintain a fixed tunneling current, which requires the probe to be able to change its distance with the surface. However, these changes in tip separation are very small, and require very precise instrumentation. In order to achieve this precision, the tip is placed at the end of a hollow ceramic piezoelectric cylinder. Piezoelectric ceramics are materials, known as electrets, that respond to electric fields by expanding and contracting. By changing the electric field in the cylinder, one can move the tip across the surface at subangstrom length scales [9]. If the tunneling current begins to decrease the probe will move closer to the sample to maintain a fixed current, and vice versa. Thus, the change in position of the probe can be used to create a topographical image of the surface (Figure 7).



*Figure 6: A typical STM. A bias voltage is applied between the sample and tip. Electrons tunnel between the tip and sample, creating the tunneling current. The tip is made of a piezoelectric material, that can be shortened, elongated, and moved side to side in order to scan the surface and maintain a fixed tunneling current. The changes in height of the probe can be used to create an image of the surface. Courtesy of Michael Schmid, Vienna University of Technology*



*Figure 7: An image of a gold surface taken with a STM, courtesy of Erwin Rossen, Eindhoven University*

## **Methodology**

### **Deposition Process**

The deposition chamber is evacuated to an approximate magnitude of  $10^{-4}$  Torr. Once the chamber has reached the appropriate pressure, current is passed through the titanium wire. As the wire heats up, titanium atoms are ejected in all directions. As the titanium atoms collide with the glass slide, they form a thin layer about 10nm thick. The titanium layer is deposited prior to gold, as it acts as an adhesive for the gold. A current is then passed through the gold wire, and in a manner similar to that of the titanium, a 60-120 nm layer is deposited. To ensure that the slides have the appropriate thickness, we characterize the gold layer using STM.

The chamber consists of an 18" tall glass bell jar with a 12" outer diameter, placed on an 18"x 18"x 3/4" aluminum base plate (Fig. 8). Inside the jar are two 4" high L-shaped aluminum bars, which create a 6 1/2" x 6 1/2" square around the gold and titanium sources. The glass slides are secured to the bar with a thin brass band, 1/2" apart from one another in a linear array (Fig. 9). Four slides will fit on

each arm of the Ls, corresponding to 16 gold slides per deposition. The aluminum bars are not attached to the plate, and thus can be removed from the chamber in order to position a load of slides.

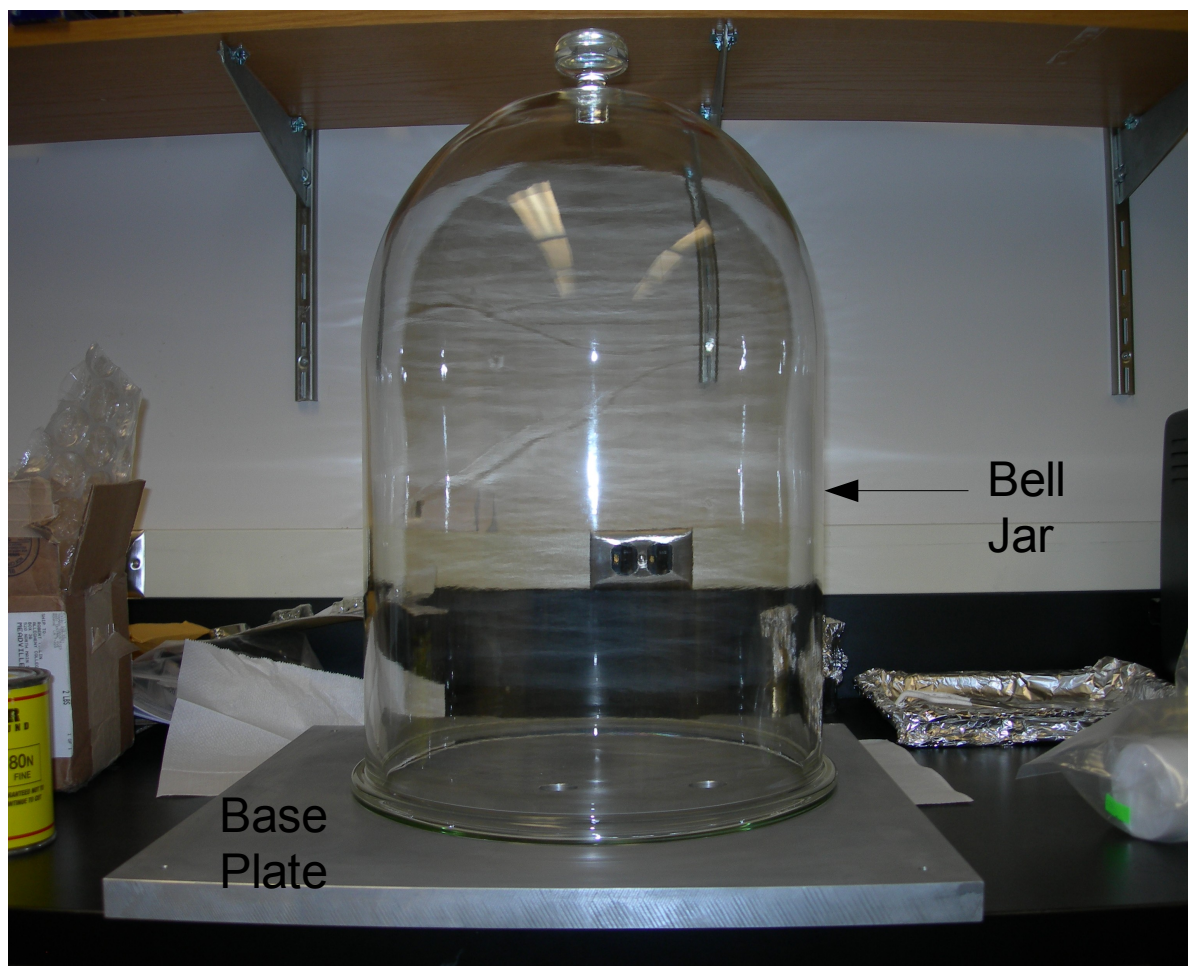
It is vital that the surface of the base plate be as smooth as possible, as small perturbations on the surface of the plate can create small leaks into the chamber. To smooth the plate, a sapphire lapping compound is applied with a lapping plate. The area of contact between the bell jar and base plate is then smoothed several times. In order to create a seal between the bell jar and base plate, vacuum grease is applied along the perimeter of the base of the jar.

Two holes are drilled in the base plate to fit a NW-25 T-flange along with an electrical feedthrough (Fig. 10). A thermocouple as well as an NW-25-16 reducer nipple are connected to the T-flange (Fig. 11). The thermocouple measures the pressure inside the chamber. Its sensitivity is on the order of  $10^{-3}$  Torr, since we hope to achieve a pressure that is an order of magnitude lower, we will wait for the gauge to read zero. The reducer nipple allows us to connect the NW-16 vacuum hose to the NW-25 T-flange. Two bulkhead clamps secure the T-flange and feedthrough to the base of the plate. A 24" NW-16 PVC reinforced vacuum hose is coupled to the reducer nipple and vacuum pump.

All of the joints require a centering ring and O-ring in order to create a seal at each point of contact (Fig. 12). Wing nut clamps are used to secure two joints together with the centering ring and O-ring at the interface of the point of contact. A Welch DUOSEAL® model 1400 belt-driven vacuum pump is used to bring the chamber down to pressure. Since the machinery of the pump requires the use of oil, a filter is placed on the pump. This prevents the oil from contaminating the optics of the SPR set-up (Fig. 13).

An 8-pin electrical feedthrough is secured to the center hole of the base plate. This allows current to flow through the gold and titanium wires during the deposition without breaking vacuum. The feedthrough wires are connected to the gold and titanium via a small inline electrical coupler. The feedthrough wires can handle a current of up to 2 amps, which limits the amount of current that can

pass through the gold and titanium wires.



*Figure 8: Bell jar on base plate. The deposition will take place within the jar.*

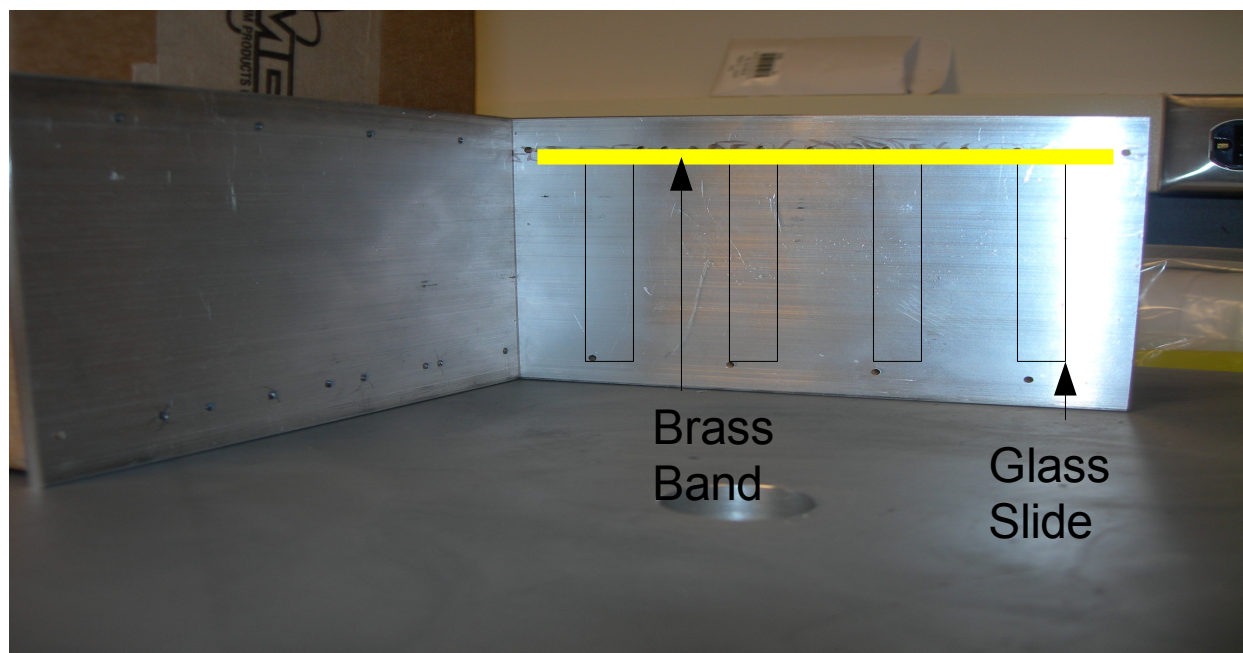


Figure 9: An L-shaped glass slide mount. The slides are secured to an arm of the L via a screw on the bottom, and a brass band running along the top. The same set-up is found on the other arm of the L (not shown). There are two such mounts, each holding 8 slides, for a total of 16 slides per deposition.

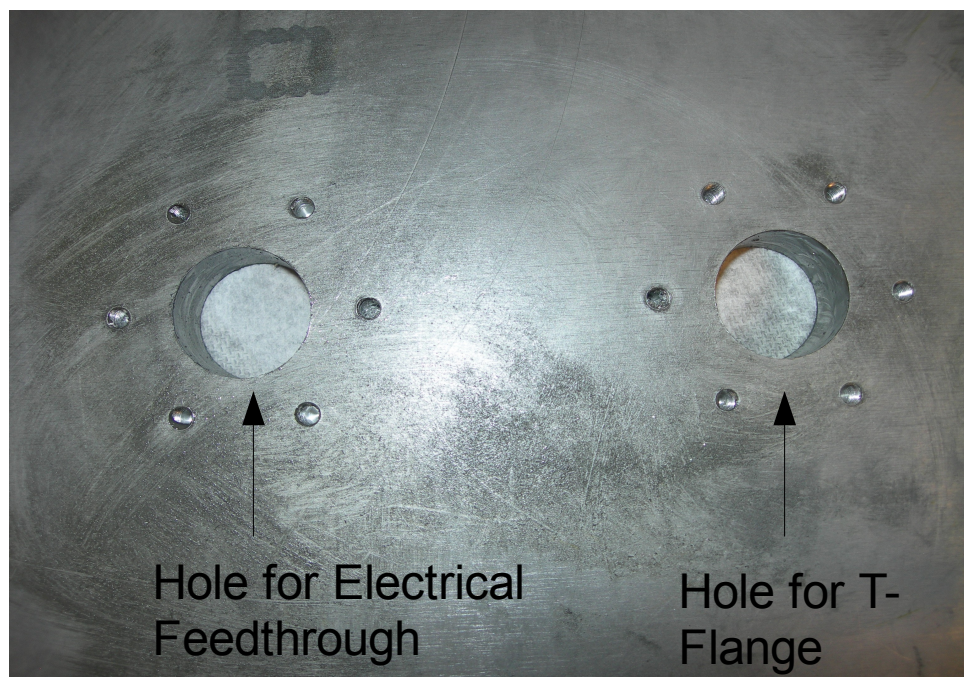
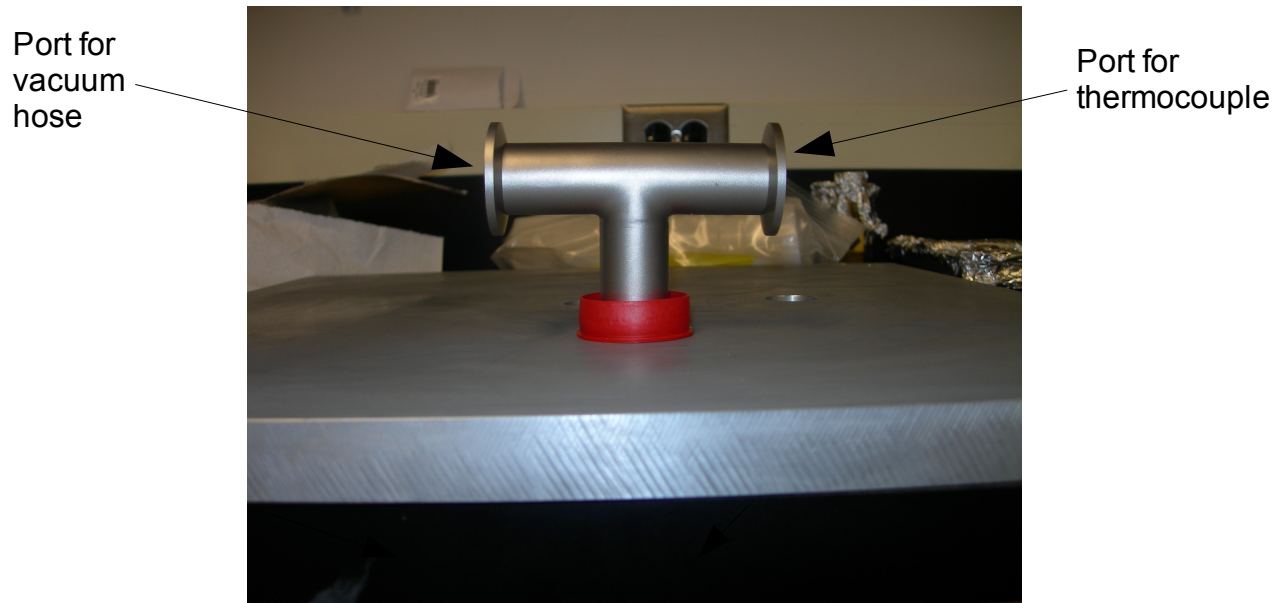


Figure 10: Bottom view of base plate. The hole for the electrical feedthrough is placed at the center of the plate, with the hole for the T-flange placed slightly to the right.



*Figure 11: NW-25 T-flange. Used to connect vacuum hose and thermocouple to the chamber. The fitting sits in the hole shown in fig. 11.*

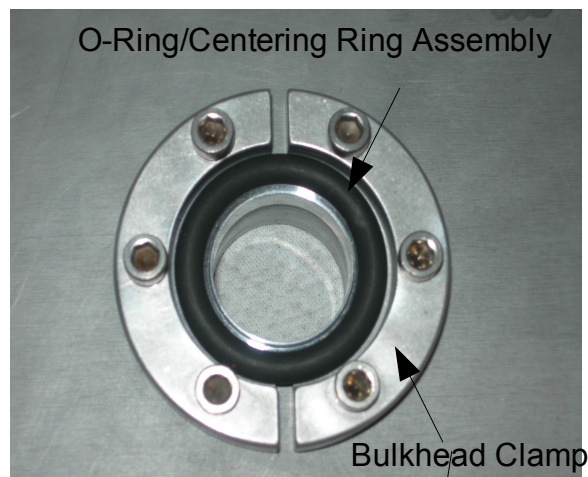
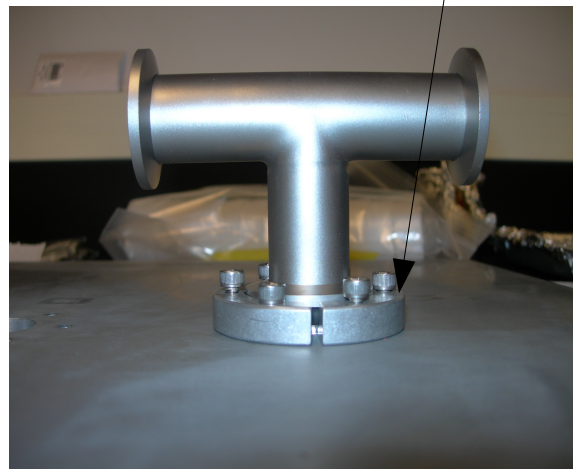
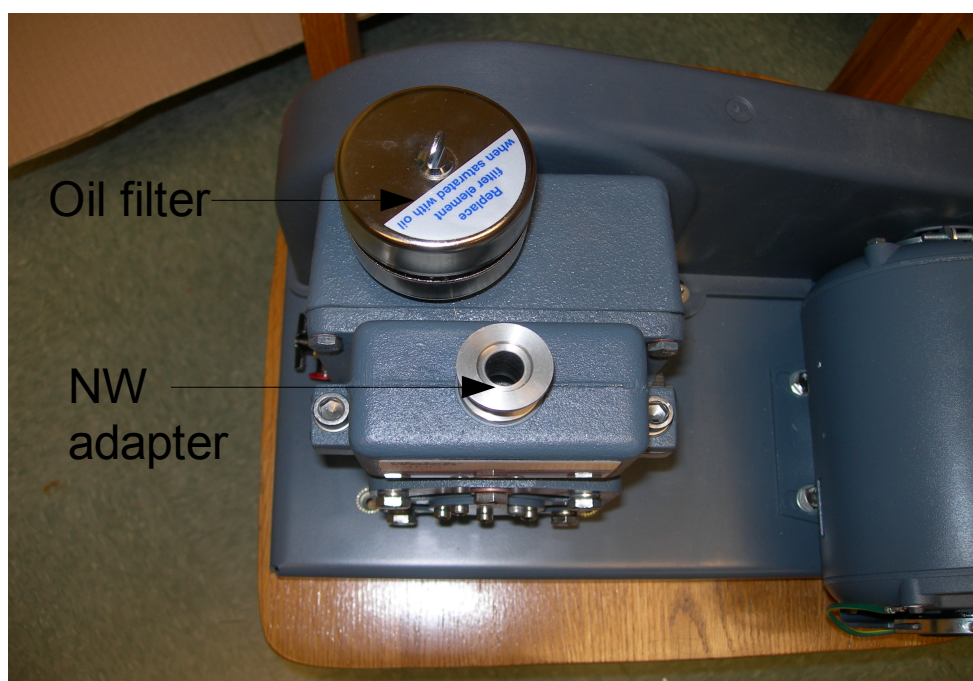
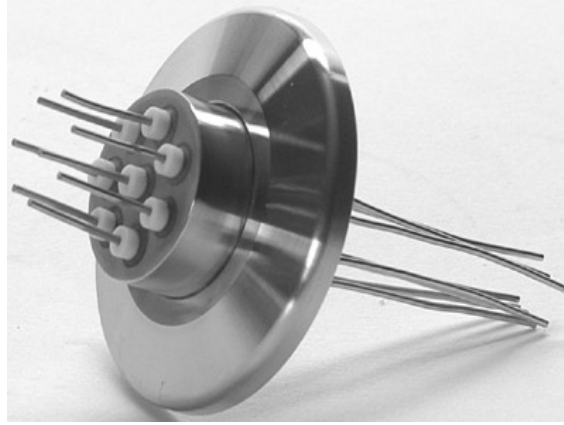


Figure 12: Centering ring and O-ring inside T-flange port with bulkhead clamp, this is the plate as viewed from the bottom (top image). Centering ring and O-ring found at each joint of device. T-flange secured with bulkhead clamp (bottom).





*Figure 14: Welch belt driven vacuum pump. The oil filter (bottom) is to prevent oil from entering the lab. The NW adapter is used to connect the NW-16 vacuum hose to the barb fitting on the pump.*



*Figure 15: NW-25 electrical feedthrough. Allows for current to flow into chamber while maintaining vacuum pressure. Feedthrough is inserted in hole at bottom of plate, as shown in figure 10.*

In order to approximate how much gold, time, and current is needed to deposit a 10 nm layer of titanium and 60nm layer of gold on each slide, we assume that a thin rectangular prism of deposited metal is being created. The top and bottom of the prism are not included, as there are no slides in the chamber that are located there. The prism has a length of 6 ½ " (length of slide mount), a width of 4" (width of slide mount), and a thickness equivalent to the thickness of the deposited layer. Multiplying this volume by the density of the metal, yields the total mass for one arm of the slide mount, since there are 4 such arms, multiplying by 4 yields the total mass of metal needed for the desired thickness. Using the latent heat of vaporization ( $L_v$ ), we can calculate the amount of energy ( $E$ ) needed for depositing the layer of mass ( $m$ ), this is given by

$$E = L_v \times m \quad . \quad (7)$$

By selecting the amount of time for the deposition, one can determine the amount of power needed. Assuming the metal is ohmic at the temperature and pressure inside the vacuum, the resistivity of the

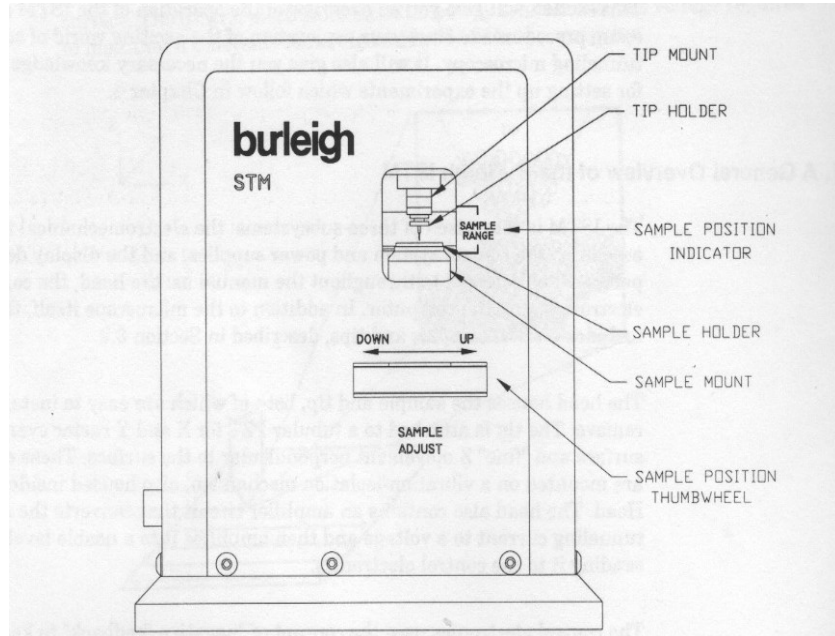
metal can be used to calculate the amount of current needed to deposit the desired layer, given by,

$$I = r \sqrt{\frac{P \pi}{l \rho}} \quad (8)$$

where  $I$  is the current,  $P$  is the power,  $r$  is the radius of the wire,  $l$  is the length of the wire, and  $\rho$  is the resistivity of the metal.

### **Slide Characterization with STM**

The STM sample holder is a 12 mm steel disc, and thus is too small for an entire gold slide. A gold slide is chosen and sliced so as to fit on the sample holder. The gold sample is mounted on the sample holder with a non-conducting cyanoacrylate adhesive. An electrical path is made between the sample and sample holder using a conductive carbon paint adhesive. This allows for the bias voltage to be introduced between tip and sample. Next, the tip must be properly prepared. A segment of platinum-iridium wire about 0.2"- 0.4" is cut. In order to ensure that the tip is approximately sharp to one atom, the wire is sheared diagonally. The tip is then placed in the tip holder, which is placed on the tip mount on the STM. The sample holder is then placed on the sample mount, and can be vertically adjusted to change the tip-sample separation. Figure 16 shows a diagram of our Burleigh STM. Because the tip-sample distance is so small, the STM must be vibrationally isolated. This prevents the tip from colliding with the sample, causing damage to both [9]. In order to determine the thickness of the gold, a small slice is cut into the gold sample. Because the gold layer is so fragile, simply using tissue paper will remove the gold without scratching the glass. Thus, there will be a dip in the STM image of the gold, corresponding to the thickness of the gold layer. It is assumed that the deposition process produces a relatively even coating of gold on each slide, and that the thickness of the titanium layer is negligible.



*Figure 16: A diagram of our STM. The platinum-iridium tip is placed in the tip mount. The sample holder, which contains the surface to be analyzed, is placed on the sample mount. The vertical position of the sample can be manually changed with the sample position thumbwheel [9].*

## Results and Analysis

The apparatus is in the process of being constructed. We are still waiting for the arrival of parts needed for both the vacuum and electrical systems of the chamber. A set of wingnut clamps and blank off caps are waiting to be received, at which point we can complete the vacuum system. The blank off caps will be used to connect the thermocouple to the T-flange. For the electrical system, we are waiting for the electrical feedthrough as well as the gold and titanium wires.

Both sides of the base plate have been smoothed with a coarse lapping powder. The bell jar will be placed on the smoother side of the plate. While smoothing has removed many of the inconsistencies, there are still some regions that may pose a threat to the vacuum pressure. Additional smoothing may be done. The vacuum grease is intended to act as a good sealant, and should compensate for the surface's lack of uniformity.

The two holes for the T-flange and electrical feedthrough have been drilled near the center of the plate, along with the corresponding bolt pattern for the bulkhead clamps. In addition, four holes have been drilled at the corner of the plate so that it can be mounted on a set of four legs for support.

The L-shaped aluminum bars have been cut, and the screw holes have been drilled. 1/8" holes have been punched into the brass bands that will secure the slides. The holes need to be tapped, and the bars must be screwed together until slides can be properly mounted.

## **Conclusions**

Once the remaining parts have arrived, it will be possible to complete the vacuum and electrical systems. The vacuum pressure will be tested first. Once we have attained a satisfactory pressure, we will be ready to begin the initial depositions. There is of course no reason to assume that the slides will be ready for experimental use. Thus, we will attempt to measure the thickness with a STM, as discussed earlier.

The deposition chamber will need some type of structure, such that it is easily accessible in the lab. It can be mounted on a simple metal frame with four legs of support. The base plate would be bolted to the top of the structure, leaving room underneath for the vacuum pump. The thermocouple gauge and pump switch will be mounted to the structure as a matter of convenience.

In order to maximize the amount of gold slides created per deposition, it might be advantageous to consider a roof-like structure which would sit on the L-shaped slide mounts. One could then place additional slides on the underside, facing the gold source, thus increasing the yield per deposition. It is also of interest to determine the lifetime of the gold and titanium wire. While a theoretical calculation can be made, empirical evidence would be of use, as these wires are expensive.

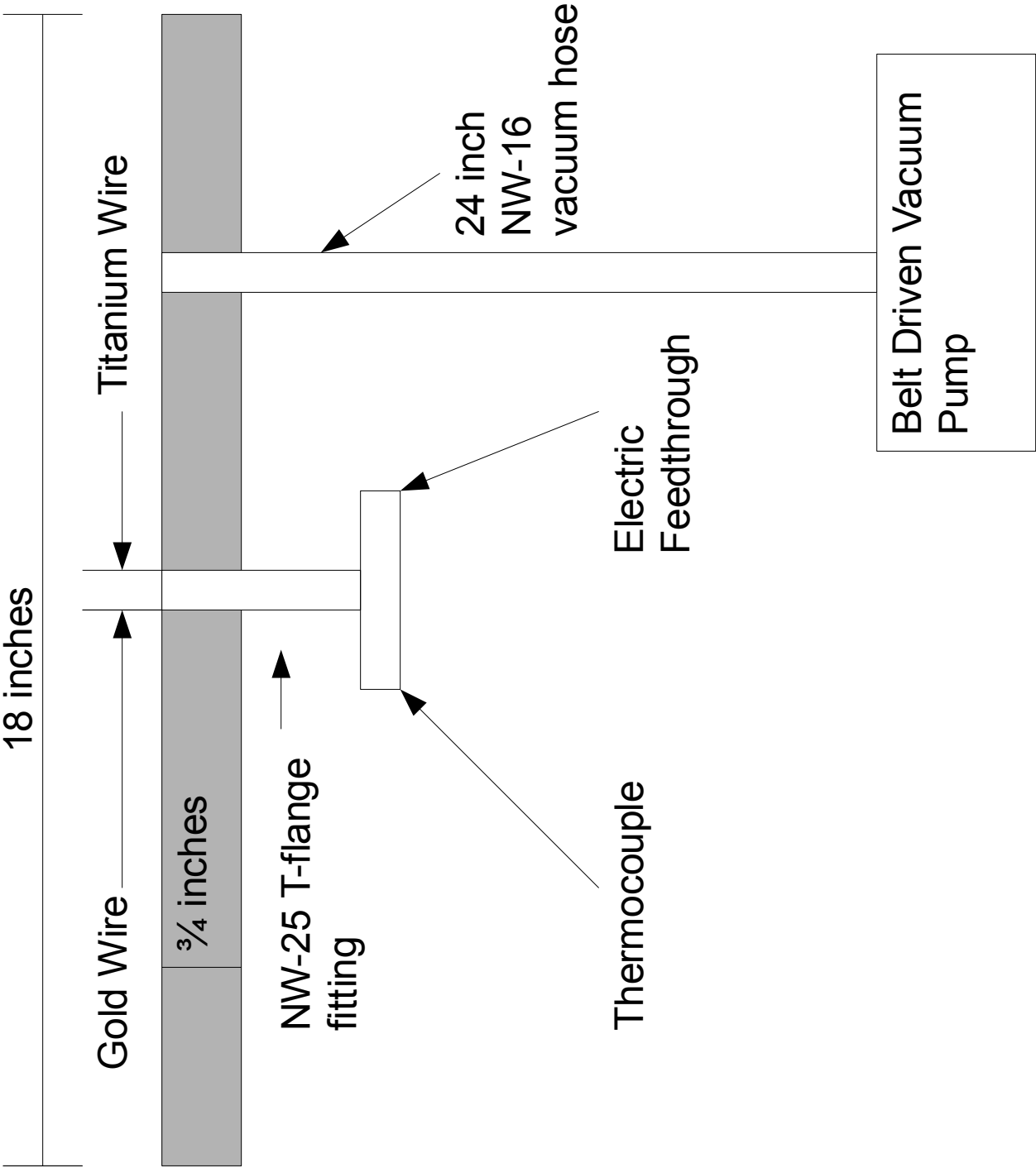


Figure 16:  
Schematic of  
deposition  
chamber.

## Appendix II: Project Cost

| Item                                      | Cost (\$) | Quantity |
|-------------------------------------------|-----------|----------|
| <b>Vacuum Components</b>                  |           |          |
| Welch Vacuum Pump                         | 1845      | 1        |
| HyVac Glass Bell Jar                      | 1684.64   | 1        |
| MDC 2ft. vacuum hose                      | 44        | 1        |
| 5.3 Oz Tube Vacuum Grease                 | 21.67     | 1        |
| Welch NW-16 adapter                       | 46.5      | 1        |
| Welch Vacuum Exhaust Filter               | 152       | 1        |
| Duniway Thermocouple Gauge                | 256       | 1        |
| <i>Subtotal</i>                           | 4049.81   |          |
| <b>Flange Fittings</b>                    |           |          |
| NorCal NW-25 T-Flange                     | 84        | 1        |
| NorCal NW-25-16 Reducer Nipple            | 40        | 1        |
| NorCal NW-16 Wing Nut Clamps              | 22.4      | 4        |
| NorCal NW-25 Wing Nut Clamps              | 30        | 4        |
| NorCal NW-25 Bulkhead Clamps              | 40.8      | 2        |
| NorCal NW-16 Centering Ring & O-Ring      | 11        | 2        |
| NorCal NW-25 Centering Ring & O-Ring      | 37.8      | 6        |
| NorCal NW-25 Blank off Cap                | 16.6      | 2        |
| <i>Subtotal</i>                           | 282.6     |          |
| <b>Electrical Components</b>              |           |          |
| NorCal 8-Pin NW-25 Electrical Feedthrough | 175       | 1        |
| MDC Electrical Coupler                    | 90        | 1        |
| American Elements 12" Gold Wire           | 571.6     | 1        |
| American Elements 10" Titanium Wire       | 391.4     | 1        |
| <i>Subtotal</i>                           | 1228      |          |
| <b>Metal</b>                              |           |          |
| 18"x18"x1/4" Aluminum Plate               | 200.39    | 1        |
| Lapping Paste (80 and 290 Grit)           | 50.48     | 1        |
| Machine Oil                               | 15.72     | 1        |
| 1 1/32" Shank Drill Bit                   | 46.23     | 1        |
| 6"x4"x1/8" Aluminum Bar                   | 26.37     | 1        |
| Steel Punch                               |           |          |
| <i>Subtotal</i>                           | 339.19    |          |
| <b>Project Total</b>                      | 5899.6    |          |

### Appendix III: Deposition Calculations

The volume of the deposited prism ( $6 \frac{1}{2}'' \times 4'' \times 2.36 \times 10^{-6}''$ ) is multiplied by the density of the metal. This gives the mass of one of the arms of the L-shaped mount, thus multiplying by 4 will give the total mass,  $M$ , per deposition. Using Eq. 7 and the latent heat of vaporization for the metal,  $L_v$ , we can calculate the total amount of energy needed per deposition,  $E_{dep}$ :

$$E_{dep} = L_v M \quad .$$

The amount of power needed to vaporize and deposit this amount of metal is given by,

$$P = \frac{E_{dep}}{t} \quad .$$

If we assume that the metal will be ohmic during deposition, then the amount of current needed to pass through the metal is given by,

$$I = \sqrt{\frac{P}{R}} \quad . \quad (\dagger)$$

The resistance of the wire,  $R$ , is related to the resistivity by

$$R = \frac{\rho l}{A} \quad ,$$

where  $\rho$  is the resistivity of the wire,  $A$  is the cross-sectional area of the wire, and  $l$  is the length of the wire. Substituting the expression for resistance and power into  $(\dagger)$  yields,

$$I = \sqrt{\frac{P A}{\rho l}} = \sqrt{\frac{E_{dep} A}{t \rho l}} \quad (\ddagger)$$

There are certain variables in  $(\ddagger)$  that cannot be controlled.  $E_{dep}$ , is dependent on the metal, and the required thickness.  $\rho$  is also characteristic of the metal, and since we ordered gold and titanium wires with diameters of .80mm and .75mm respectively, the value of  $A$  is also fixed. Recall that the electrical feedthrough can handle a current of up to 2 amps, we can thus alter the time for deposition,  $t$ , along with the length of the wire,  $l$ , to ensure that we don't destroy the feedthrough. Table 1 gives

examples of appropriate values for  $t$  and  $I$  that will produce the appropriate current.

|          | Mass/Deposition                  | Energy/Deposition  | Estimated Time of Deposition | Power | Current   |
|----------|----------------------------------|--------------------|------------------------------|-------|-----------|
| Gold     | $7.77 \times 10^{-5} \text{ kg}$ | $127.82 \text{ J}$ | 40 minutes                   | .05 W | 1.87 Amps |
| Titanium | $9.07 \times 10^{-7} \text{ kg}$ | $7.97 \text{ J}$   | 5 minutes                    | .03 W | 1.52 Amps |

*Table 1: Deposition values for gold and titanium. The density of gold and titanium is  $19300 \text{ kg/m}^3$  and  $4506 \text{ kg/m}^3$  respectively. The latent heat of gold and titanium is  $1645 \times 10^3 \text{ J/kg}$  and  $8789 \times 10^3 \text{ J/kg}$  respectively. The resistivity of gold and titanium is on the order of  $10^{-8} \Omega \text{m}$ .*

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