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Author:
Matthew Leone

Special Thanks:
Todd Kaiser

MODU-LAB PVD

OPERATIONS MANUAL

This document is intended to provide users with a complete and thorough set of instructions for the operation and use of the MODU-LAB thermal evaporation PVD system. The manual is primarily focused for the safe deposition of aluminum films onto 100mm wafer substrates for use in a semiconductor fabrication sequence.

QUICK REFERENCE:

1. Turn on *Power Strip* and ensure *Compressor*, *Valve Control Power* and *Chamber Pressure* switches are ON.
2. Open *Forline Valve*
3. Start *Turbo Pump Control*
4. Prepare evaporation sample
5. Open *Vent Valve*
6. Unload Chamber
    a. Remove *Mirror Assembly*
    b. Remove *Wafer Holder*
    c. Remove *Filament Shield*
    d. Remove *Filament*
7. Load Chamber
    a. Place evaporation sample into *Filament*
    b. Place wafers into *Wafer Holder*
    c. Replace *Filament* into *Clamps*
    d. Replace *Filament Shield*
    e. Replace *Mirror Assembly*
8. Close *Forline Valve*
9. Close *Vent Valve*
10. Open *Rough Valve* while holding door shut
11. When *Chamber Pressure* (Pirani) < 200mTorr, *Set Point Light* will come on, close *Rough Valve*
12. Open *Forline Valve*
13. Open *HiVac Valve*
14. When *Chamber Pressure* (Cold Cathode) $\leq 10^{-5}$Torr, *Set Point Light* comes on at 10^{-4}Torr, the system is ready for deposition
15. Ensure *Deposition Power Control* knob is set to ZERO, turn Deposition Enable switch to ON
16. Slowly turn *Deposition Power Control* to 60%, Be careful to monitor *Chamber Pressure* (Cold Cathode), if pressure rises above the set point, 10^{-4}Torr, deposition will automatically shut off and *Deposition Power Control* should be backed down to a lower percentage.
17. Wait 30-50 seconds when *Deposition Power Control* is at 60% until sample is entirely evaporated
18. Turn *Deposition Power Control* to ZERO, turn *Deposition Enable* switch to OFF
19. Let PVD cool for 5 minutes
20. Close *HiVac Valve*
21. Open *Vent Valve*
22. Unload Chamber (see step 6)
23. Replace *Mirror Assembly* and *Wafer Holder* or reload chamber (see step 7)
24. Close *Vent Valve*
25. Close *Foreline*
26. Open *Rough Valve* while holding *Chamber Door* shut unto *Chamber Pressure* (Pirani) reads <50mTorr
27. Close *Rough Valve*
28. Shutdown PVD
    a. Stop *Turbo Pump Control*
    b. Turn off *Power strip*

NOTE: QUICK REFERENCE step numbers do not correspond to DETAILED OPERATION step numbers.

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INTRODUCTION & THEORY

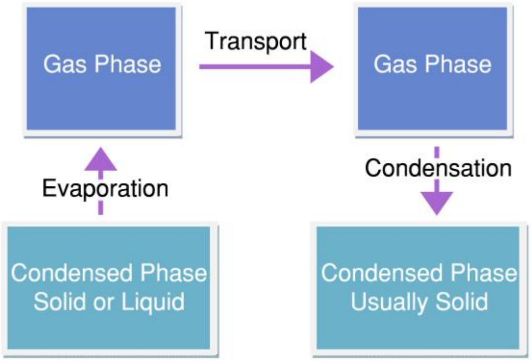
The broad term, Physical Vapor Deposition(PVD), includes two forms: evaporation and sputtering. Both which describe a means of depositing a thin film of material onto a substrate, usually in a vacuum system. The difference between the two is in the way in which a material is transformed into a vapor form.

Evaporation includes all methods that heat a material past its melting point until it is transformed into its gas phase. The vapor is transported to the substrate via thermal energy where it condenses to form a thin film. Methods of heating a material may include e-beam, filament (thermal), laser or others. Different methods provide different advantages and disadvantages but the common advantages to evaporation PVD (vs. sputtering) include: fast deposition rate, low substrate damage, low cost, and little contamination.

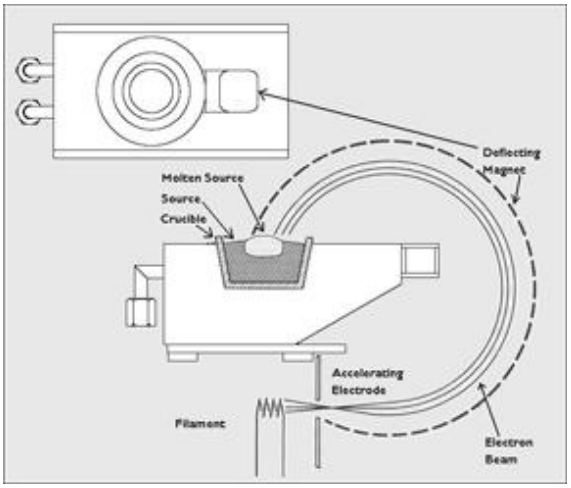
Sputtering describes a system wherein a target material is bombarded with ions that break off particles of the target material which are projected towards a substrate. Sputtering PVD has many advantages including, a large range of materials that can be sputtered, in situ cleaning, excellent film control i.e. uniformity, adhesion, thickness, etc.

The method described in this manual is for a filament (thermal) evaporation PVD system. A key component is the vacuum system. A vacuum system is necessary in evaporation PVD to remove particles between the source and substrate. By doing so evaporated particles have a straight path to the substrate. Thus it is necessary for the vacuum system to create a mean-free-path longer than the distant between the source to substrate. If this criterion is not met, film quality will be dramatically compromised. Thus, a large portion of the operation instructions are dedicated to this vacuum system and how it can be successfully operated.

If throughout the use of this document, items are mislabeled, instructions not made clear, situations are not fully described, etc, please make an addition under the USER COMMENTS sections to aid future users.



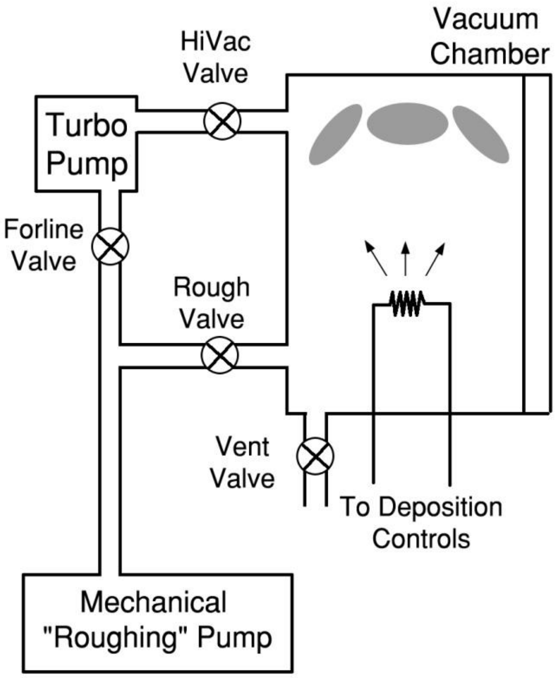
Above: Overview of PVD process



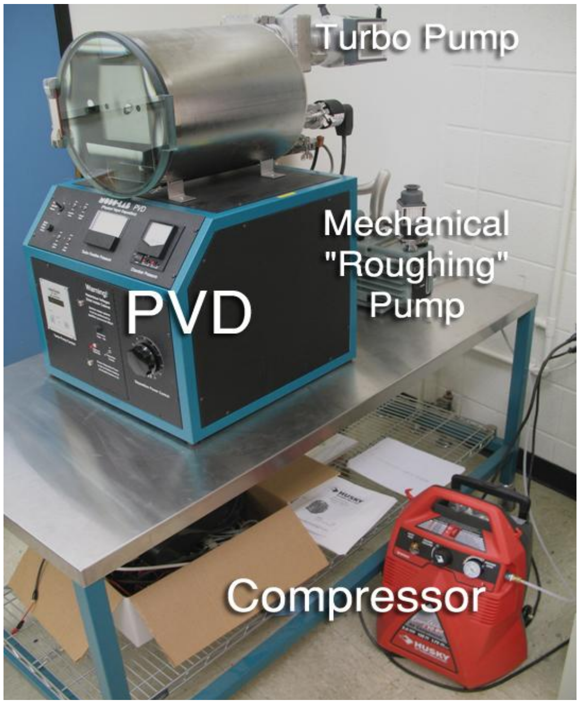
Above: Illustration of e-beam evaporation system
www.ee.byu.edu

Above: Illustration of a sputter PVD system
Kyushu University

EQUIPMENT OVERVIEW

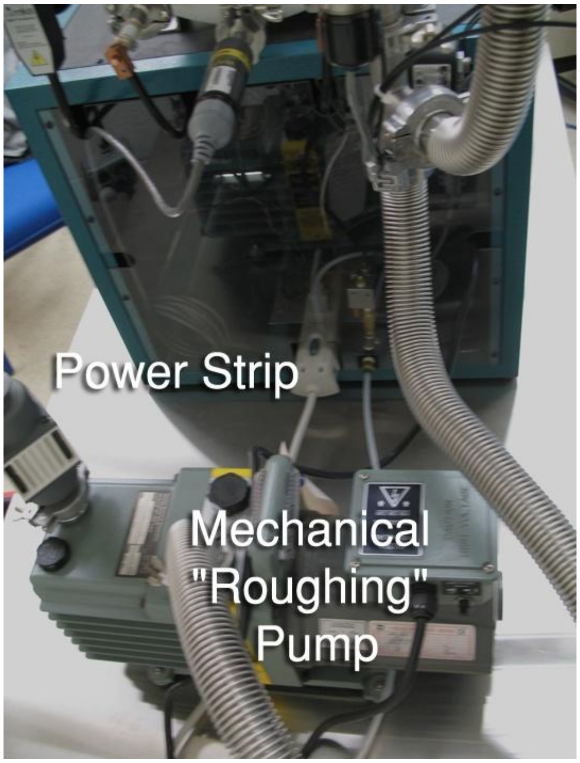


Above: Schematic of Modu-Lab thermal PVD



Above: Broad Overview of Components

Above: Front-View of Modu-Lab PVD



Above: Rear-View of Modu-Lab

DESCRIPTION OF MAIN COMPONENTS

VACUUM CHAMBER

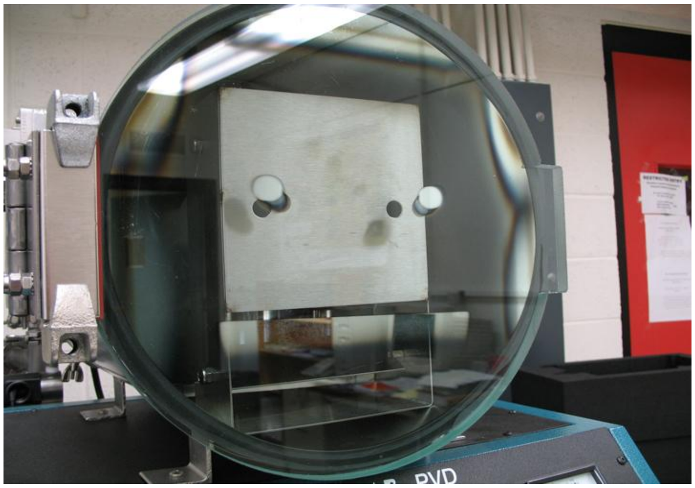
1. Mirror Assembly**:** Located in the front of the vacuum chamber, this mirror assembly provides viewing of the tungsten *Filament* and evaporation sample. Similar in operation to a periscope.

2. Filament**:** Used to heat and evaporate samples when a large current is applied across its ends. Comes in various shapes and sizes for different applications. Will become very brittle and fracture after multiple deposition cycles. The *filament* is held in place with two screw clamps.

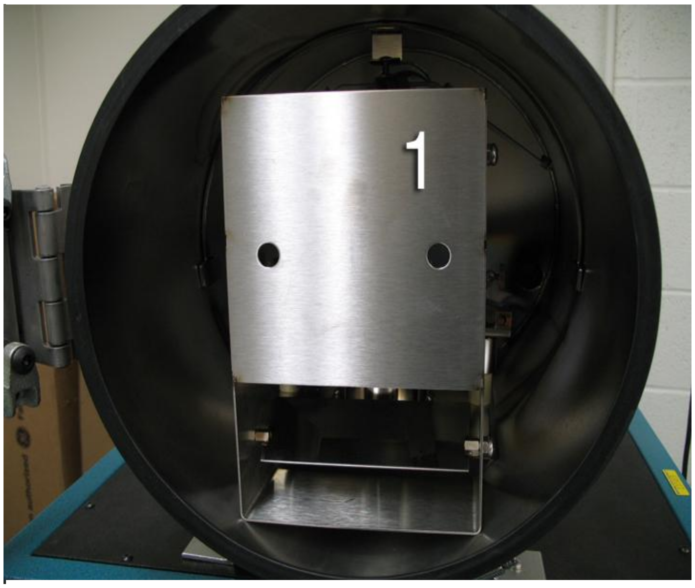
3. Filament Shield**:** The shield attempts to limit deposition of material to wafer holder and not chamber door. Fits tightly around based and most likely will require two hands to remove safely. Will become very hot after deposition, and should be left to cool for an extended period of time.

4. Wafer Holder**:** Holds four wafer substrates suspended above *Filament* and evaporation sample. Angled beams seek to maximize deposition uniformity. Wafers are held in place via two spring clamps and holder is loosely suspended with screw and notch assembly.

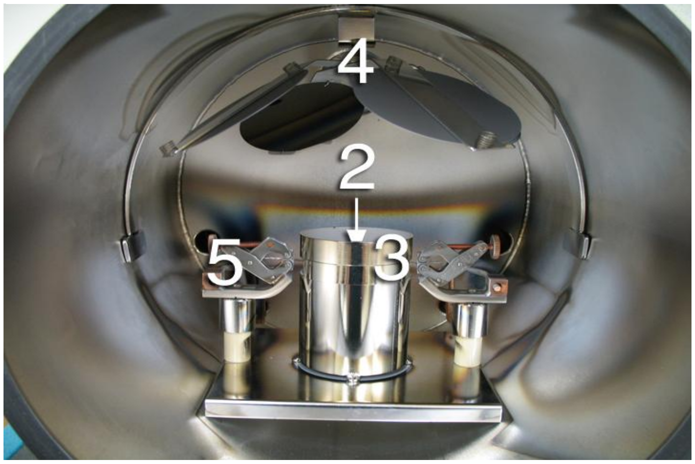
5. Screw Clamps**:** Secures *filament* in place and provides a bridge for current to flow. Filament should rest in notched end pieces for correct operation



Above: Front-view of vacuum chamber with door closed



Above: Opened vacuum chamber with *Mirror Assembly* in front



Above: Inside vacuum chamber with numbered components

DESCRIPTION OF MAIN COMPONENTS

FRONT PANEL

***6. Turbo Pump Control*:** Program module for *Turbo Pump*.

***7. Deposition Enable* switch:** Allows current to flow for deposition and activates *Deposition Power Control* knob.

***8. Deposition Power Control* knob:** Analog (variac) adjustment of current being delivered to filament. Should be slowly turned while evaporating but can be quickly brought to zero when finished.

Above: *Turbo Pump Control* fully ramped

Above: Deposition Controls

VALVE CONTROL SWITCHES

***9. Valve Control Power*:** Activates various valve switches. Normally, switch is left in ON position and power is supplied when *power strip* is turned on.

***10. Forline Valve*:** Connects the *Mechanical "Roughing" pump* to the back of the *Turbo Pump*. Necessary to prevent damage to the *Turbo Pump*. The *Turbo Pump* is unable to exhaust a low pressure vacuum to atmospheric pressure thus the Forline valve enables the *Mechanical "Roughing" Pump* to create a low pressure exhaust region behind the *Turbo Pump*.

***11. Vent Valve*:** Used to vent Vacuum Chamber to atmospheric pressure and allow chamber door to be opened.

***12. HiVac Valve*:** Connects *Turbo Pump* to Vacuum Chamber to reduce chamber pressure to deposition pressure of $\sim 10^{-5}$mTorr.

***13. Rough Valve*:** Directly connects *Mechanical "Roughing" Pump* to vacuum chamber and allows pressure to be reduced from atmospheric to ~200mTorr.

Above: Numbered valve control switches

DESCRIPTION OF MAIN COMPONENTS

GAUGES

14. Turbo Forline Pressure **gauge:** Indicates the pressure behind the Turbo Pump. Before beginning deposition, this gauge should read <50mTorr to prevent damage to the Turbo Pump.

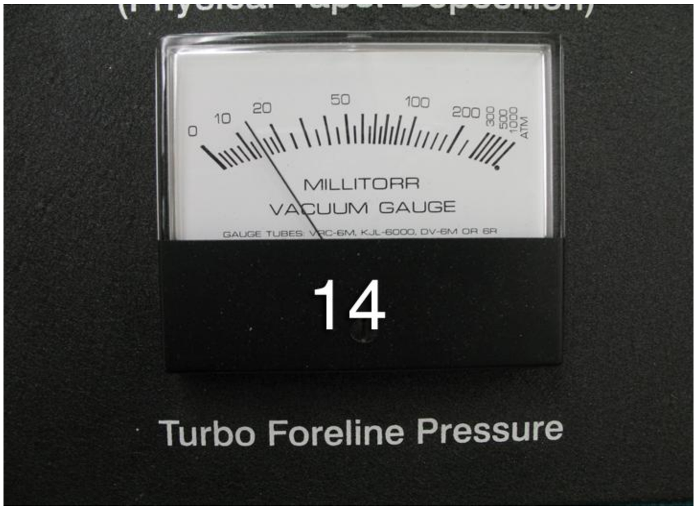
15. Chamber Pressure **gauge:** Displays the chamber pressure used two pressure gauges for different pressure ranges.

Pirani: Left (Black) needle, displays chamber pressure during rough pump down.

Range: 760-10^{-3}mTorr.

Cold Cathode: Right (Red) needle, displays chamber pressure during HiVac pump down.

Range: 10^{-2}-10^{-9}mTorr.



Above: *Turbo Forline Pressure* gauge with open *Forline Valve*

Above: *Chamber Pressure* gauge with initial pressure readings before pump down

PUMPS & POWER

Turbo Pump: Used to create low pressure vacuum for evaporation. Located on the upper-backside of PVD. (see EQUIPMENT OVERVIEW)

Mechanical "Roughing" Pump: Used to pump down chamber from atmospheric pressure so Turbo Pump can create low pressure vacuum. Sits behind PVD and plugged into *power strip (see EQUIPMENT OVERVIEIW)*

***Compressor*:** Used to quickly vent chamber, switch is usually left ON. *(see EQUIPMENT OVERVIEIW)*

***Power Strip*:** Provides power to PVD and *Mechanical "Roughing" Pump(see EQUIPMENT OVERVIEIW)*

PREPARING AN ALUMINUM SAMPLE

1

Obtain a sheet of Ultra High Vacuum(UHV) aluminum foil, a pair of scissors, and a ruler.

UHV aluminum foil can be found in the clean room. It is high grade, pure, aluminum.

2

Using latex gloves, measure and cut out a rectangular segment of foil.

A 30cm^2 rectangle of aluminum will create a 0.5-0.7μm thin-film on the surface of the wafers. Watch Out The PVD can be overloaded with too large a sample. At a deposition pressure of 10^{-5}mTorr, the largest sample that can be successfully evaporated is roughly 50-60cm^2. If a thicker metal film is necessary, a better solution is to perform multiple evaporations followed by an anneal.

3

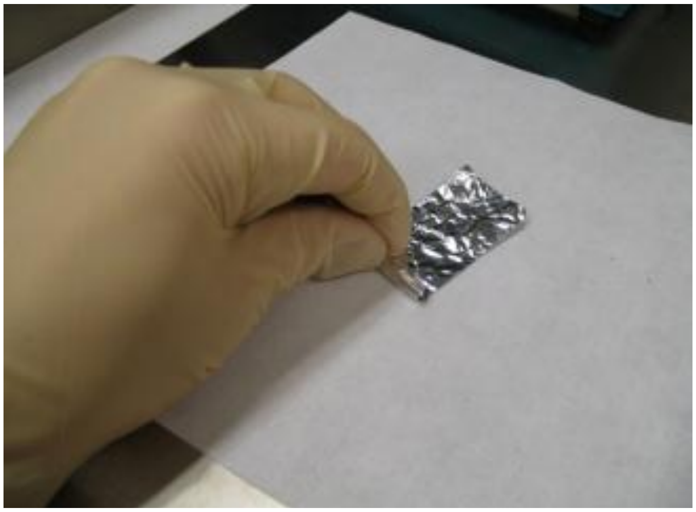
Roll segment to fit into *Filament*

If the sample is a 3x10cm pieces, roll the sample along the 3cm side. If a larger sample is used, folding or cutting into smaller segments may be necessary. Make sure the rolled aluminum length does not exceed the *Filament* length.

USER COMMENTS:

Above: Supplies for an aluminum evaporation sample

Above: A 30cm^2 UHV aluminum foil segment



Above: Rolling the aluminum foil segment to fit in the *Filament*

I. INITIALIZATION

1 Turn on *Power Strip* located to the rear of the PVD.

The *Power Strip* is connected to the *Mechanical "Roughing" Pump* and *PVD*.

2 Ensure the *Chamber Pressure* and *Valve Control Power* switches are ON.

These switches are normally left ON. All other valve switches should be in the CLOSED position.

3 Open *Forline Valve*.

Upon opening, the *Turbo Forline Pressure* gauge should indicate a dropping pressure. Once the pressure reads <50 mTorr the *Turbo Pump* can be started.

4 Press START on the *Turbo Pump Control* panel.

The *Turbo Pump* will take several minutes to get up to its operating speed of ~27000 RPM. The display will indicate when the pump is at operating speed.

5 Prepare evaporation sample.

(see Preparing Aluminum Sample section)

6 Open *Vent Valve*.

An audible hissing sound can be heard as the vacuum is released. It will take several minutes for the chamber to equalize at which time the door will be able to open.

Above: Starting the PVD by turning on the *Power strip*

Above: Controls and switches corresponding to step number

Above: *Turbo Pump Control* indicating pump is at speed.

USER COMMENTS:

II. UNLOADING

7 Put on latex gloves to prevent contamination in the PVD

8 Remove *Mirror Assembly.*

The *Mirror Assembly* simply rests at the mouth of the vacuum chamber. When removed, place it mirror-side down. By doing so, the drilled-holes can act as a support for the wafer holder.

9 Remove *Wafer Holder.*

Stabilize the *Wafer Holder* by placing its support screw into one of the holes in the *Mirror Assembly*. This will prevent the *Wafer Holder* from rolling around when trying to load wafers. (see picture)

10 Remove *Filament Shield.*

The Filament Shield fits snugly onto the base and may require two hands to remove.

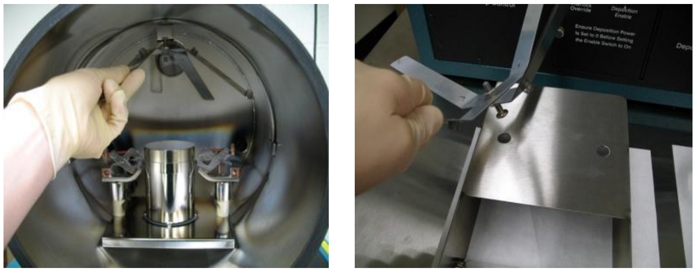
11 Unscrew clamps and remove *Filament.*

Watch Out After repeated evaporations the *Filament* will become very brittle and can easily be broken. Extra *Filaments* should be nearby in case one is broken.

USER COMMENTS:

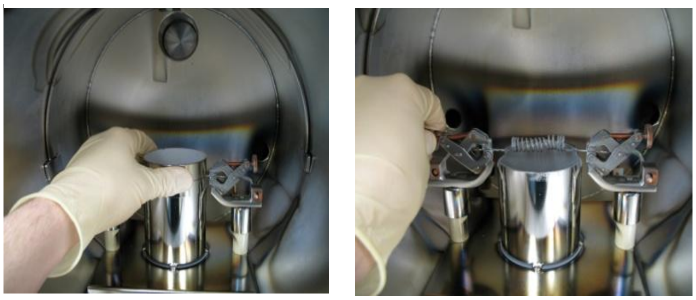
Upper Left: Latex gloves, extras can be found in clean room

Upper Right: Removal of *Mirror Assembly*



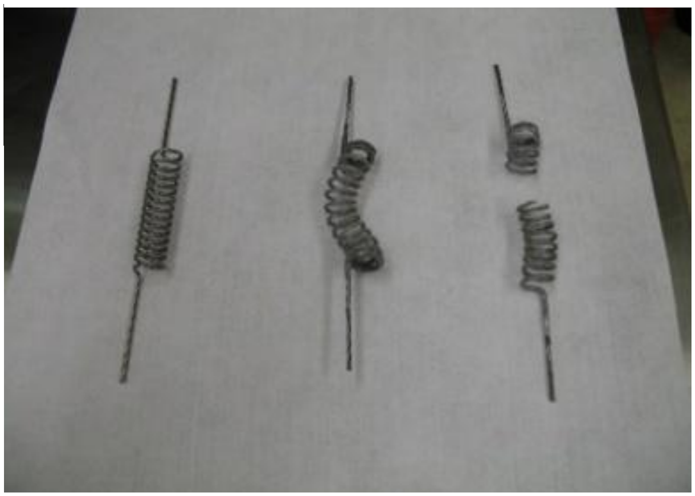
Upper Left: Removal of *Wafer Holder*

Upper Right: Stabilizing *Wafer Holder* in *Mirror Assembly*



Upper Left: Removal of *Filament Shield*

Upper Right: Unscrewing clamps to remove *Filament*



Above: Tungsten Filaments at various stages Leftmost-New; Middle-Used but functional; Right-Broken and unusable

III. LOADING

12 Load evaporation sample into *Filament*.

It's possible the *Filament* will fall out during pressurization/venting so ensure the sample is snug within the *Filament* by crimping the ends or bending in the middle.

13 Load wafers into *Wafer Holder*.

Wafers are secured via two spring clips. Before trying to load individual wafers, make sure the *Wafer Holder* is stabilized with the *Mirror Assembly*. Lock wafers into place by pressing spring clip and sliding wafer beneath. It's possible to load 1-4 wafers. When loading two wafers, place opposite one another in the *Wafer Holder* to keep things balanced.

14 Replace *Filament* in screw clamps.

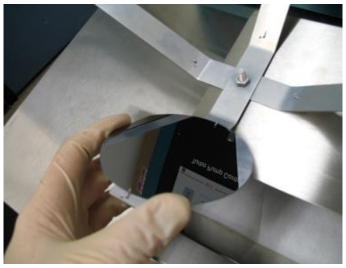
Note the ridges on the edges of the screw clamps. (see picture) The *Filament* should be resting in these ridges before tightening.

15 Replace *Filament Shield*

16 Replace loaded *Wafer Holder*

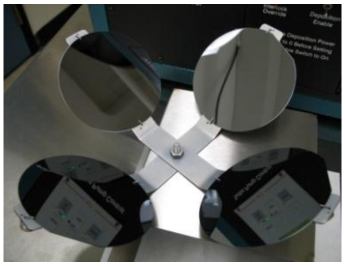
17 Replace *Mirror Assembly*

USER COMMENTS:



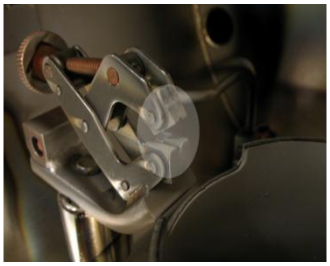
Upper Left: Aluminum evaporation sample loaded into *Filament*

Upper Right: Loading a wafer into *Wafer Holder*



Upper Left: Close-up of a spring clip

Upper Right: Fully-loaded *Wafer Holder*

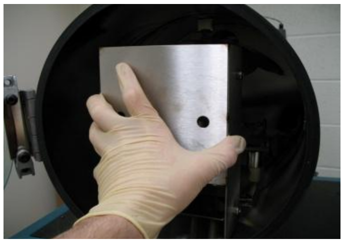


Upper Left: Replacing loaded *Filament* into screw clamps

Upper Right: Close-up of ridges on screw clamps

Upper Left: Replacing *Filament Shield*

Upper Right: Replacing loaded *Wafer Holder*



Above: Replacing *Mirror Assembly*

IV. PUMP DOWN

18 Close *Forline Valve*.

19 Close *Vent Valve*.

20 Open *Rough Valve* while holding chamber door shut.

Door should become sealed to vacuum chamber and *Chamber Pressure (Pirani)* gauge should indicate a dropping chamber pressure. All other valves are CLOSED.

21 When left set point LED lights-up on *Chamber Pressure* gauge, close *Rough Valve*.

The left (PIR) set point LED is set for a *Chamber Pressure (Pirani)* of ~200mTorr.

22 Open *Forline Valve*.

23 Open *HiVac Valve*.

24 When *Chamber Pressure (Cold Cathode)* reaches ~10^{-5}mTorr, PVD is ready for deposition

Watch Out The right (CC) set point LED is set higher than deposition pressure. It will take roughly 15-20 minutes for the chamber to reach this pressure.

Above: Switches corresponding to step number. Initial pump down from atmospheric to ~10^{-1}mTorr

Above: Switches corresponding step number. High Vacuum pumps down from 10^{-1}-10^{-5}mTorr

Above: *Chamber Pressure (Cold Cathode)* reads ~10^{-5}mTorr, Ready for deposition

USER COMMENTS:

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V. DEPOSITION

25 Ensure that *Deposition Power Control(DPC)* is set to ZERO then turn *Deposition Enable* switch to ON.

26 Slowly increase *Deposition Power Control(DPC)* to +60% to evaporate sample. Hold for 1-2 minutes to completely evaporate the sample.

As *Filament* begins to glow, evaporation sample should melt and wick onto *Filament*. Watch out As the *Deposition Power Control* is increased, the chamber pressure will rise (needle will fall). If the *Chamber Pressure (cold cathode)* rises above the set point of 10^{-4}mTorr (right LED), the deposition controls will automatically shut off until pressure is lowered. Lower the pressure by decreasing the *Deposition Power Control*.

27 Once sample is completely evaporated, turn *Deposition Power Control(DPC)* to ZERO and turn *Deposition Enable* switch to OFF.

28 Let PVD cool for five minutes.

USER COMMENTS:

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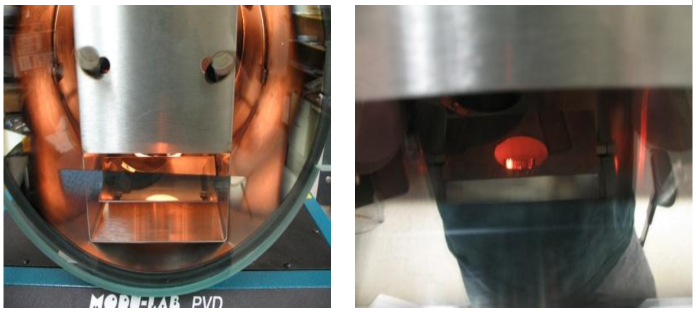
Upper Left: Initial deposition controls

Upper Right: Increasing the *Deposition Power Control*



Upper Left: View through chamber door as evaporation begins

Upper Right: Filament is visible through bottom mirror

Above: Aluminum sample begins to melt at DPC = 40%

Above: Aluminum sample evaporates at DPC = +60%

VI. UNLOAD & POWER DOWN

29 Close *HiVac Valve.*

30 Open *Vent Valve.*

Chamber Pressure will take several minutes to equalize to atmospheric pressure. Door should not be forced open, only a small force should be necessary to open the chamber.

31 Follow UNLOADING procedure to remove wafers.

Watch Out *Filament* and *Filament Shield* will still be very hot. *Filament* and *Filament Shield* only need be unloaded if a subsequent evaporation is going to take place, otherwise, only unload *Mirror Assembly* and loaded *Wafer Holder*. Replace *Mirror Assembly* and *Wafer Holder* when completed.

32 Close *Vent Valve.*

33 Close *Forline Valve.*

34 Open *Rough Valve* while holding chamber door shut.

Let *Chamber Pressure (Pirani)* gauge pump down to <50mTorr.

35 Close *Rough Valve.*

All valves should be CLOSED

36 Stop *Turbo Pump Control* turn off *power strip.*

END OF PROCEDURE

USER COMMENTS:

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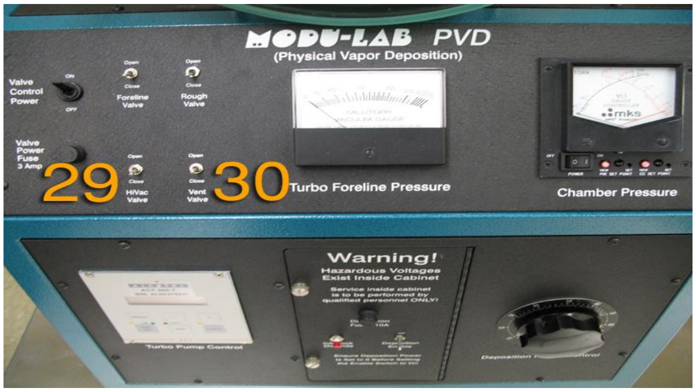

Above: Switches corresponding to sequence number

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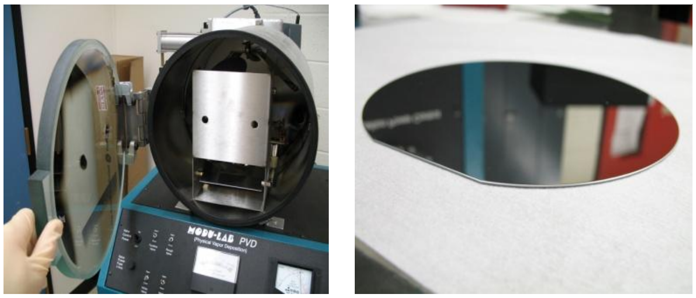
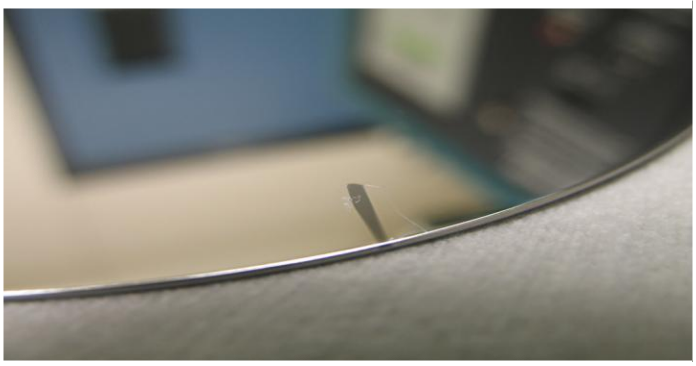


Upper Right: Chamber is equalized and door is easily opened

Upper Left: Unloaded wafer with evaporated aluminum film



Above: Spring clip mark on edge of wafer

If this mark is not visible, evaporation may not have taken place. Thin film can be characterized with conductivity measurements or profilometer data