DENTON VACUUM

BARRIERS BECOME BREAKTHROUGHS

Process Technology at Denton

September 2012

The Goal of this Training

Your success as a sales representative depends on your ability to understand **all** of your customer's needs – technical, financial, business and emotional.

The key to understanding your customers' technical needs is understanding their process technology requirements.

Denton products cover an extraordinarily wide range of process technologies. Compounding this, these processes are performed in vacuum systems, which are built on an entirely unique stand-alone technology set.

The goal of this training is not to make you process technology experts. It's not even to give you the information you need to make sales.

The goal of this training is to give you a basic set of concepts **– concepts you can then use to further your education** – in customer conversations, in exchanges with Denton process engineers, and in off-line study on the internet and in texts. **It's up to you.**

Process Technology at Denton

Evaporation	Heat materials to their boiling point & condense the evaporant onto a surface	***Thermal Evaporation*** ***E-beam Evaporation***
Sputtering	Use a high energy particle stream to knock atoms off a target and onto a surface	***Ideal for use in large area deposition systems***
Plasma Enhanced Chemical Vapor Deposition (PECVD)	Chemically react gases in a high energy plasma; condense the resulting species onto a surface	***Create unique, engineered thin films***

Process Technology at Denton

Ion Etching	Use a stream of energetic ions to etch away materials.	***Provides a precision alternative to conventional etching processes.***
Directed Ion Beam Deposition	Use a stream of energetic ions to sputter.	***Provides a precision alternative to conventional etching processes.***

Vacuum Technology

Vacuum Technology

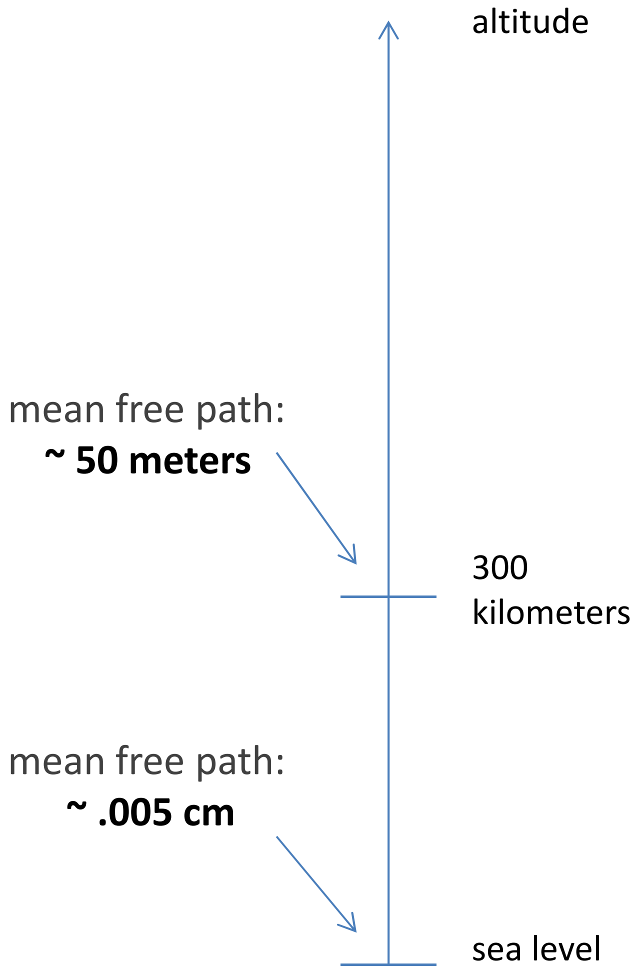
- Vacuum technology is so wide and deep a subject matter that one can get a PhD in it and still not be considered a broad based expert.
- Some Denton customers are vacuum fanatics with detailed requirements – others could care less so long as the tool delivers.
- As a Denton sales representative, you will encounter both.
- This training module is not intended to make you a vacuum expert, but give you a brief overview of the technology and its impact on our processes.
- The book you will receive in this training session, “Introduction to Vacuum Technology” by Brian Hata, is a good reference for work with us and your customers.

Why Process Under Vacuum?

Processing under vacuum removes from the process chamber any ambient gases (N2, O2, etc.) and trace contaminants (e.g. oil vapor, excess humidity) that can interact with and contaminate the substrate and/or film material.

As ambient air is removed from a process chamber, the **mean free path** of atoms, ions and species is increased. Loosely defined, **mean free path is the distance a gas atom or molecule travels before colliding with another atom or molecule.**

The longer the mean free path, the higher the probability that the source atoms and molecules being transported to the surface of a substrate will arrive there unimpeded by ambient air. This translates to higher deposition rates, better quality films, and more predictable, reliable processes.



altitude

mean free path:
~ 50 meters

300 kilometers

mean free path:
~ .005 cm

sea level

Vacuum Measures

Vacuum levels are most commonly specified in torr, where pressure at sea level is 760 torr.

(one torr is roughly equal to the fluid pressure exerted by a millimetre of mercury, i.e., a pressure of 1 torr is approximately equal to 1 mmHg)

The **"rough vacuum"** regime = 1 atm to 10^{-3} torr

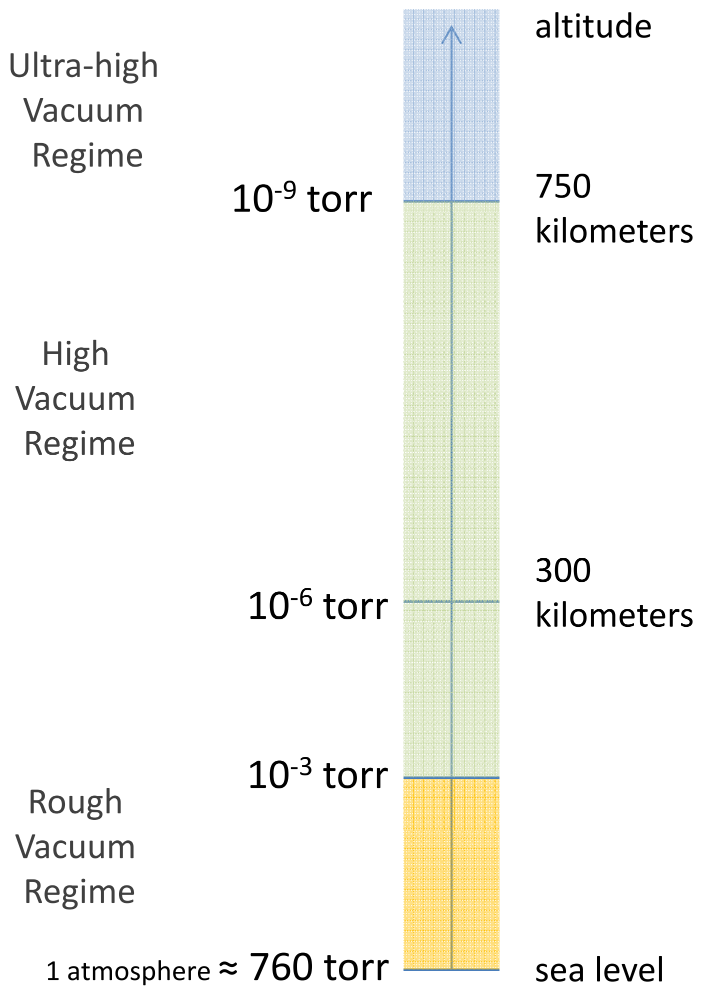
The **"lower high vacuum"** regime = 10^{-3} to 10^{-6} torr

The **"upper high vacuum"** regime = 10^{-6} to 10^{-9} torr

The **"ultra high vacuum"** regime = 10^{-9} to 10^{-12} torr

Most Denton systems operate in the lower and upper high vacuum regimes. (10^{-3} to 10^{-9} torr)

Occasionally users will want to systems to be capable of demonstrating ultra-high vacuum performance.



Ultra-high Vacuum Regime

10^{-9} torr

High Vacuum Regime

10^{-6} torr

10^{-3} torr

Rough Vacuum Regime

1 atmosphere ≈ 760 torr

altitude

750 kilometers

300 kilometers

sea level

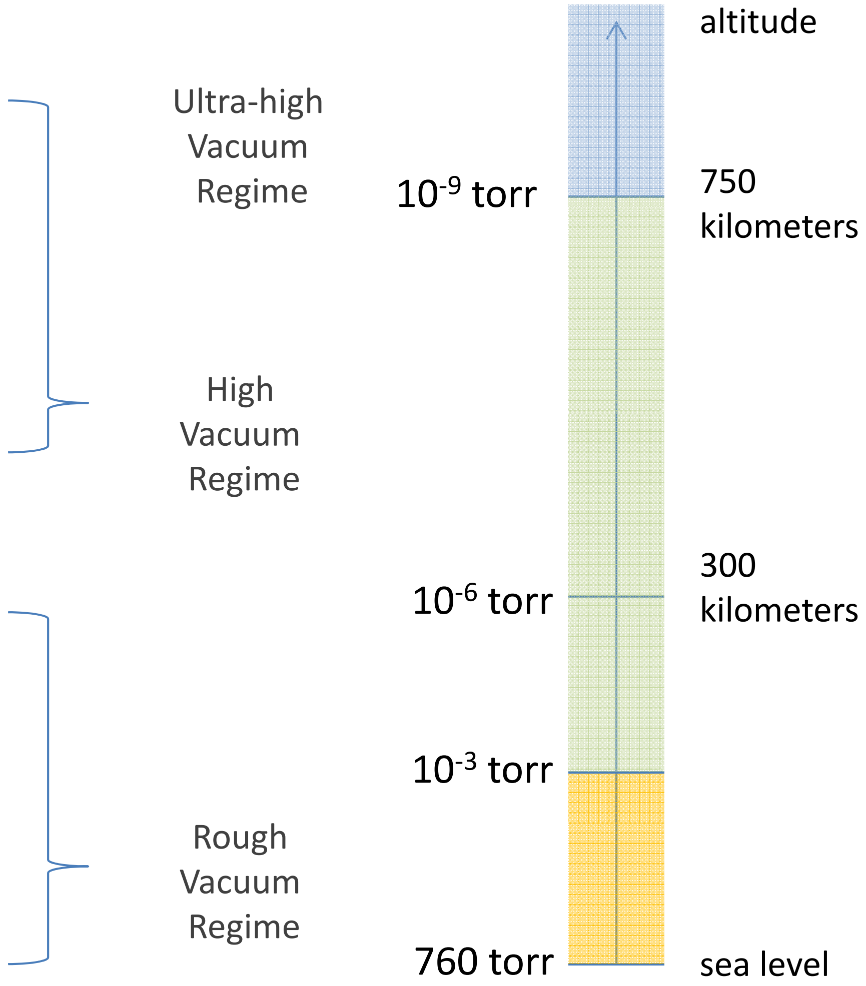
Vacuum Measurement & Characterization

Ion Gauges: *measure by analyzing the ion current created by the ionization of residual gas molecules in the chamber.*

Cold Cathode Guages: *measure by ther current created by the ionization of residual gas molecules in the chamber using a high voltage discharge.*

Pirani Gauges: *measure by tracking the change in resistance of an exposed filament as pressure changes.*

Capacitance Monometers: *measure by tracking the deflection of a metal diaphragm that forms one element of a parallel plate capacitor.*



Ultra-high Vacuum Regime

High Vacuum Regime

Rough Vacuum Regime

altitude

10^{-9} torr — 750 kilometers

10^{-6} torr — 300 kilometers

10^{-3} torr

760 torr — sea level

Generating High Vacuum

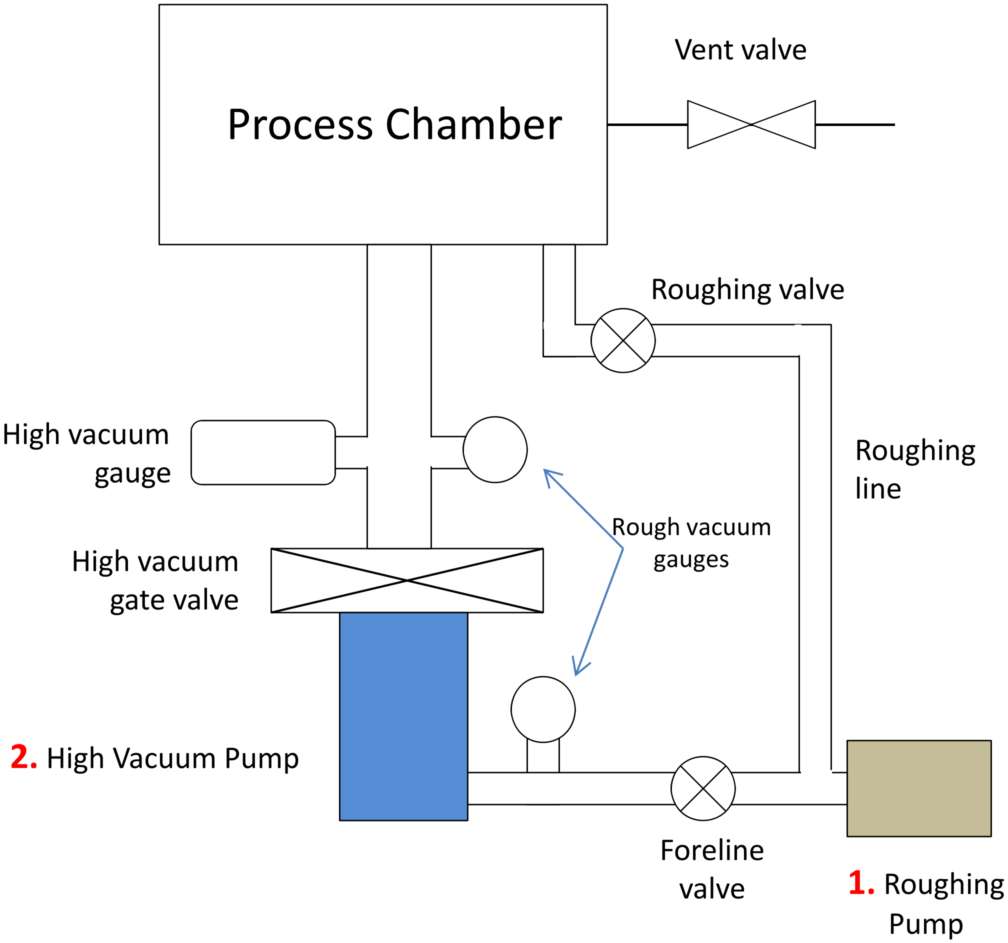
Generating high vacuum is a two step process:

1. A **“roughing pump“** acting in isolation pumps down the process chamber to the rough vacuum regime.

2. A **“high vacuum pump”** – which can’t operate in the rough vacuum regime – then completes the pump-down process.

The roughing pump removes almost all of the gas plus a significant amount of water vapor in the ambient air.

The high vacuum pump provides the final pump-down to “base” pressure.

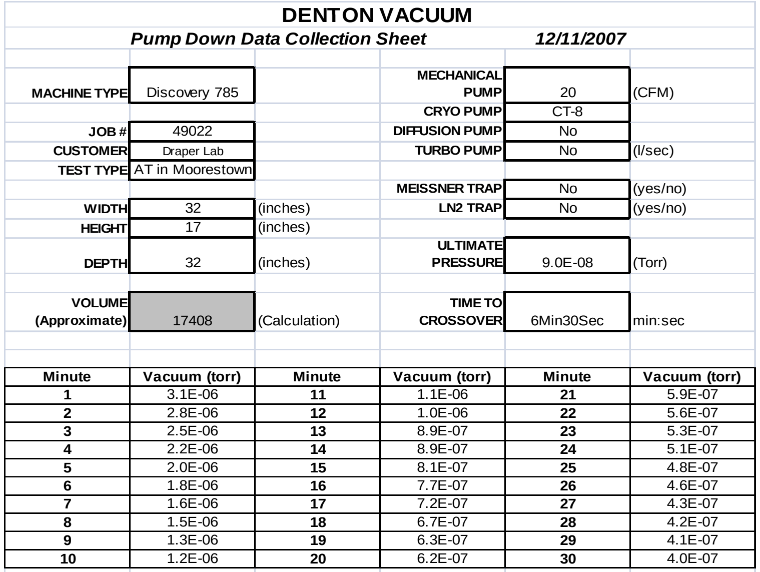


Vacuum Pump Down Curves

Pump down curves measure the time needed to pump down the process chamber to base pressure.

A smooth, rapid pump-down to base pressure (typcially in the 10^{-6} to 10^{-7} torr range) indicate:

- Proper matching of pump sizes and chamber size.
- Proper system design through the selection of proper chamber materials and components combined with a minimum of feed-throughs and other potential points of leakage.
- Proper maintenance of seals and other system components.
- Management of ambient humidity to minimize the impact of water vapor on system pumpdowns.



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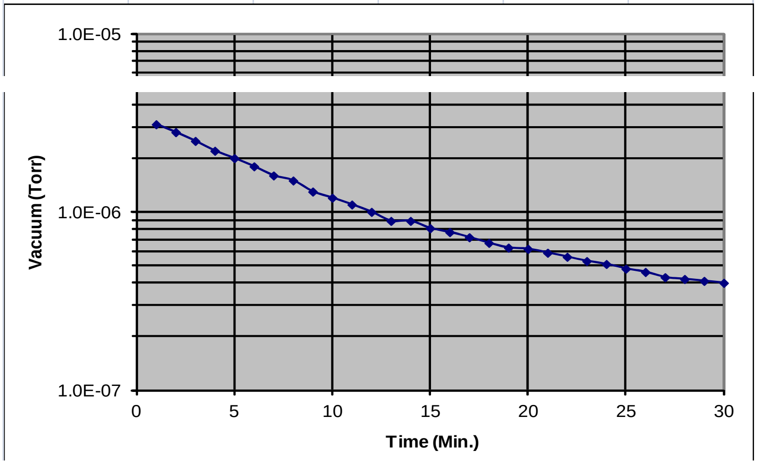
Pump Down Data Collection Sheet ***12/11/2007***

MACHINE TYPE	Discovery 785		**MECHANICAL PUMP**	20	(CFM)
			CRYO PUMP	CT-8	
JOB #	49022		**DIFFUSION PUMP**	No	
CUSTOMER	Draper Lab		**TURBO PUMP**	No	(l/sec)
TEST TYPE	AT in Moorestown				
			MEISSNER TRAP	No	(yes/no)
WIDTH	32	(inches)	**LN2 TRAP**	No	(yes/no)
HEIGHT	17	(inches)			
DEPTH	32	(inches)	**ULTIMATE PRESSURE**	9.0E-08	(Torr)
VOLUME (Approximate)	17408	(Calculation)	**TIME TO CROSSOVER**	6Min30Sec	min:sec

Minute	Vacuum (torr)	Minute	Vacuum (torr)	Minute	Vacuum (torr)
1	3.1E-06	**11**	1.1E-06	**21**	5.9E-07
2	2.8E-06	**12**	1.0E-06	**22**	5.6E-07
3	2.5E-06	**13**	8.9E-07	**23**	5.3E-07
4	2.2E-06	**14**	8.9E-07	**24**	5.1E-07
5	2.0E-06	**15**	8.1E-07	**25**	4.8E-07
6	1.8E-06	**16**	7.7E-07	**26**	4.6E-07
7	1.6E-06	**17**	7.2E-07	**27**	4.3E-07
8	1.5E-06	**18**	6.7E-07	**28**	4.2E-07
9	1.3E-06	**19**	6.3E-07	**29**	4.1E-07
10	1.2E-06	**20**	6.2E-07	**30**	4.0E-07



Vacuum Component Options

High vacuum pumps are typically **turbomolecular pumps** (which use a series of high speed rotor and stator blades to remove residual gas) or **cryo pumps** (which cryogenically entrap residual gases).

There are even more variations in roughing pumps, ranging from **rotary vane pumps** (which uses a sliding vane to compress and remove ambient air) to **roots blowers** (which pump directly from the chamber without compression).

To build a working familiarity with these and other vacuum components, consult **"Introduction to Vacuum Technology".**

Turbo
High Vacuum
Pump

Cryogenic
High Vacuum
Jump

Rotary Vane
Roughing Pump

Roots Blower
Roughing Pump

Characterizing Vacuum Performance

A **helium leak detector** is a stand-alone, special purpose mass spectrometer used to detect a tracer gas (helium) that may be emitted from or by a vacuum chamber. With its own vacuum pumping system, this class of system is frequently used to troubleshoot pump-down problems. Not normally sold by Denton.

Helium Leak Detector

A residual gas analyzer or **RGA**, can be integrated through a dedicated vacuum feed through on the process chamber or be a stand-alone unit. It is a mass spectrometer used to detect a wide range of residual gases within the process chamber. It can be used diagnostically to look for particular signatures (e.g. hydrocarbons) that can indicate a vacuum system problem, or as a process development and reliability tool that can track and record multiple residual gas signatures through the process cycle. Sold by Denton as an option.

Why Vacuum Matters

- Before a deposition or etching process most customers pump-down their process chamber to high vacuum. This provides a clean and clear starting point for the customer's process.

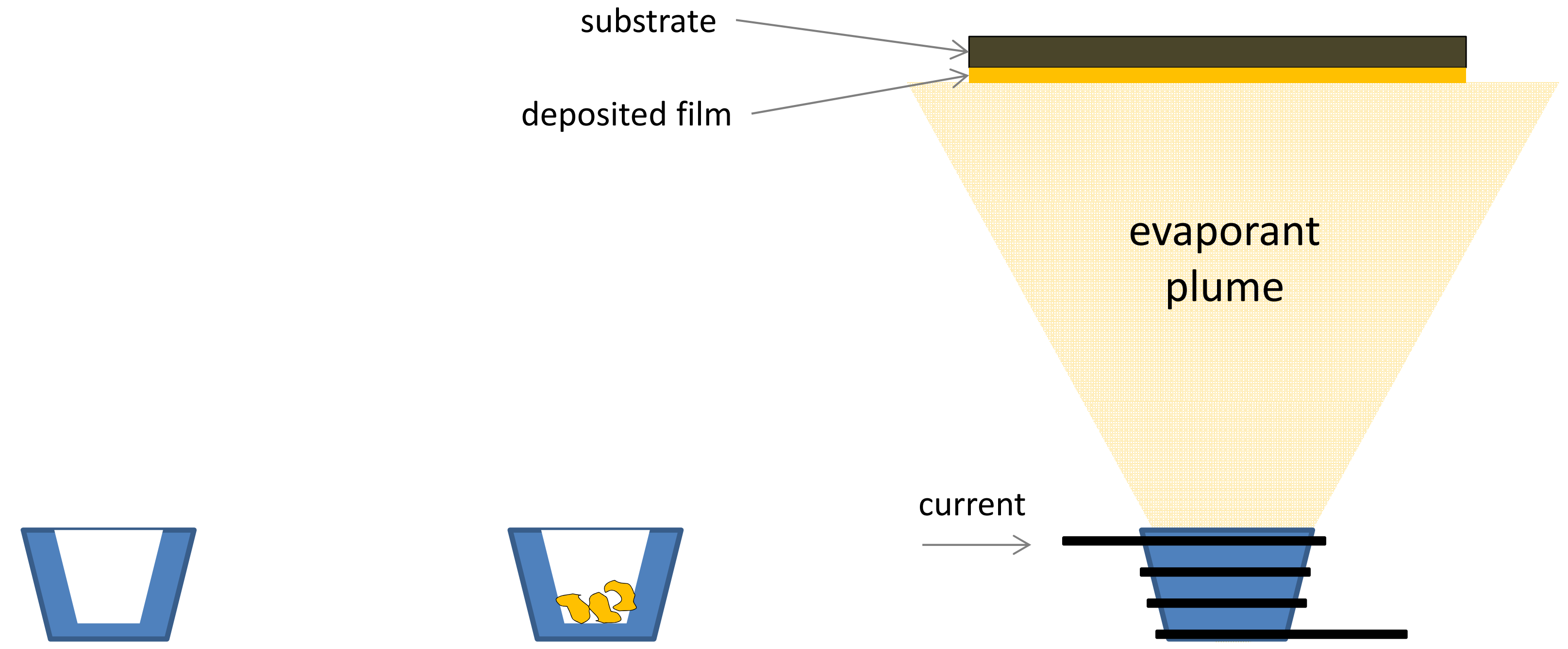
- A system that takes a significant amount of time to pump down (more than one hour) will – at best – impact customer productivity. On a new system, this indicates a poor design or workmanship. Poor design includes undersized pumps, the selection of inappropriate materials and components, and vacuum piping and valves that are undersized or improperly plumbed. Workmanship problems include chamber leaks, improperly mounted components, etc.

- Systems that are specified to meet ultra-high vacuum standards may require longer to pump down and will require different design rules and higher grade (more expensive) components.

- Denton focuses on delivering highly reliable vacuum systems as the starting point of a complete customer process solutions. **We don't cut corners, and the result is a highly reliable platform on which to do research, develop new products, or undertake high volume production.**

Evaporation

Thermal Evaporation



Empty Crucible
(high temperature metal)

Crucible Loaded with Source Material

Evaporation
(resistive heating)

heating the source material to high temperature evaporates the material – vapor plume transports the evaporant to the substrate where it condenses as a film

Thermal Evaporation

Deposition Rate

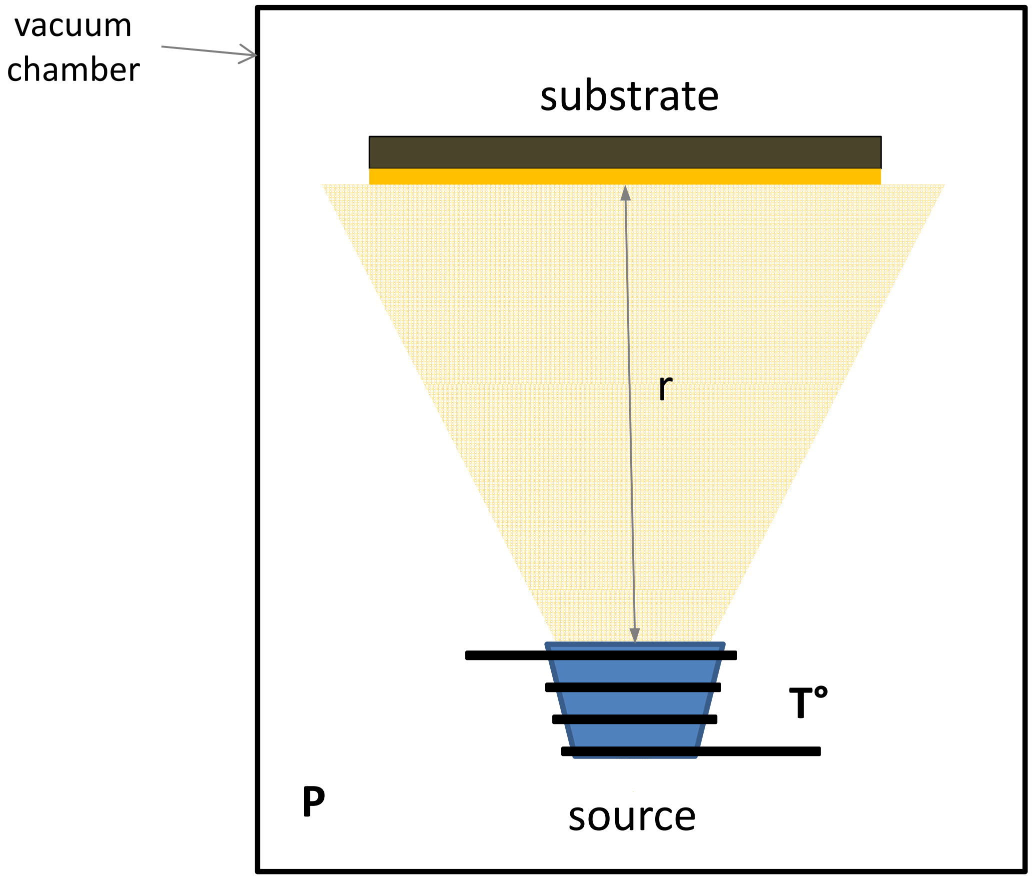
Key Factors Impacting
the Rate of Material Deposition

r : the source to substrate distance
(larger r – lower deposition rate)

T°: the source temperature
(higher T – higher deposition rate)

P: the chamber pressure (torr)
(lower P - higher deposition rate)

Low chamber pressures (in the 1 X 10^{-3} *range) remove air molecules that can impede the low energy path of evaporant molecules from the source to the substrate. This increases the "mean free path" – the average distance a molecule travels before it hits another – and so improves the deposition rate.*



Thermal Evaporation

Advantages & Disadvantages

(+) very cost effective

(+) good for metals and low melting point materials

(+) systems easy to run & maintain

(+) widely used

(-) low deposition rate (1-20 Å /min.)

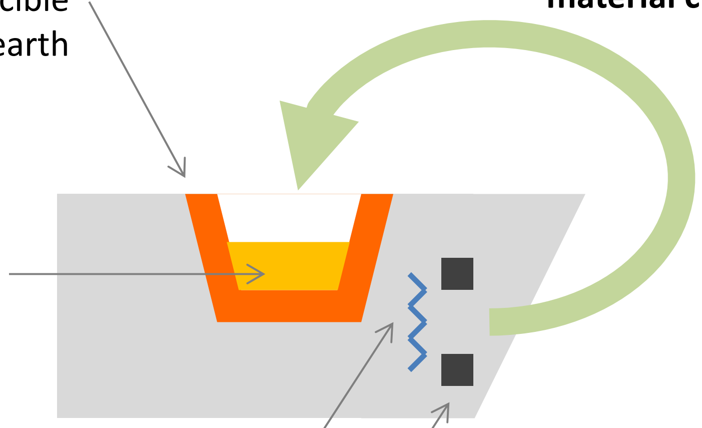
(-) not good for high melting point dielectric materials

(-) at higher operating temperatures, the crucible begins to contaminate the source material

What's needed is an evaporation process that deposits more quickly and at higher temperatures without contaminating the source material.

E-beam Evaporation Source

E-beam evaporation sources direct a high energy electron beam directly into a water-cooled copper crucible. Driven by up to 15 kW of power, the beam heats the source material to temperatures higher than what can be practically attained in a resistance heated crucible. Water cooling of the crucible limits contamination of the source material.



electron beam is directed 270° into the source material crucible

water cooled copper crucible or hearth

source material

cathode filament

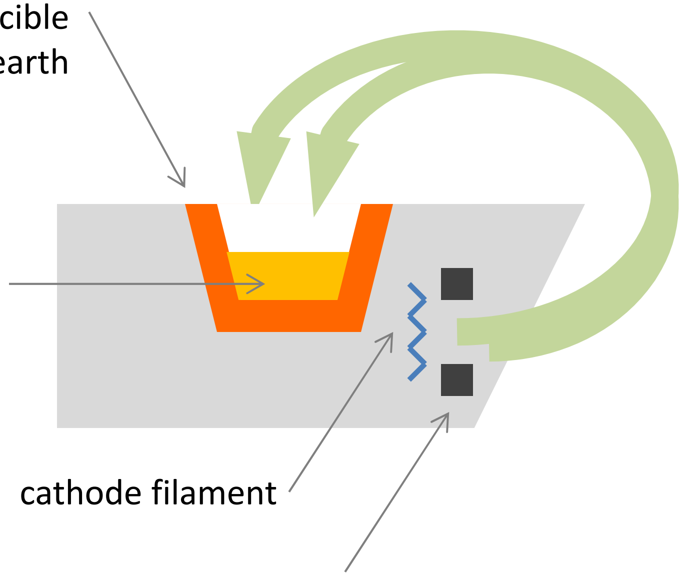
magnetic lenses to focus and position electron beam

E-beam Evaporation Source

E-beam evaporation sources direct a high energy electron beam directly into a water-cooled copper crucible. Driven by up to 15 kW of power, the beam heats the source material to temperatures higher than what can be practically attained in a resistance heated crucible. Water cooling of the crucible limits contamination of the source material.

Magnetic lenses can be programmed to "sweep" the beam over the source material.

processes using materials with high melting points (dielectrics) often use electron beam sweep to provide more uniform heating



water cooled copper crucible or hearth

source material

cathode filament

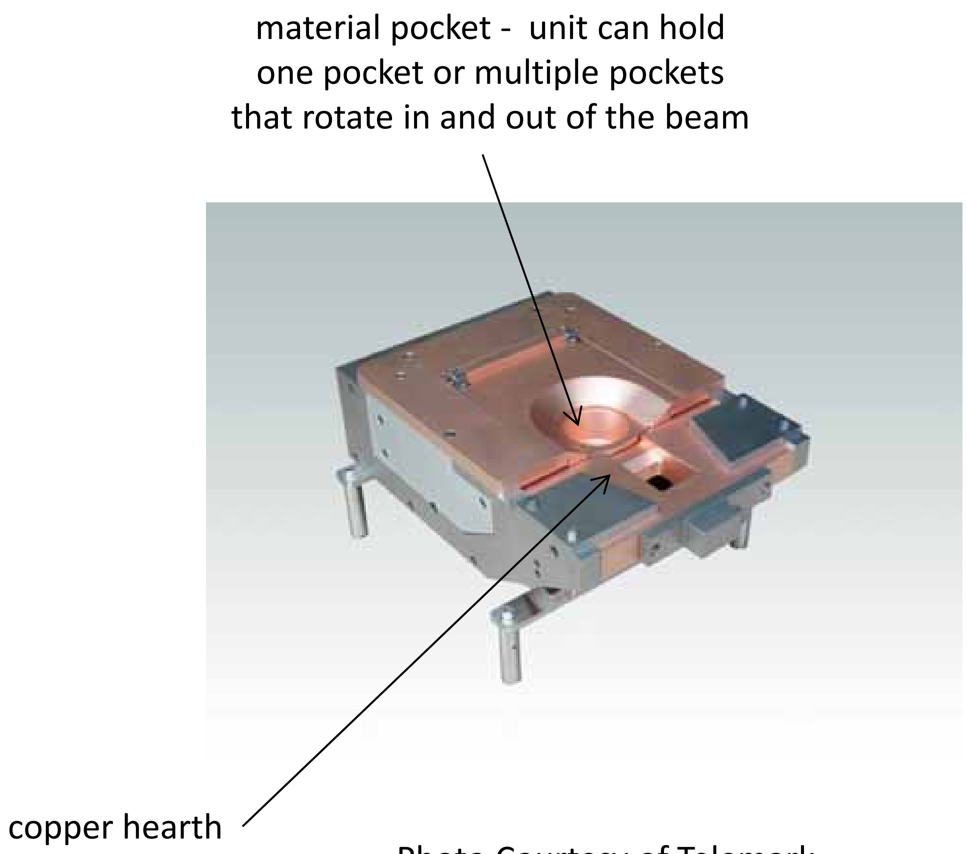
magnetic lenses to focus and position electron beam

E-beam Evaporation Source

- E-beam evaporation sources come in a variety of styles and power levels.

- Multiple sources in a single deposition system can support multiple films deposited sequentially

- Multiple sources can also deposit different materials simultaneously (co-evaporation).



material pocket - unit can hold one pocket or multiple pockets that rotate in and out of the beam

copper hearth

Photo Courtesy of Telemark.

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E-beam Evaporation

Working Examples

Integrity series "box coater" using e-beam evaporation

Single evaporation source;

Quartz heaters to elevate the temperature of the substrates during deposition.

viewport covers

substrate fixture

quartz
substrate heaters

E-beam
evaporation source

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E-beam Evaporation

Working Examples

Integrity series "box coater" using e-beam evaporation

Two evaporation sources;

Removable deposition shields line the walls of the vacuum chamber – protect the vacuum chamber from material that condenses out of the evaporant cloud; when shields are removed, high value materials can be recovered and the shields cleaned via sandblasting.

deposition shields

E-beam evaporation sources

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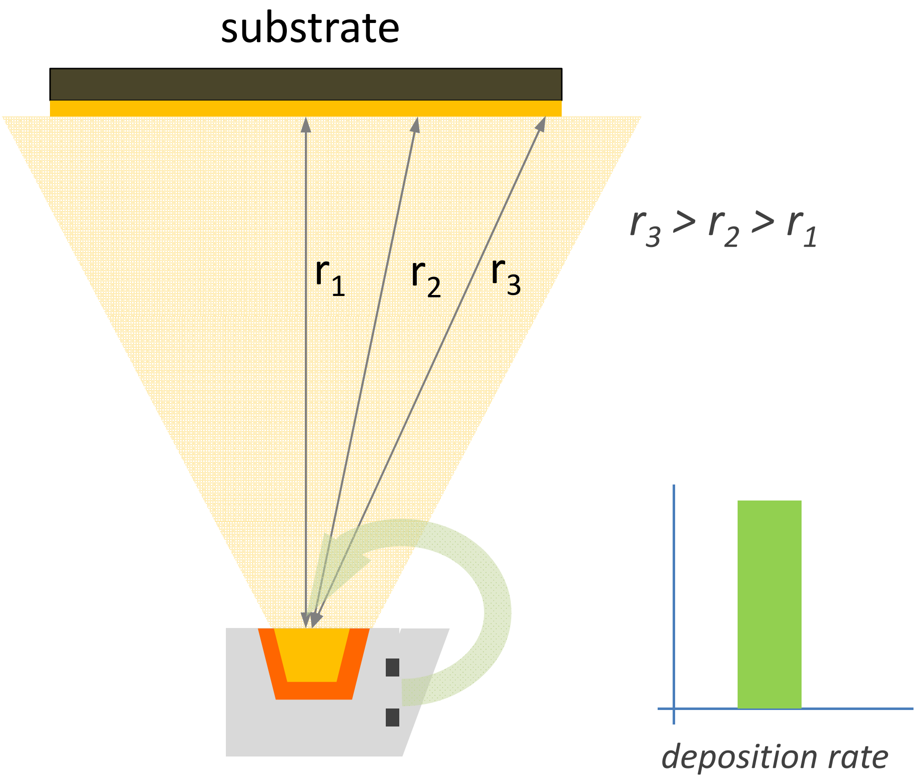
Evaporation Uniformity

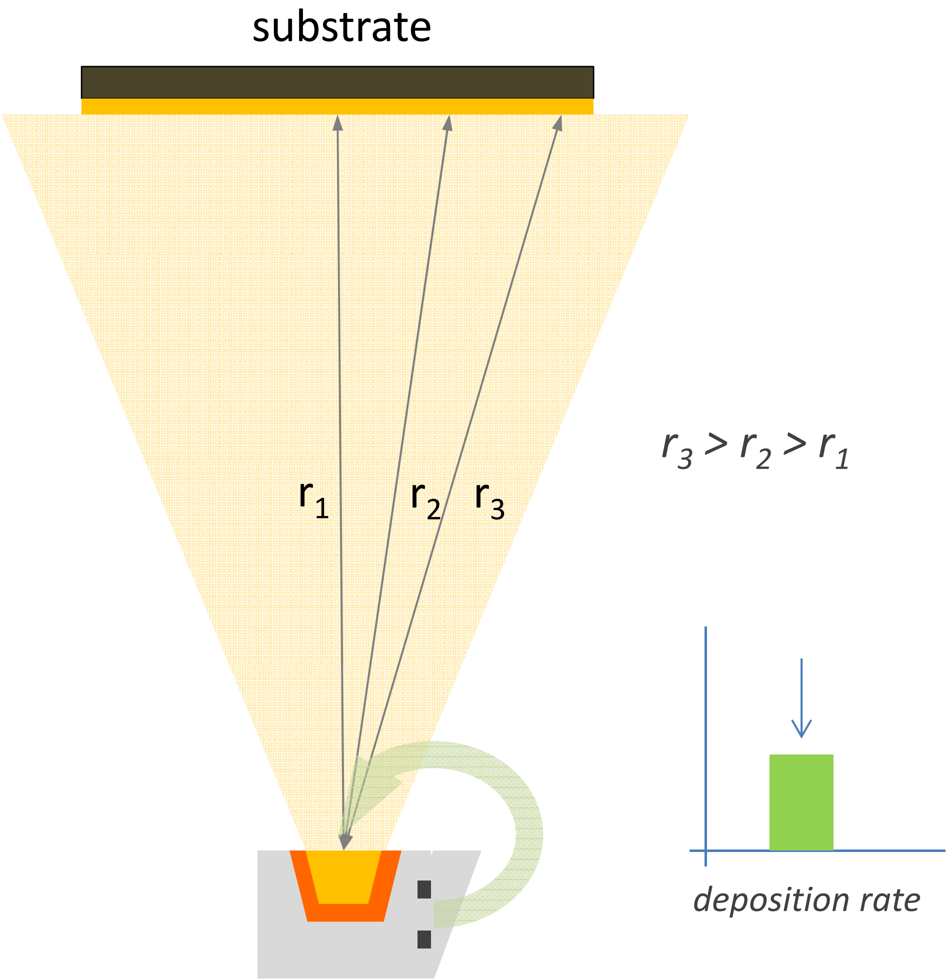


- Uniformity of films is critical - in an multi-layer optical coating, target film thicknesses may range as low as under 1 nanometer with overall uniformities measured as a function of total reflectance or transmission.

- As this example shows, given points on a substrate may be at different distances from the source.

- At differing distances from the source deposition rates will also vary, leading to non-uniformity.

Evaporation Uniformity



- One method to improve uniformity – **increase the source to substrate distance.**
- This <u>reduces</u> the differences in distance between given points on a substrate.
- The trade-off: as source-to-substrate distance increases, **deposition rate decreases and film properties (index of refraction, stability) may be compromised.**

Evaporation Uniformity

Dome Fixtures

Dome fixture detail

Multiple substrates mounted in a dome-shaped fixture to **equalize the distance** between the source and each individual substrate.

Fixture rotates to further enhance uniformity.

Source-to-substrate distance can be optimized for base uniformity and deposition rate.

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Evaporation Uniformity

Knudsen Dome Fixture

Knudsen Dome
System Detail

Fixtures are closely mounted around the evaporation source to increase material utilization and limit material condensation on the side walls of the vacuum chamber.

Fixture rotates to further enhance uniformity.

Source-to-substrate distance can be optimized for base uniformity and deposition rate.

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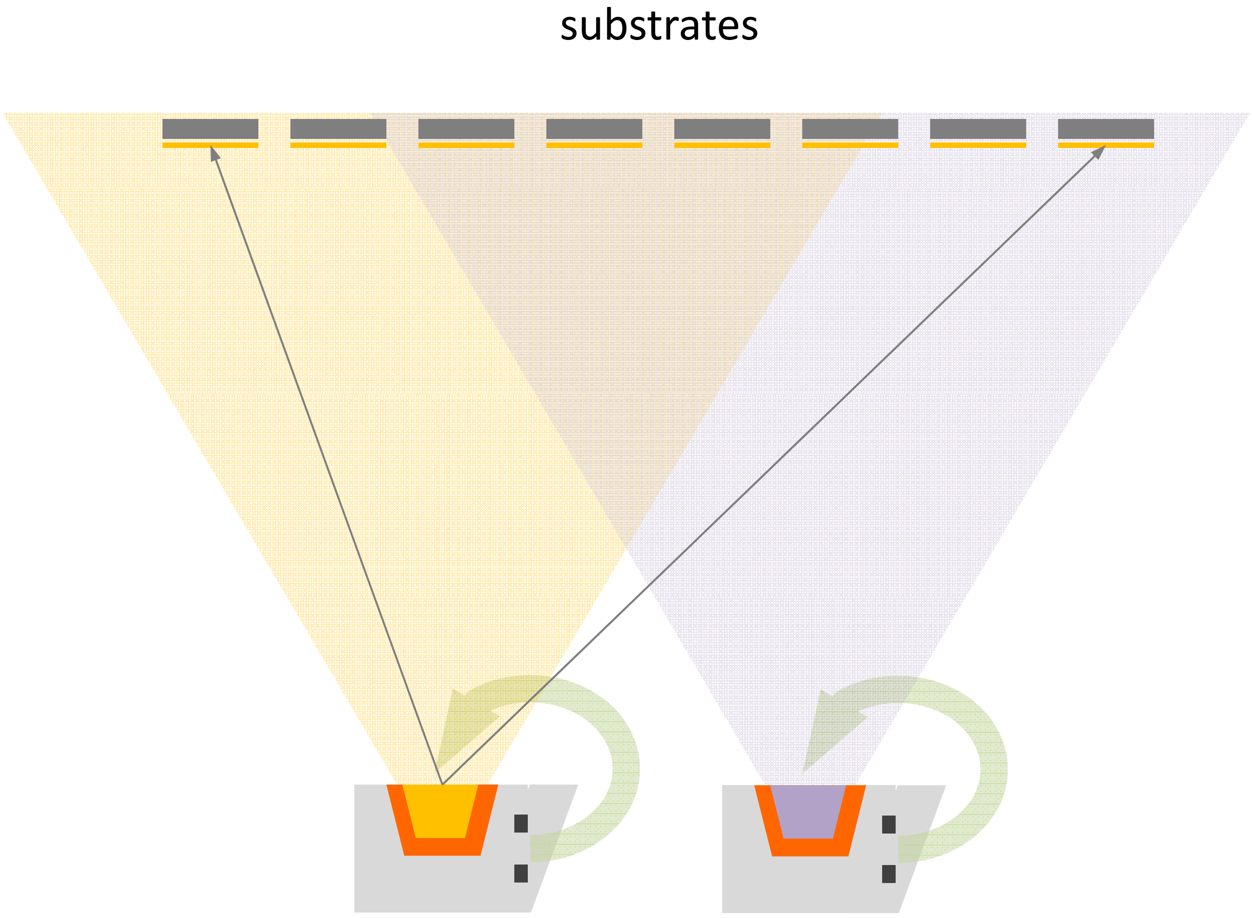
BARRIERS BECOME BREAKTHROUGHS

Evaporation Uniformity

Multiple Sources & Substrates



In multi-source depositions, there is no central source point

Distances between source and substrates significantly vary

Simple dome fixtures may be unable to deliver target uniformities

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Evaporation Uniformity

Planetary Fixture System

In this design, four planetaries each holding 4 wafers.

Each planetary rotates; entire assembly rotates to assure uniform deposition.

Planetaries are geared so that a wafer or substrate will have little chance of ever returning to the exact same position during the course of a deposition - this helps improves uniformity.

BARRIERS BECOME BREAKTHROUGHS

Evaporation Uniformity

Planetary Fixture System

Planetary rotation typically driven by a offset gear drive that is shielded from the deposition.

High degrees of uniformity can be achieved in such systems - better than plus or minus five percent.

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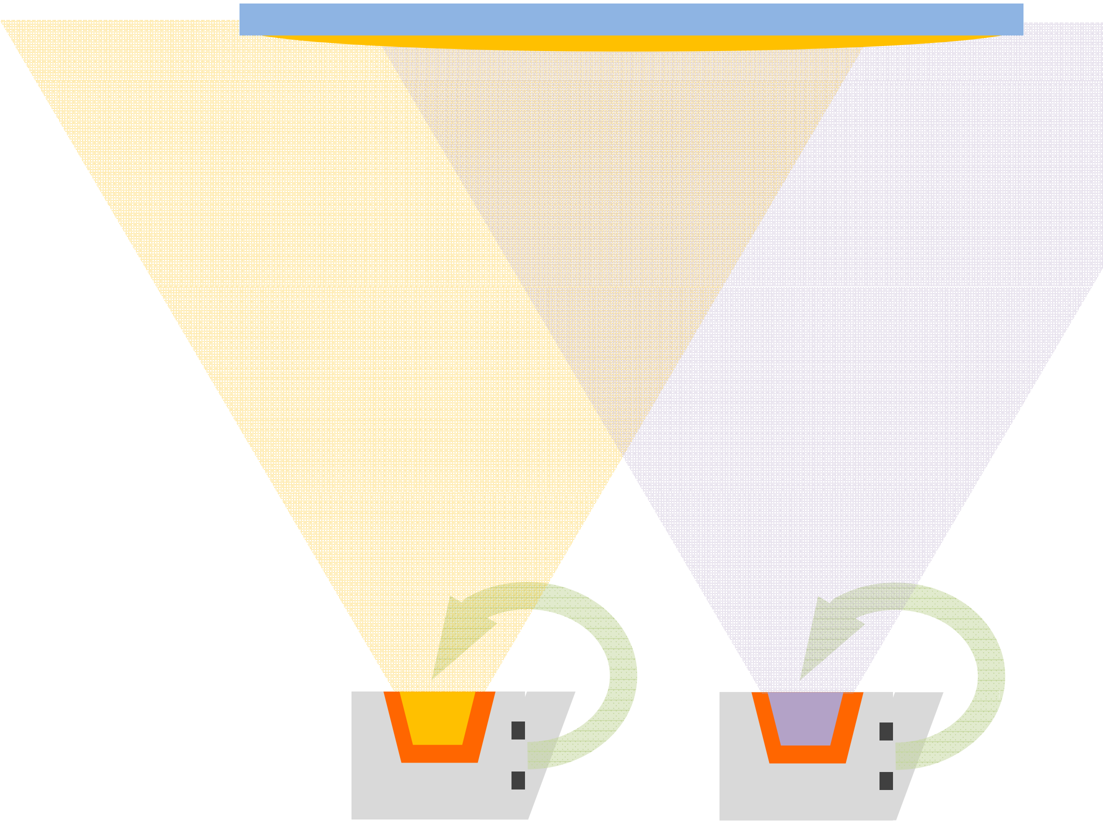
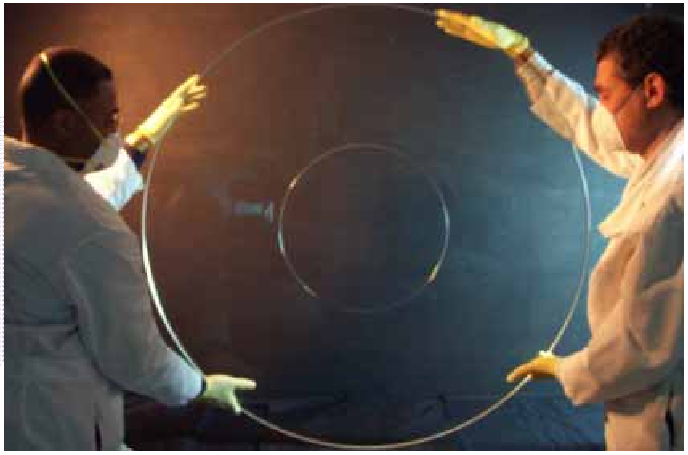
Evaporation Uniformity

Large Optics and Substrates



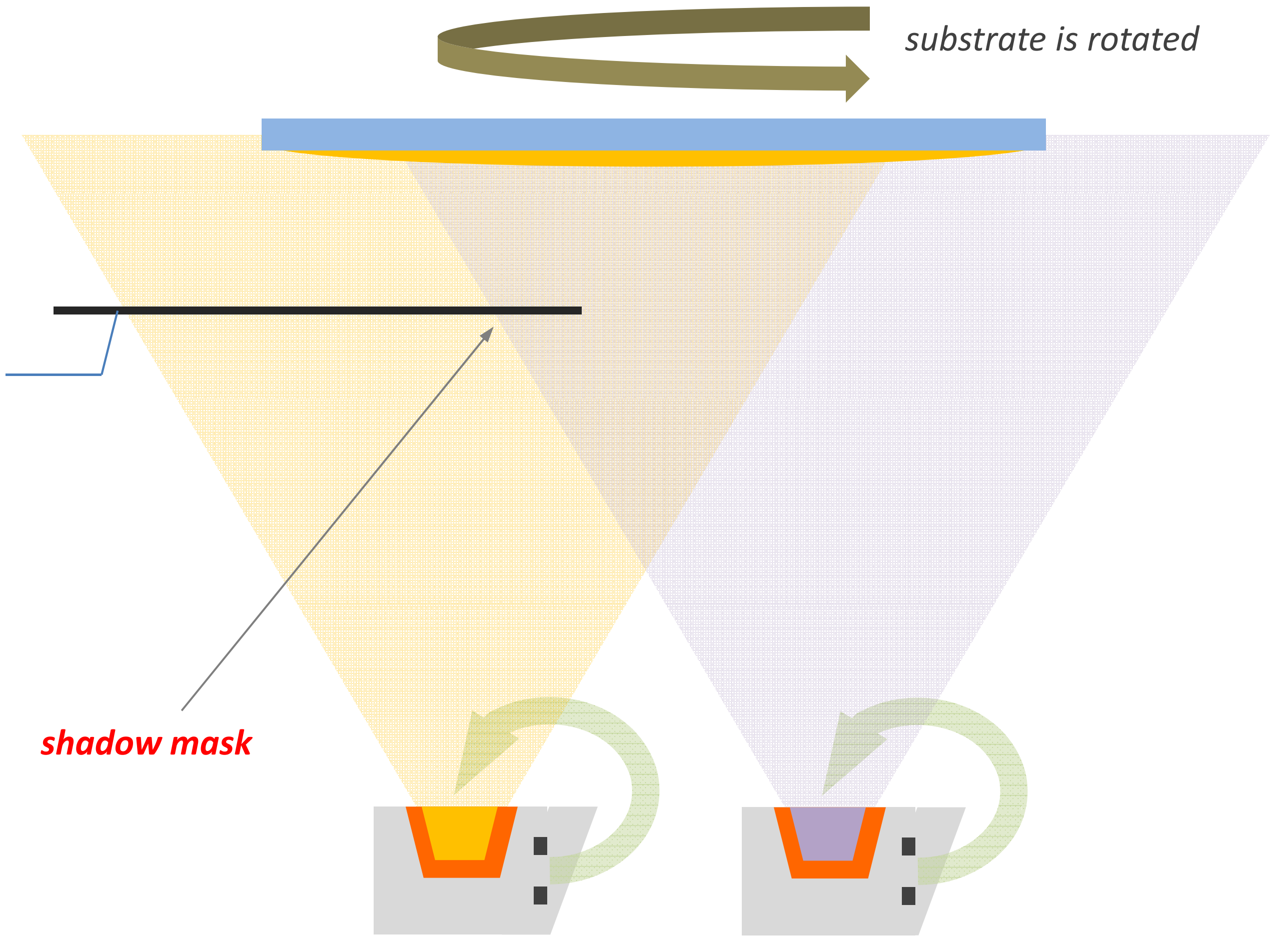


Large optics require multiple, very thin layers of materials that reflect, filter, absorb, and protect.

These must be completed in single deposition run – there is no room for error.

Evaporation Uniformity

Masks for Large Optics & Substrates



Substrate rotation helps improve uniformity.

For the very best (under 2%) uniformity, a shadow mask is inserted between the source(s) and substrate.

This diverts the evaporant plumes to reduce variations in deposition rates and thickness.

Evaporation Uniformity

Masks for Large Optics & Substrates

Integrity box coater with multiple evaporation sources.

Single substrate design rotates.

Shadow mask in-place at top of chamber.

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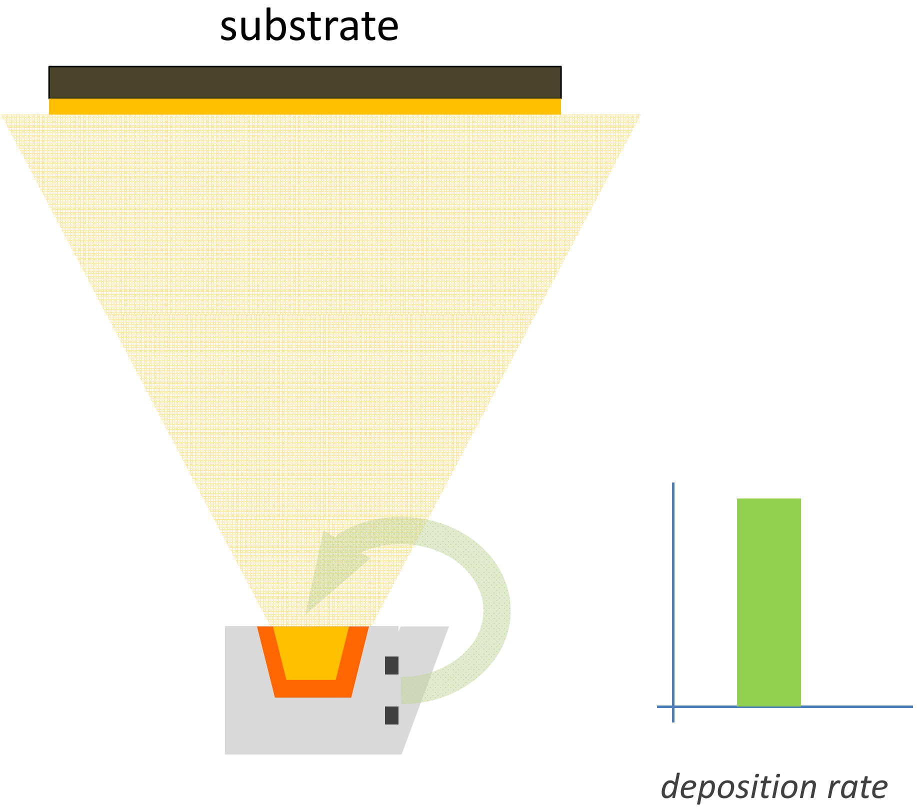
Evaporation Deposition Rate



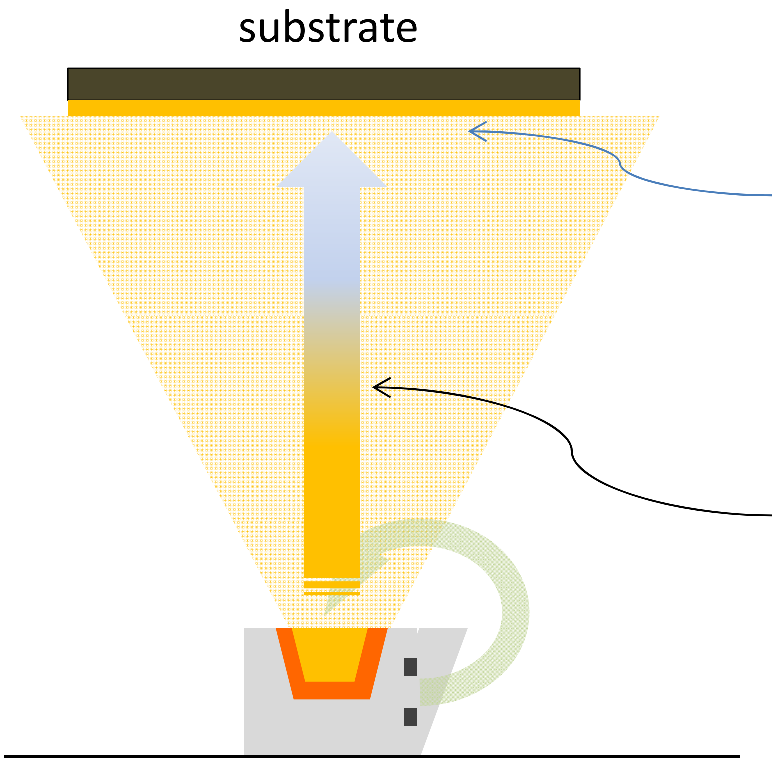
High deposition rates improve productivity and cost of ownership and help form dense films that meet specification for adherence, humidity stability, optical transparency and reflectance, durability and electrical performance.

Improving deposition rates involves trade-offs:

Lower source-to-substrate distances degrade uniformity.

Higher source temperatures increase deposition rate, but may literally boil-off the source material creating particles ("spitting") or a non-uniform evaporant plume.

Evaporation Deposition Rate



Surface energy in the 0.1 eV range.

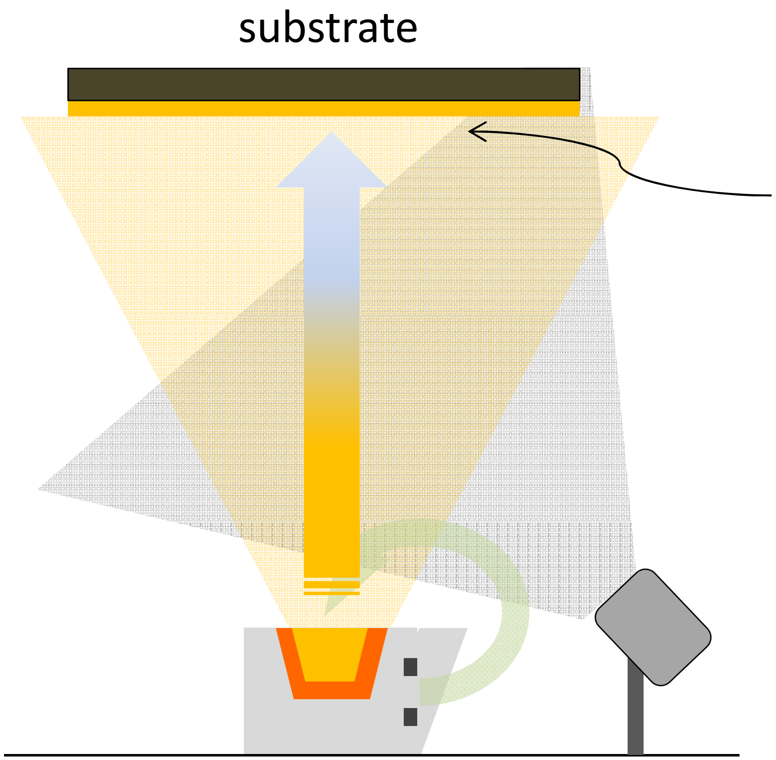
As the evaporant plume rises out of the source material density per unit area drops and the potential energy of source material at the substrate surface declines.

The issues are the quantity of evaporant material that reaches the substrate and the potential energy of that evaporant material as it reaches substrate.

The quantity of evaporant material is largely fixed by the source-to-substrate distance and the temperature at the evaporation crucible.

However, the potential energy of the evaporant can be increased.

Ion Beam Assisted Evaporation



Surface energy increased from the 0.1 eV range to 100 to 1000 eV range.

Index of refraction improved by densification of the film.

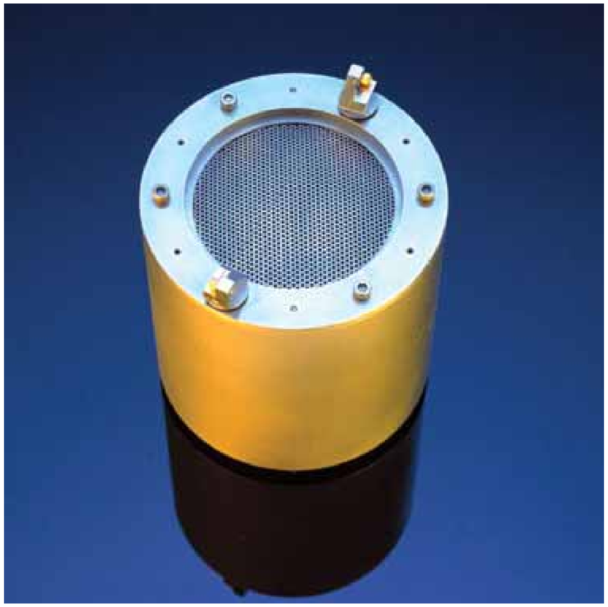
Ion gun located inside process chamber.

An ion gun placed in the vacuum chamber can be used to increase the potential energy of evaporant materials.

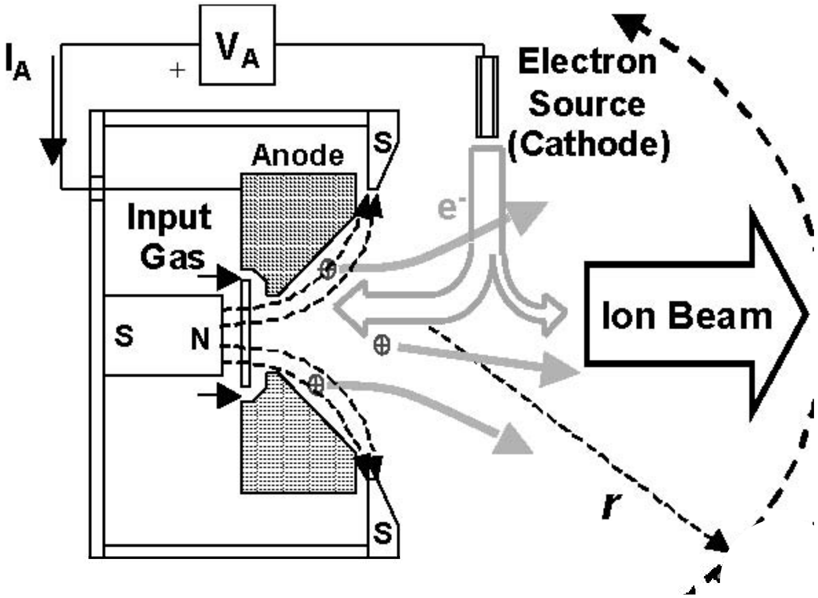
Using argon gas as a source the ion gun injects a stream of high energy, inert ions into the evaporant plume. This increases the deposition rate and the density of evaporated films.

The ion-gun can also be used to preclean the substrate. Some material properties can be enhanced with an oxygen as the feed gas into the ion gun.

Ion Gun – Principles of Operation



Veeco Mark II
Ion Source



Input gas typically argon; oxygen may be used to modify the film properties; water cooled to support high voltages required; must operate in a vacuum.

Ion Beam Assisted Evaporation

Working Example

Integrity e-beam evaporation system with multiple evaporation sources and a single ion gun.

Ion gun helps compensate for the large source to substrate distance.

ion gun

Large source to substrate distance

evaporation sources

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Evaporation Uniformity

Quartz Crystal Oscillator Control

Fabricating high end optics for aerospace and astronomical applications is highly demanding:

- Multiple, variable thickness layers (ranging as low as 1 nanometer) that together must achieve a set transmission or reflectance over a given optical, IR, or UV wavelength.
- All films must be deposited in a single process run.

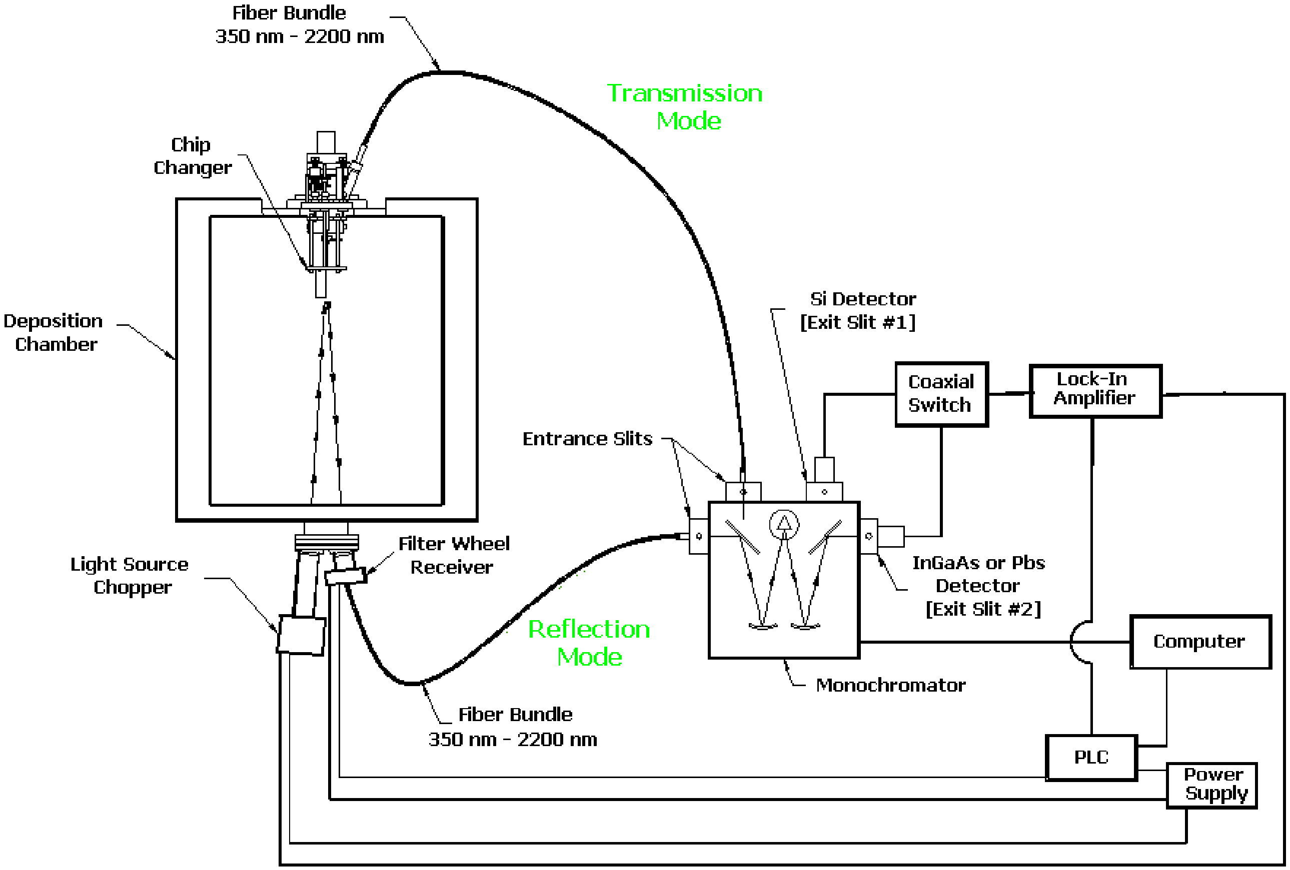
A common way to control thickness
Is via a quartz crystal oscillator. Exposed to the evaporant flux, the quartz crystal's resonant frequency changes as materials builds up on it. A controller translates this into a display of deposition rate and coating thickness. An automatic crystal changer swaps in a new crystal when required.

Evaporation Uniformity

Optical Monitoring Control

An optical monitor is another approach to controlling endpoint detection in evaporation systems.

Optical film properties - the defining product characteristic - are measured real-time on sample chips allowing deposition times to be automatically lengthened or shortened to achieve target optical properties.



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Evaporation Uniformity

Optical Monitoring System Control

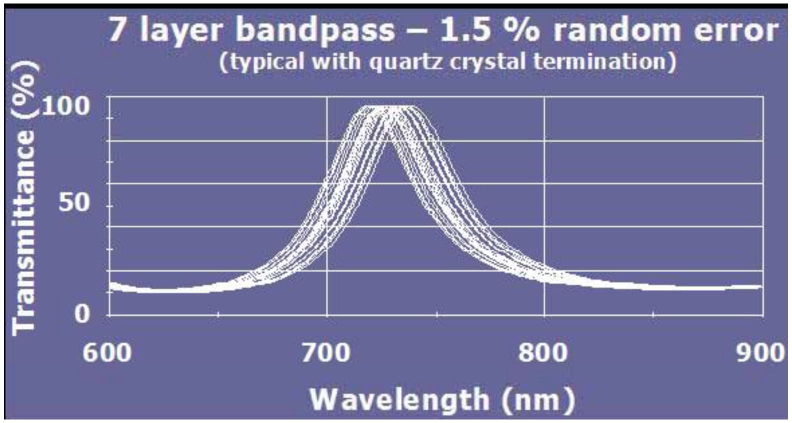
Real-time control of critical film properties allows -

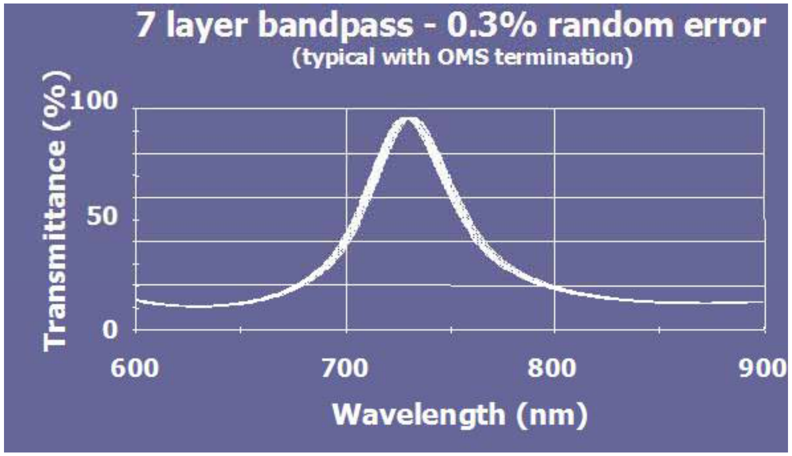
(1) Well defined process recipes to be defined and tested.

(2) Multi-layer depositions to be controlled by the optical monitor to adjust for minor variations in deposition rates and operating conditions.

The outcome – superior, more consistent end-products.

Denton builds its own optical monitor system (OMS) for these applications.





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How Do Our Customers Use Evaporation?

Microscopy

Deposit materials on SEM samples to enhance contrast and/or mechanical strength

Semiconductors

Deposit low temperature metals for power & compound semiconductors & military device packaging.

Optics

Dielectric and metal coatings for lasers, optical filters, astronomical and military optics.

Solar

Deposit CIGS (copper-indium-gallium-selenium) solar cells in research scale systems.

Thermal vs. E-beam Evaporation

Deposition	Material	Typical Evaporant	Impurity	Deposition Rate	Source Material Temperature Range	Cost
Thermal	Metal or low melting point materials	Au, Ag, Al, Cr, Sn, Sb, Ge, In, Mg, Ga CdS, PbS, CdSe, NaCl, KCl, AgCl, MgF_2, CaF_2, $PbCl_2$	High	1 to 20 Å/second	~ 1800° C	Low
E-beam	Both metal and dielectrics	All above, plus: NI, Pt, Ir, Rh, Ti, V, Zr, W, Ta , Mo Al_2O_3, SiO, SiO_2, SnO_2, TiO_2, ZrO_2	Low	10 to 100 Å/second	~ 3000° C	High

Source Dr. E. Chen, Applied Physics 289r, Harvard University

Sputtering

If evaporation is so good, why do we sputter?

- The large vacuum chambers needed for evaporation do not easily support high volume production or large substrates
- Getting good uniformity on evaporated films involve many trade-offs *(source to substrate distance, material temperature, fixturing, masks, etc.)*
- The low energy (< 1 eV) of the atoms deposited during evaporation can produce films with low film density and less than optimal adherence.
- Evaporation processes struggle to deposit alloys with good bulk consistency
- Evaporation processes do not always provide good “step coverage” over substrates with varying heights

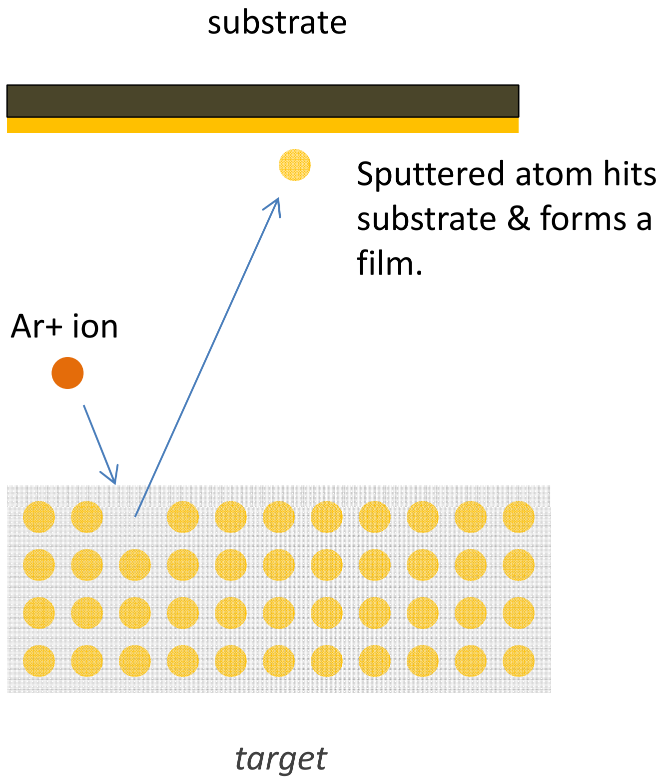
Sputtering Mechanics

In **its most basic form**, sputtering begins with the creation of an inert gas ion (Argon) in a vacuum chamber.

The Ar+ ion is accelerated into a target made out of the source material.

The impact of the Ar+ ion drives an atom of the source material off the target and onto the substrate.

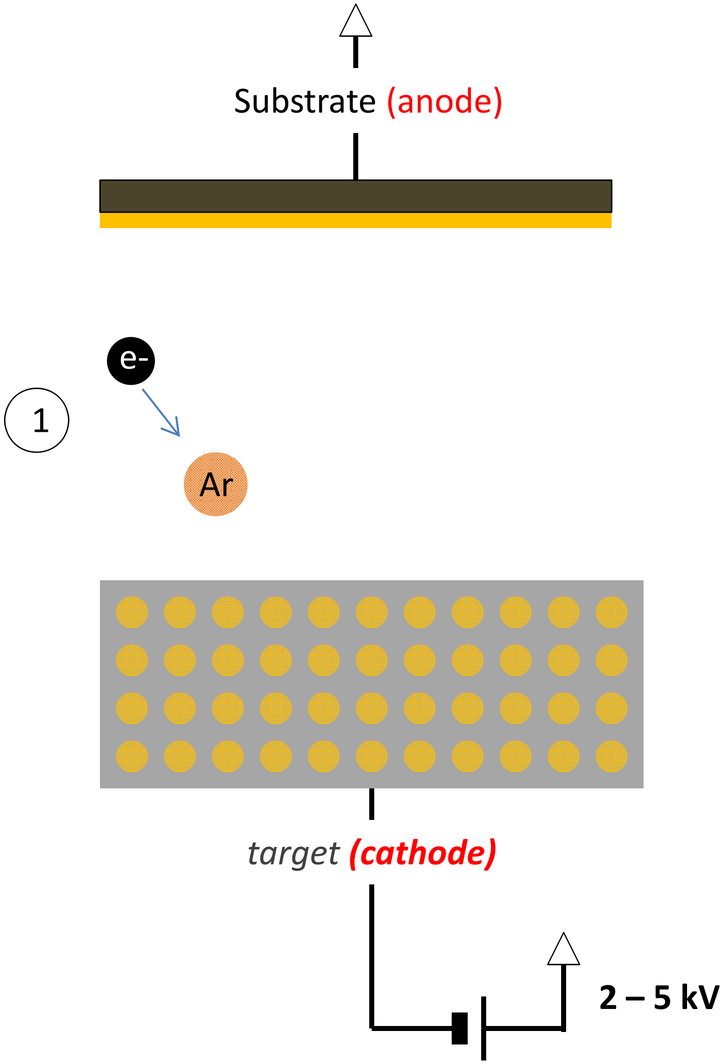
This is momentum transfer – not evaporation.



DC Diode Sputtering

Target (source) and substrate are placed on two parallel electrodes to form a diode

① DC voltage applied across the diode accelerates free electrons in the chamber that collide with gaseous Ar atoms that have been injected into the chamber.

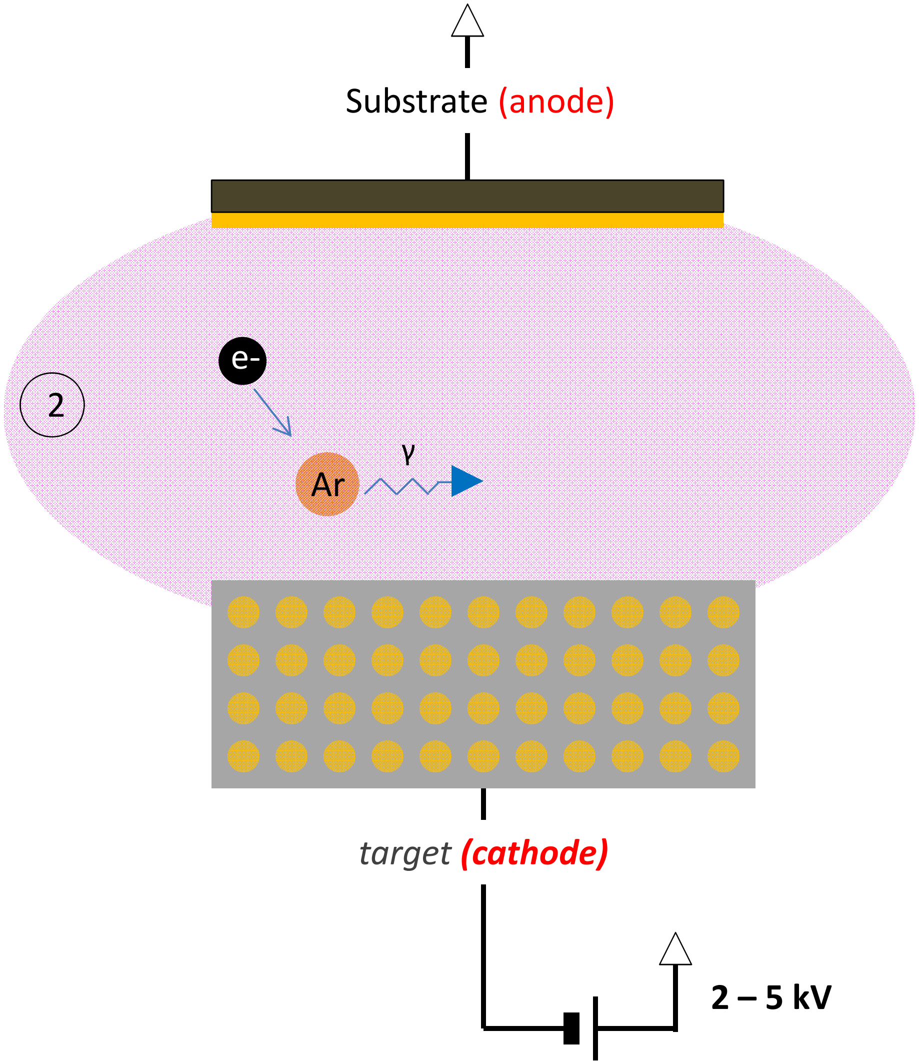


DC Diode Sputtering

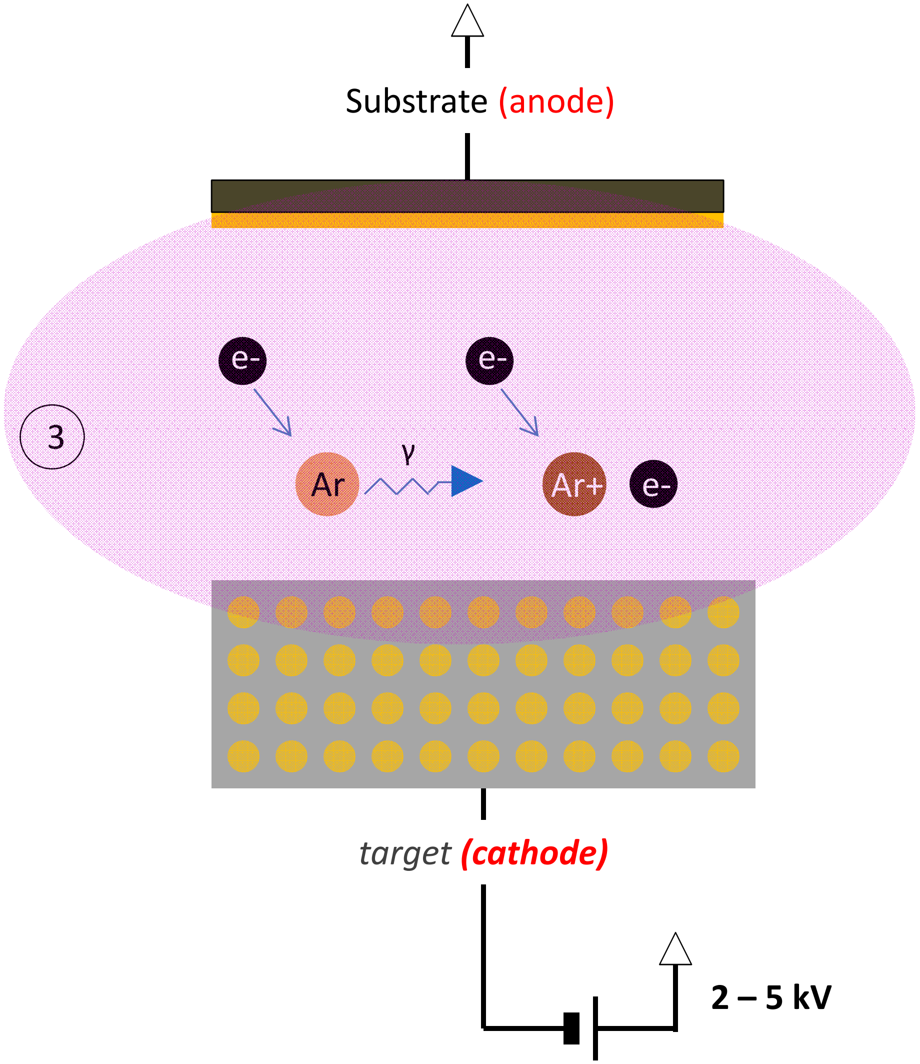
Target (source) and substrate are placed on two parallel electrodes to form a diode

DC voltage applied across the diode accelerates free electrons in the chamber that collide with gaseous Ar atoms that have been injected into the chamber.

② These free electron-Argon atom collisions excite the Ar atoms, releasing photons (γ) that causes the characteristic glow.



DC Diode Sputtering



Target (source) and substrate are placed on two parallel electrodes to form a diode

DC voltage applied across the diode accelerates free electrons in the chamber that collide with gaseous Ar atoms that have been injected into the chamber.

These free electron-Argon atom collisions excite the Ar atom, releasing a photon (γ) that causes the characteristic glow.

③ These collisions also <u>ionize</u> Ar atoms, creating a <u>second</u> electron that further excites other AR atoms and generates more electrons.

DC Diode Sputtering

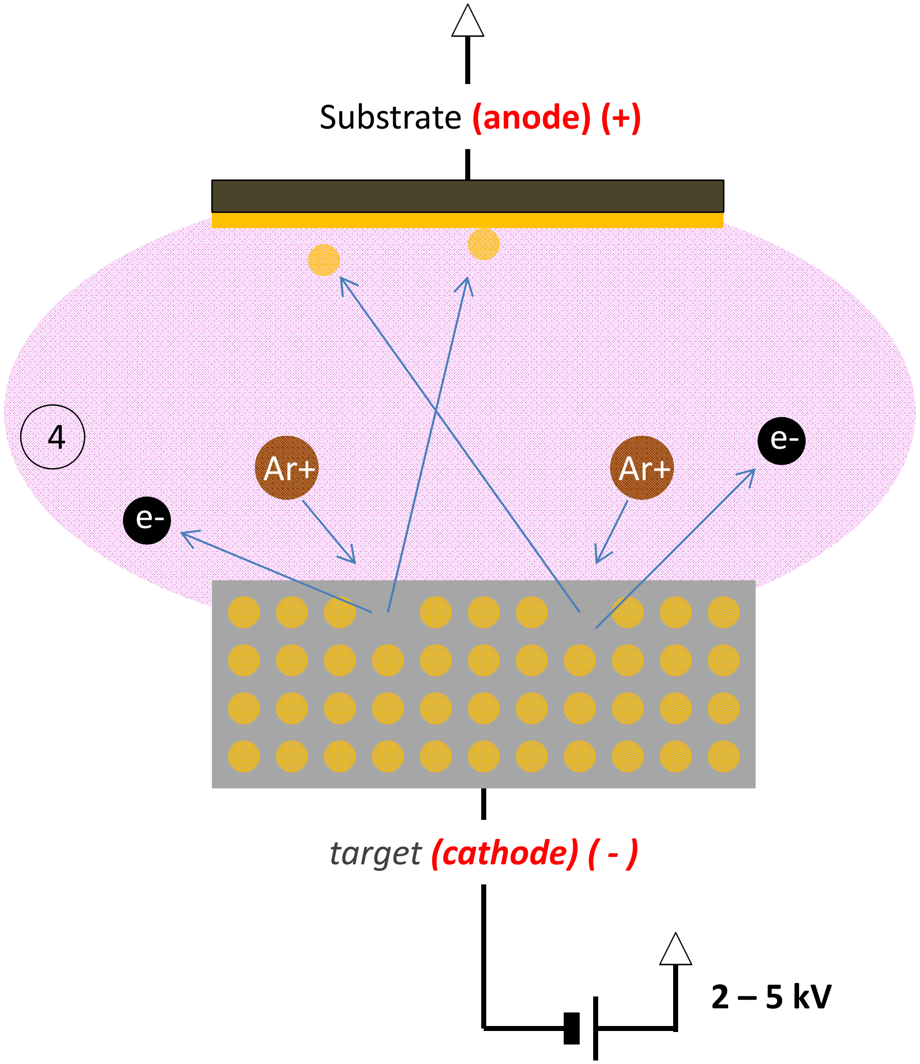
Target (source) and substrate are placed on two parallel electrodes to form a diode

DC voltage applied across the diode accelerates free electrons in the chamber that collide with gaseous Ar atoms that have been injected into the chamber.

These free electron-Argon atom collisions excite the Ar atom, releasing a photon (γ) that causes the characteristic glow.

These collisions also ionize Ar atoms, creating a second electron that further excites other AR atoms and generates more electrons.

④ Positively charged Argon ions are accelerated toward the negatively charged target (cathode) & drive (1) atoms off the target into the substrate and (2) more electrons.



DENTON VACUUM
BARRIERS BECOME BREAKTHROUGHS

Trade-offs in DC Diode Sputtering

Maintaining the plasma discharge requires:

L · P > 0.5 (cm · torr)

where

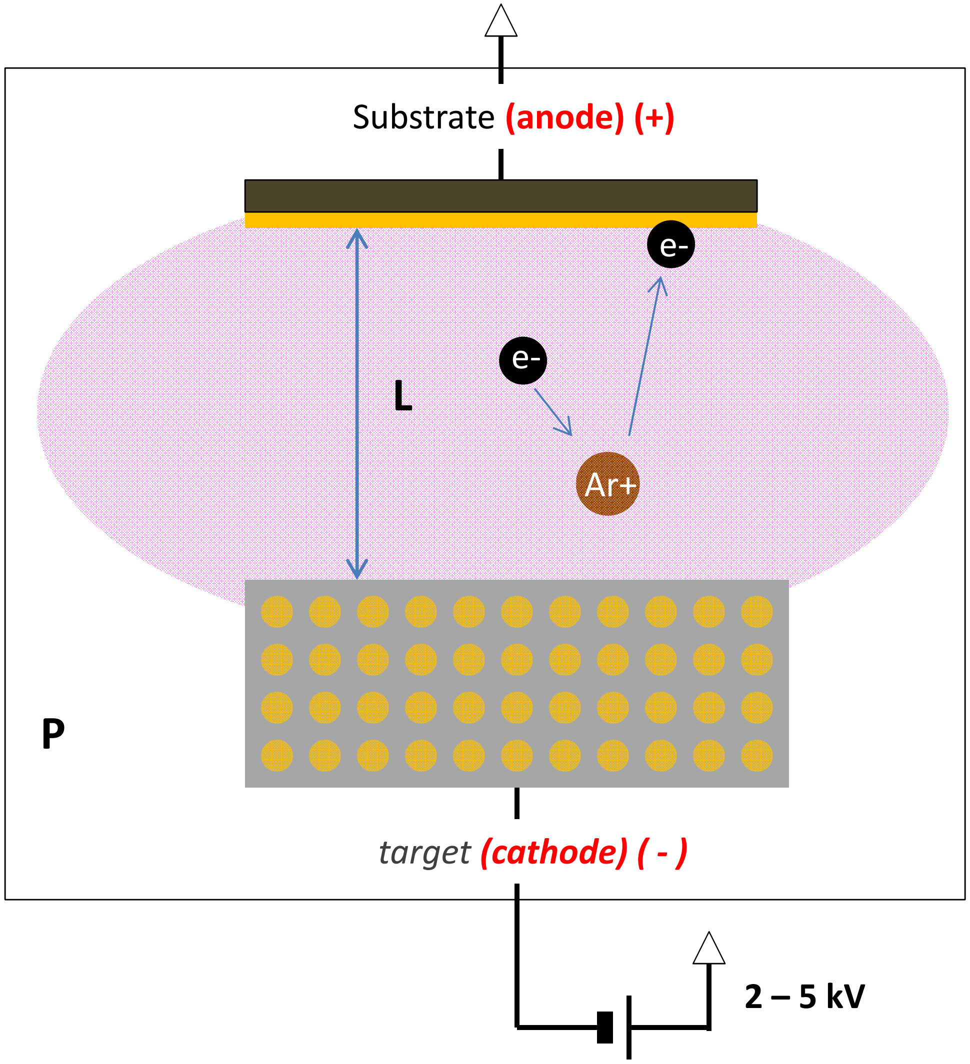
L - the cathode to anode space

P - the chamber pressure

Why?

If the cathode to anode space gets too small, there will not be enough excitation to maintain the plasma discharge.

If the argon pressure is too low, 2nd electrons generated by initial Argon atom collisions will hit the substrate before hitting other Argon atoms.



Trade-offs in DC Diode Sputtering

But higher argon pressures negatively impact **R**, the deposition rate:

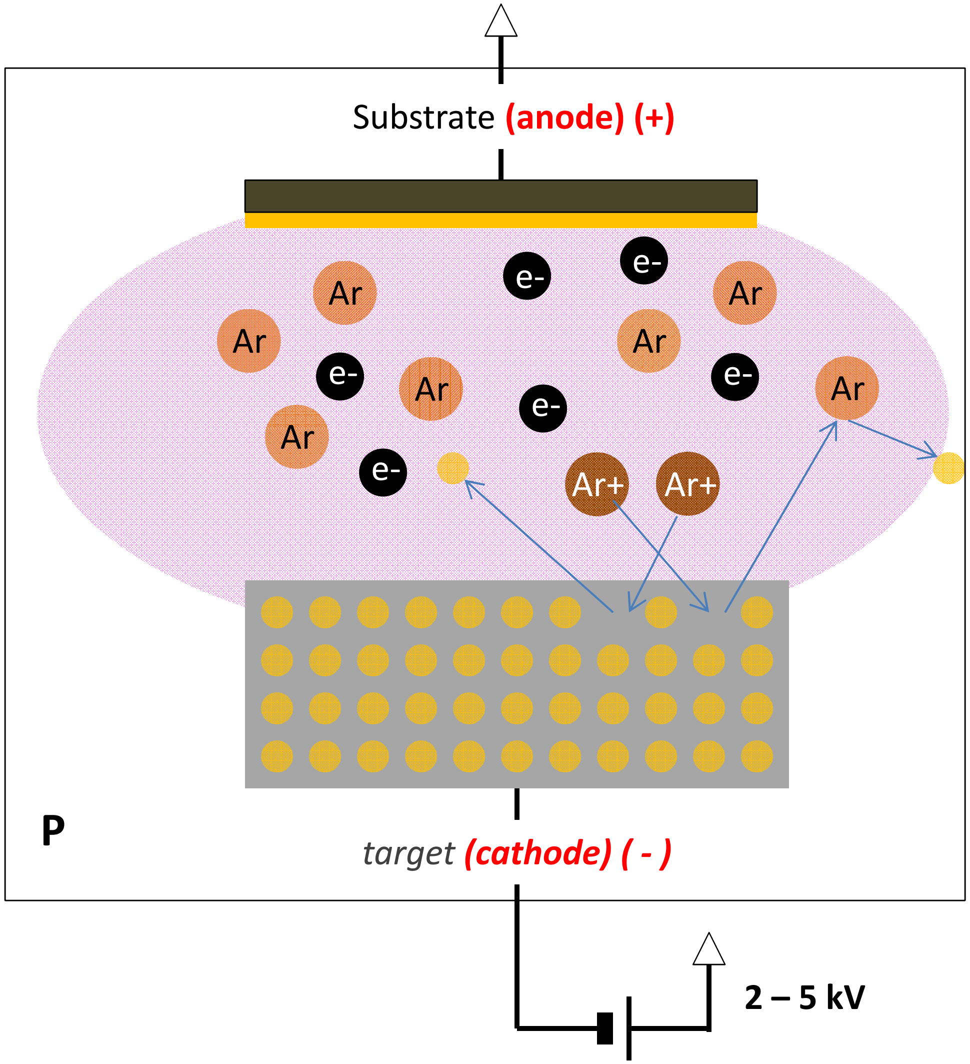
$$R \approx \frac{1}{L \cdot P}$$

Why?

At higher Argon pressures, sputtered atoms hit hundreds of Argon atoms before reaching the substrate.

This reduces the deposition rate & causes the source to deposit on the chamber wall and back onto the target.

So, Argon pressures must be high enough to fill the space with Argon atoms that will intercept electrons before they hit the substrate, but not so high that they impede sputtered atoms & kill the deposition rate.



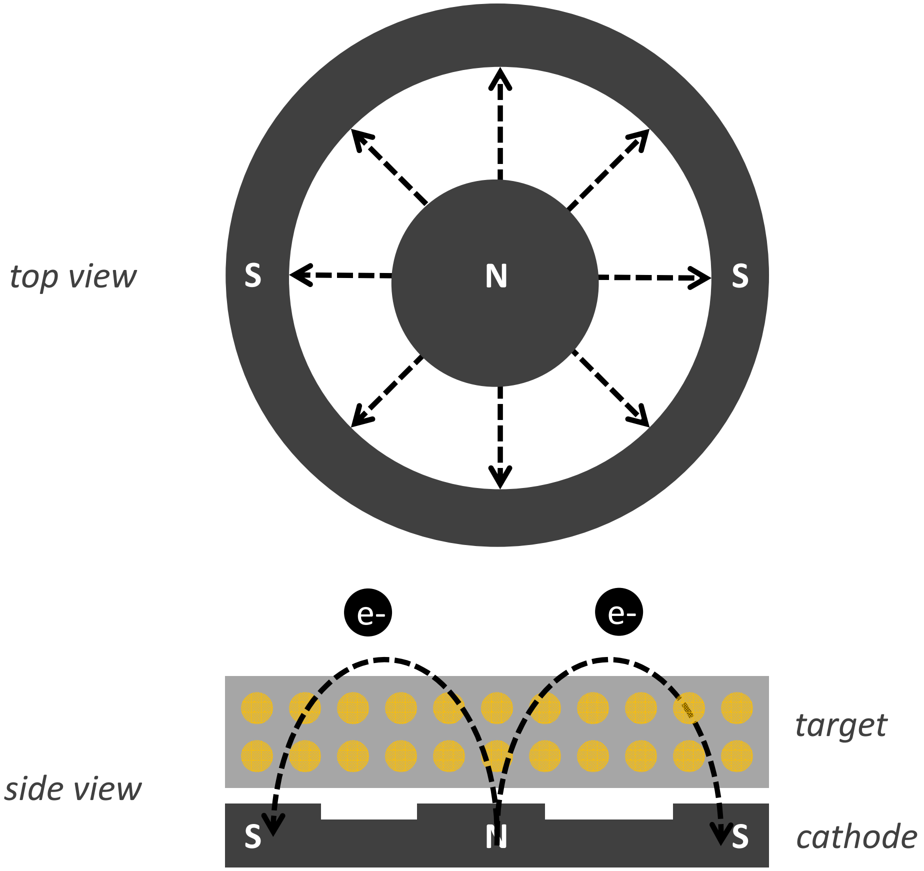
DC Magnetron Sputtering

DC magnetron sputtering mitigates the trade-offs forced by diode sputtering.

The source material target is now mounted to a specially designed magnetron sputtering cathode.

Permanent magnets in the cathode apply a magnetic field parallel to the target's surface.

Free electrons which otherwise would be attracted to the substrate are now trapped near the target's surface.

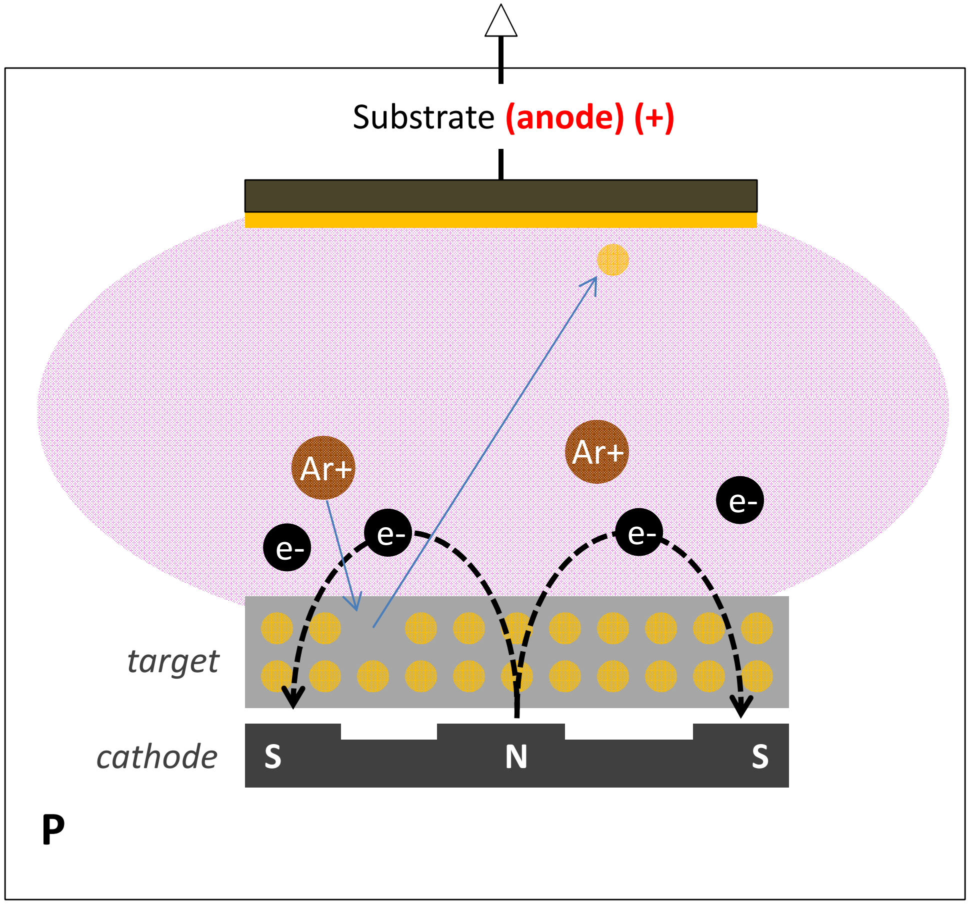


DC Magnetron Sputtering

Now . . .

- The process can utilize the low Argon pressures needed to create an unimpeded path for material atom transport. (There are fewer Argon atoms to bump into.)

- Electrons that might otherwise be free to be attracted to the substrate (and limit the excitation and ionization processes) are now magnetically confined to the area above the target.



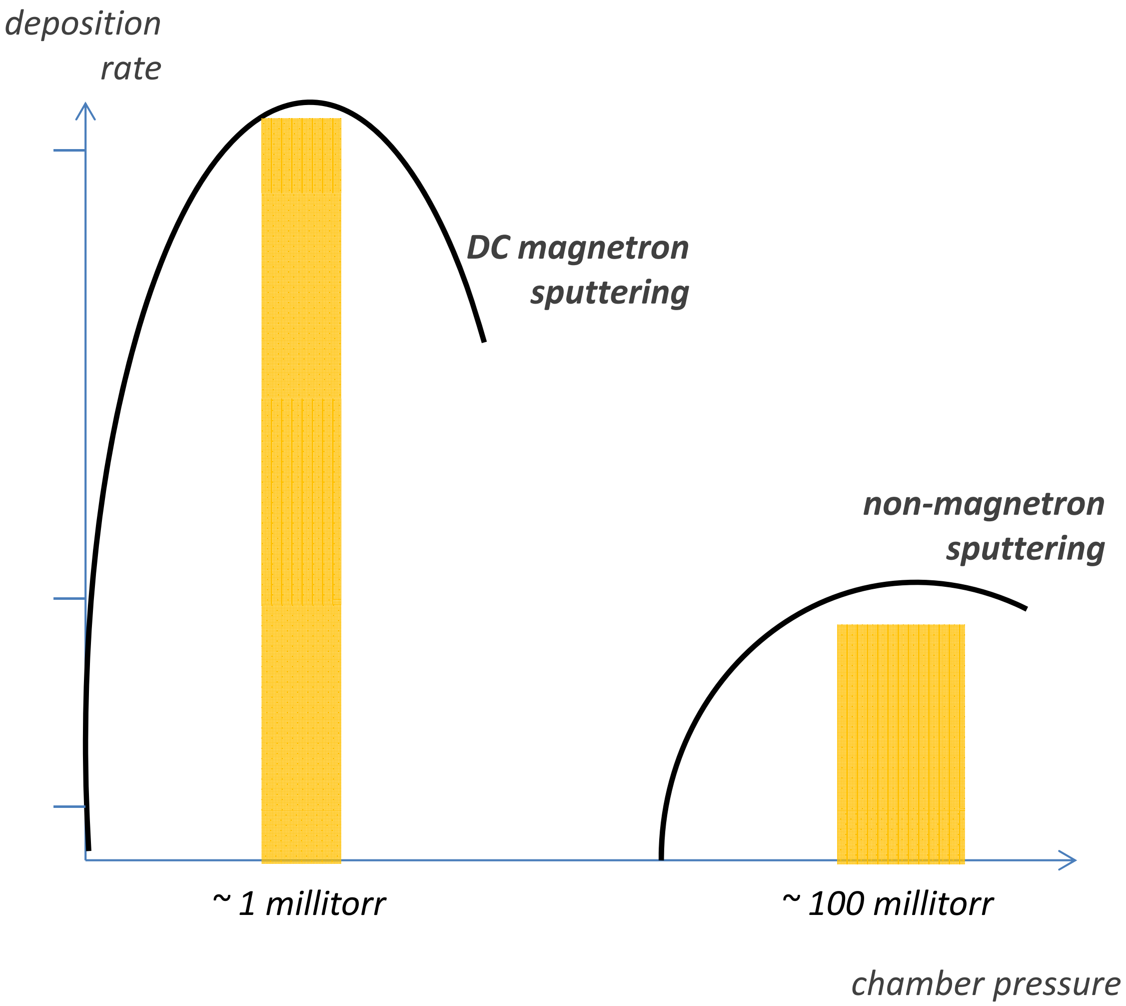
DENTON VACUUM
BARRIERS BECOME BREAKTHROUGHS

DC Magnetron Sputtering

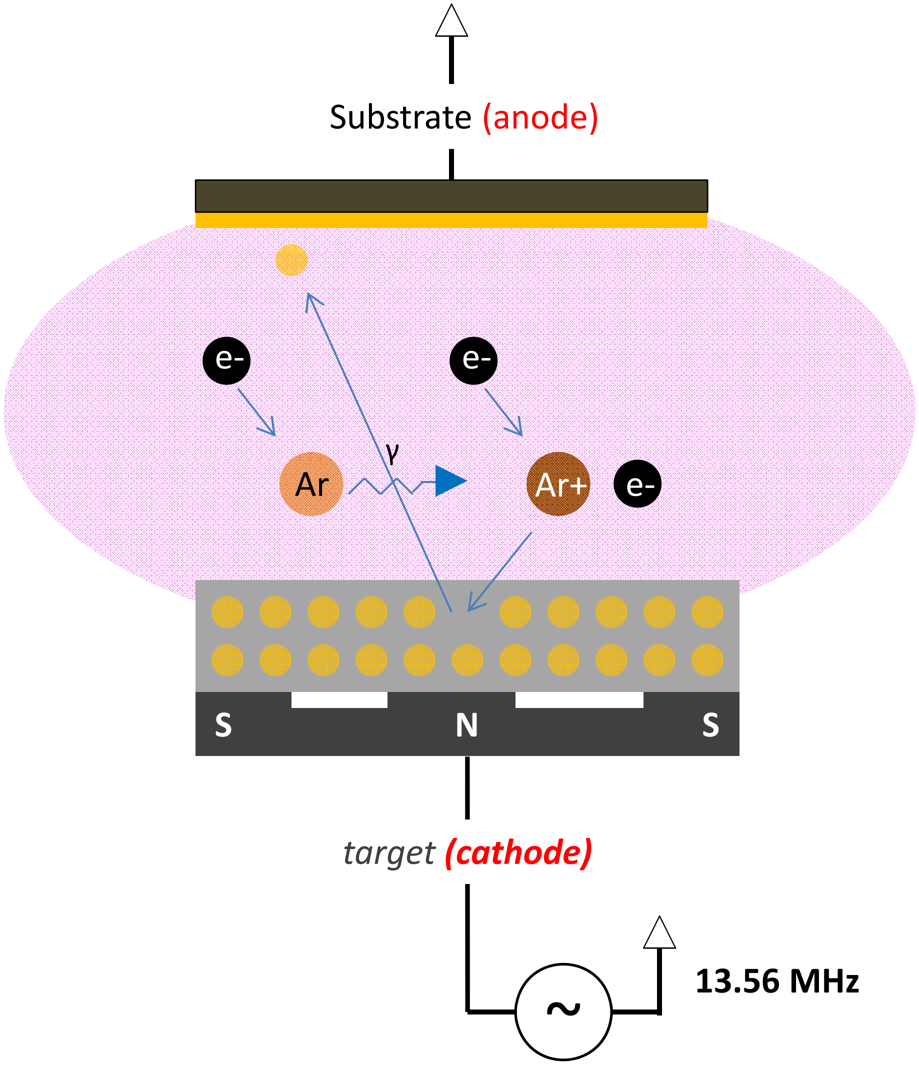
To compare the processes:

the required pressure to maintain the plasma discharge in magnetron sputtering is 100 X less than that of non-magnetron sputtering.

the deposition rate is 100 X higher



RF Sputtering



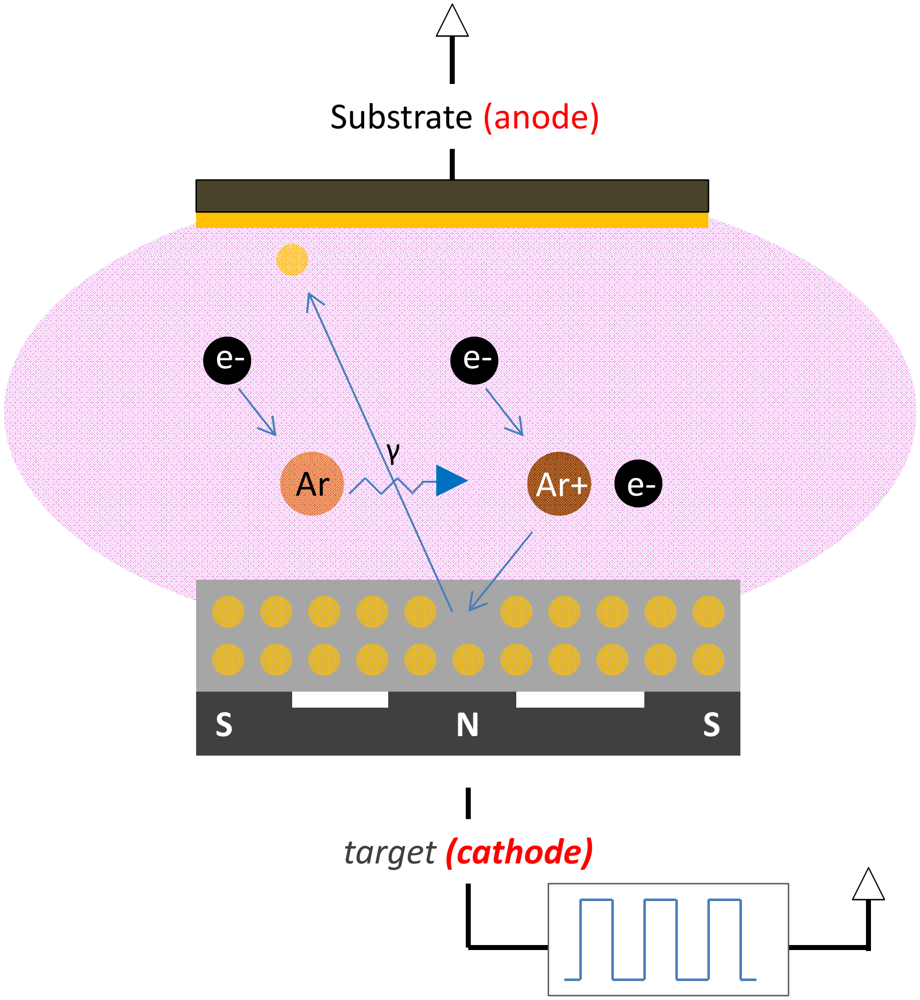
DC sputtering does not work with dielectric materials. In this case the target material is an insulator that will build up a charge as Ar+ ions impact – this reduces the voltage potential between the anode and cathode and the glow discharge can't be sustained.

Using AC power (typically at 13.56 MHz) enables electrons and ions in the plasma to follow the switching of the cathode between negative and positive states.

Sputtering takes place when the cathode is biased in the negative state.

Typically higher voltages required than DC sputtering combined with more challenges in system electrical design and fabrication.

DC Pulsed Sputtering



RF sputtering involves many design trade-offs including higher voltages and more complex power supplies.

From a process standpoint,

DC pulse sputtering ,a more recent development, sends an alternating voltage pulse through the cathode – anode assembly.

DC pulse sputtering typically lower cost to implement than RF sputtering – power supplies are less complex, and system design need not address possible RF leakage into other components.

Sputtering Configurations - Confocal

Confocal design mounts multiple cathodes and targets around a rotating single stage (frequently heated) that holds the substrate. Supports multiple materials that can be co-sputtered simultaneously or one at a time.

This provides extremely good uniformities (better than +/- 3%) along with well formed, dense films.

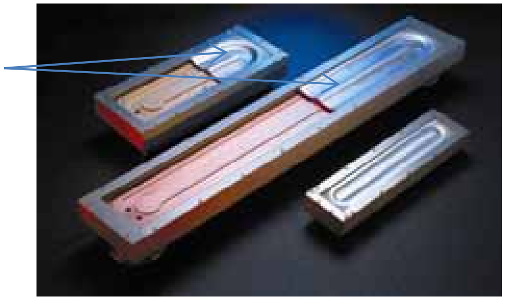
Typically used in **Explorer** and **Discovery** systems configured for sputtering.

Sputtering Configurations – Phoenix 400

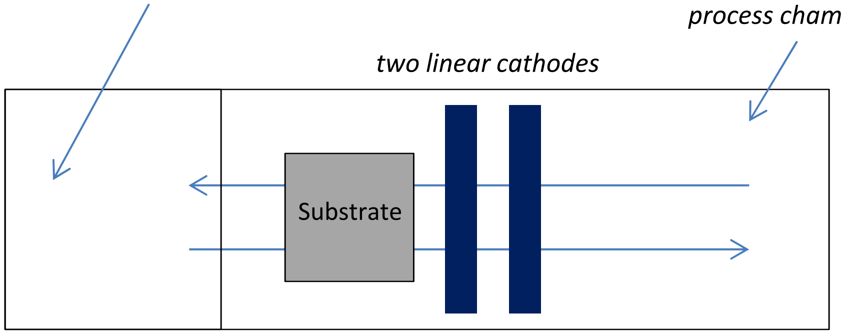
Linear cathode designs are scaled-up to deposit large area devices such as circuit assemblies, ceramic components, flat panel displays, organic LEDs, and thin film solar modules.

Cathodes in these systems are long and thin, allowing cathodes to be arrayed in series, thus enabling higher throughputs. Substrates may rastered back and forth pass under the cathode(s) more than once for improved uniformity and throughput.

Vertical
Load Lock
(Entry & Exit)



linear cathodes



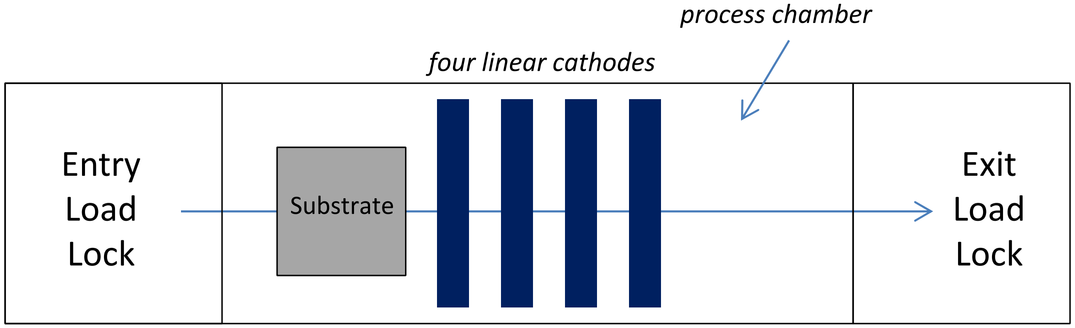
Top View - Phoenix 400

Sputtering Configurations – Phoenix In-line

For maximum throughput, large area deposition system process substrates in a single pass.

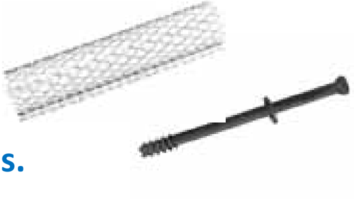
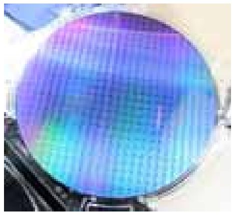
Substrates are loaded in an entry load lock which is then pumped to vacuum. It is then moved into the process chamber and passes under the cathode(s) in a single pass, and is then moved into the exit load lock.

Variations include: sputter-up or sputter down modes; different cathodes and targets for different materials; multiple process zones; substrate heating and cooling; vertical orientation.



Top View - Phoenix In-line

Where Does Denton Use Sputtering?

Microscopy	Deposit materials on SEM samples to enhance contrast .	
Emerging Technologies	Deposit low temperature dielectric materials for thin film batteries and thermoelectric generators.	
Medical	Sputter films for transducers, to color-code implants and to bio-isolate stents, cardiac leads, & related products.	
Solar	Deposit front and back contact metals for small and large area thin film solar panels	
Semiconductor	Deposit metals on wafers and substrates for development and production scale processes.	

Plasma Enhanced Chemical Vapor Deposition - PECVD

Chemical Vapor Deposition Overview

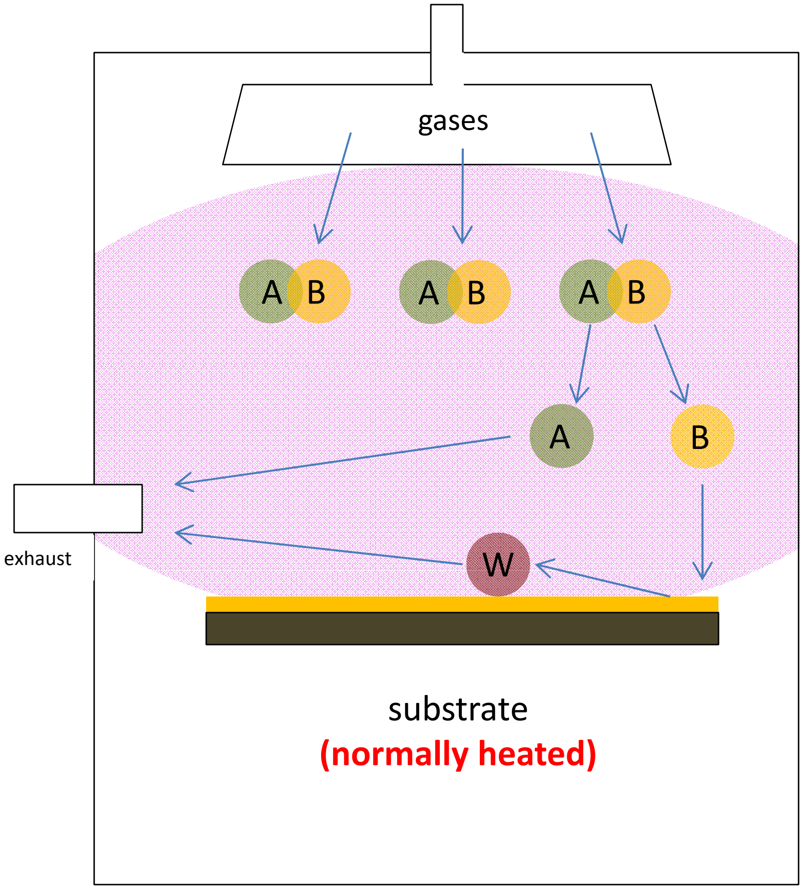
CVD works when a reactant gas(es) is introduced into a vacuum chamber.

Gases are decomposed by either heat (standard CVD) or by plasma activation.

Gas species are absorbed by the heated substrate surface; reaction takes place on the substrate surface.

Volatile byproducts are then exhausted out of the system.

Many different materials can be deposited by CVD including amorphous silicon, silicon dioxide, silicon nitride



substrate

(normally heated)

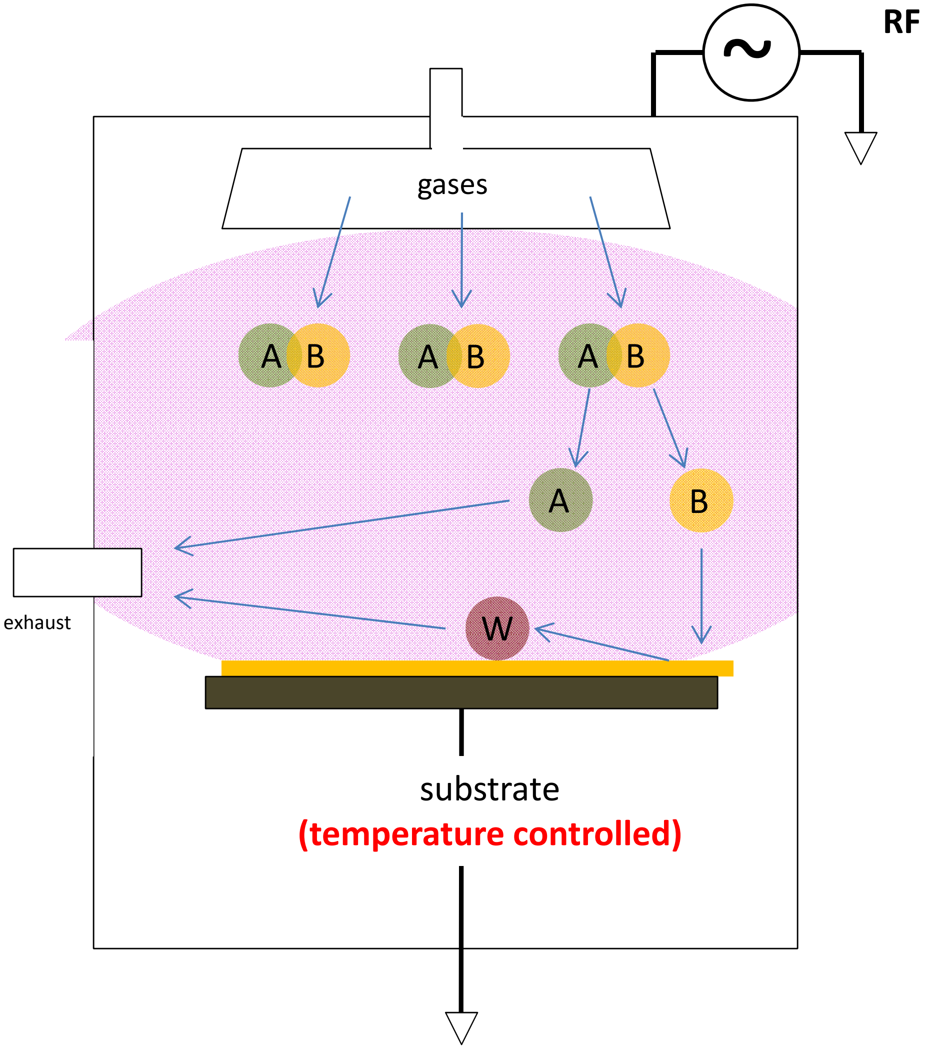
Plasma Enhanced Chemical Vapor Deposition

Plasma enhanced CVD works using an RF induced plasma to activate the feed gases.

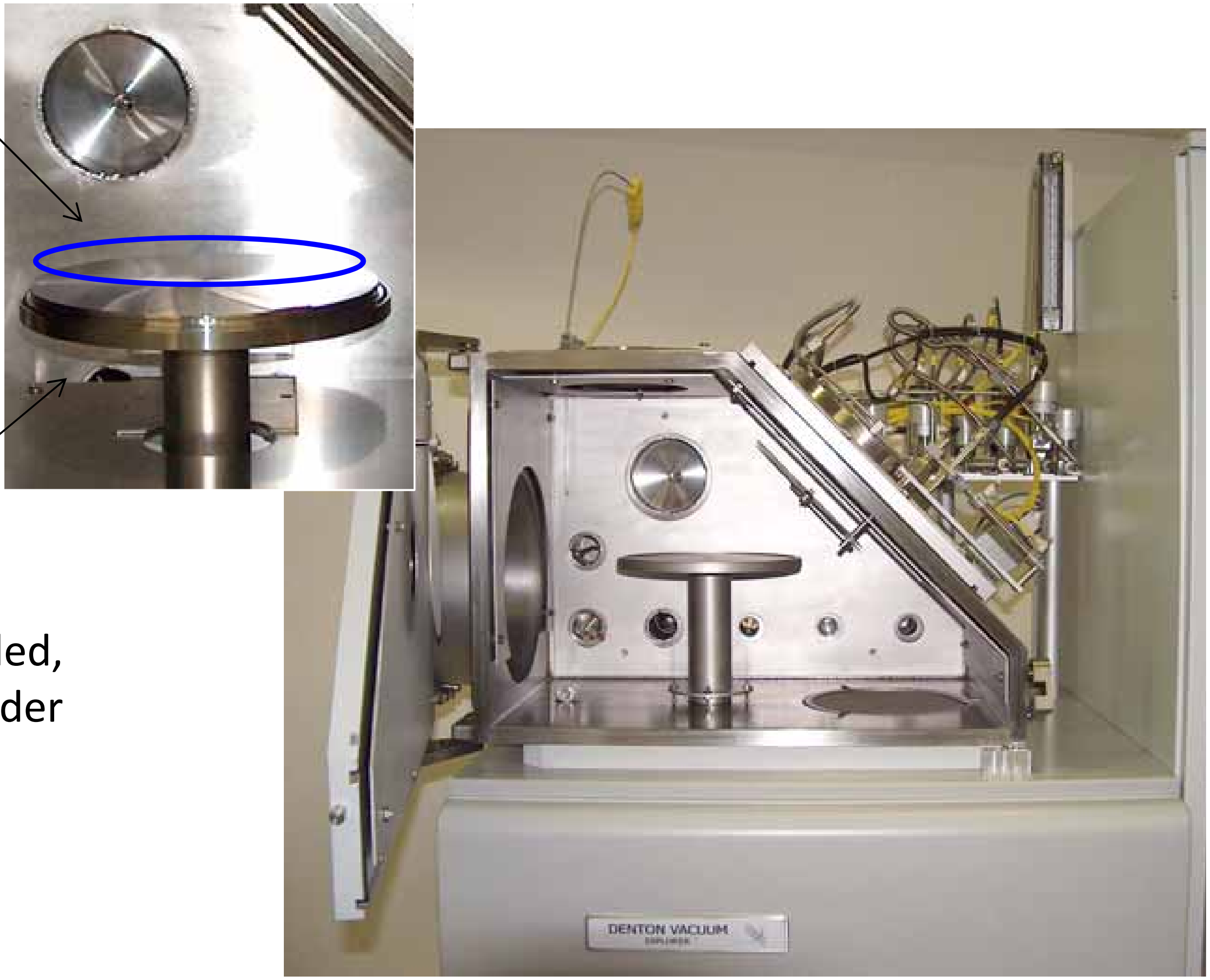
These are low temperature processes (under 300º C), enabling deposition of films on metals and other materials that can't sustain high temperatures.

Typical PECVD processes:

Material	Feed Gases
Amorphous Silicon (α- Si)	Silane (SiH 4) Dichlorosilane (SiH_2Cl_4)
Silicon Dioxide (SiO_2)	$SiH_4 + N_2O$ $SiH_4 + O_2$
Silicon Nitride (Si_3N_4)	SiH_4 + Ammonia (NH_3) $SiH_4 + N_2$



PECVD Configurations - Voyager



Gas distribution ring

RF powered, water cooled, rotating substrate holder

Where Does Denton Use PECVD?

Thin Film Solar	Feedstock gases doped to make amorphous silicon solar cells. (Not a Denton core technology.)
DLC* for Military Coatings	Pure amorphous silicon forms a durable, IR transparent film for nose cones & windows.
DLC for Wear Coatings	DLC provides a highly durable, self-lubricated wear surface for a variety of industrial & consumer products.
Medical Implants	Sputtering provides unique biocompatible coatings – an emerging application.

*DLC – diamond-like carbon

Deposition Process Overview

Process	Materials	Uniformity	Impurity	Grain Size	Film Density	Deposition Rate	Substrate Temperature	Directional	Cost
Thermal Evaporation	Metals or low boiling point materials	Good	High	10~100 nm	Good	~ 1-20 Å/sec.	50-100 C°	Yes	low
E-beam Evaporation	Both metal and dielectrics	Good	Low	10~100 nm	Good	~ 10-100 Å/sec.	50-100 C°	Yes	high
Sputtering	Both metal and dielectrics	Best	Low	~ 10 nm	Better	Metal: ~ 100 Å/sec. Dielectric: ~ 1-10 Å/sec.	200 C°	to some degree	higher
PECVD	Mainly dielectics	Better	Very Low	10~100 nm	Better	~ 10-100 Å/sec.	200-300 C°	to some degree	highest

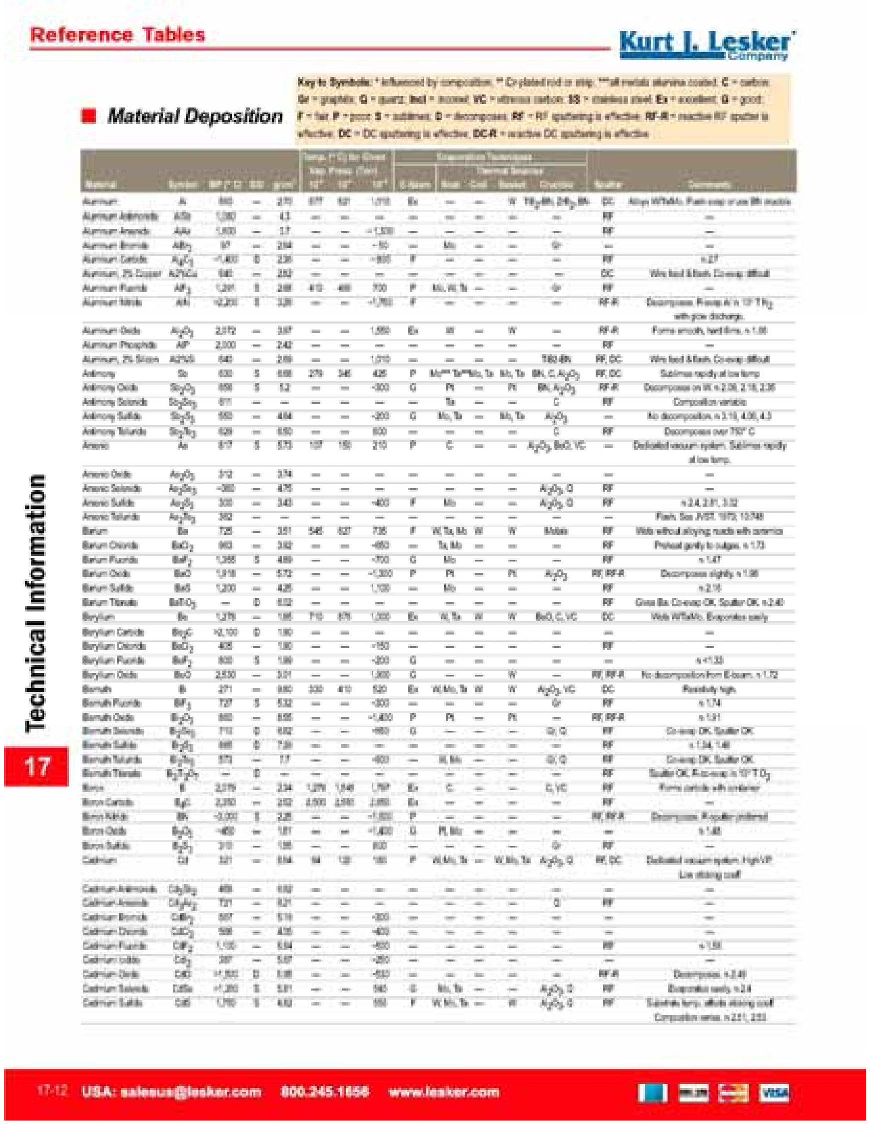
Source Dr. E. Chen, Applied Physics 289r, Harvard University

Deposition Process Reference

Sometimes the competition is a good source of technical information.

The Lesker handbook that you'll be given gives a good summary of materials and their processing options.

Always come back to Denton for verification, but this table (and the others in the handbook) are good guide on a variety of vacuum and deposition topics.



Reference Tables

Kurt J. Lesker Company

Material Deposition

Technical Information

17

17-12 USA: salesus@lesker.com 800.245.1656 www.lesker.com

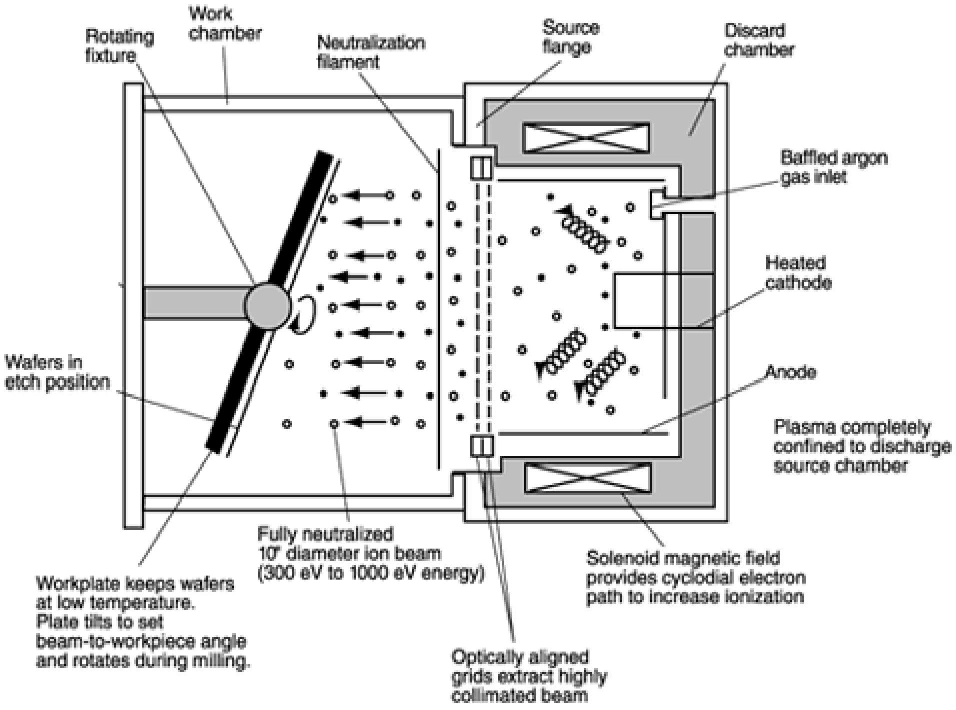
Ion Beam Etch (IBE) & Reactive Ion Beam Etch (RIBE)

Ion Beam Etch (IBE) - Overview

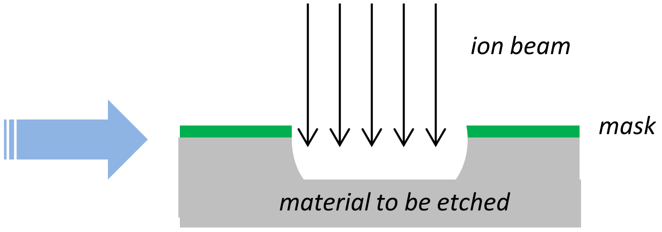
Also known as **Ion Beam Milling**, this process uses high energy argon ions from an ion source to physically impact the substrate & remove materials.

The substrate is placed at an angle so that material that is physically removed from the substrate does no re-deposit; the substrate is rotated to assure uniformity of etch. The process generates high temperatures – water cooling is essential.

Typically used to etch substrates and wafers with a photoresist etch mask. Ideal for metals that can't be reliably etched with chemicals or for small features. The Ar ion beam etches everything – it is non-selective. Photoresist also etches, but at a rate three to ten times less than the metal.


drawing from Ion Beam Milling, Inc.

The directional beam of Ar ion etches primarily in a single dimension, which can produce sharply defined **anistropic** etch that's superior to wet etches.



Denton HDG (Horizontal Dual Gun)

Ion beam etch

Reactive ion beam etch

Compatible with a range of materials

- Dielectrics; Si, SiO2, Al_2O_3,, polyimide, etc.
- Metals: NiFe, Cu, Au, Al, etc.

Existing Applications

- Thin film heads
- Photomask
- Detectors and Sensors
- Lasers
- MEMS
- Surface Texturing
- III/V and traditional SEMI

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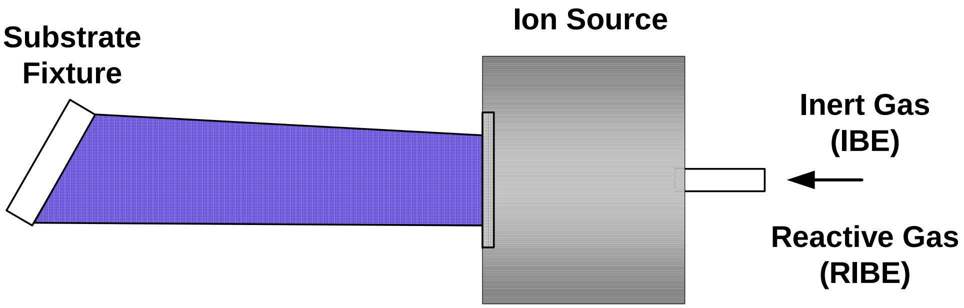
Ion Beam Etch

Physical etch “ion milling”

- Highly collimated beam allows for precise anisotropic etching of any material
- Provides greater control of etch features than other technologies
  - Higher aspect ratios
  - Excellent repeatability
  - Tighter resolution at lower power then larger tools

Reactive etch component offers greater control

- Etch selectivity
- Higher aspect ratios
- Higher etch rates



BARRIERS BECOME BREAKTHROUGHS

HDG Tilt Fixture, Single Rotation

Available in 6 and 8 inch diameter

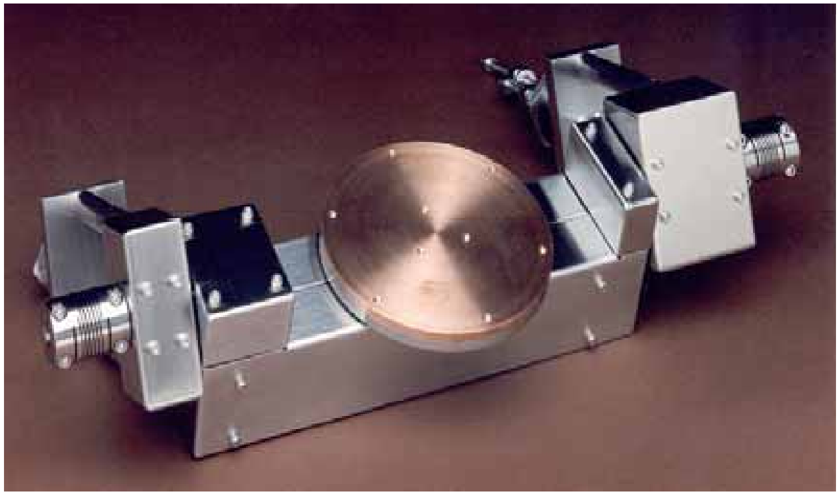
Water-cooled

Etch Uniformities of less than ± 5%

Tilt feature

- Provides capability to achieve tailored sidewall profiles with minimal sputtered re-deposition on overlying mask

- Allows greater deposition uniformity potential.



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