PPG Flat Glass
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Physical Vapor Deposition of Coatings On Glass

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Acknowledgements:

Tom Waynar, Andrew Wagner, Ed Kapura, (PPG Industries, Inc.)

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Outline

- **Solar Control Coatings on Glass**
- **Magnetron Sputtering**
- **Vacuum Basics**
- **Coating Process**

Emissivity and Glass

Emissivity: The relative power of a surface to absorb and emit heat by radiation.

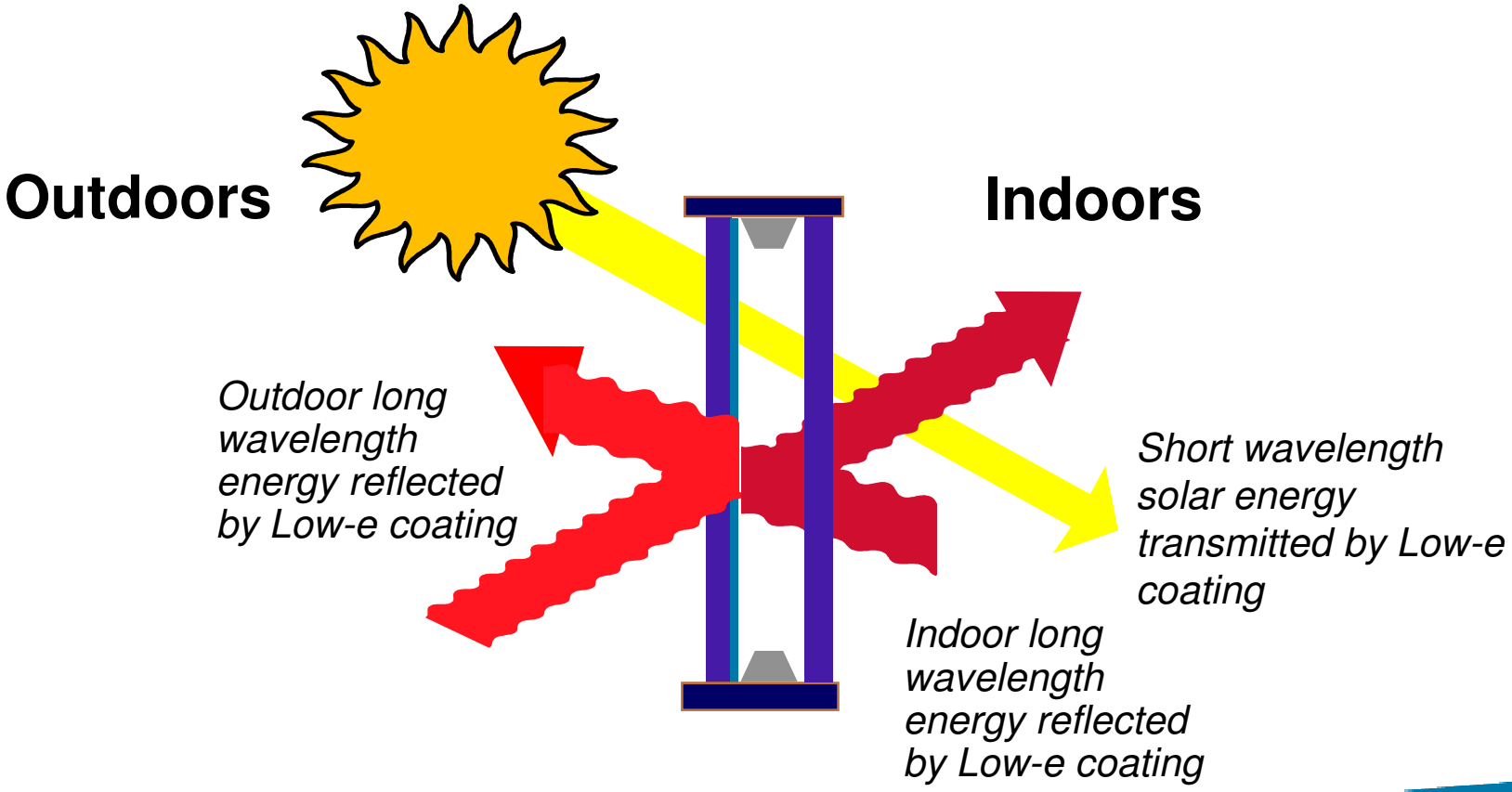
Glass: High emissivity surface

- Efficient heat absorption and radiation

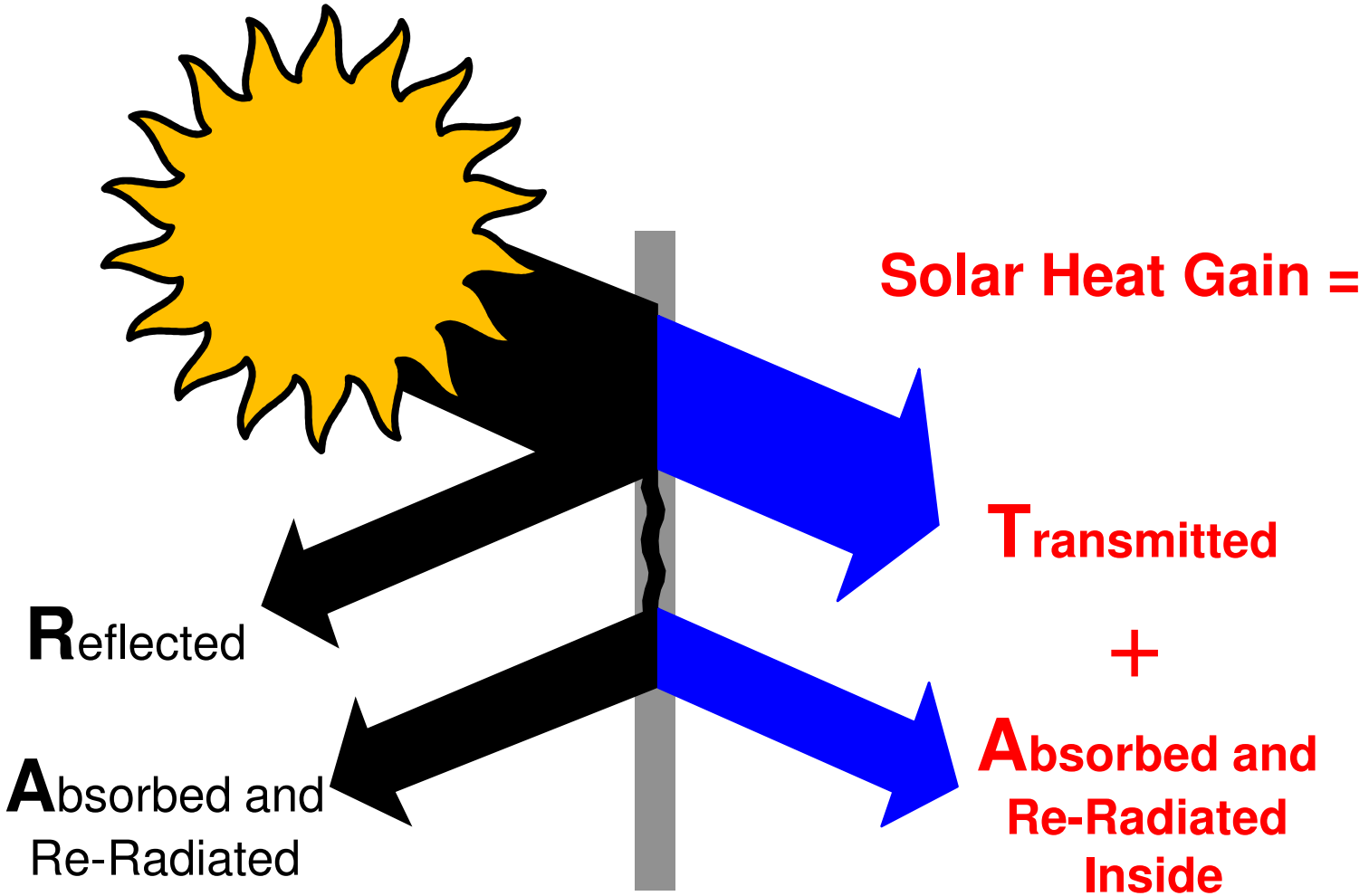
Low-e Coating: Low emissivity surface

- Efficient heat reflector and poor heat emitter
- Thin films of metal, metal oxides and others

Low-E Coatings reflect long-wave energy

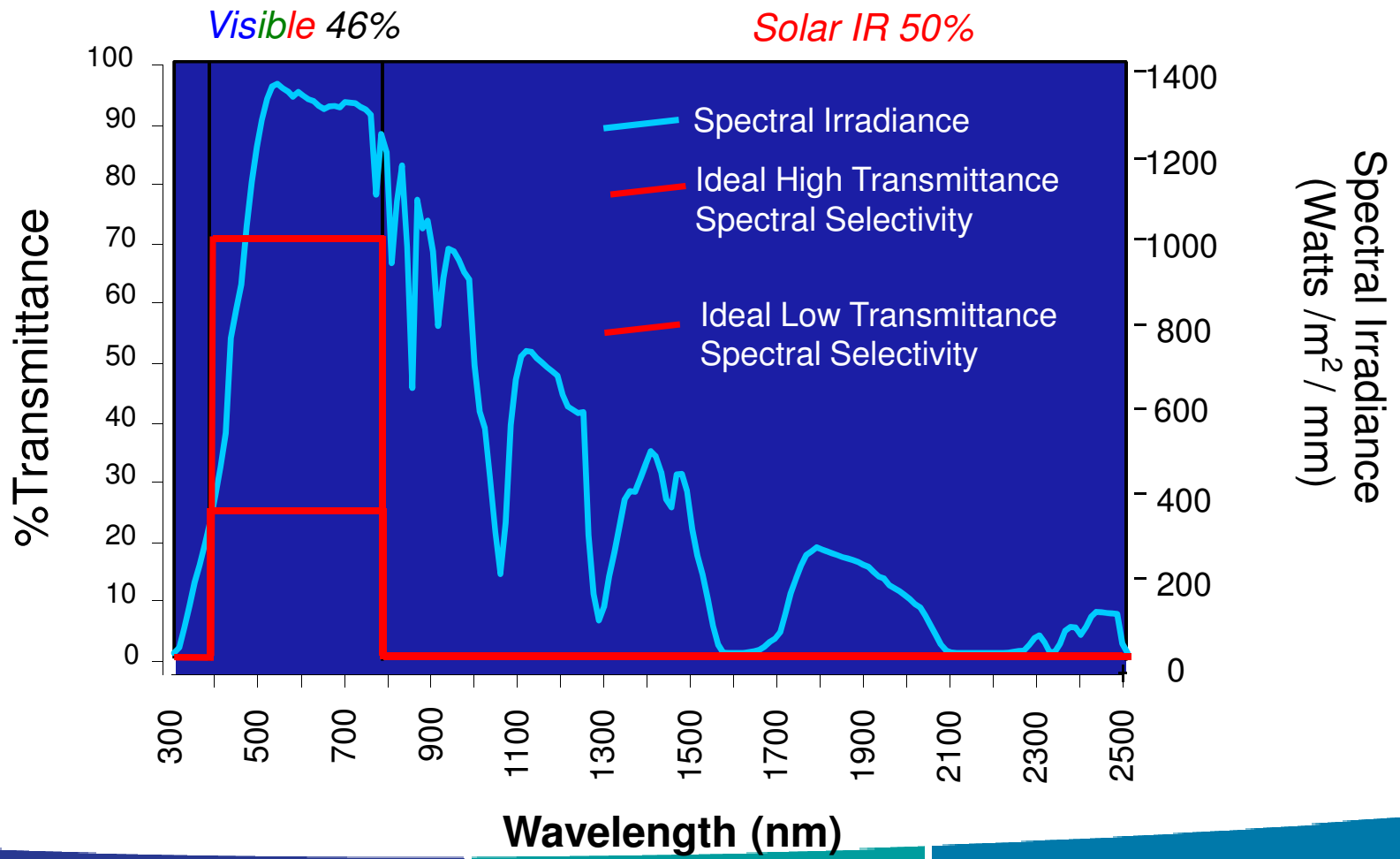


Solar Heat Gain



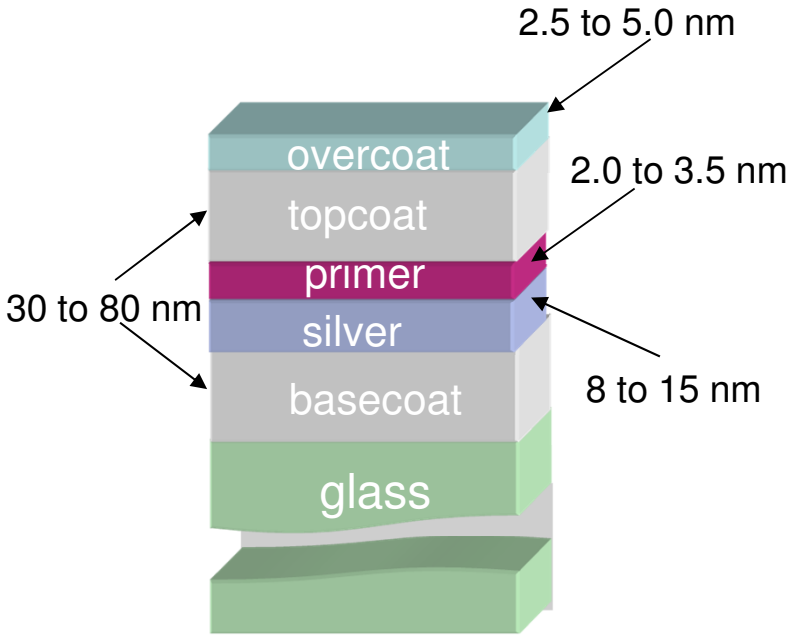
Spectrally Selective Glazing

Solar energy distribution at sea level for air mass = 2



Spectrally Selective Glazing

- **Silver Layer**
  - provides solar & thermal performance
  - reflective in visible and IR
- **Dielectric Layers** (base and topcoat)
  - antireflect the silver layer in the visible
  - acts as a nucleation layer for silver
  - provide chemically & mechanically durability
  - non-absorbing in visible spectrum
  - low cost and non-toxic
- **Primer (sacrificial) Layer**
  - protects silver during sputtering process
  - provides durability
  - stabilizes coating at high temperature
- **Overcoat Layer**
  - (optical) extension of topcoat
  - provides additional durability

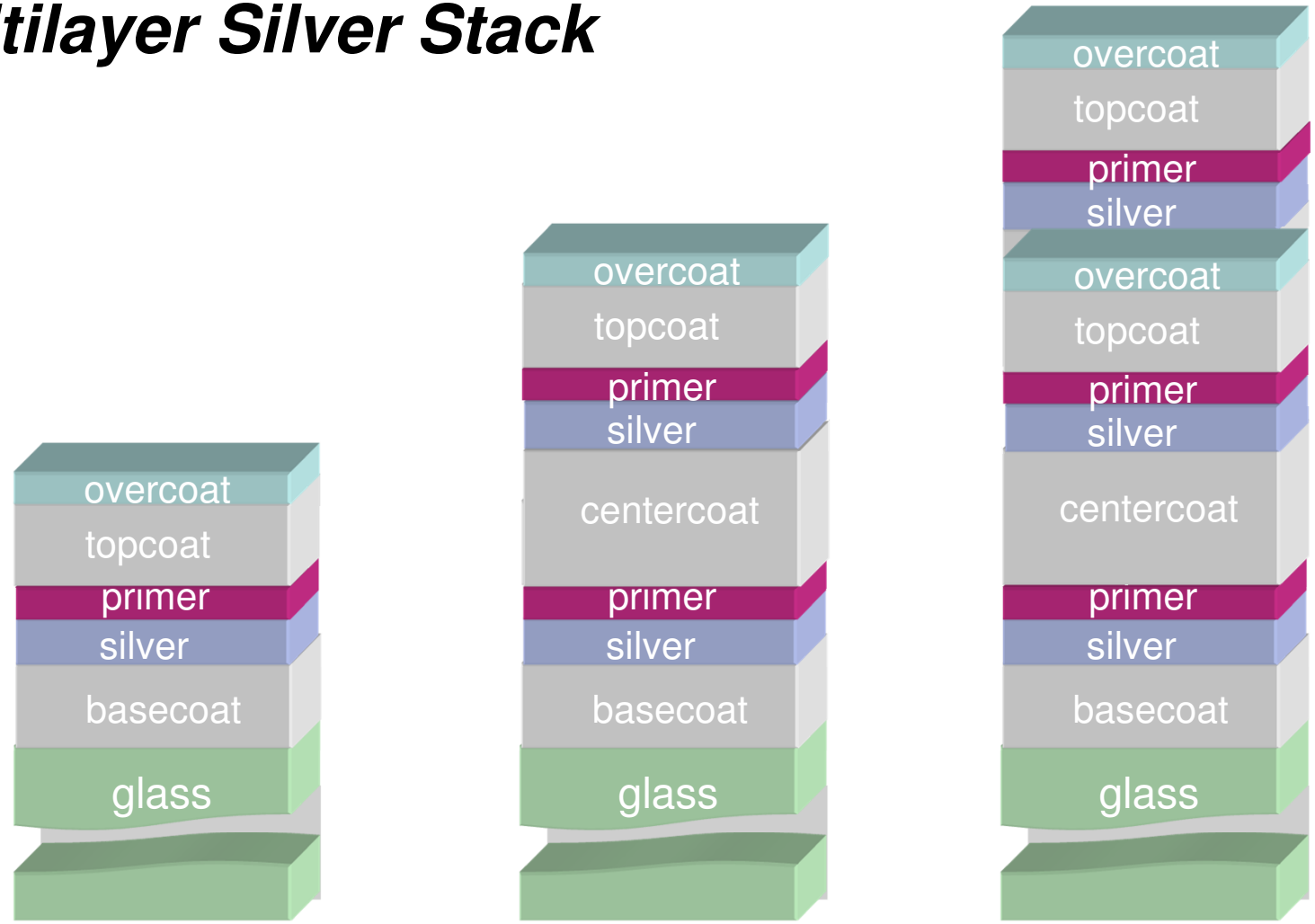


1 Layer Silver

Dielectric/Silver/Dielectric Stack

Spectrally Selective Glazing

- ***Multilayer Silver Stack***

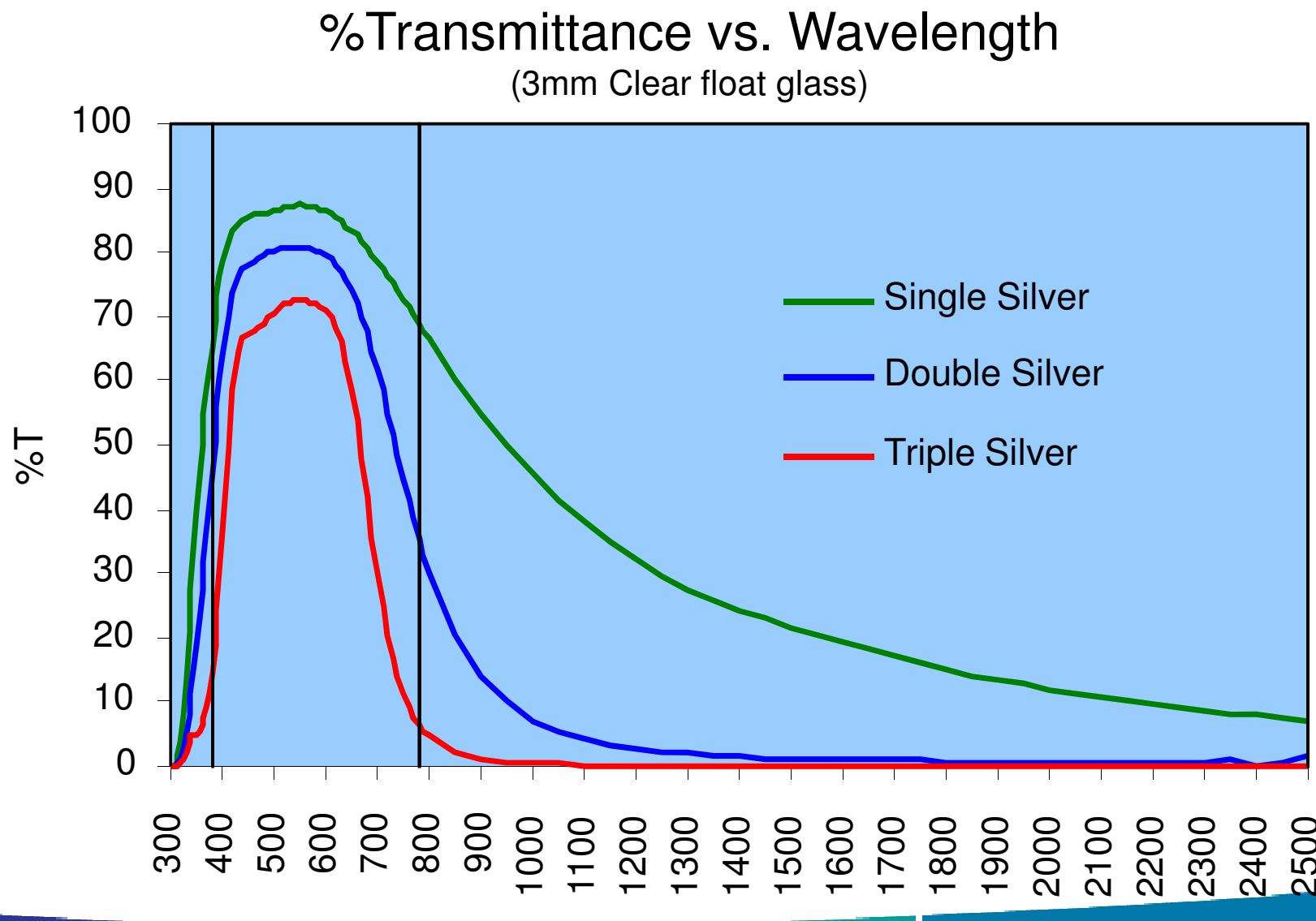


1 Layer Silver

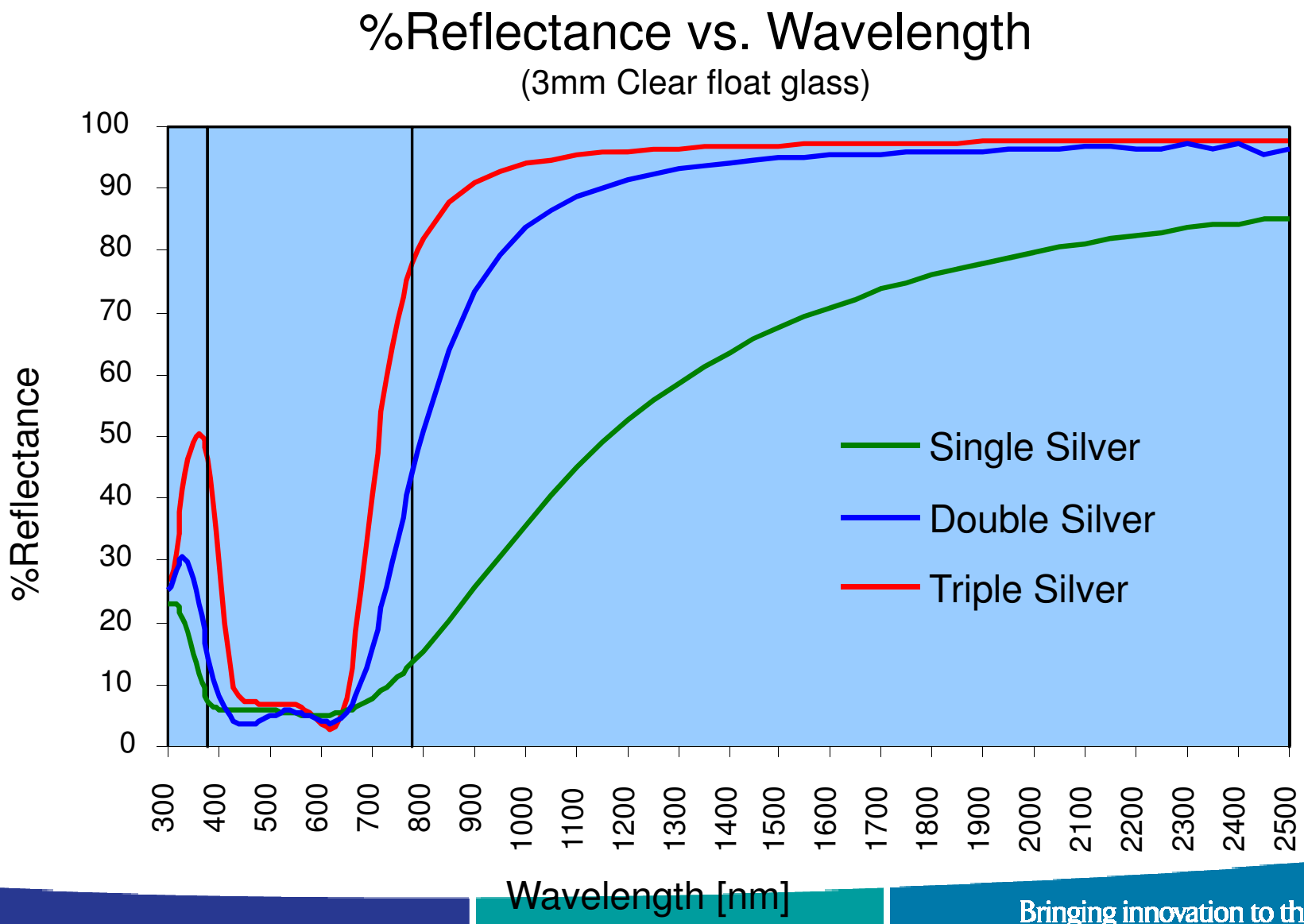
2 Layer Silver

3 Layer Silver

Coating Performance



Coating Performance



Spectrally Selective Glazing

Basic Performance – Solar Control, Low Emissivity Coatings

Number of Silver Layers *[metal oxide–silver–metal oxide]*	VLT	SHGC	LSG	U-Value
Uncoated	79	0.70	1.13	0.48
1 Layer	73	0.52	1.40	0.31
2 Layers	70	0.38	1.84	0.29
3 Layers	64	0.27	2.37	0.28

Commercial IG Unit: 1-inch units with ½-inch airspace and two 1/4-inch clear lites. Coating on #2 surface.

Spectrally Selective Glazing

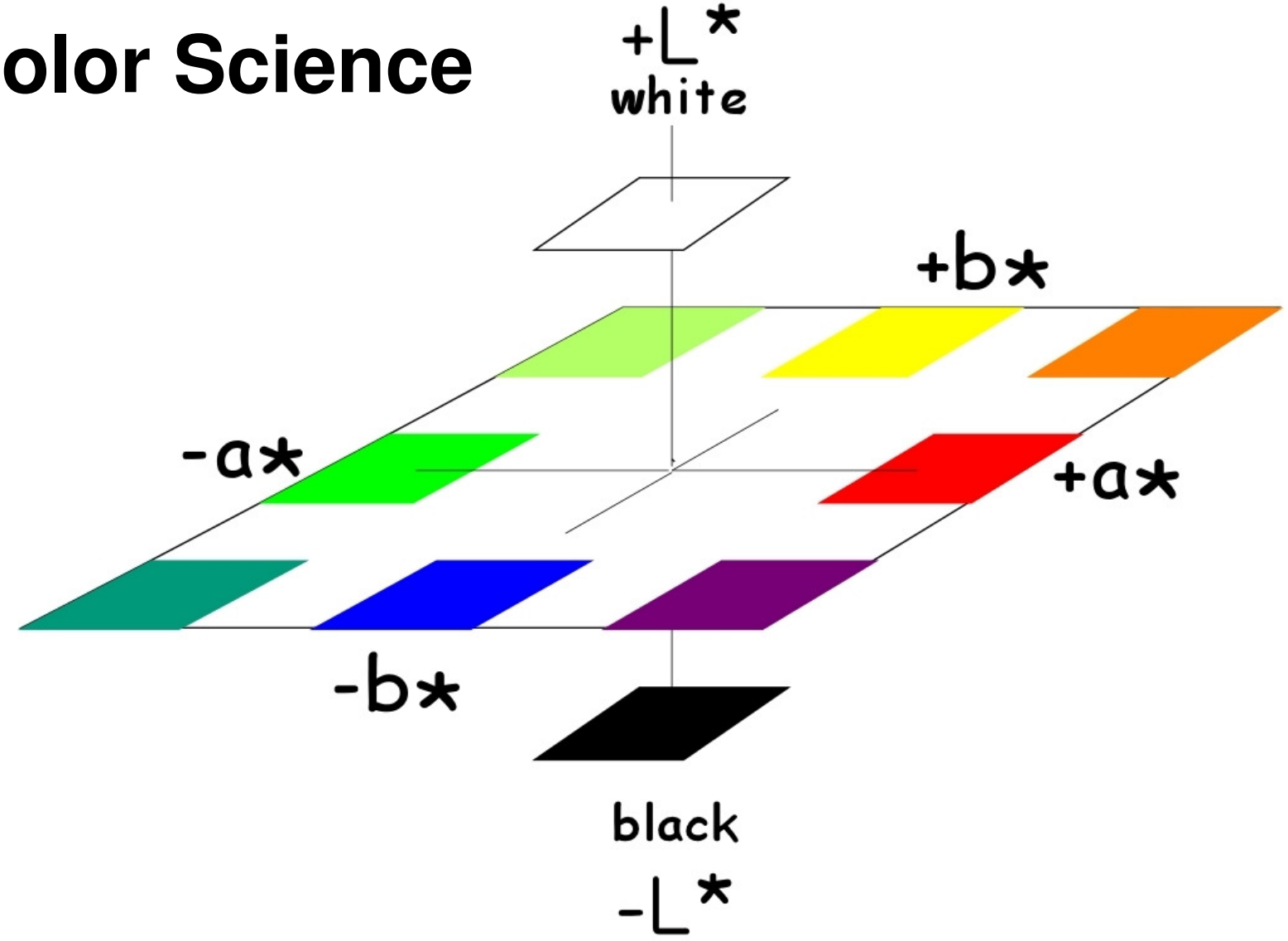
Advantages of high LSG ratio Product

- Allows more daylighting
- Reduces
  - utility costs
  - capital costs
  - carbon footprint
- Enhances design through use of glass

Color is Critical to Quality

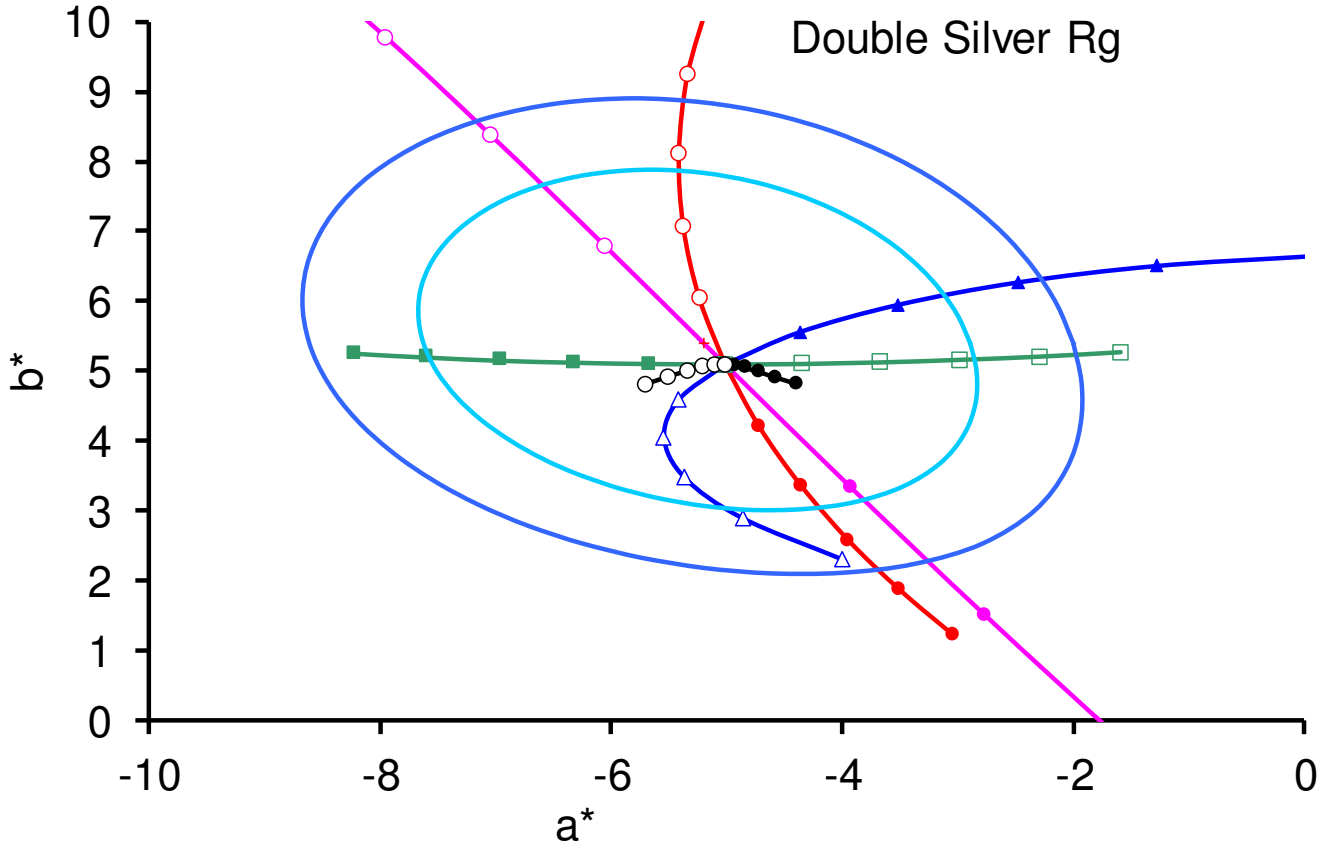
- **Color is a perception!**
  - Instruments are used to quantify color
  - Light source * Object * Observer sensitivity
  - Sunlight ≃ D65 (6500K)
  - The eye has receptors for three primary colors – Calculate Tristimulus values

Color Science



Color Control

- "Spider Diagrams" - effect of variation of the coating layers on color.
- Originally determined by experiment



Outline

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- Magnetron Sputtering
- Vacuum Basics
- Coating Process

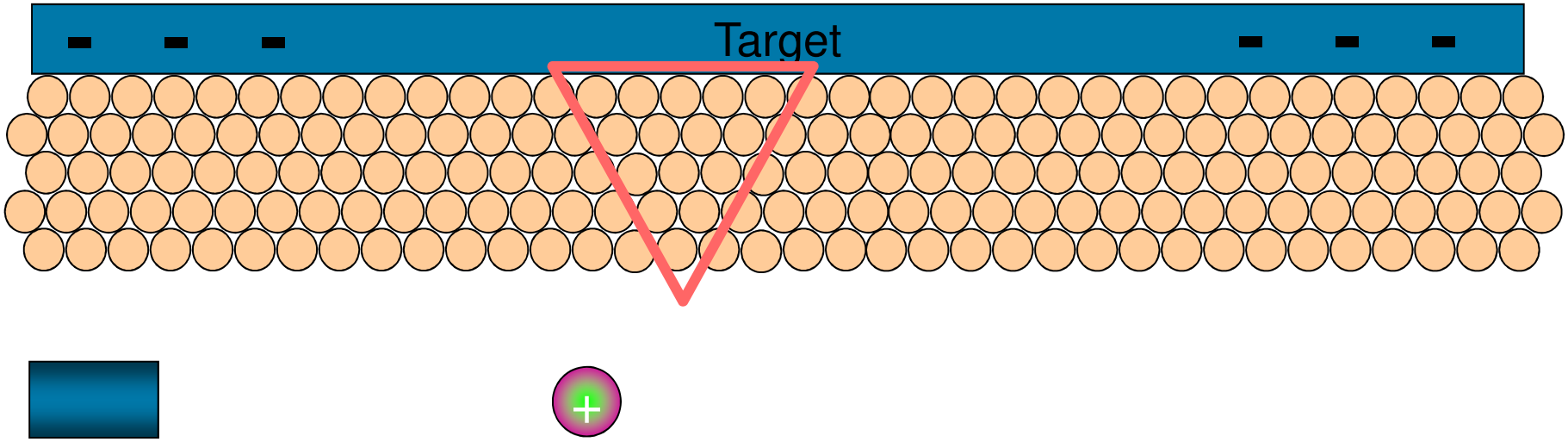
Sputtering

•Sputtering is the removal of material from a solid target by energetic ion bombardment.

•The ions come from a magnetically confined plasma created above the target surface.

•Sputter deposition is the process of coating a substrate with the material removed from a target by sputtering.

Sputter Deposition



Sputter Rate and Deposition Rate

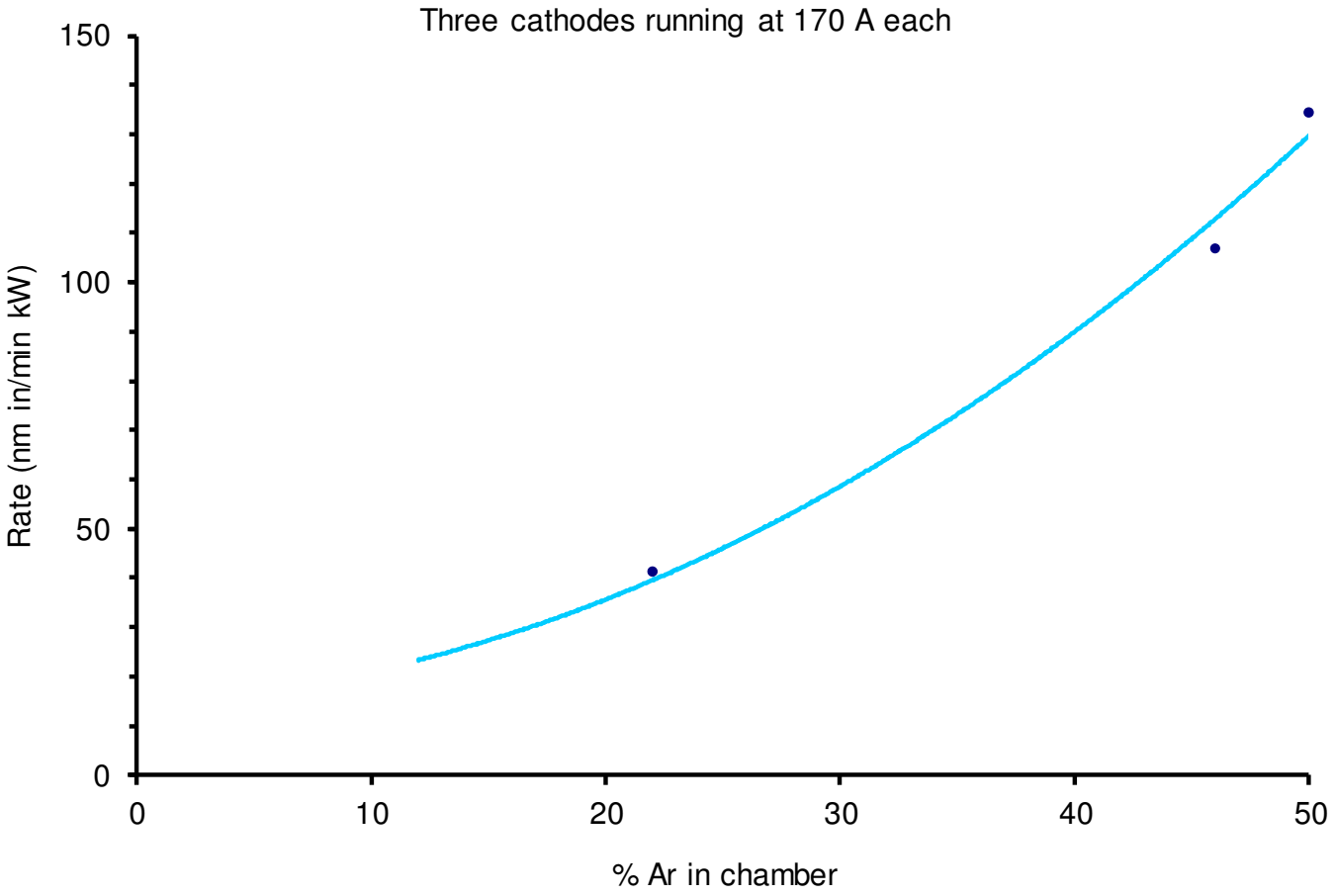
- Sputter rate refers to how fast material is being removed from the target
  - Sputter rate is different for every material
  - Large differential between metal mode vs. reactive mode

- Deposition rate refers to how fast of that material is deposited on the substrate

Reactive Sputtering

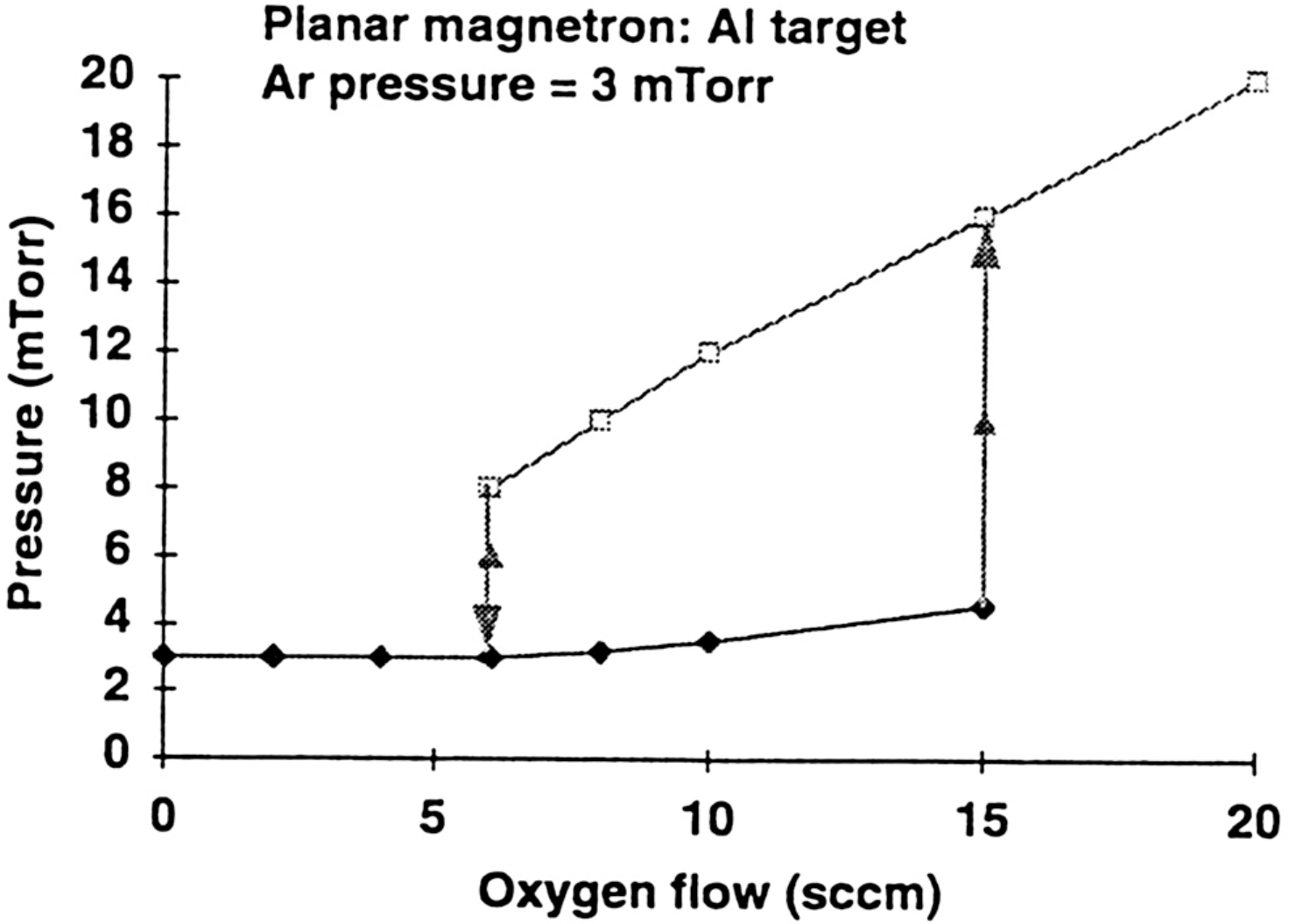
- **Oxidation of cathode targets occurs**
  - Reduces sputter rate
- **Oxide deposition on anodes and surroundings**
  - Insulates conductive surfaces
  - Charge build-up
- **Gradient is effected**
- **Arcing can occur**
- **Cleaning cycle reduces issue**

Oxide Rate Enhancement With Argon

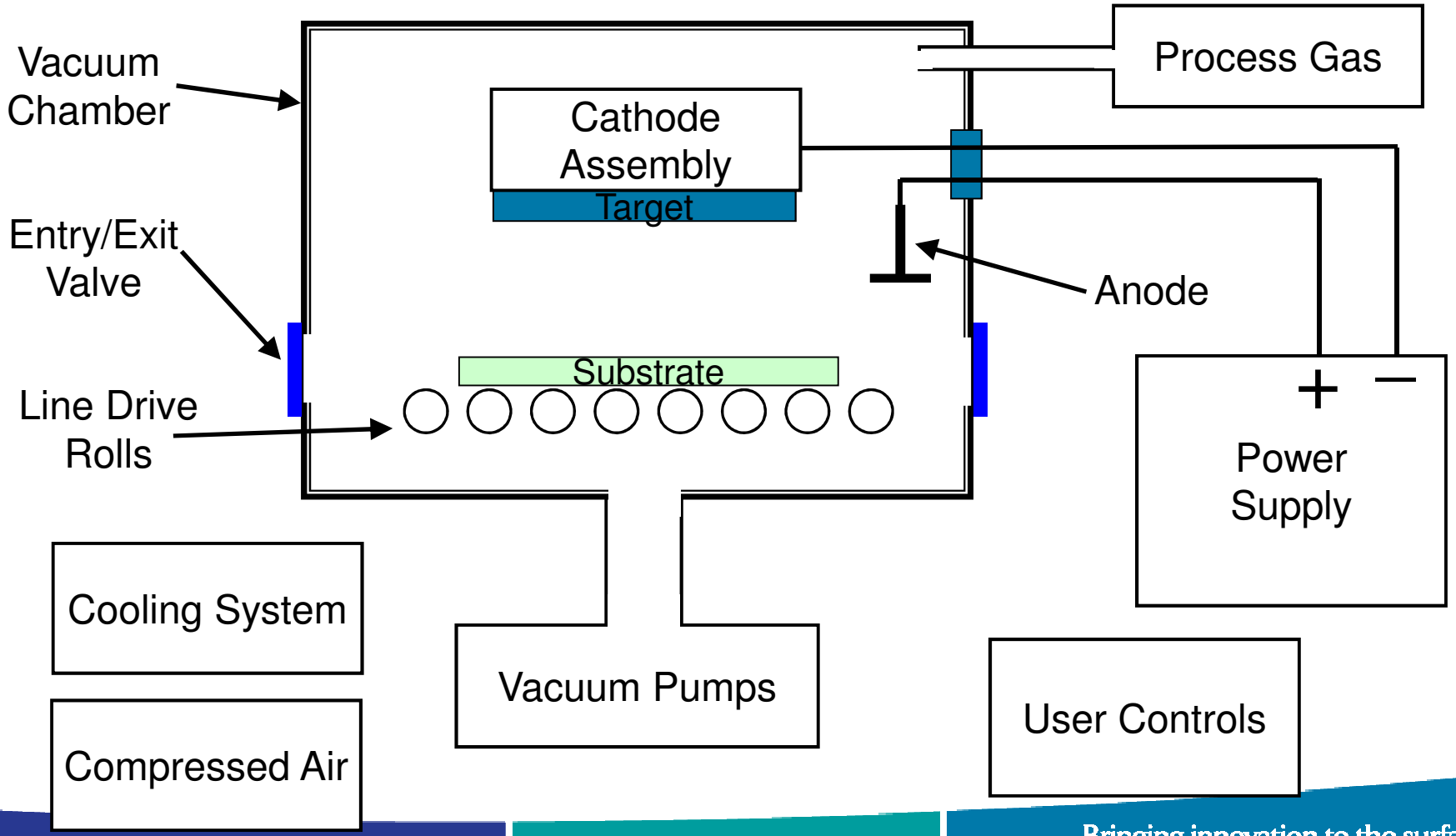


Issues: Stability - gradient

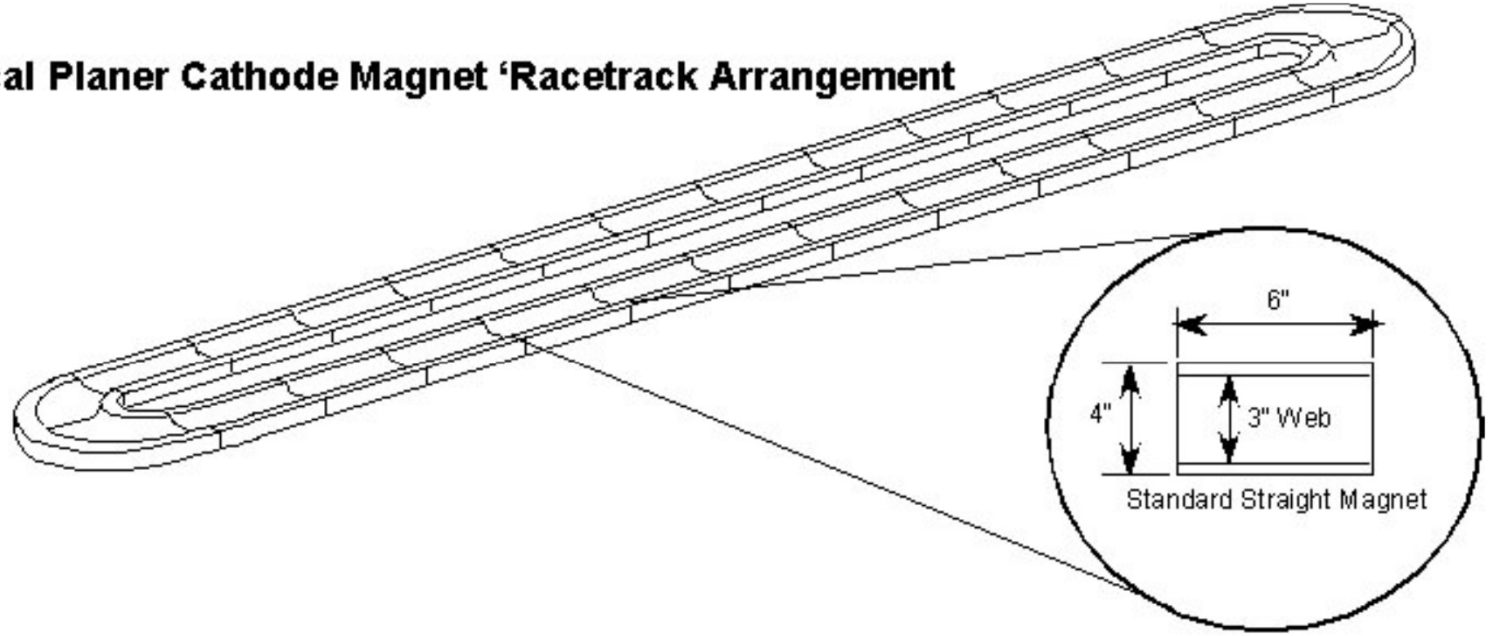
Switching


Planar magnetron: Al target
Ar pressure = 3 mTorr
Pressure (mTorr)
20
18
16
14
12
10
8
6
4
2
0
0
5
10
15
20
Oxygen flow (sccm)

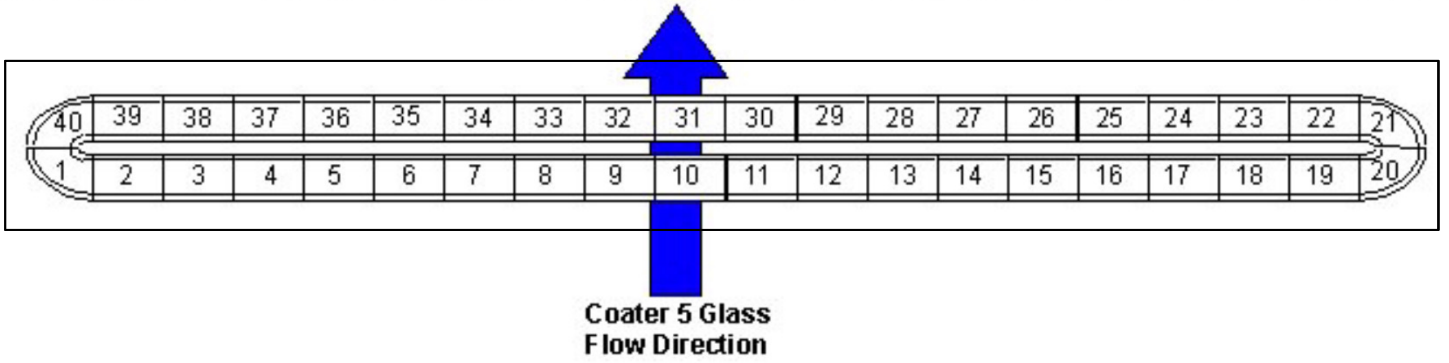
Sputter Coating Machine



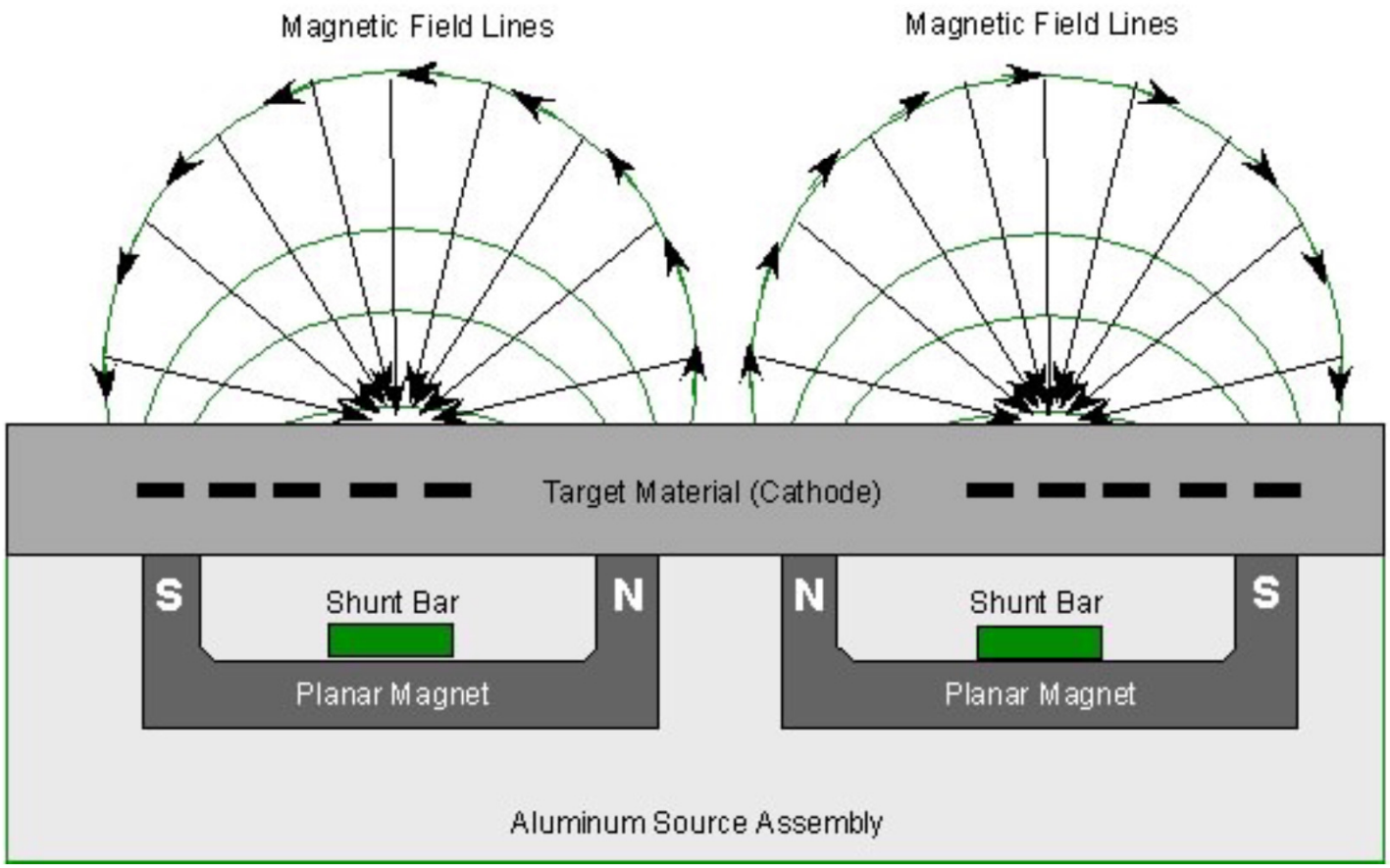
Typical Planer Cathode Magnet 'Racetrack Arrangement



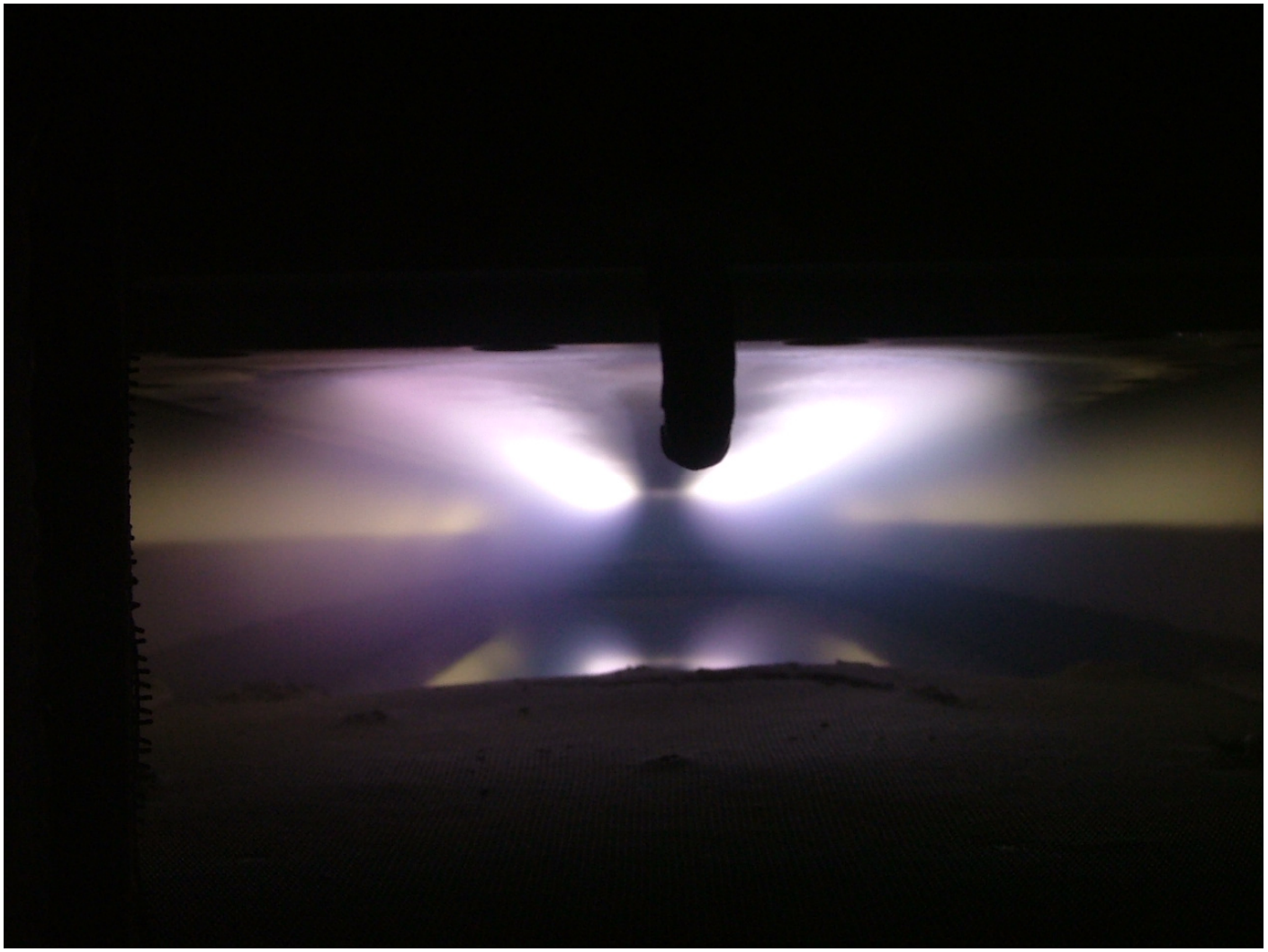
Actual Number Layout of a Standard 100" Planar Magnet Racetrack on Coater #5



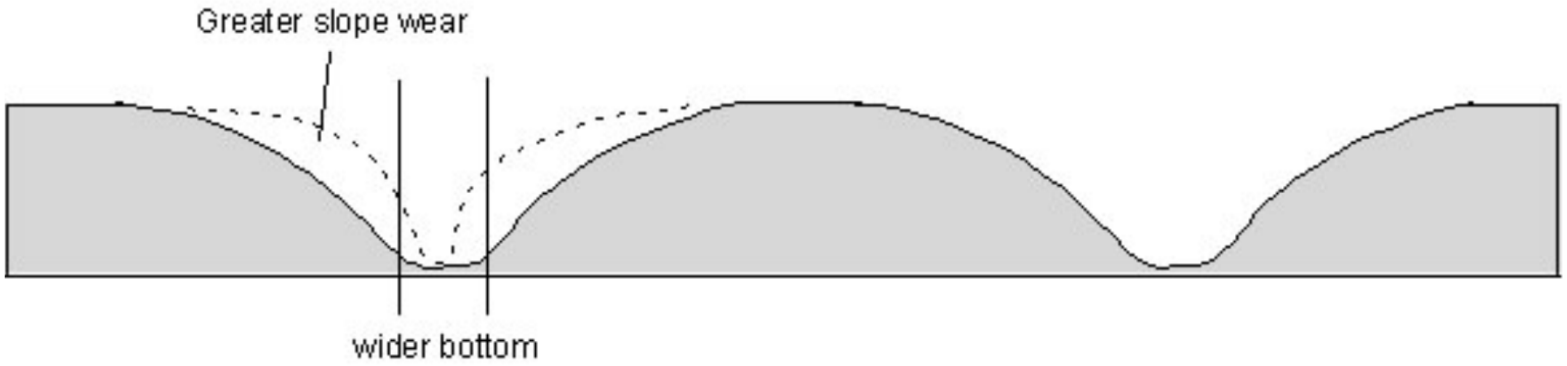
Magnetron Sputtering Process



Plasma



Wear Groove on a Coventional Planar Target



Wear Groove on a HU Planar Target

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Vacuum Ranges

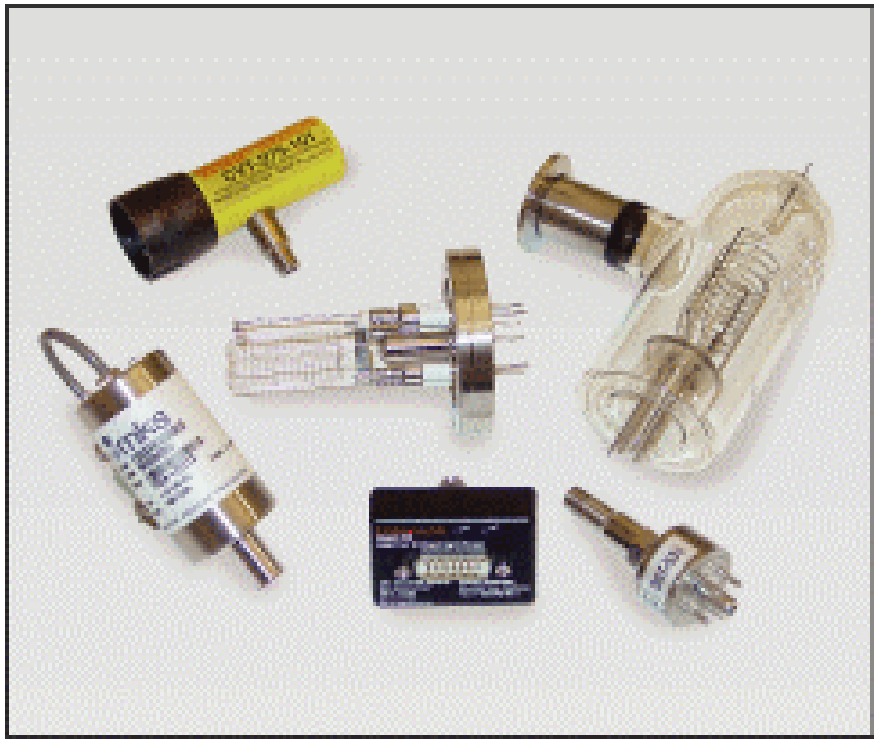
- **Low vacuum (rough vacuum)– 760 torr to 1 torr**
- **Medium vacuum – 1 torr to 1 x 10^{-3} torr**
- **High vacuum – 1 x 10^{-3} torr to 1 x 10^{-6} torr**
- **Very High vacuum – 1 x 10^{-6} torr to 1 x 10^{-9} torr**
- **Ultra High vacuum – Less than 1 x 10^{-9} torr**

Ideal vs. Real Vacuum

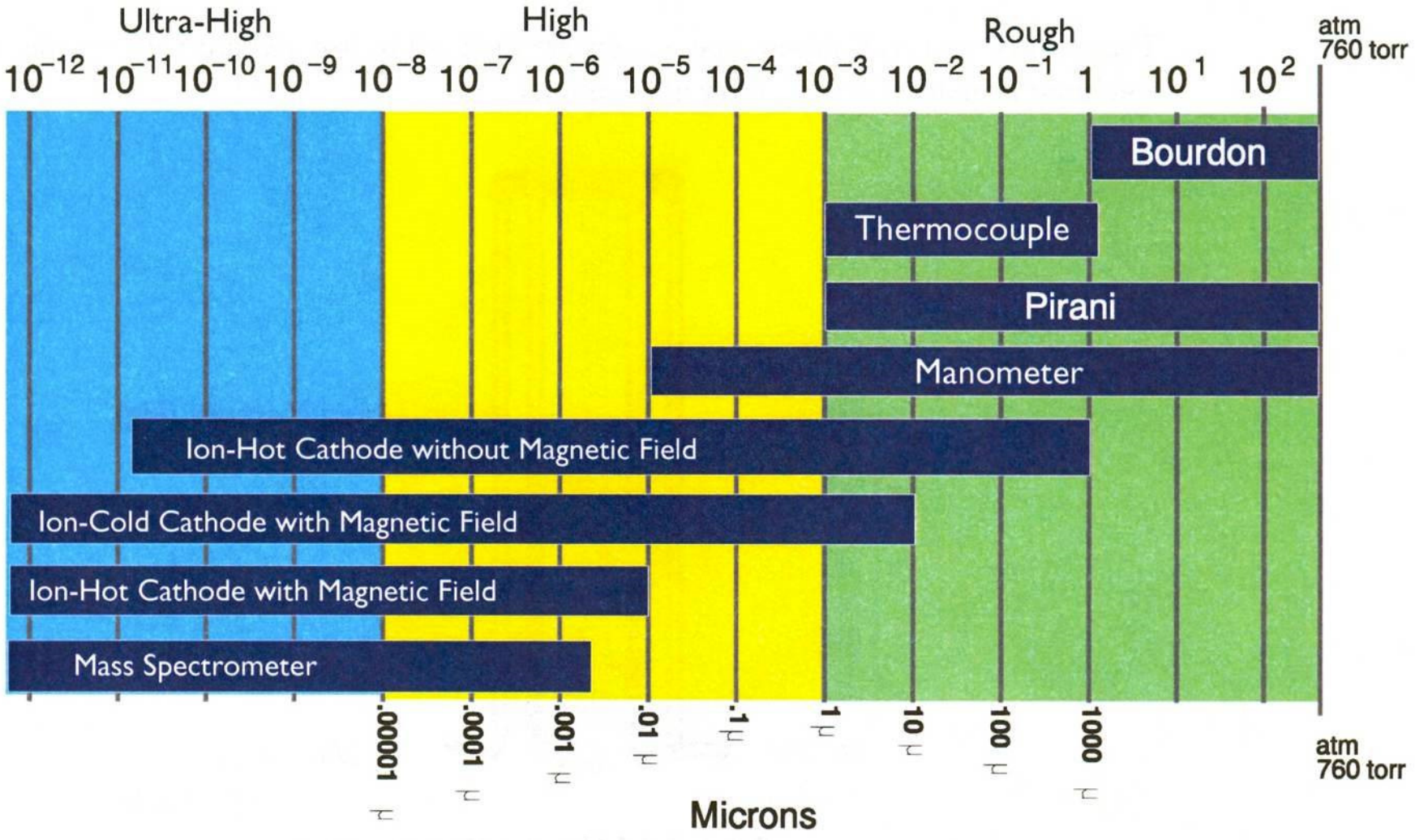
- There is no such thing as a “Perfect Vacuum”.
  - Space ~ 1 x 10^{-18} torr (800 atoms/ft^3)
  - Best vacuum on earth ~1x10^{-15} torr

- The 3 main ways undesired gasses get into a vacuum are:
  - Leaks
  - Outgassing
  - Backstreaming

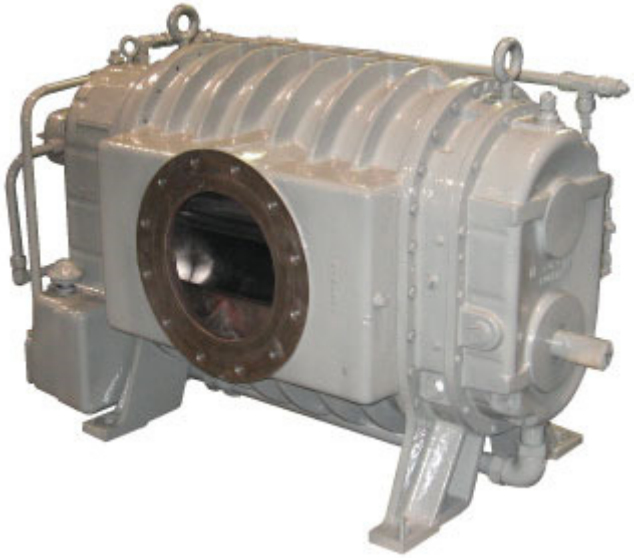
Vacuum Gauges



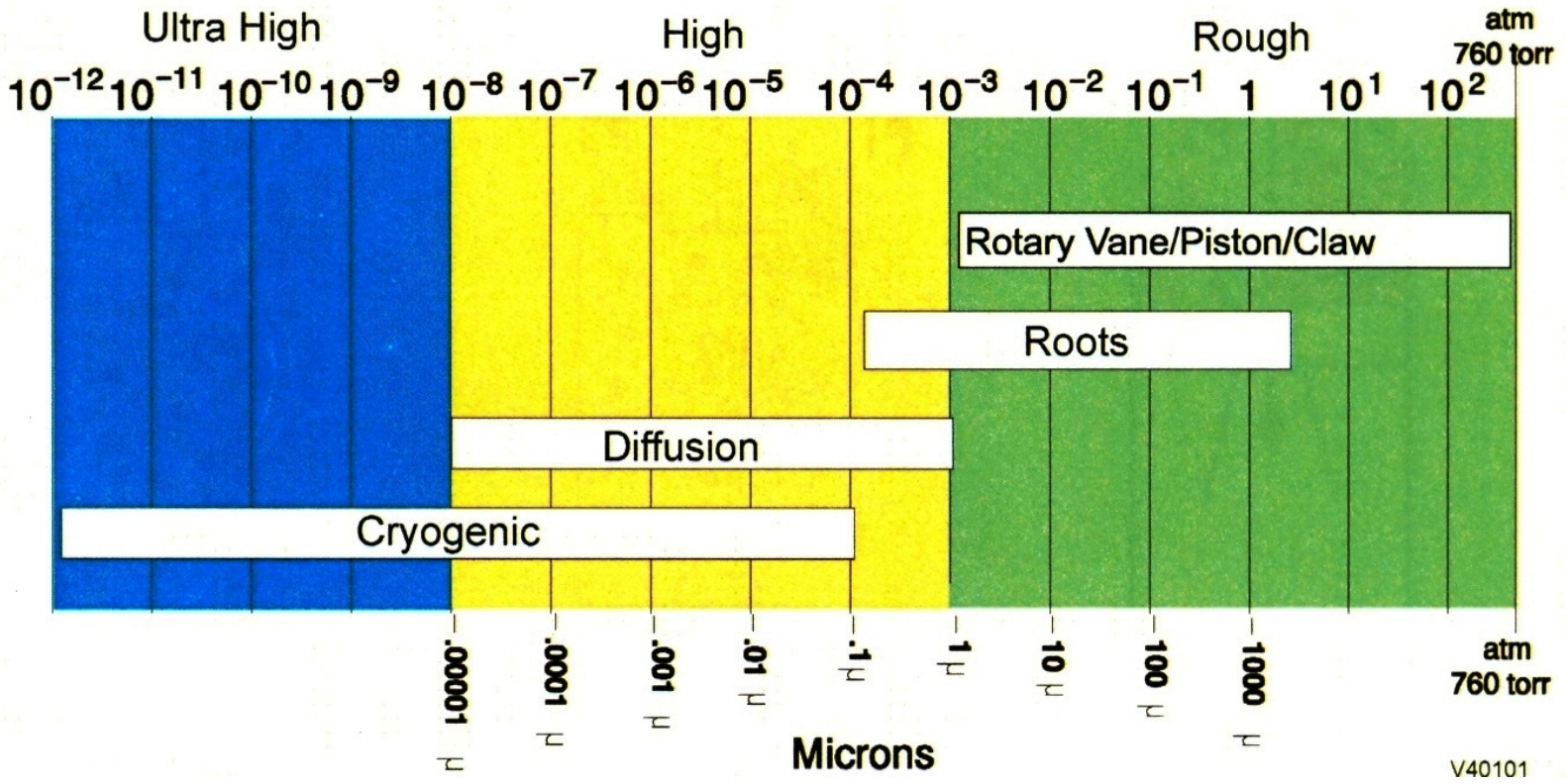
Pressure Gauge Ranges



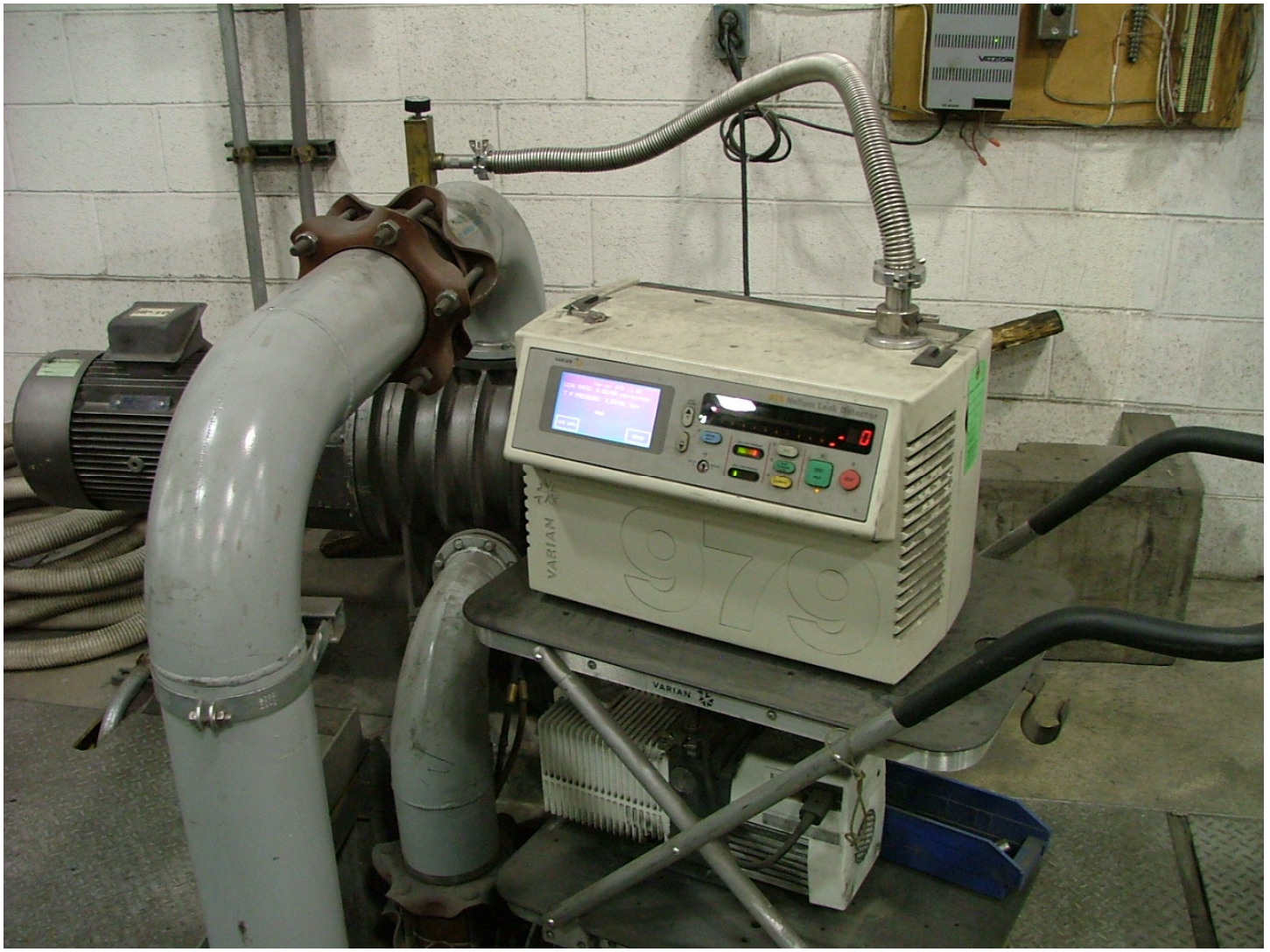
Vacuum Pumps



Vacuum Pump Ranges



Leak Detectors



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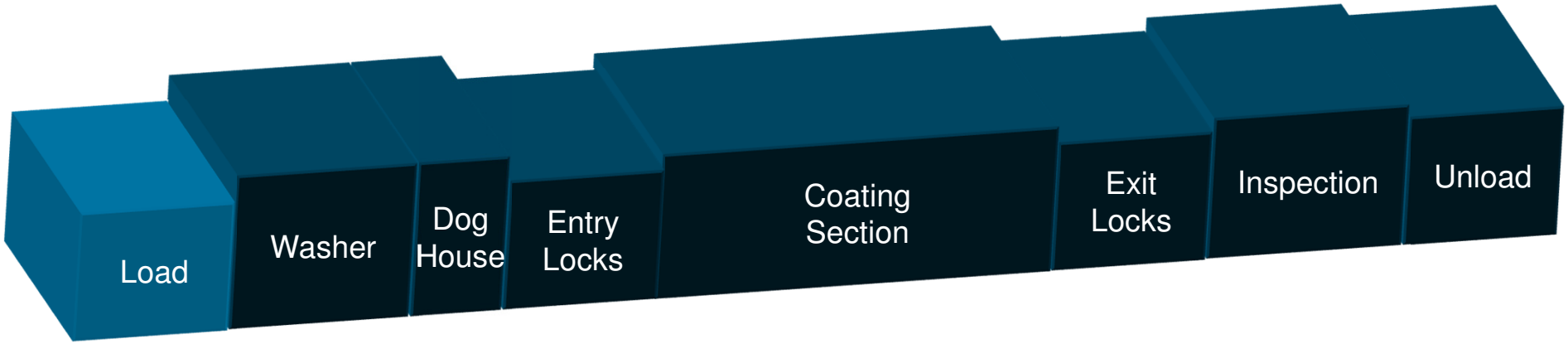
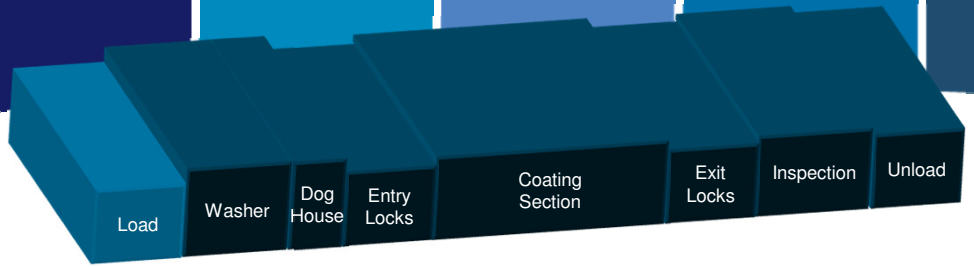
What Is A Glass Coater?

- A coater is a machine that applies a thin film coating to glass

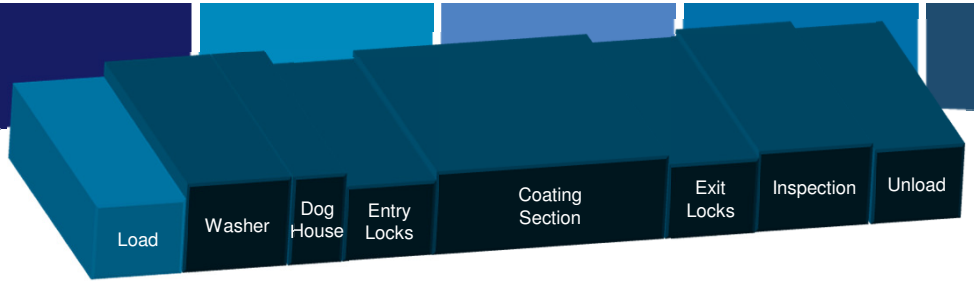
- A Coating Process is everything from putting the glass on the conveyor to getting it back off

Coating Process Block Diagram

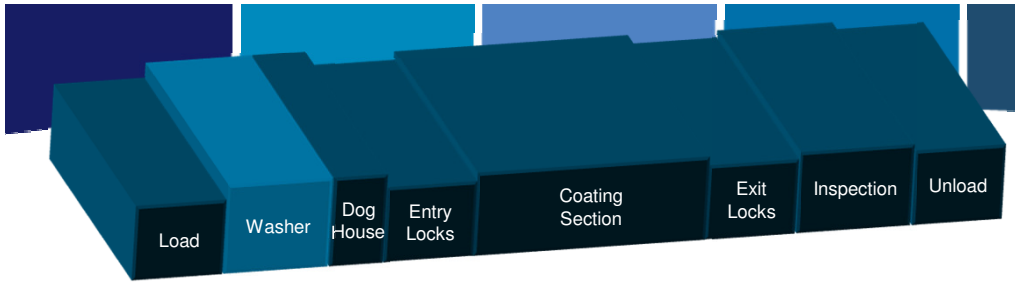




Lehr Freefall


Load
Washer
Dog House
Entry Locks
Coating Section
Exit Locks
Inspection
Unload

Robot Load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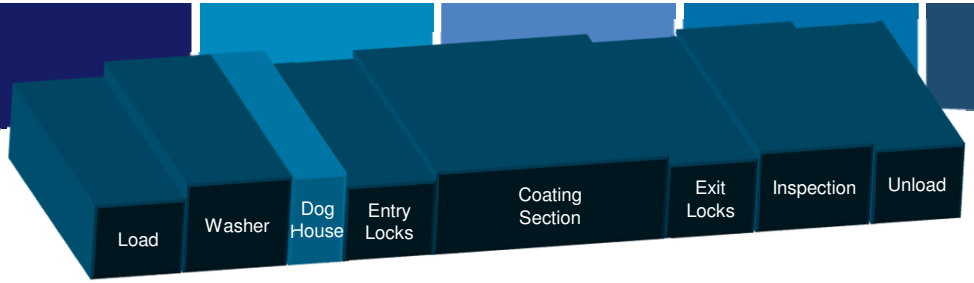
Dog House
Entry Locks
Coating Section
Exit Locks
Inspection
Unload

Washer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Dog House
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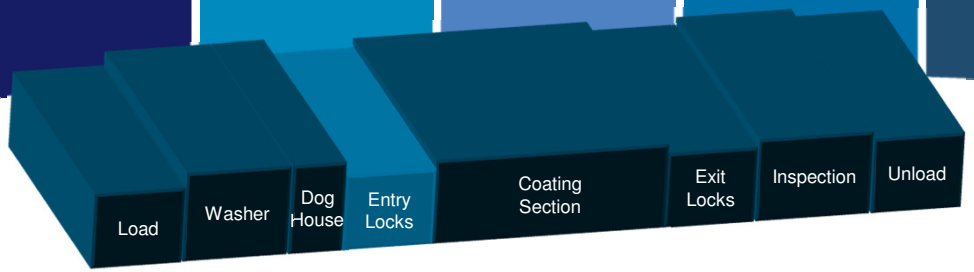
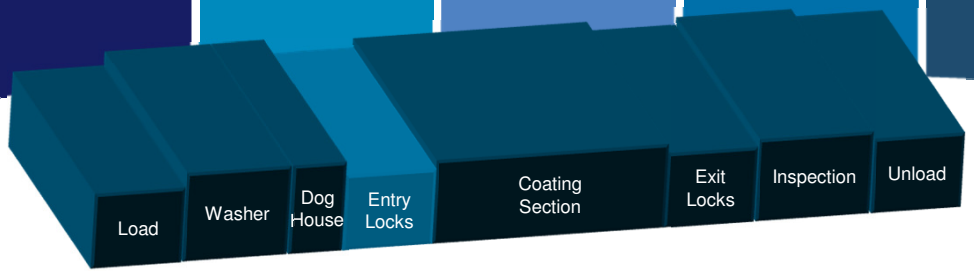
Doghouse



Entry Locks

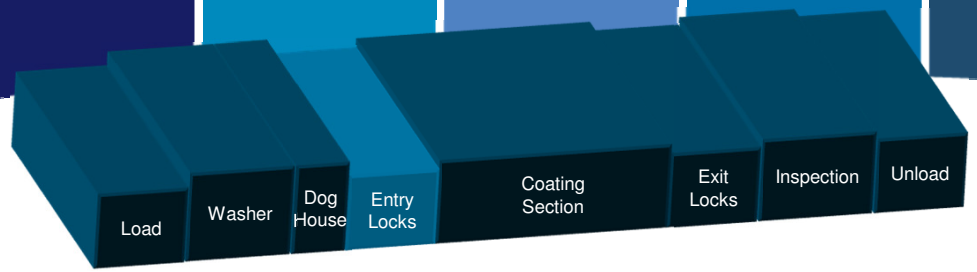
- The entry lock system consists of 3 chambers: Lock, Hold, and Buffer
- This is how we get glass into the vacuum coating chamber



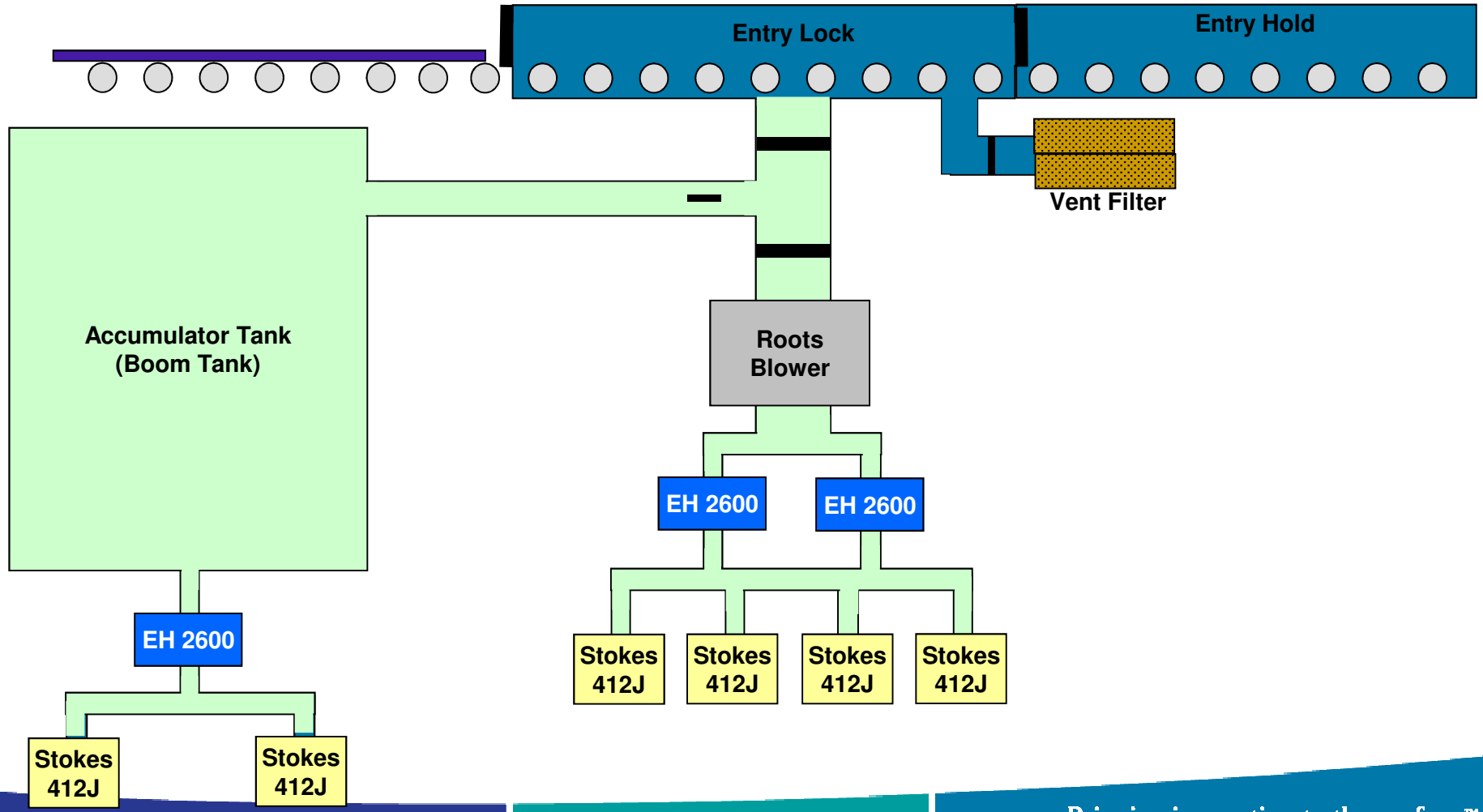
Entry Lock

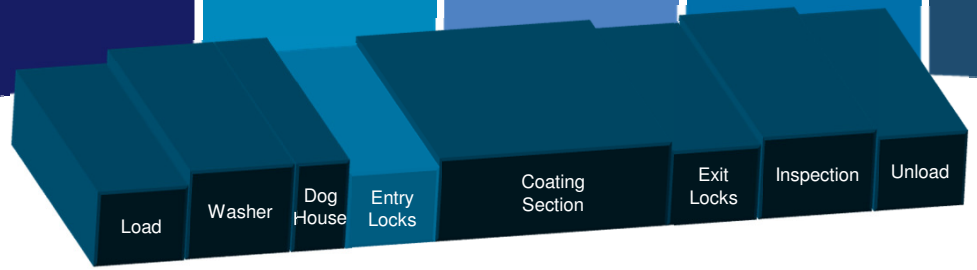
The Lock cycles between atmospheric pressure and vacuum (760 torr to 20 mtorr)

It consists of a chamber with slit valves to hold the vacuum, rolls to transport the glass, pumps to make the vacuum, and vent valves to return to atmospheric pressure

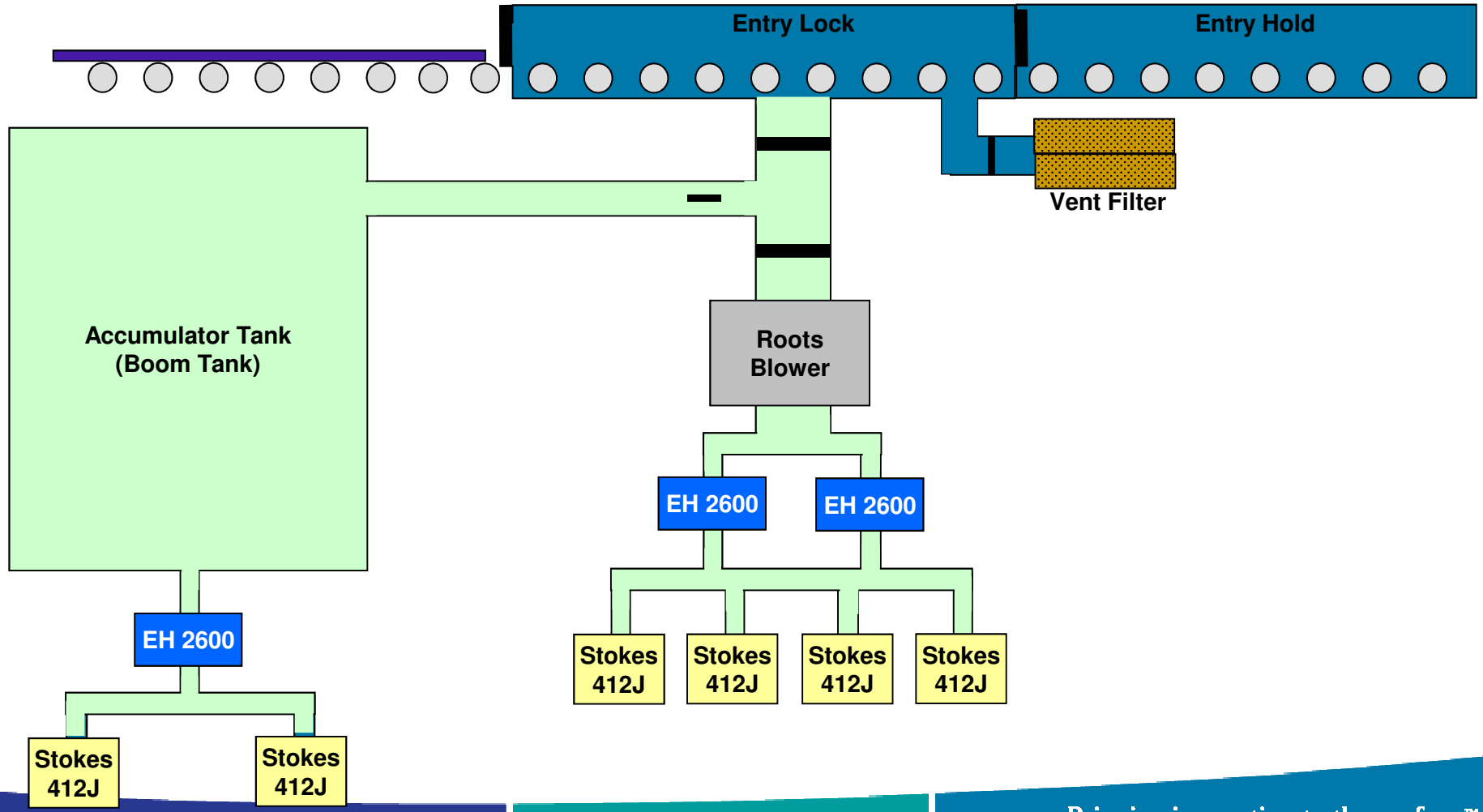


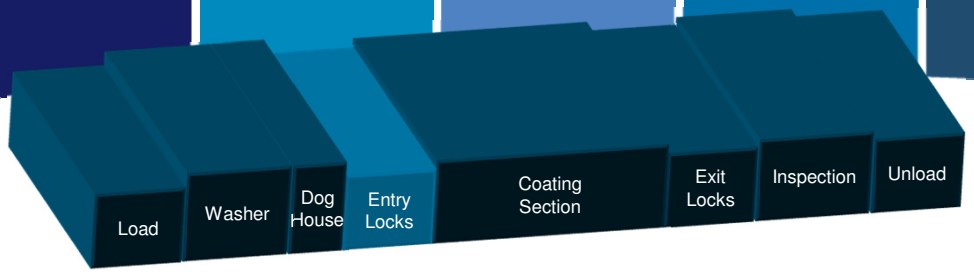
Entry Lock Pump Cycle





Entry Lock Pump Cycle



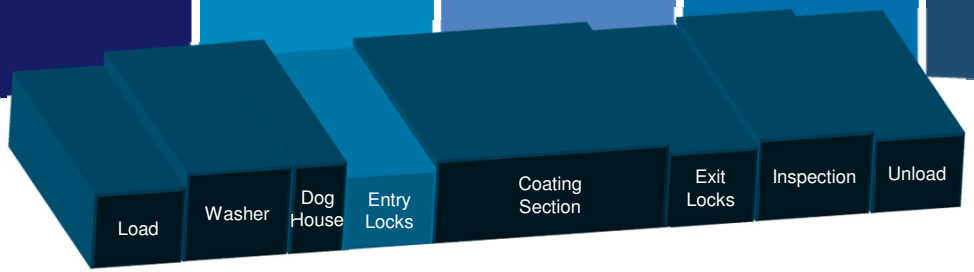


Entry Hold

The Hold is always under vacuum (< 20 mtorr)

It is pumped with diffusion pumps and cryogenic pumps

It is the last point where glass can be stopped before it enters the coating chambers

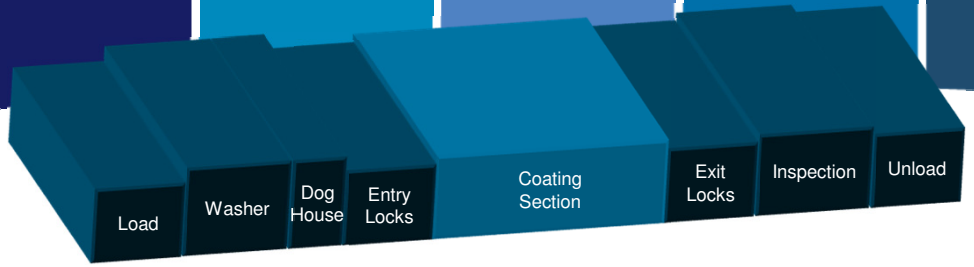


Entry Buffer

The Buffer is always under high vacuum

It is pumped with diffusion pumps

The glass loads are converted from a batch flow (loads) to continuous flow through the coater through the use of the gap reduction rolls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Dog House
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Coating Section
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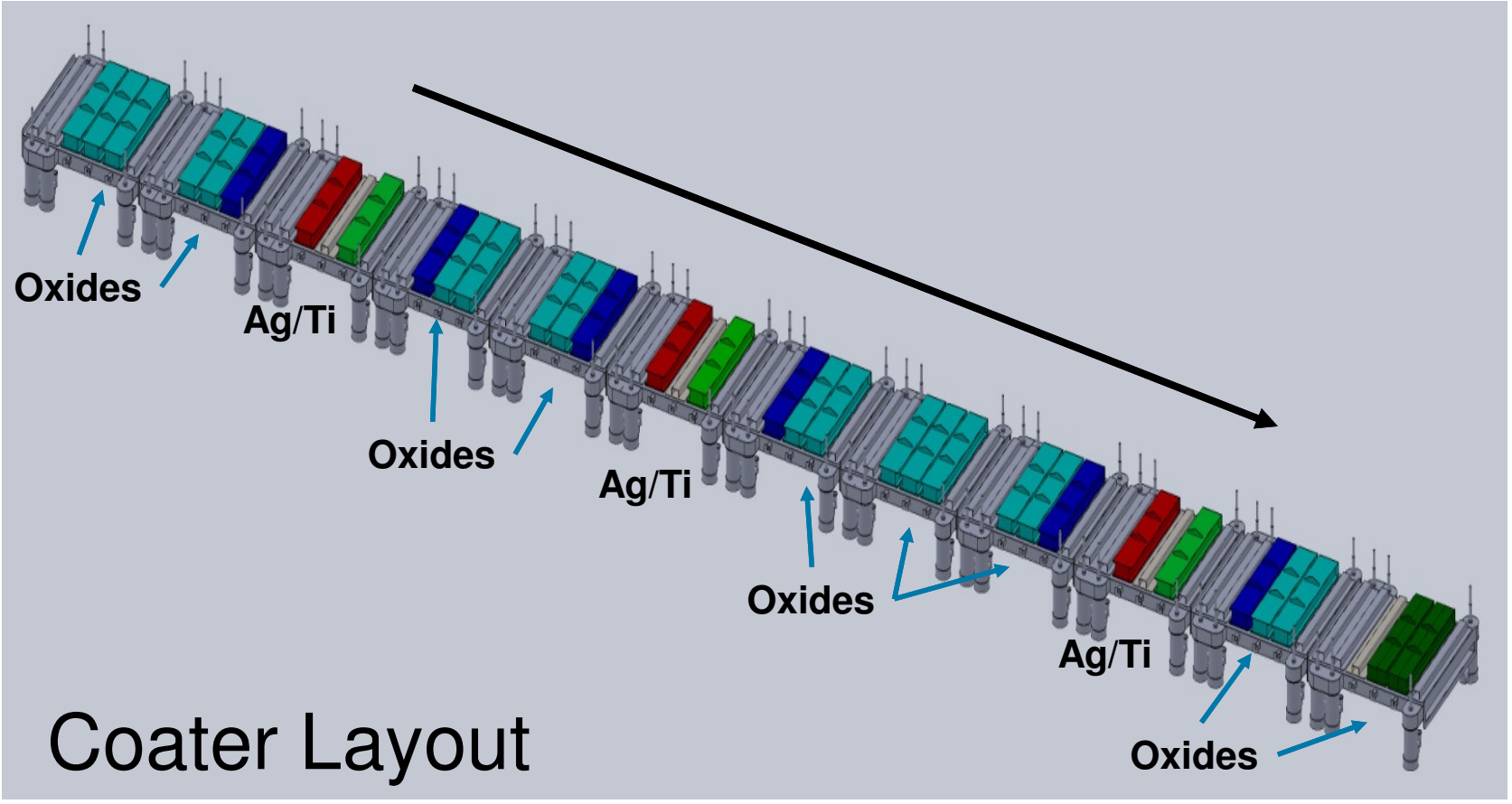
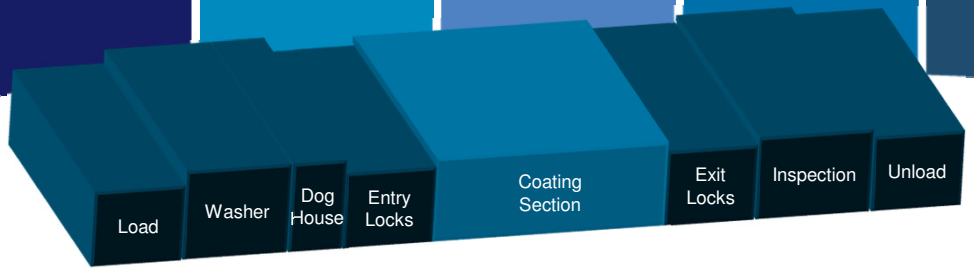
Inspection
Unload

Coat Zones


Oxides
Ag/Ti
Oxides
Ag/Ti
Oxides
Ag/Ti
Oxides
Coater Layout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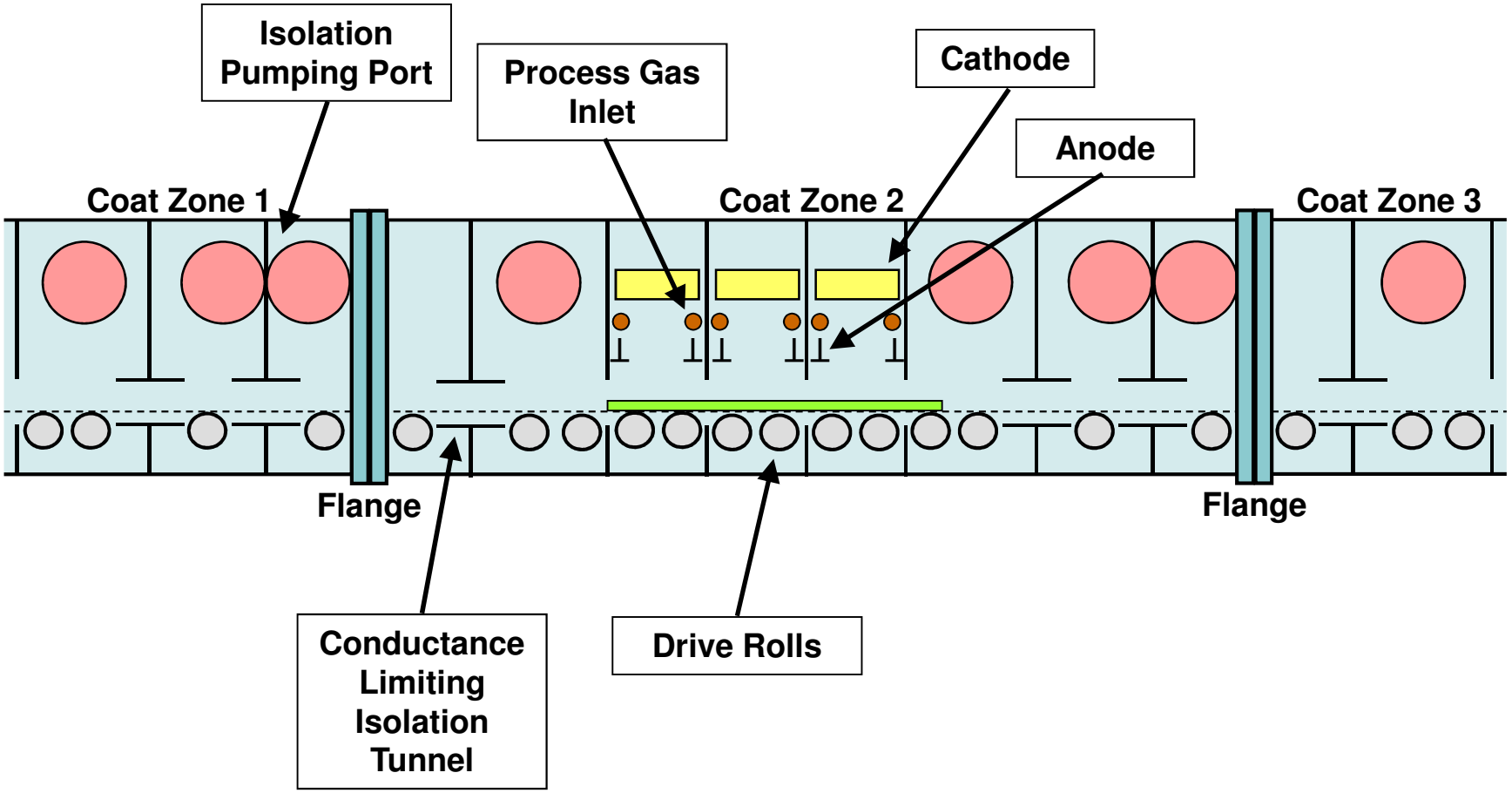
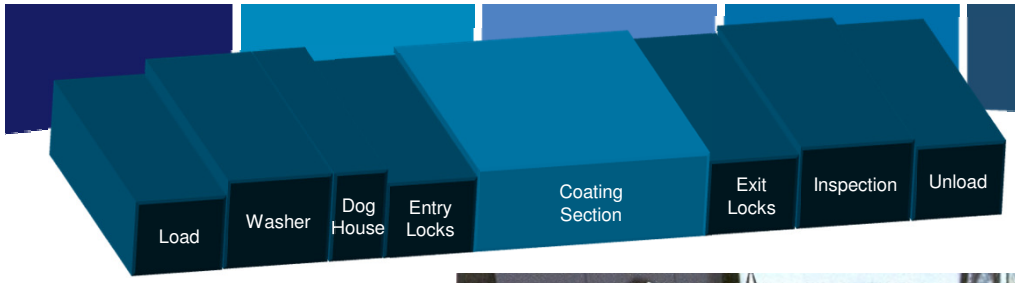

Isolation Pumping Port
Process Gas Inlet
Cathode
Anode
Coat Zone 1
Coat Zone 2
Coat Zone 3
Flange
Flange
Conductance Limiting Isolation Tunnel
Drive Rolls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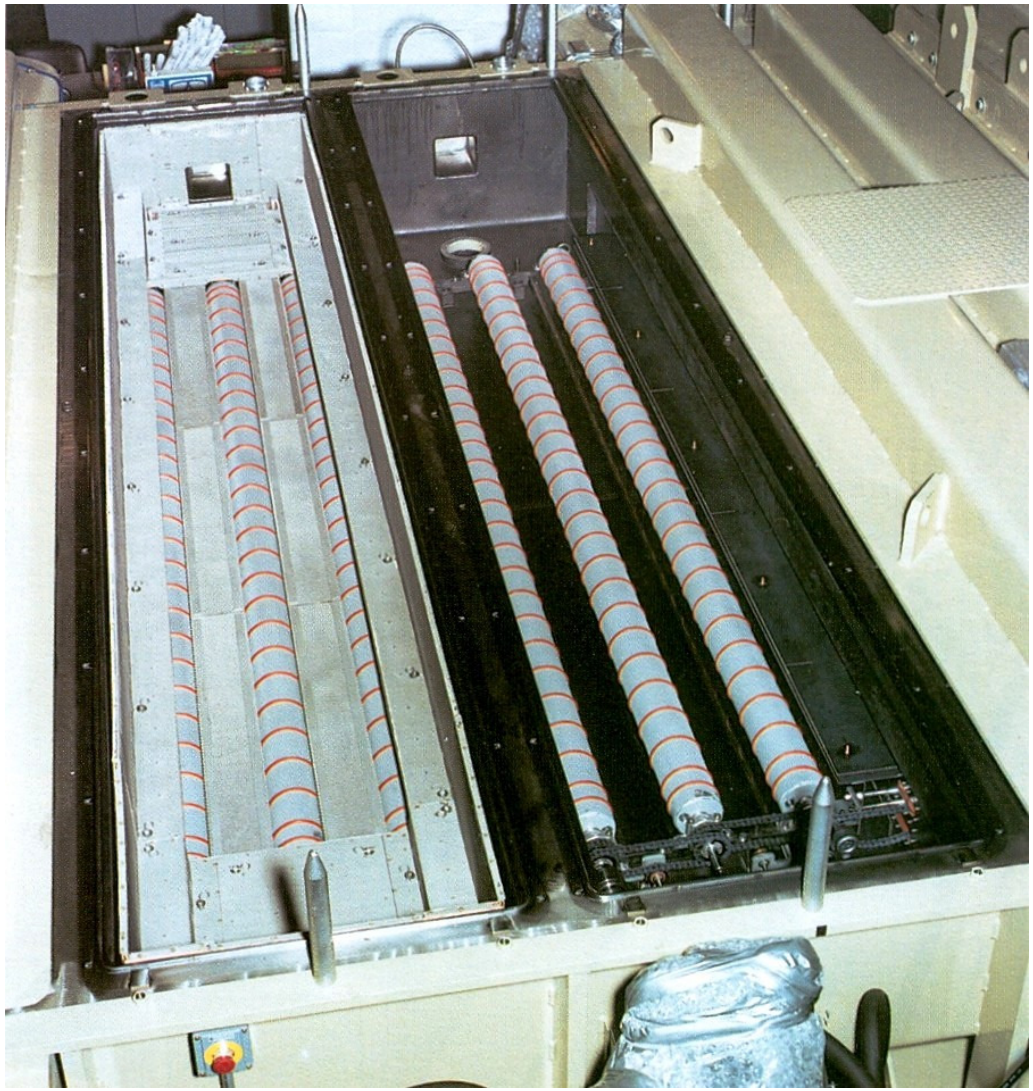

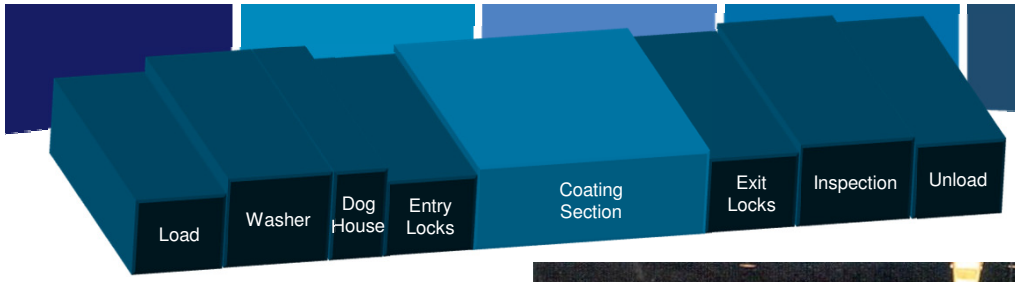
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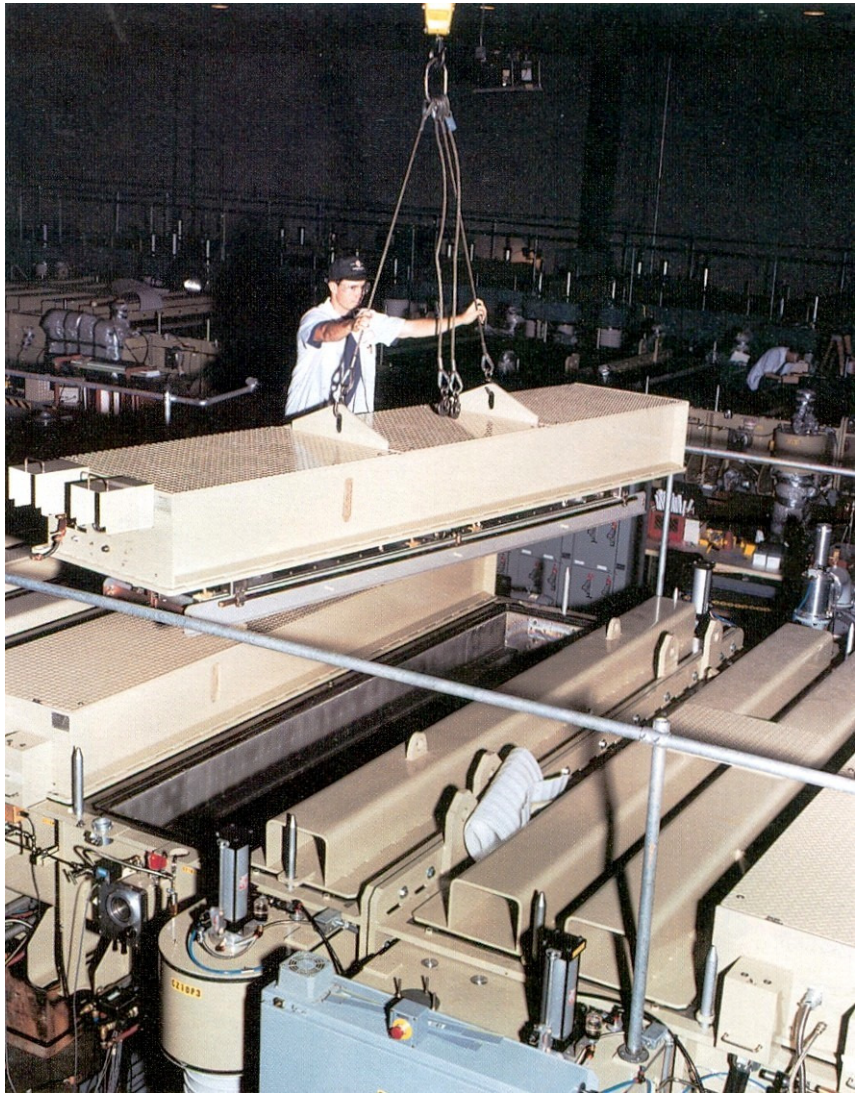
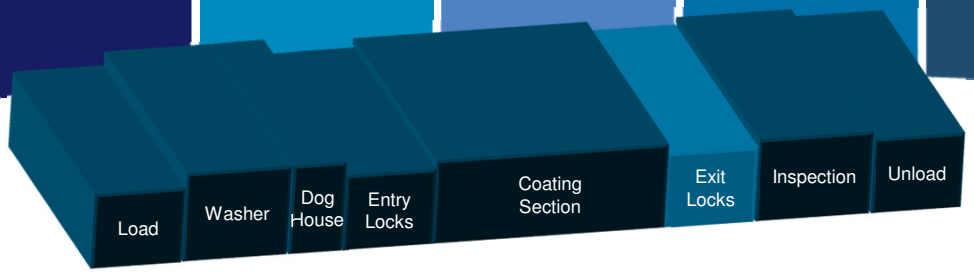
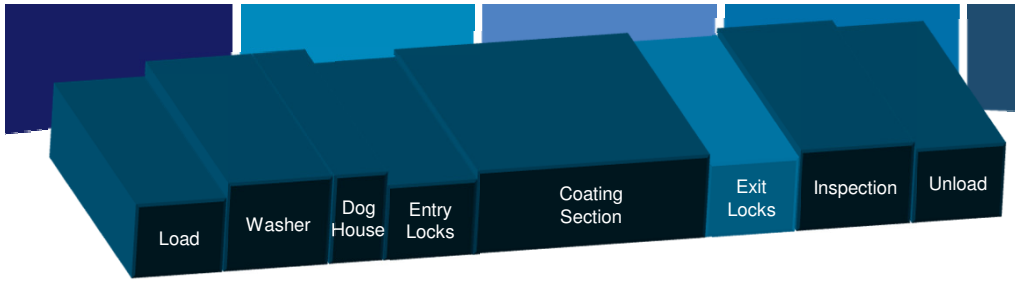




Exit Locks

The exit lock system consists of 3 chambers: Buffer, Hold, and Lock

They compliment the entry lock system and convert the continuous flow of glass into individual loads that can be cycled out of the coater


Load
Washer
Dog House
Entry Locks
Coating Section
Exit Locks
Inspection
Unload

Inspection


DANGER

Quality Control – On Line

- Glass substrate inspected at load station
- All coated glass is visually inspected in an on-line inspection booth for defects and color. Rejects are marked and discarded.

Glass Defects

Edge Damage

Breakage

Stain

Primary Defects

Coating Defects

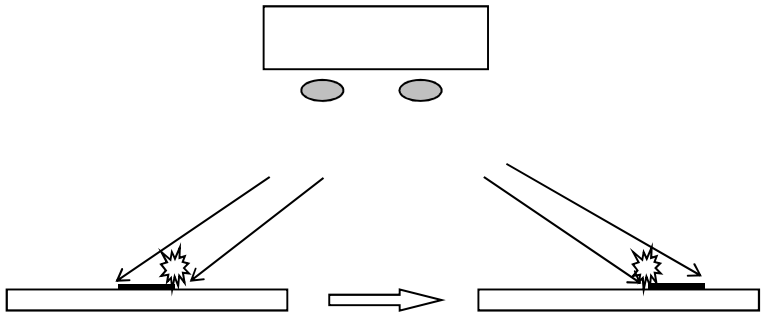
Color Streaks / Bands

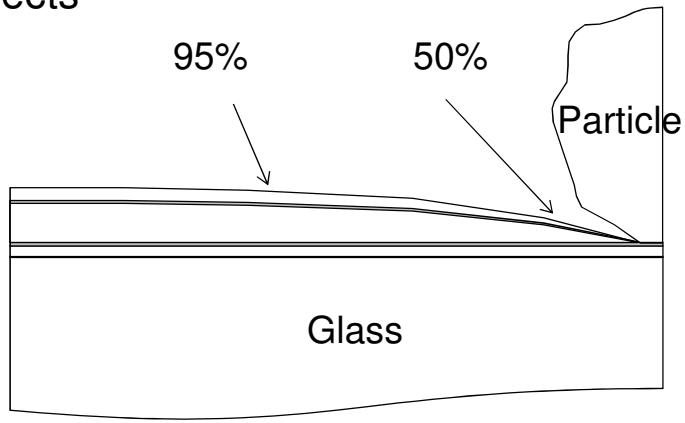
Voids / Pinholes

Arcs / Lightning Tracks

Pinhole Identification In Low-E:

Pinholes can be catalogued to help identify the of source of defects

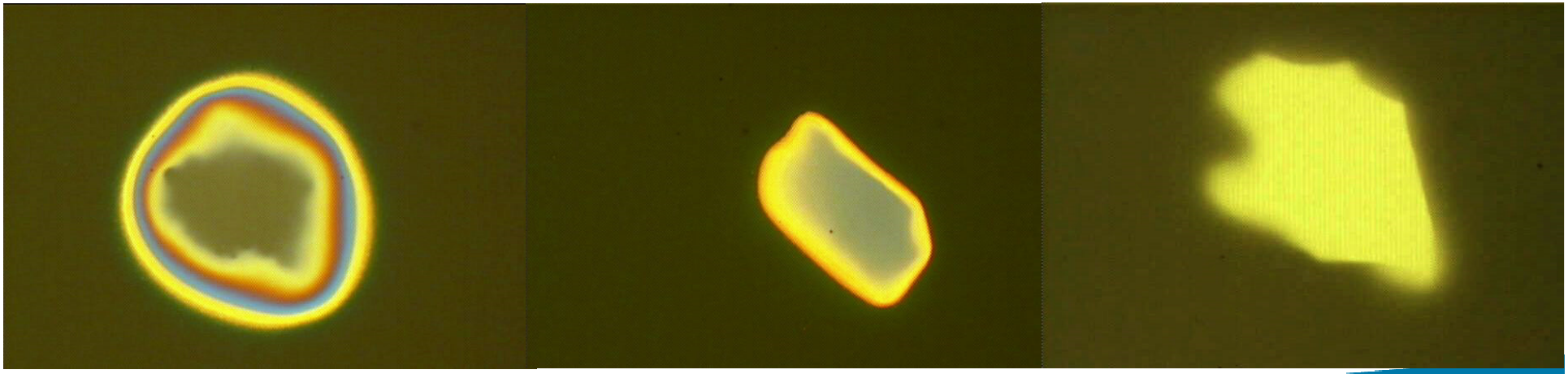




CZ1 base oxide (or before)

CZ6 center oxide

CZ8 Top oxide

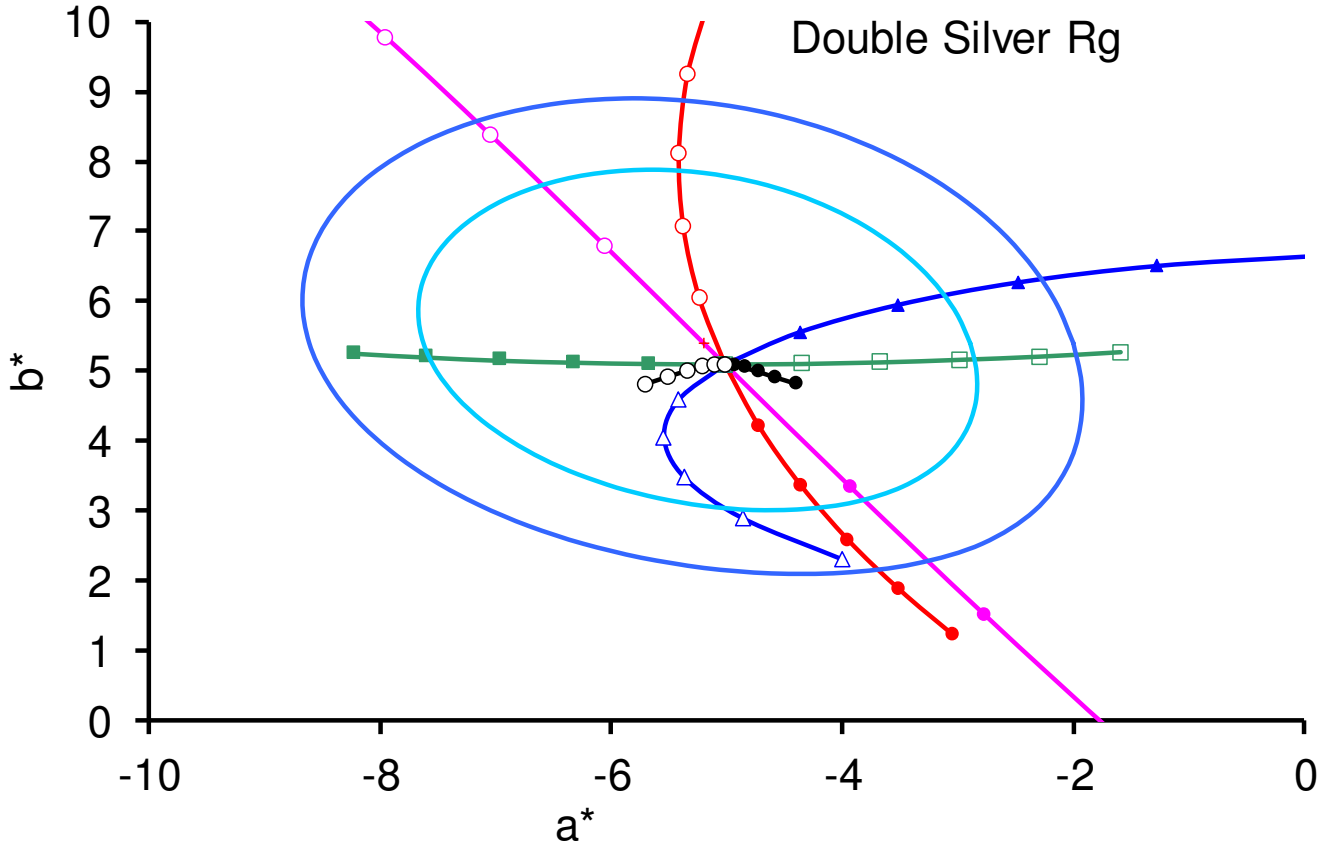


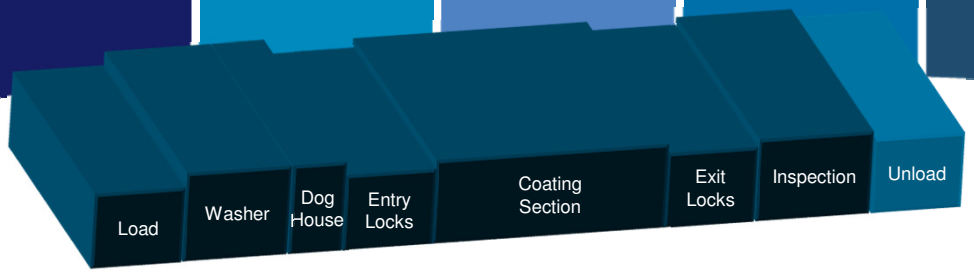
Quality Control – Off Line

- **Coater QC laboratory checks:**
  - Color
  - Light transmission
  - Emissivity
  - Chemical and mechanical durability
- **Checks are made at scheduled intervals and glass is released only if all requirements are met.**
- **All instruments are calibrated.**

Color Control

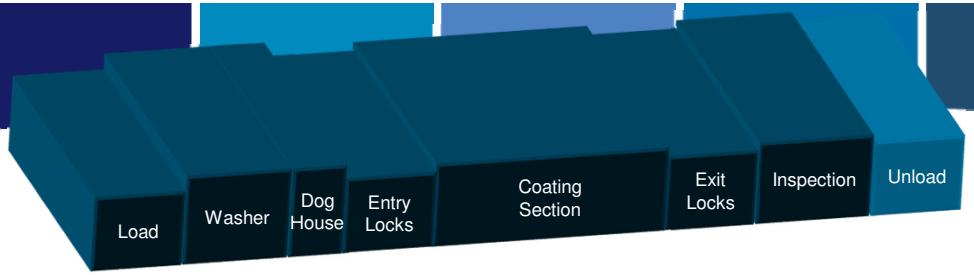
- "Spider Diagrams" - effect of variation of the coating layers on color.
- Originally determined by experiment





Interleaving

Small Plastic beads are applied to keep the glass from sticking together after it is packed



Unload or Pack End

Product Packaging

- **Maintain Superior Product Quality, and Provide a Safe, Efficient, Container for Shipment.**
- **Reasonable Protection of Coated Glass from Mechanical and Chemical Damage.**
- **Labeling:**
  - Product Label
  - Direction of Coated Surface
  - Finished Stock Ticket
  - Glass *Handle with Care*

Questions

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