Overview of Magnetron Sputtering System (DaON 1000S)

by

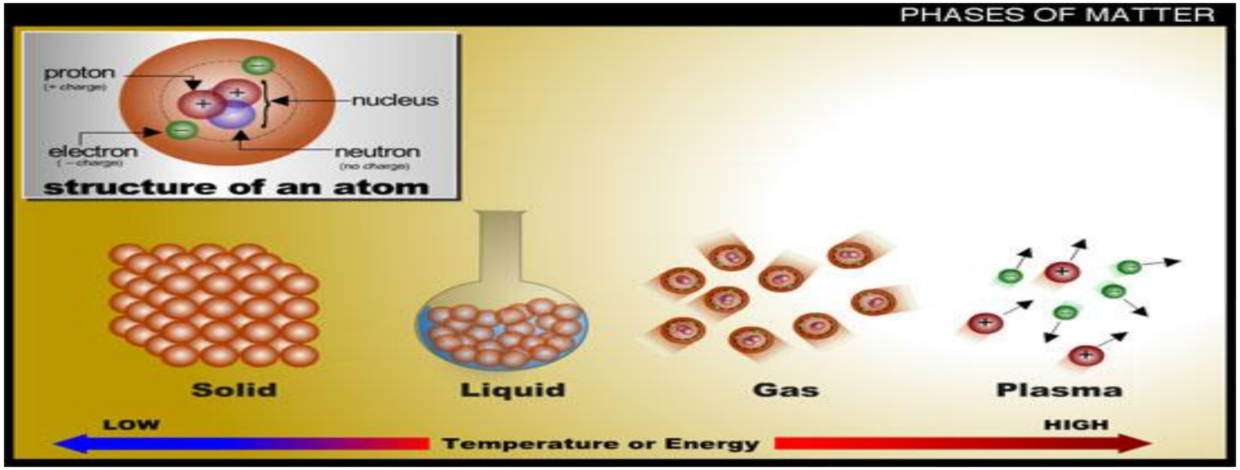
Murtaza Saleem

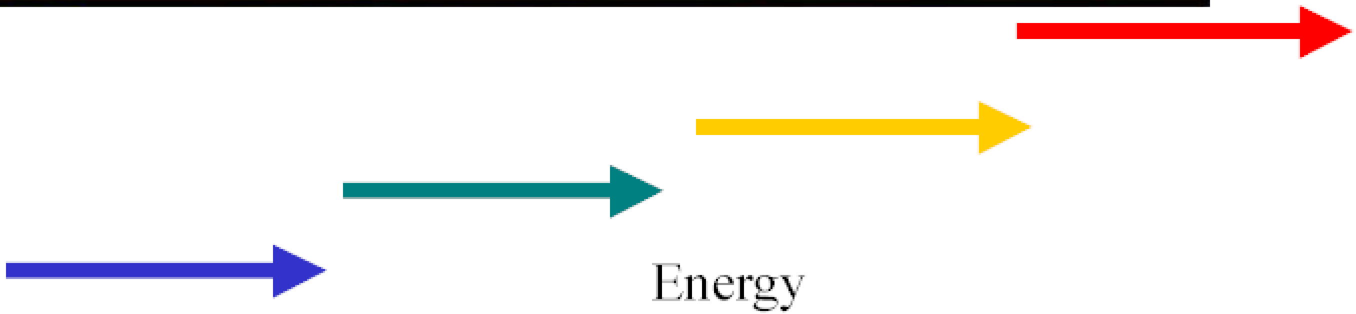
Contents

- Plasma, plasma regimes and processing
- Sputtering, sputter parameters, sputter yield
- Advantages and applications of sputtering
- Types of sputtering
- Magnetron Sputtering
- Operational overview of Daon1000S
- Precautions and safety measurements
- Vacuum system
- Target and substrate modules
- Remarks

What is a Plasma?

- States of Matter (Ancient View)
  - Earth, Water, Wind, Fire
- States of Matter (Modern View)
  - Solid, Liquid, Gas, Plasma

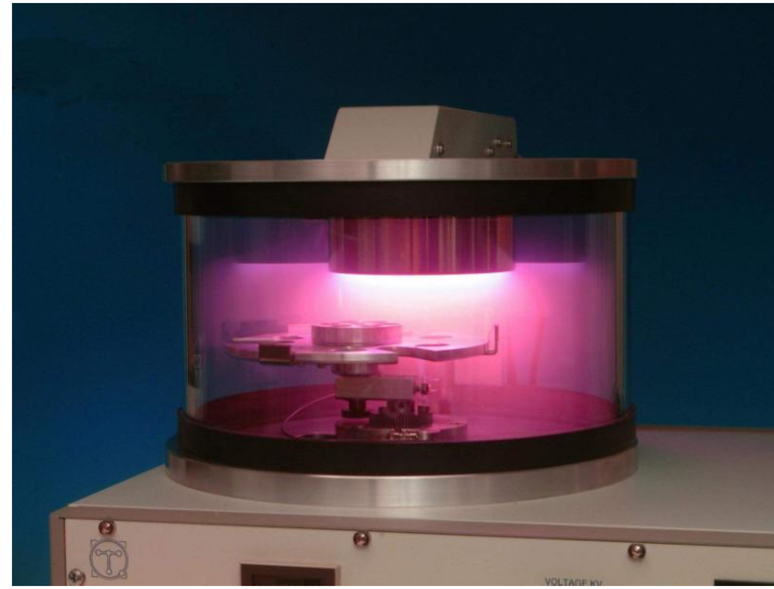




Plasma

Create plasma:

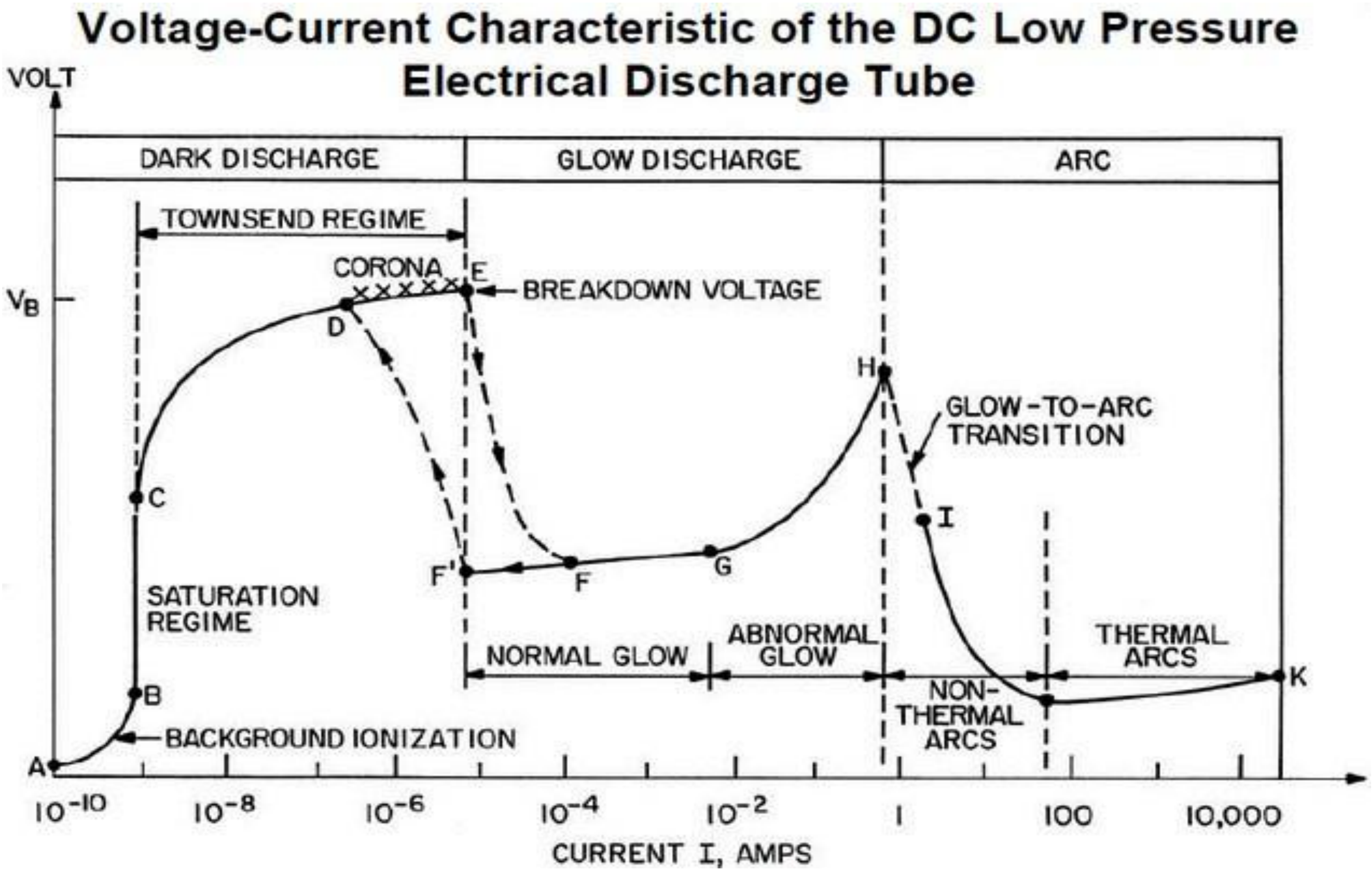
- Discharge from capacitor
  - High voltage > breakdown voltage of gas
- Sufficient acceleration gives energy to ionize the gas (Ar)
  - $e^- + Ar = 2e^- + Ar^+$

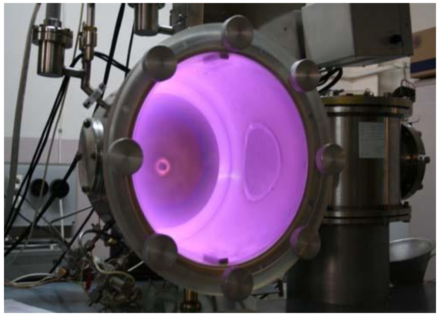


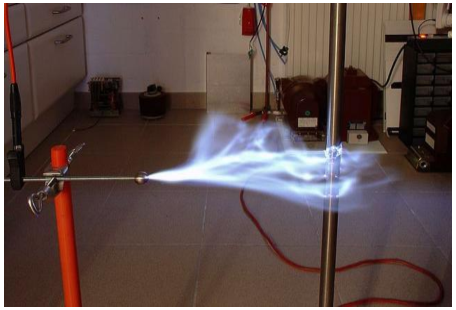
- Ar ions are accelerated towards the target for sputtering
  - Release of secondary electrons
- Sufficiently low pressure
  - So electrons achieve necessary energy before collisions
  - *Too* low pressure gives too few collisions to sustain the plasma

The glow comes from de-excitation of atoms after collision with electrons that has too low energy for complete ionization

Different plasma discharge regimes



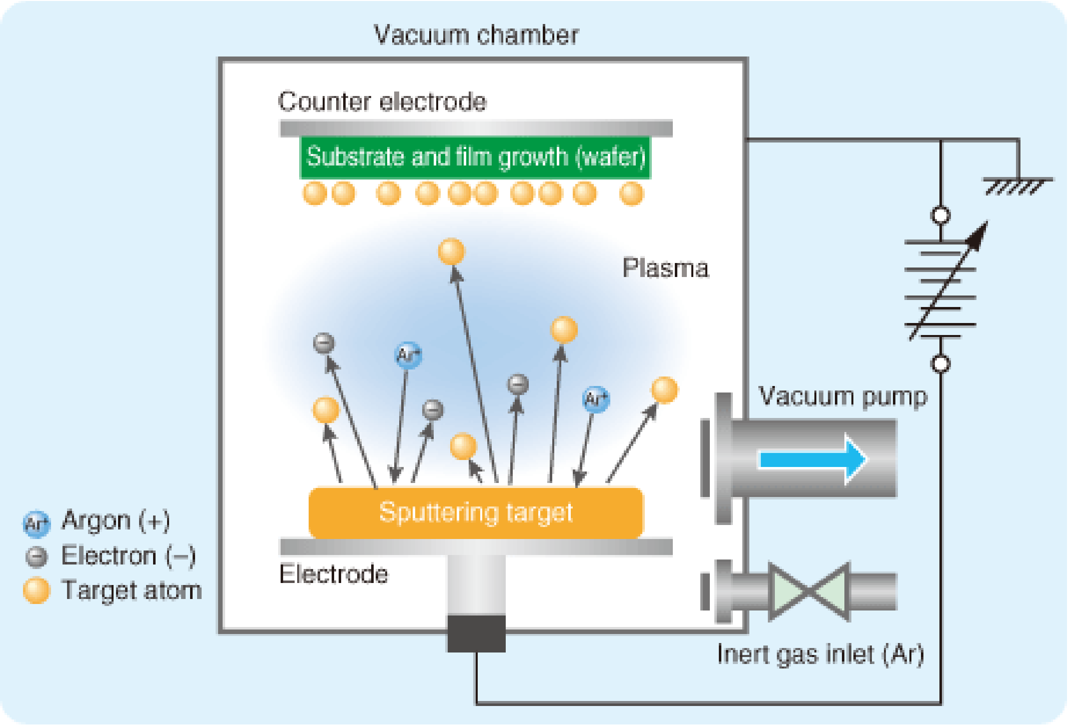


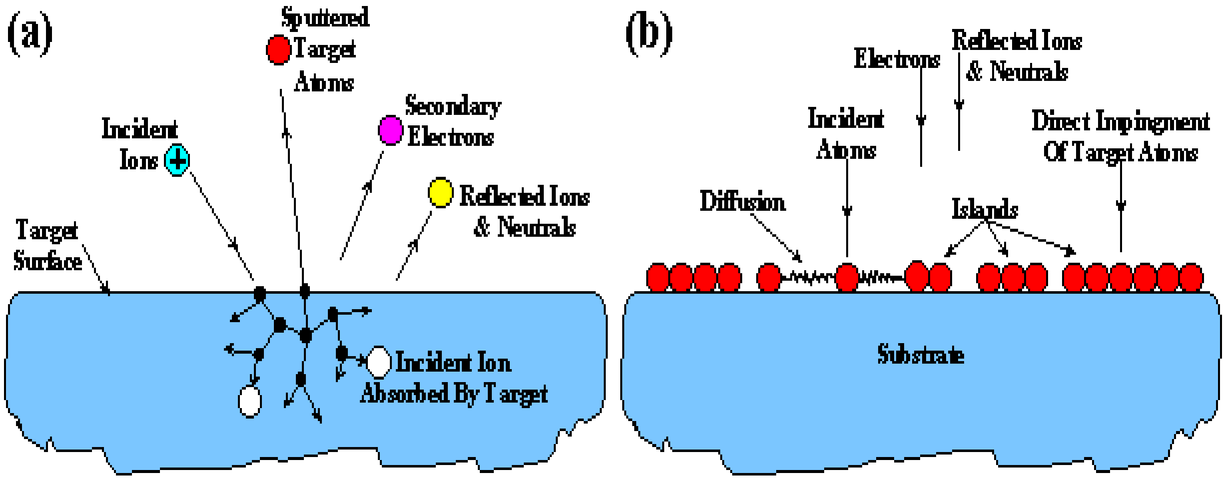


Sputter deposition setup

Steps of the sputtering process

- Plasma provides ions
- Ions accelerated in electric field between target (cathode) and substrate (anode)
- Sputtering of target
- Transport of sputtered material
- Adsorption to substrate
- Surface diffusion
- Nucleation and film formation

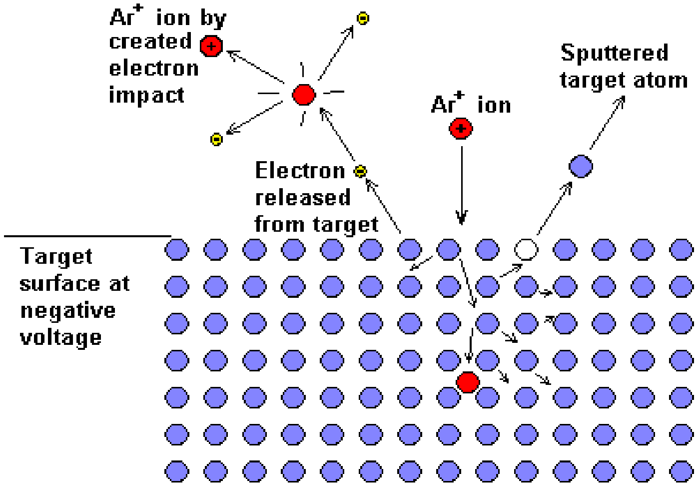




Ion interaction with target

Increasing ion energy

E<10eV	Adsorption, bouncing off surface, or surface damage
10eV-5keV	Sputtering
E > 5keV	Ion implantation



At sputtering energies

- Nuclear stopping is effective
- Interaction with top layers

Sputtered atoms typically have 10-50eV of kinetic energy

- Two orders of magnitude larger than for evaporation
- This leads to better surface mobility when the atoms reach the substrate

Elastic collision: Conservation of momentum and kinetic energy

- A qualitative view of sputtering can be achieved by considering an elastic model
- But for a thorough analysis one need to consider the coupled effect of bond breaking and physical displacement

Sputtering parameters

- Deposition rate (Å/sec, micron/min)
- Substrate temperature
- Gas pressure/plasma type (DC, RF, microwave, hot filament)
- Target/substrate geometry, relative motion (uniformity)
- Distance between target and substrate

Sputter yield

Depend on

- Ion and target atomic mass
- Ion energy
- Target crystallinity
- Angle of incidence

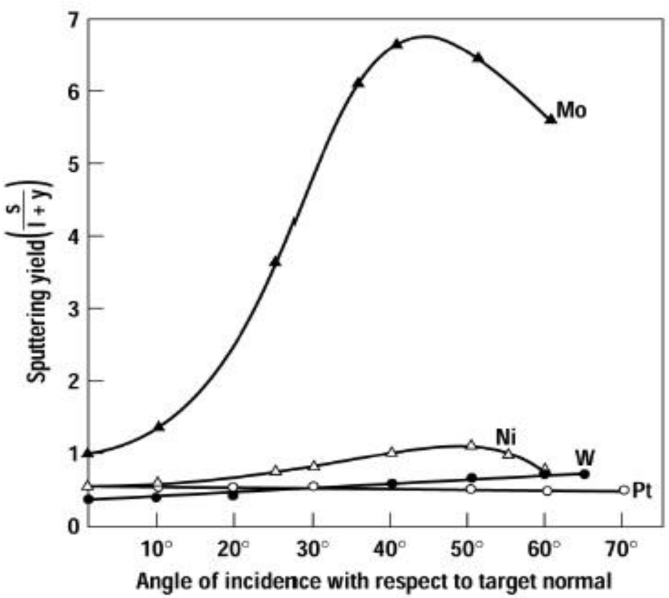


Figure 12.15 Typical angular dependence of the sputter yield for several different materials. The sputter profiles follow a cosine distribution *(after Wehner, reprinted by permission, AIP).*

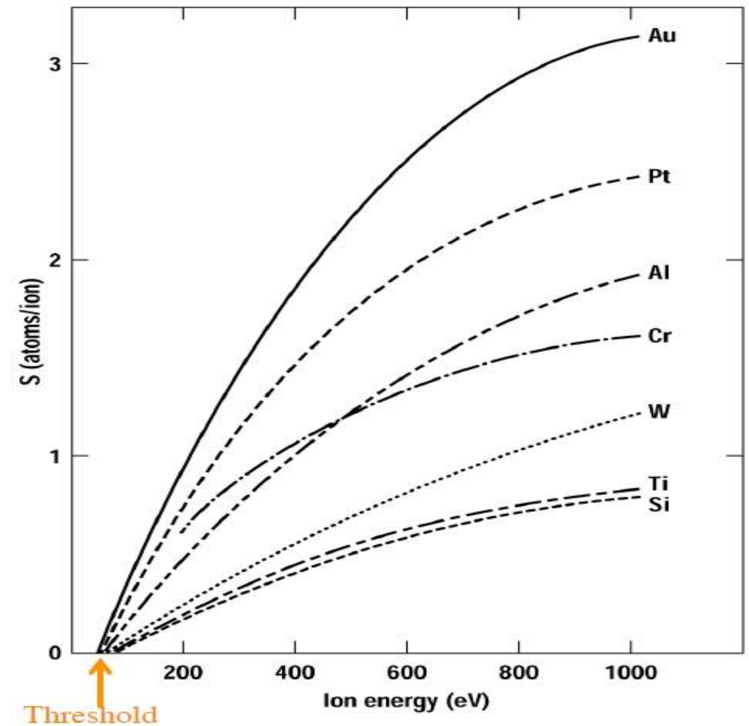


Figure 12.13 Sputter yield as a function of ion energy for normal incidence argon ions for a variety of materials *(after Anderson and Bay, reprinted by permission).*

$$S = \frac{number\ of\ sputtered\ atoms}{number\ of\ incident\ ions}$$

Stoichiometry and step coverage

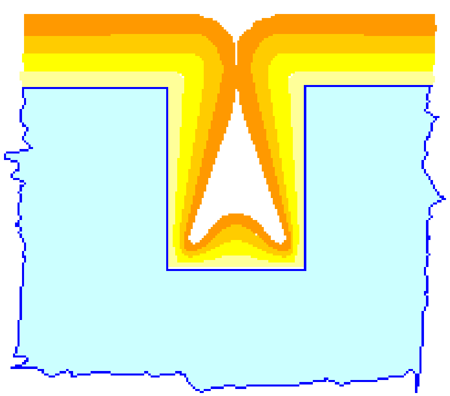
Deposited stoichiometry depend on differences in thermalisation in the plasma

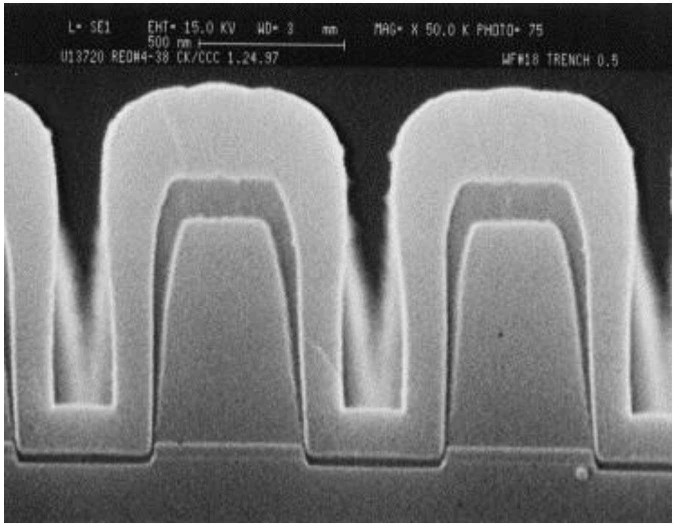
- Multiple targets
- Different areas on target
- Use target composition to yield the wanted film composition

Base pressure is also important for the film quality, as contamination by N and O can affect the reflectivity of the film.

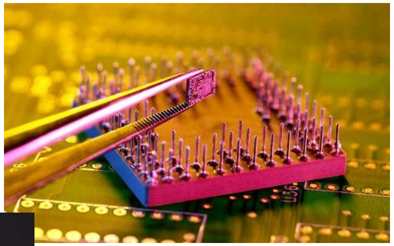
Step coverage improvement by:

- Heating
  - Diffusion
- Biasing
  - Resputtering

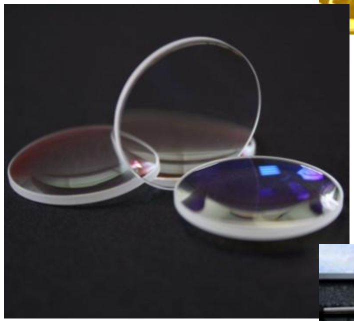




Advantages of sputter deposition

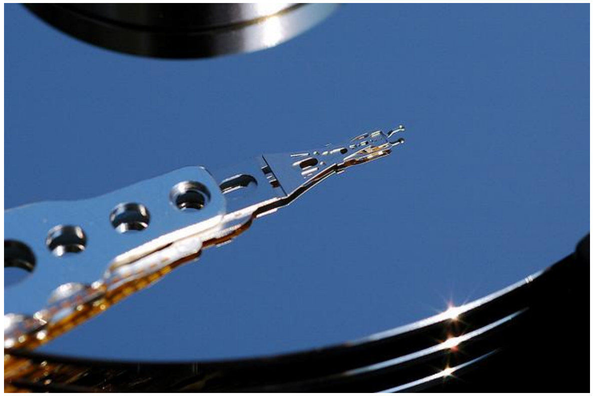


- Low substrate temperature
- High melting point materials can be deposited



- Good adhesion
- Good step coverage compared to evaporation

- Less radiation damage than e-beam evaporation
- Well suited for alloys and compounds



- Versatility and scalability

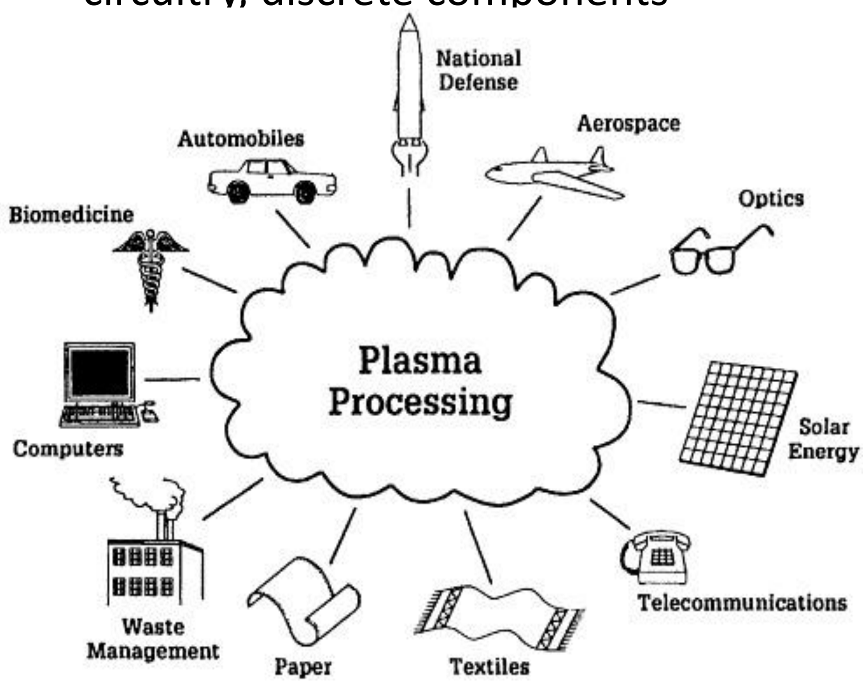
Application examples of sputtering

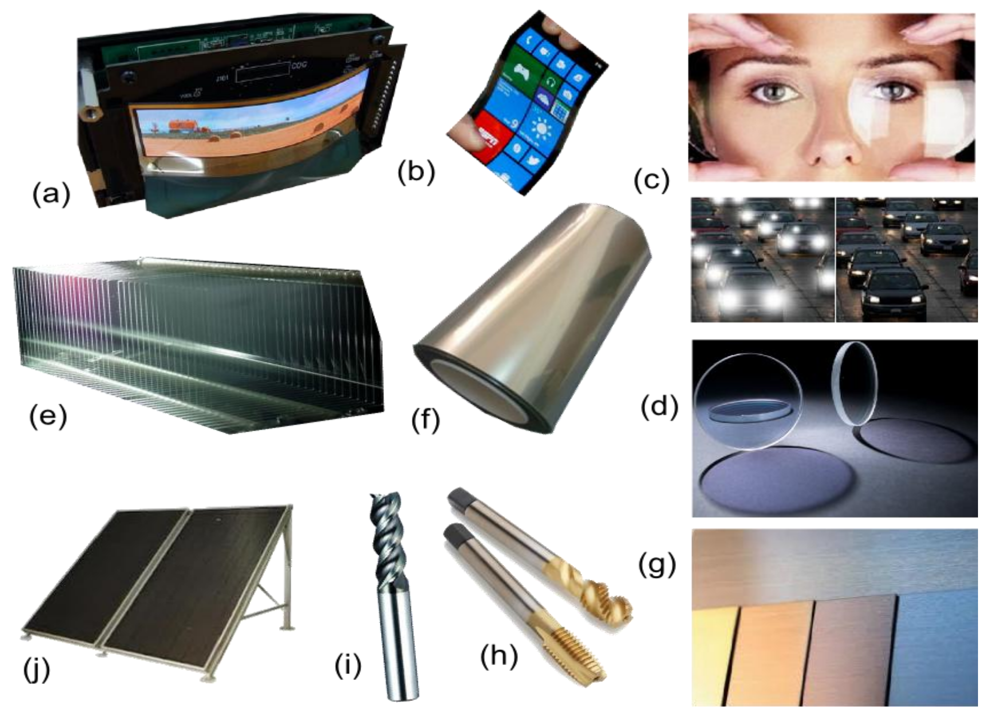
- Developed in last 30yrs into a sophisticated coating tool

- Optical-interference filters and protective coatings for lenses, mirrors, transparent conductive coatings (ITO), for displays, heat filters for architectural glass

- Mechanical -hard coatings for tools, low friction coatings for bearing surfaces, anti-corrosion coatings in aircraft industry

- Electronics - especially semiconducting industry, metallisation, barrier layers, display circuitry, discrete components





Types of sputtering systems

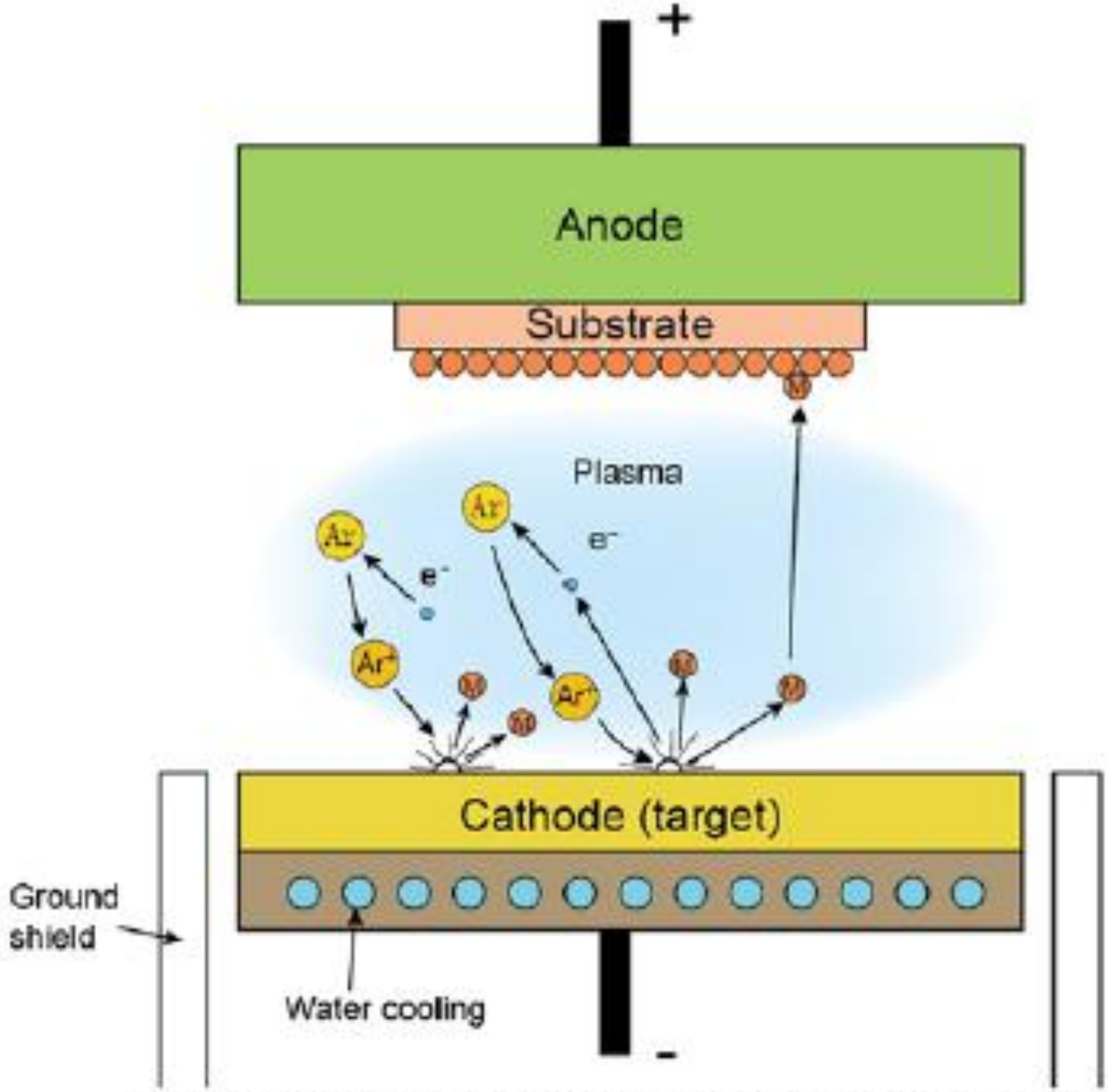
- **Diode** (1960s, slow, rather high pressure [~0.1mb],
secondary electrons at substrate, tendency to arc, conducting targets only)

- **R.F.** (60s,70s, good for insulators, slow,
lower pressure than diode, [~0.005 mb], secondary electrons at substrate)

- **Magnetron (DC and RF)** (late 70s, 80s)
(the modern system, fast [minimising contamination], low pressure [minimal pump throttling needed hence improved pumping of contaminants],
no secondaries to heat substrate)

- **Ion beam** (for ultra-clean work, research, slow,)

- **Hybrids** (all types of combination system,
may include evaporation, microwave sources etc.)



In a DC diode sputtering system, Argon is ionized by a strong potential difference, and these ions are accelerated to a target. After impact, target atoms are released and travel to the substrate, where they form layers of atoms in the thin-film

Problems with DC sputtering

•Relatively high pressure overloads pumps, means contamination, lack of control over process.

•Bombardment of substrate by energetic neutrals and -ve ions (contamination)

•Bombardment of substrate by energetic secondary electrons (heating)

•Cannot be used with insulating targets; arcing by surface charging

•Low deposition rate (increases contamination)

Alternatives to DC Sputtering

- Reduce working pressure (increase plasma density for a given working pressure), by additional excitation:

1. R.F. (13.56MHz)

2. External magnetic coils.

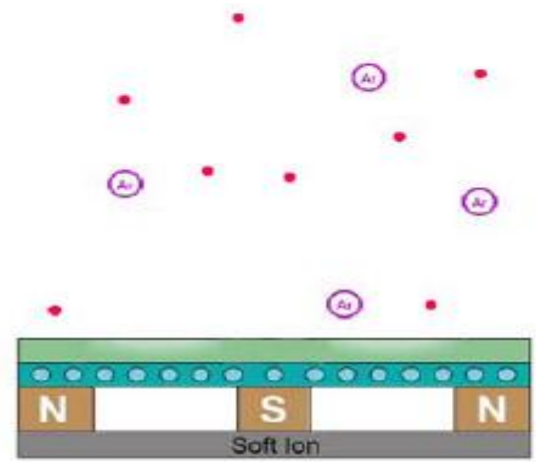
3. Use an ion beam system in UHV (very slow)

4. Magnetron sputtering - has become the industry norm.

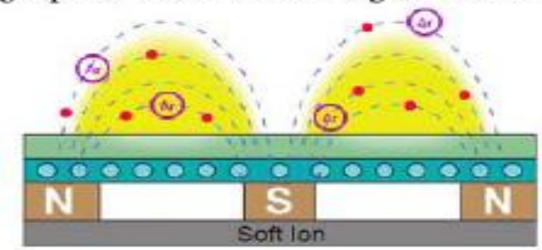
Magnetron sputtering

- Here magnets are used to increase the percentage of electrons that take part in ionization events, increase probability of electrons striking Ar, increase electron path length, so the ionization efficiency is increased significantly.

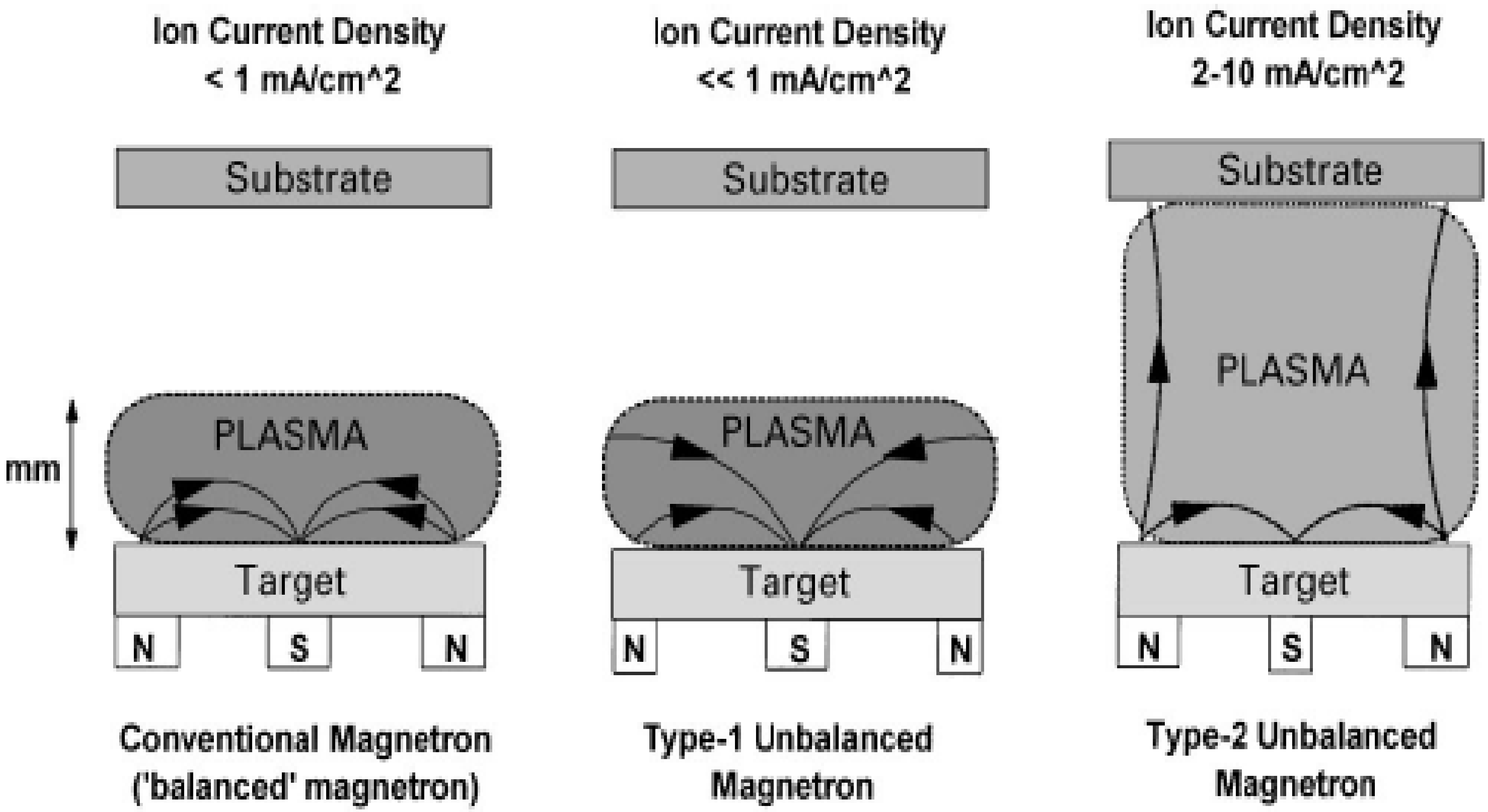
- Another reasons to use magnets:
  - Lower voltage needed to strike plasma.
  - Controls uniformity.
  - Reduce wafer heating from electron bombardment.
  - Increased deposition rate
  - Good control over reactive sputtering



In a non-magnetron sputtering system, the plasma is not confined, and electrons and Argon ions propagate through space, sometimes colliding with the substrate.



In a magnetron sputtering system, the plasma is confined to an area where the magnetic field is strong. The nearness of the plasma to the target causes faster deposition rates, greater Argon ion replenishment, and less substrate damage from stray particles.



Schematic representation of the plasma confinement observed in conventional and unbalanced magnetrons.

Things affect film structure

- Things that control grain structure are:
  - Substrate
  - Base pressure (or contamination level)
  - Deposition temperature
  - Deposition rate
  - Later processing temperature
  - Process pressure (#collisions)

Sputtering – thin film properties affected

- Stress
- Crystallinity/amorphousness
- Gas and other impurity incorporation
- Density and structure
- Stoichiometry or composition
- Effect of <u>all above</u> on optical, electrical, magnetic or mechanical properties.

Sputtering of compounds

•Compounds of two or more components are possible

Methods

•Several targets (co-sputtering)

•Compound or alloy target

(Note: components sputter at different rates, but an equilibrium will be established after a certain time which results in composition of original target material being deposited as a thin film. The exception is when component is released as a gas (O_2, N_2), and hence depleted from depositing film.)

•Multi-component target (discrete pieces of second material)

Reactive sputtering

- The main problem is **control**:

- The critical reaction occurs at the target surface

- A mixture of argon and reactive gas (O_2, N_2) is used.

- Too much reactive gas, sputter-yield falls, gas build-up uncontrollably and deposited layer is **gas-rich**.

- Too little reactive gas, sputter-yield increases uncontrollably and layer is **metal-rich**

DaON-1000S sputtering system

R&D Sputter system

DaON-1000S is R&D equipment to research characteristics of the thin film and develop devices to be used co-sputtering system for making in-situ multilayer thin films.

Applications

① Magnetic Data storage
- CoRt, FePt, CoCrPt, etc.

② Electronics & Semiconductor
- Ag. Al, Au, Cr, Ni, Pd, etc.

③ Display
- LCD(TFT & color filter)
- PDP(PDP-filter)
- OLED, Touch Panel, Electric Paper

④ Glass
- Architectural Glass
- Automotive glass
- Anti-reflective and Antistatic coatings

⑤ Photovoltaic
- CIGS, Si based thin films, CdTe wafer based cells

Fig. DaON-1000S

Major Specification

1. Process Chamber

Base Pressure	5 x 10^{-6} Torr
Material	SUS304
Type	"D" Shape Chamber
Dimension (mm)	W450 x D450 x H450
	Chamber wall water cooling
Top & bottom Port	ISO250
Pumping Port	ISO200
View Port	ISO80
Extra Port	2.75" CF

2. Pumping Unit

Rotary Pump	Woosung vacuum/ MVP36 3Ph 60Hz(600lpm)
Turbo Molecular Pump	OSAKA TG11000FBWB, Port : ISO200

3. Heater Module

Position	Top of Process Chamber
Lamp	110V, 210mm x 3ea
Temperature Control	PID with thermocouple/Max 650℃ heating

4. Substrate Module

Sample Size	2" wafer
Rotation	0~20 rpm (DC gear motor)

5. RF Magnetron Sputter

2" three magnetron sputter cathode mount

6. Gas Supply Unit

Gas	Ar : 100sccm, N_2 : 100sccm, O_2 : 100sccm
Valve	1/4" Diaphragm Valve
Throttle V/V	CDG linked position control

7. Pressure Measurement

Low vacuum	APG100-XM (Edward)
High vacuum	AIM-S-NW25 (Edward)
Absolute gauge	BARATRON 626B(MKS, 1 Torr)

8. System Frame

Size (mm)	W1,300 x D800 x H1,800

Safety measurements

1. Electric shock
   1) Power breaker off, before maintenance
   2) Do not touch power connector
   3) Do not step on cable

2. Burn scald
   1) Rotary pump is hot
   2) TMP surface is hot
   3) Substrate is hot

1. Sputter machine check

(1) Check list

1) Account for check list

Before sample loading, every times.
Feel sound, temperature.

2) Utility

ⓐ Electricity : 220 V, A
ⓑ PCW (Process cooling water) :
ⓒ CDA (Compressed dry air) :

3) Gun

ⓐ Target state
ⓑ Gun insulation
ⓒ Shield particle
ⓓ Gun shutter moving

4) Rotary vane pump

ⓐ Volume of oil
ⓑ Color of oil

5) Turbo molecular pump

ⓐ Water leak
ⓑ Sound of moving

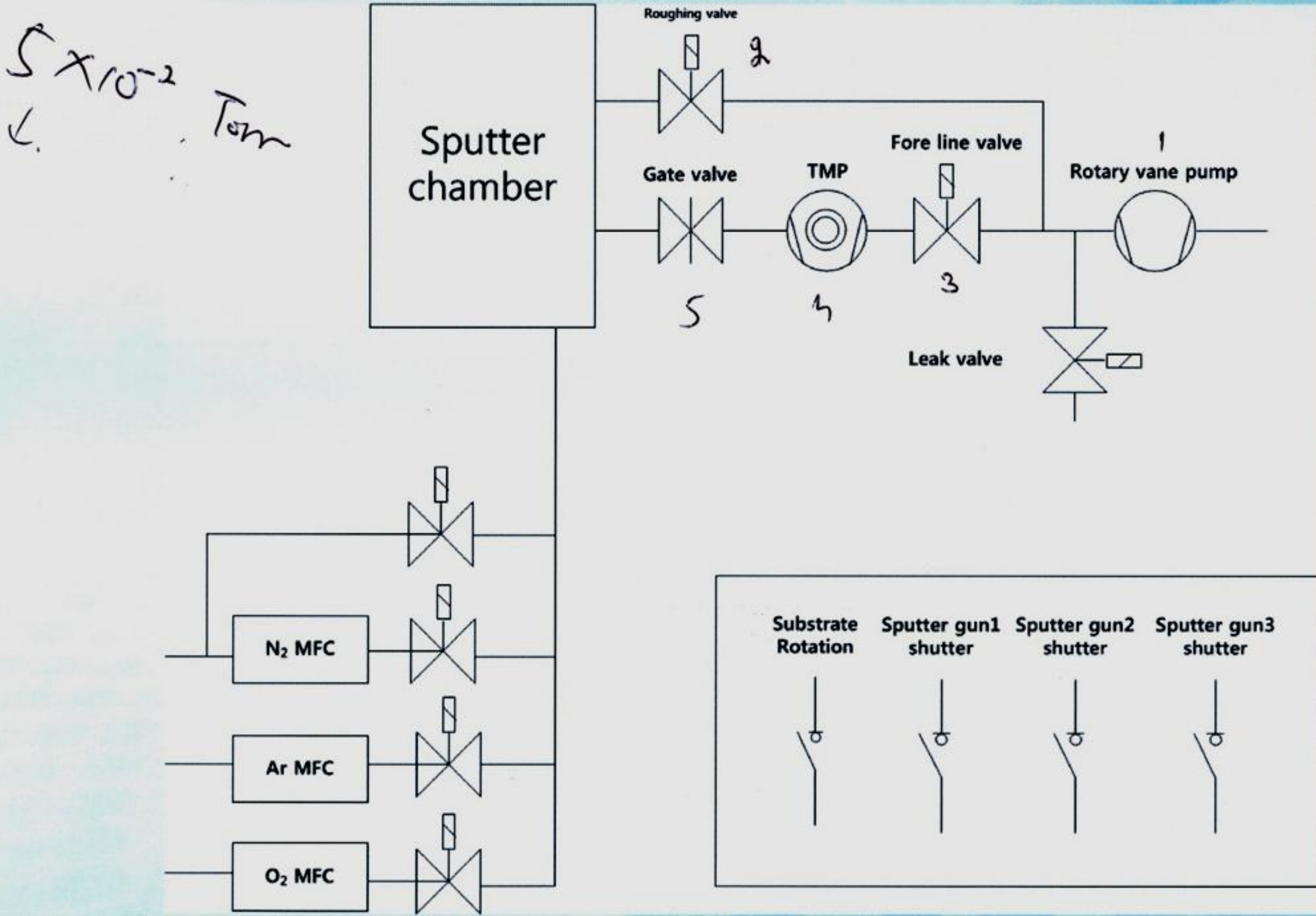
6) Process gas

ⓐ Residual pressure
ⓑ Supply pressure

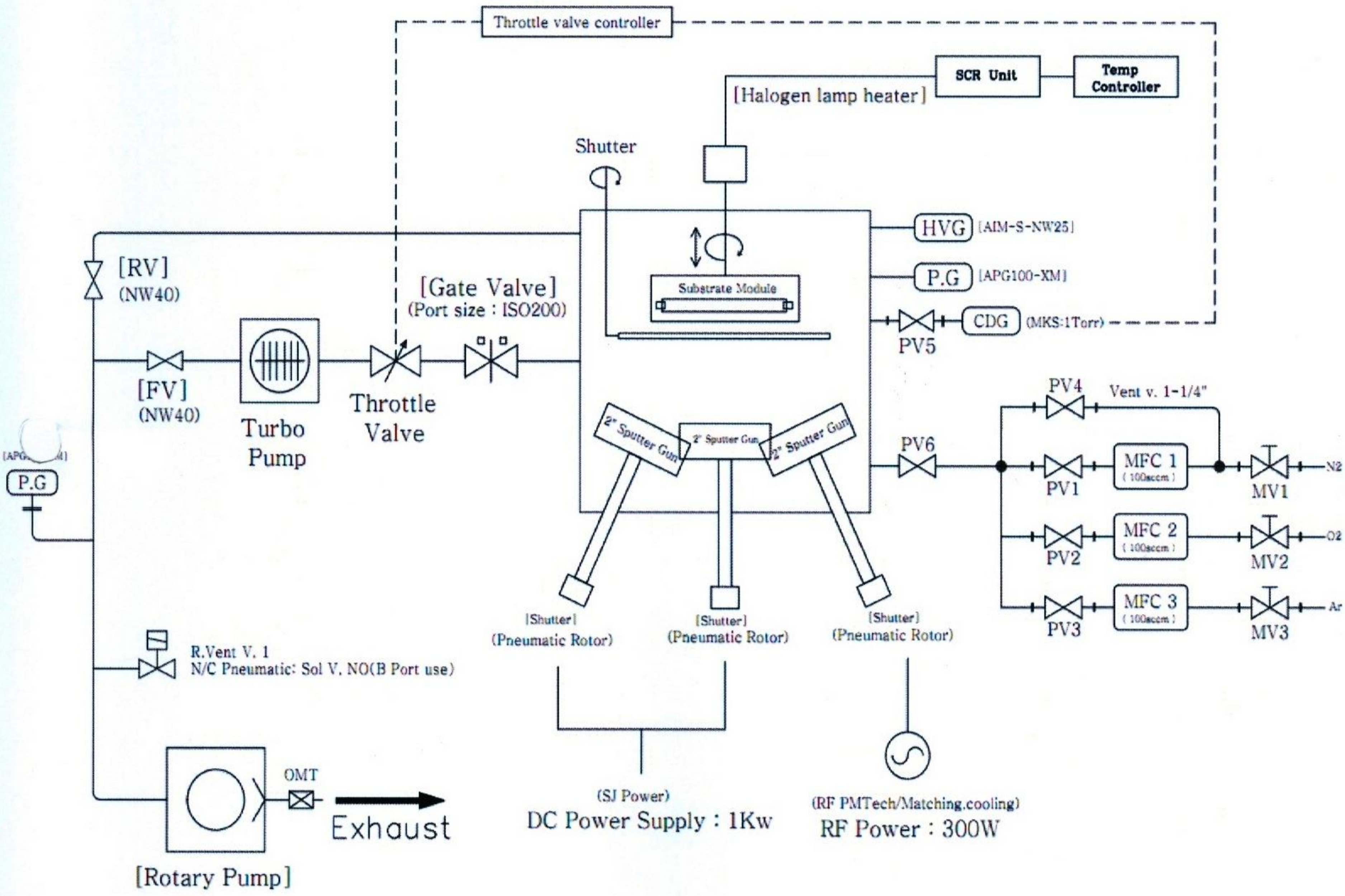
7) Door O-ring

ⓐ Stabbed
ⓑ Particle

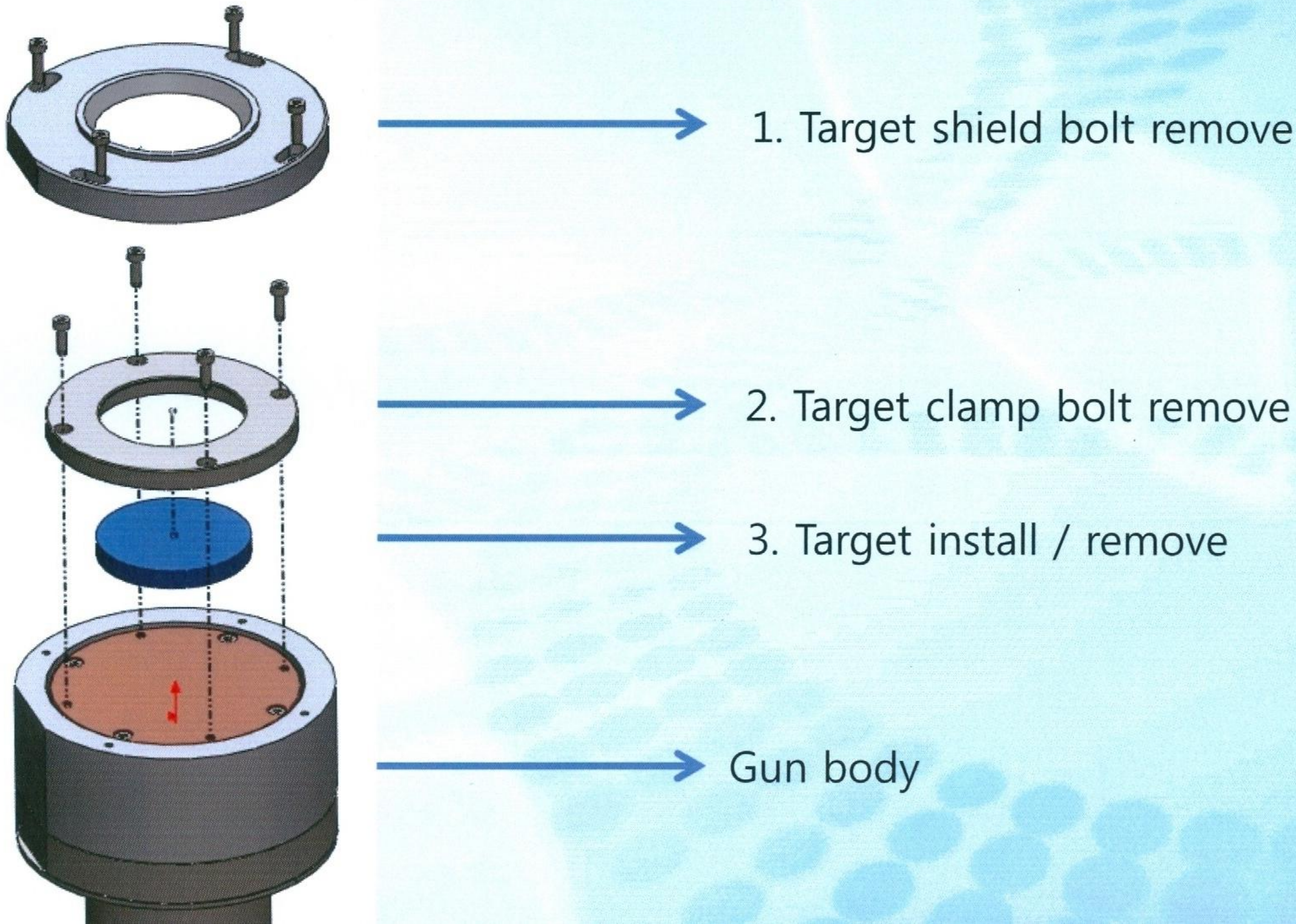
Explanation of Pump/Valve operating



System flow diagram



Sputter gun target change

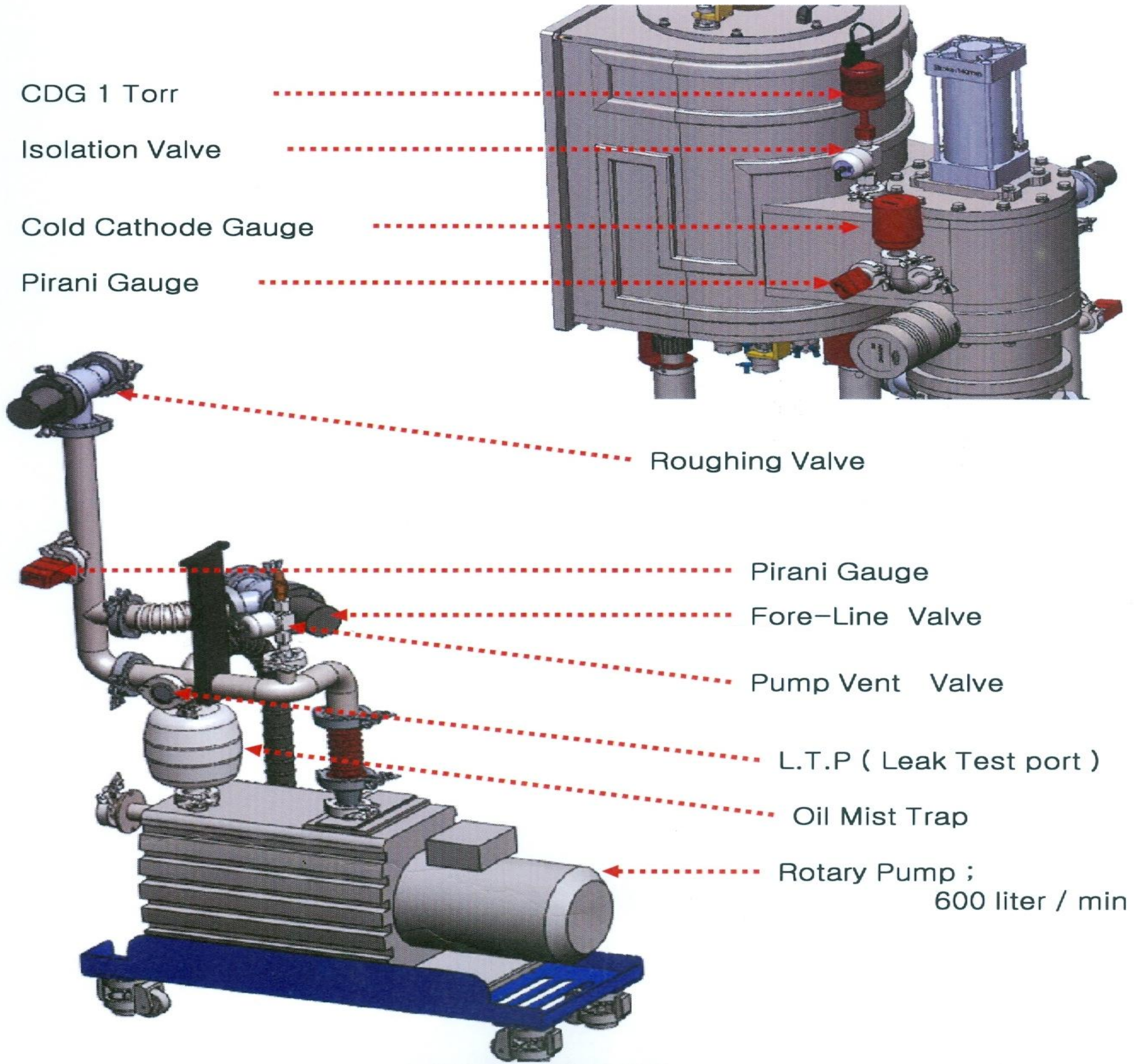


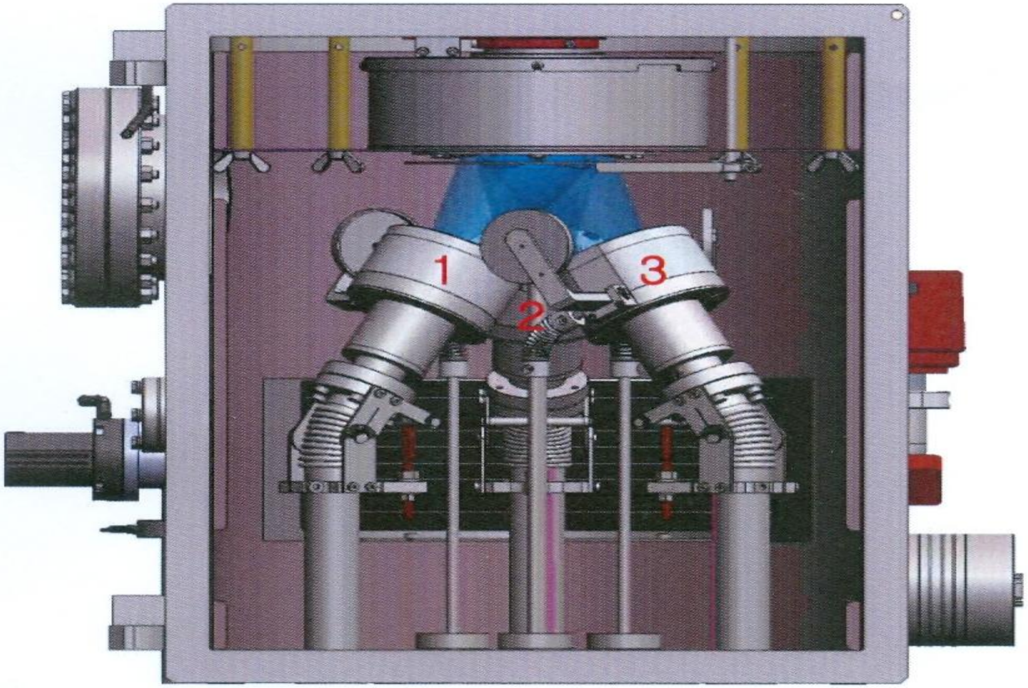
[3D Modeling]

1. Front View
2. Back side View

[Inside View – Chamber Module]

[SYSTEM VIEW – Pumping Module]





[3-Magnetron cathode with shutter]

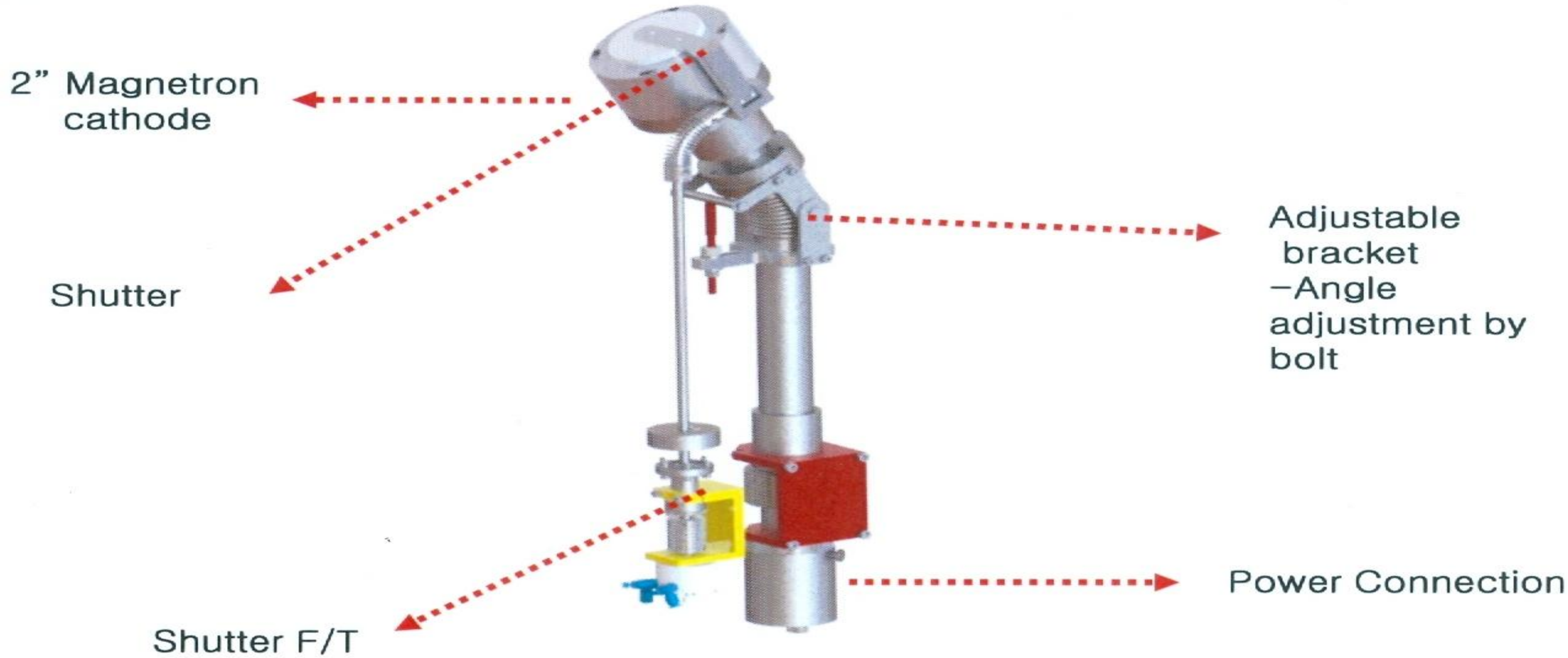
-Target Size : 2”

- Pneumatic shutter

- Co-position

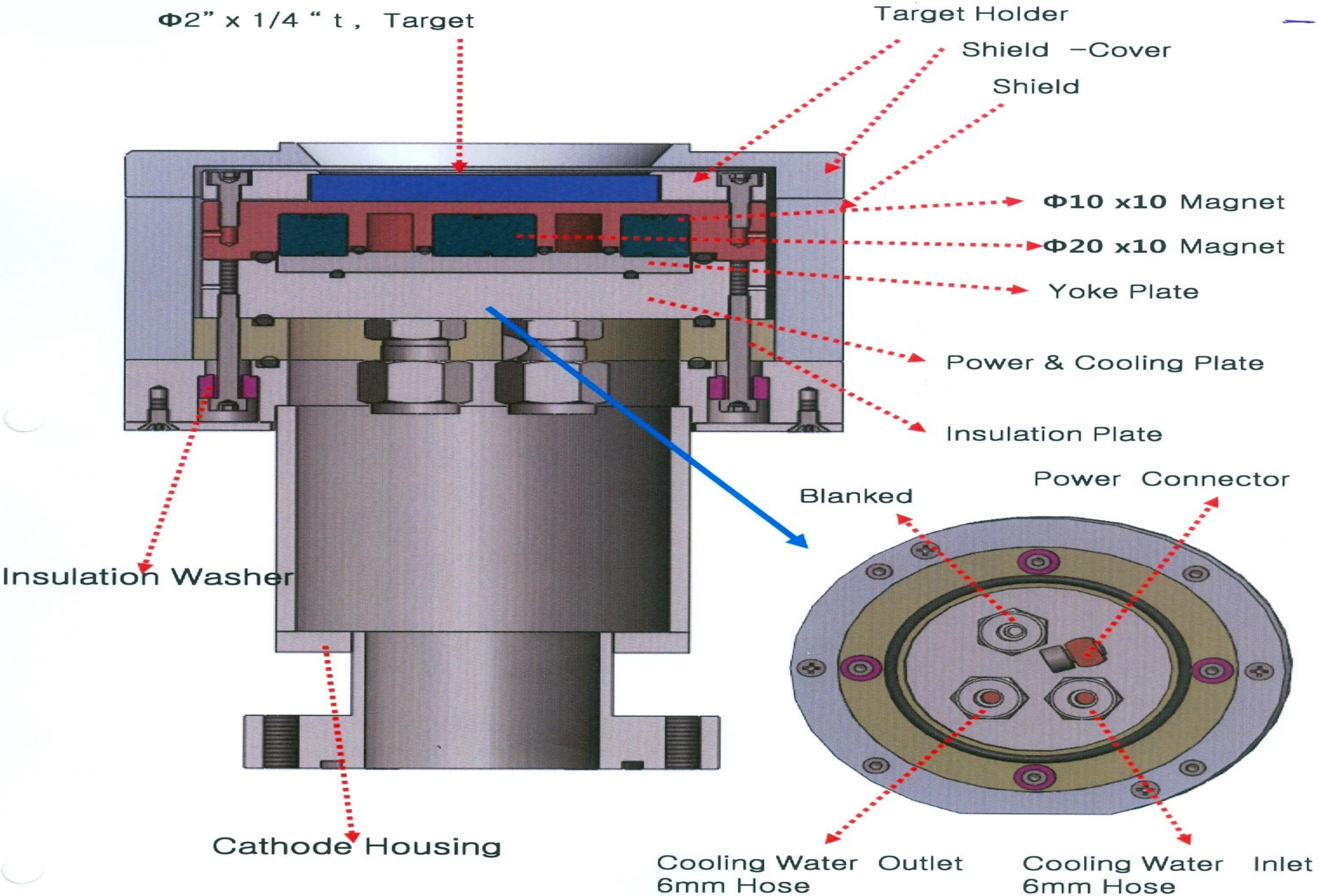
- Power : DC 1Kw 2set

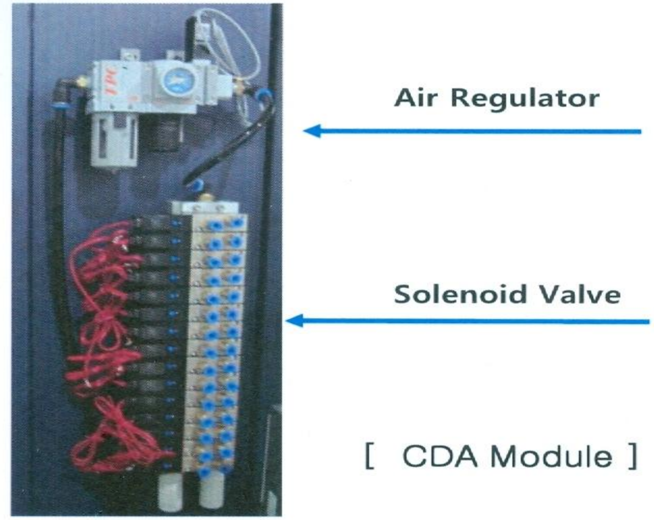
- RF 300W 1 set



CONFIGURATION – MAGNETRON CATHODE MODULE

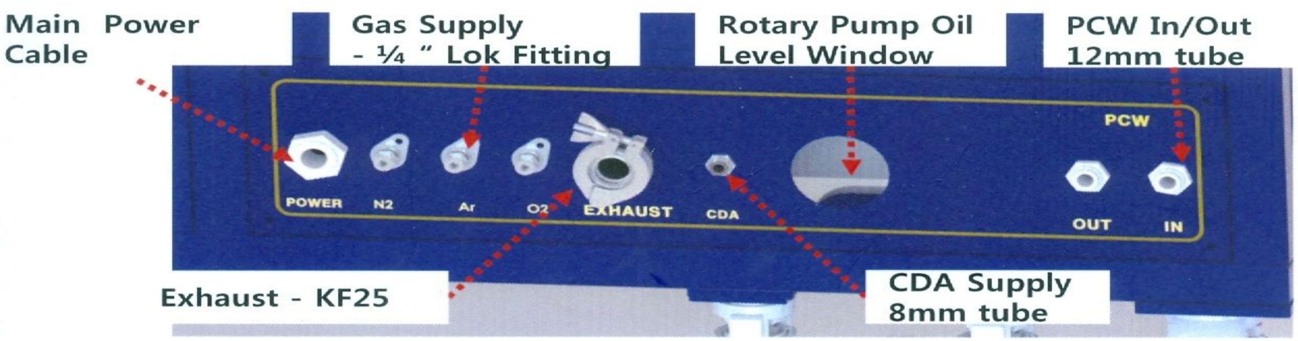
[2" Cathode View – Section]



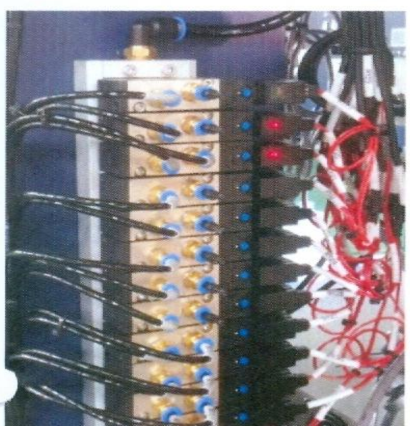


[CDA Module]

[Utility back Side View]

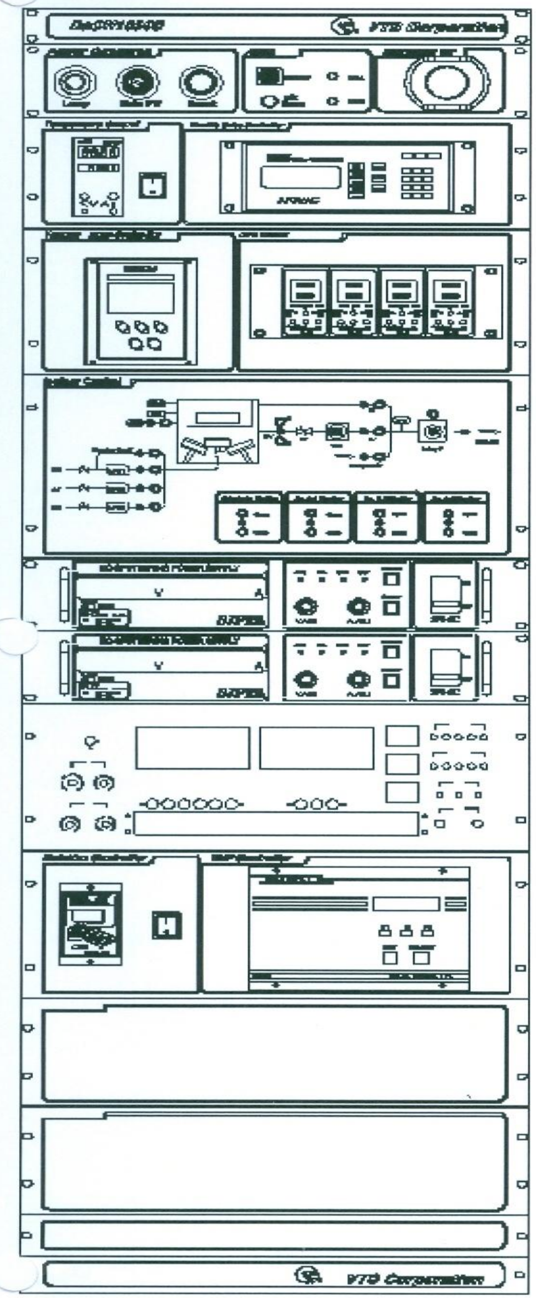


[Gas Line Module]



[PCW & Rotary Pump]

CONFIGURATION – CONTROL RACK RAYOUT



System

Power Condition

Throttle Valve Controller
& Temperature Controller

Vacuum Gauge & MFC Readout

System Control

DC Power Supply

DC Power Supply

RF Power Supply

TMP Controller

Blank

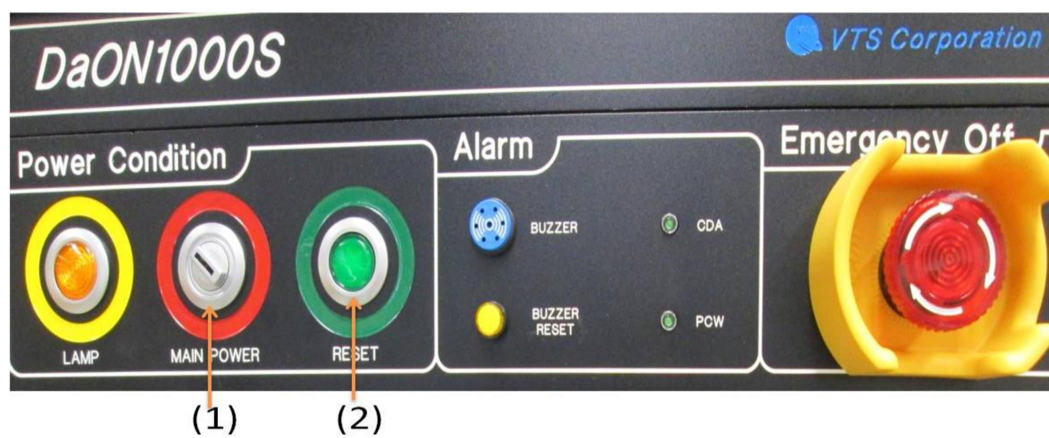
Blank

Blank

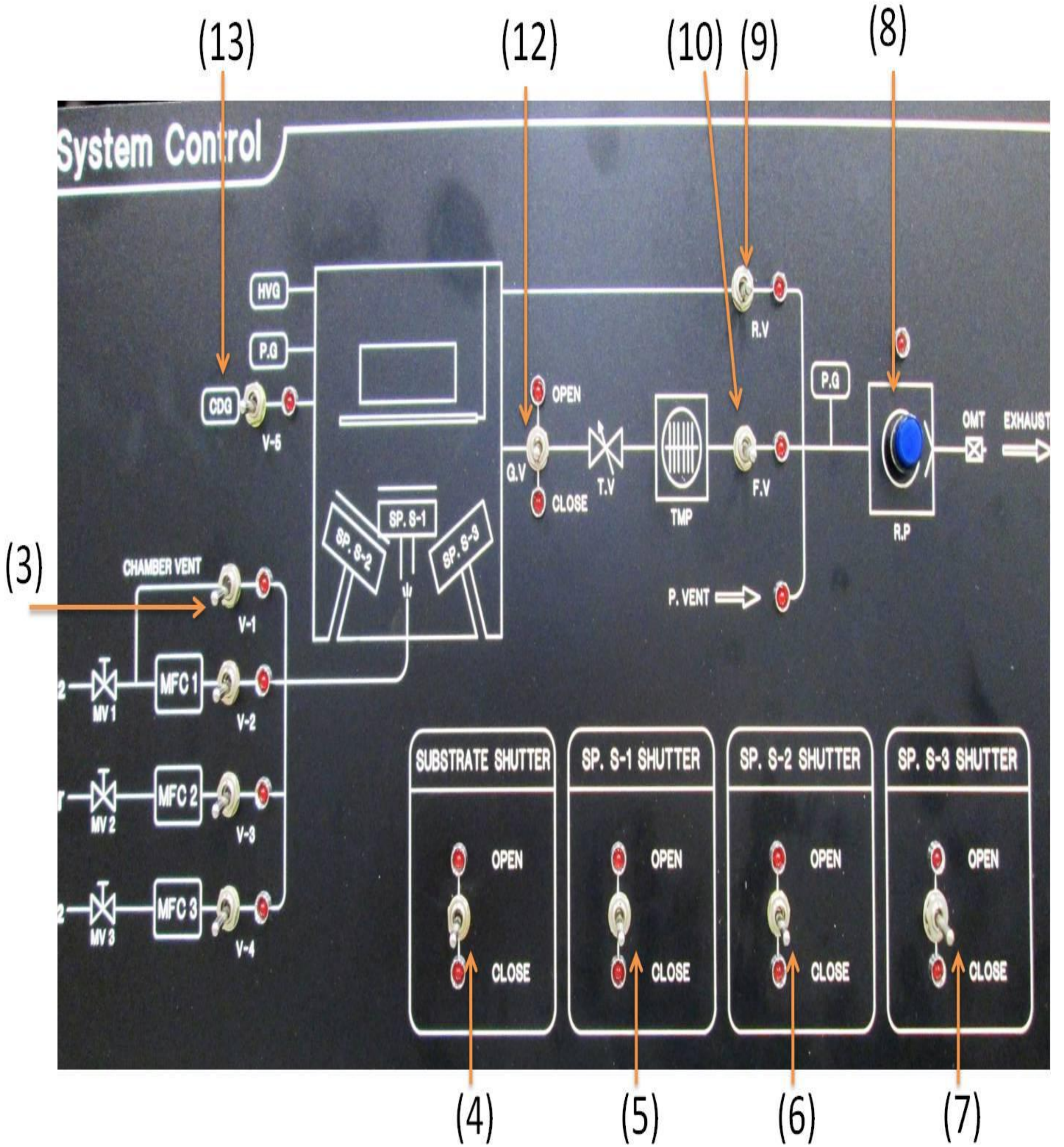
VTS logo

a. Chiller (PCW)
b. Compressor (CDA)
c. Transformer

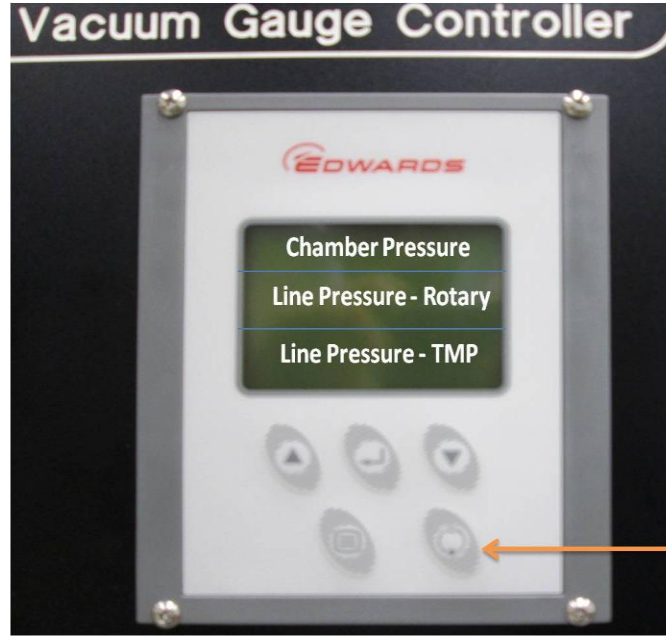
(1)Turn On
(2)Reset



3) **Chamber vent**
4) **Substrate shutter**
5) **Sputter gun-1 shutter**
6) **Sputter gun-2 shutter**
7) **Sputter gun-3 shutter**
8) **Rotary Pump (RP)**
9) **Rotary Valve (RV)**
10) **Fore valve (FV)**
11) **………**
12) **Gate Valve**
13) **Capacitive diaphragm gauge**

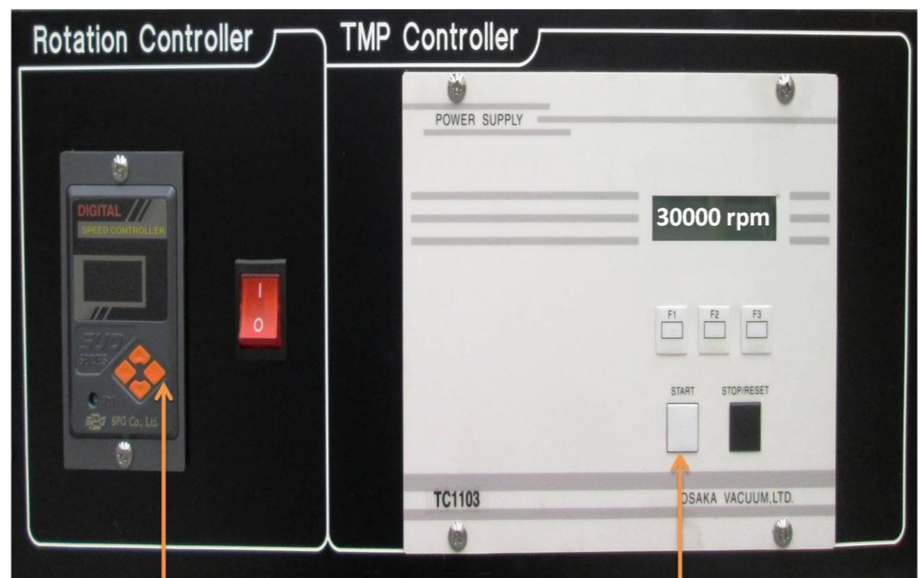


Vacuum gauge controller



High vacuum gauge ON/OFF button

(11) TMP controller ON/OFF



(16)

(11)

(14) Throttle valve controller

Working pressure can be adjusted According to the requirement using SP1- SP5 for five different ranges.

(14)

(15) Temperature controller

Substrate temperature can be adjusted Upto 500 C.

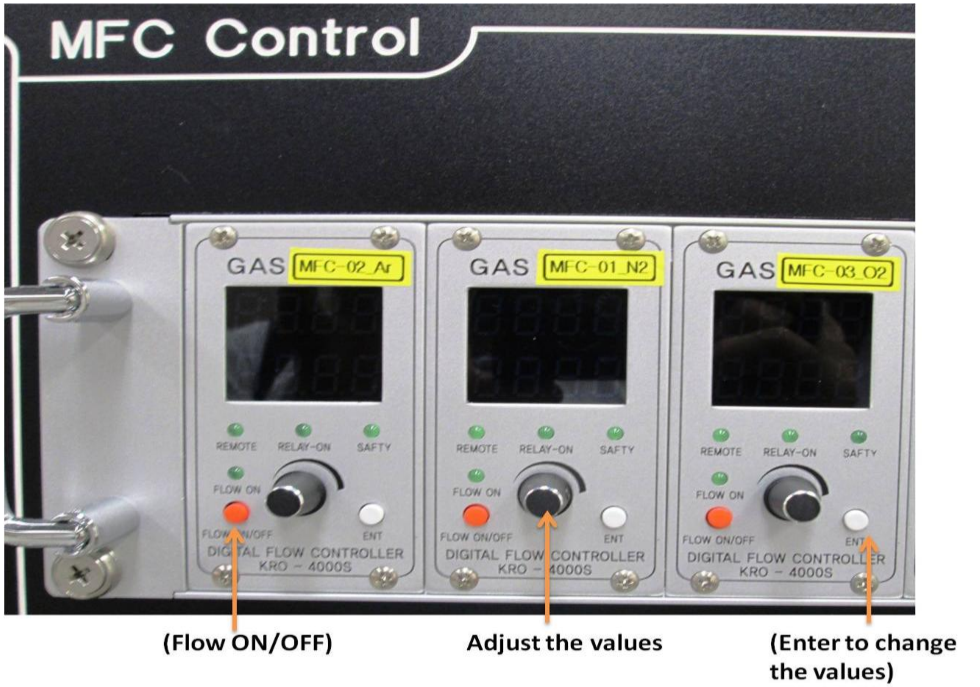
(15)

(16) Rotation controller

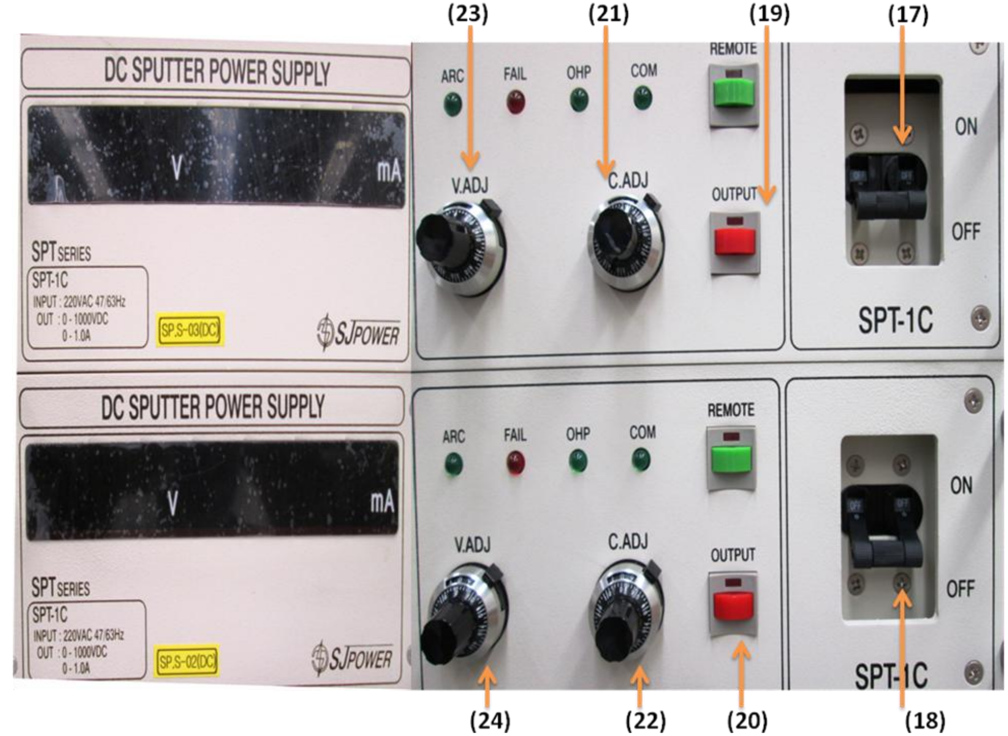
Substrate rotation can be adjusted According to the requirement.

Mass flow controller

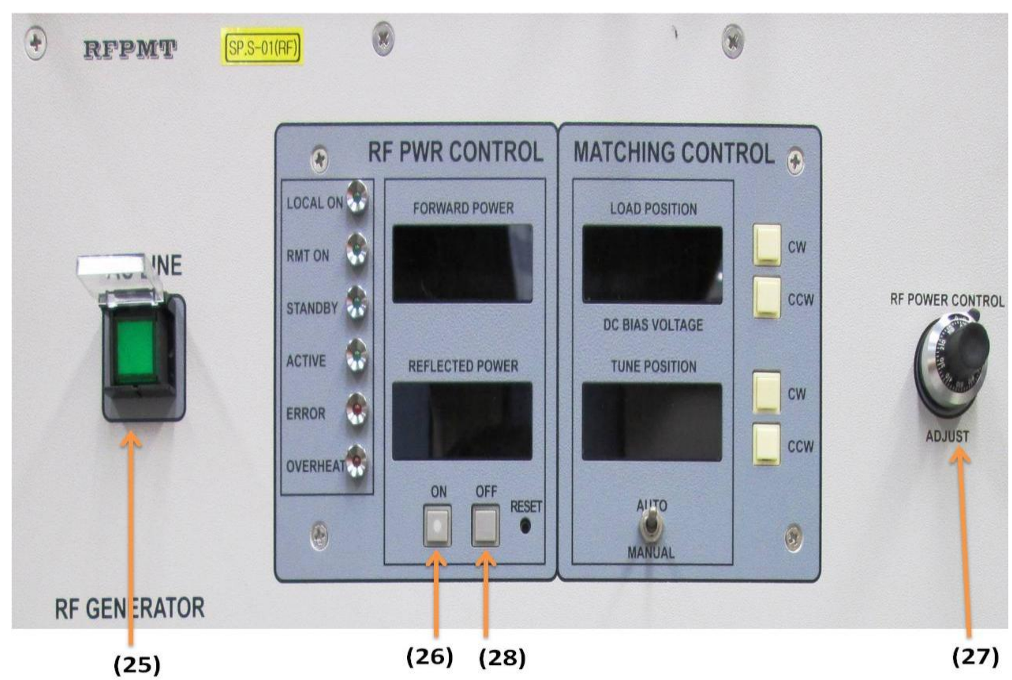
Gas (argon, nitrogen, oxygen) Can be controlled using MFC.



DC power supplies for Sputter guns 2 and 3.



RF power supplies for Sputter gun 1.



Remarks

- High quality thin films
- Uniform and phase pure structure
- No contamination due to high vacuum
- Layered structures
- Compound thin films
- Oxides and nitrides formation using reactive sputtering
- Etching of substrate and target


Thank You