An Introduction to Ion Pumps

CERN Accelerator School, May 2006
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• History
• Penning cell
• Pumping mechanism for different gases
• Pump element types
• Pumping speed
• Ion Pumps for Synchrotrons and Particle Accelerators
• In 1858 Plücker observed for the first time some pumping effect due to the electrical discharge.

• In 1937 F. Penning observed that his cold cathode gauge was evidencing a pumping effect.

• In the late 50’s the Ion Pump has been invented at Varian Associates in Palo Alto by Helmer, Jepsen and Rutherford.

• First application was to keep klystrons under vacuum
The first Ion Pump
The Penning Cell

Diagram showing the components of a Penning cell, including cathodes, a magnet, and an anode, connected to a power source.
The Penning Cell

• Cylindrical anode, two flat cathodes made of getter material.

• Crossed Electric & Magnetic Fields

• Anode voltage from 3 to 7 kV.

• Axial magnetic field from 1000 to 1300 Gauss

• Cell dimension : 15 to 25 mm diameter , 20 to 35 mm height
The Ion Pump

INLET FLANGE

ELEMENT

COVER

MAGNET

HIGH VOLTAGE FEEDTHROUGH
PRINCIPLES OF OPERATION

Plasma discharge in crossed electric and magnetic field act as an electron trap
Ionizing collision between electron and gas
Ion bombardment of titanium cathode
Some ions diffuse into the cathode
Sputtering of chemically active Ti film on anode
Gas molecules stick to Ti film (chemisorption) and are buried in the anode
Ion pumps do not pump ions
Electron trajectories
Ion Trajectories

Ion_30.avi
• \( \text{CO}_2 \), \( \text{CO} \), \( \text{N}_2 \), \( \text{H}_2\text{O} \), \( \text{O}_2 \)
• Collision between electrons and gas molecules
• Some are ionizing collision.
• The ions that are generated are accelerated towards the cathodes.
• Some ions are trapped into the cathode (eventually reemitted)
• Some atoms of the Ti cathode are sputtered and deposited on the anode.
• The background gas molecules that collide with the chemically active titanium film are chemically trapped.
• Gas pumped at the anode will not be reemitted (no bombardment)
The noble gases are not chemically active.

They are not pumped by the Titanium film.

They are implanted into the cathode but this type of pumping is not stable.

Conventional Ion pumps show the phenomenon known as Noble Gases Instability.

A small fraction of ions when they hit the cathode are reflected as neutrals.

Some of these neutrals maintain enough energy to be implanted into the anode.

They are physically buried into the cathode (no chemical reaction).

They will be buried by Titanium sputtered atoms.

Pumping is not very efficient.
Hydrogen

- Hydrogen is chemically reactive, it is pumped by the Titanium film.
- Sputtering yield for Hydrogen is very low, a very limited amount of Titanium is sputtered on the anode.
- Most of the pumping takes place into the cathode (unstable!)
- Hydrogen has a high diffusivity and solubility in Titanium.
- Hydrogen is the only gas that after being implanted into the cathode diffuse into the cathode bulk (even at room T).
- Hydrogen pumping into the cathode is stable.
- Hydrogen is pumped very well when in gas mixture with heavier gases (both at the anode and at the cathode)
Scheme

- Cathode
- Anode
- Surface dissociation
- Ionized H₂
- Buried high energy neutral
- "Reflected" neutral
- Diffusion in cathodes on dissociation
- Magnetic field
• The pumping speed of Ion Pumps is a function of gas species, pressure and amount of pumped gas.

• Speed increases with pressure because the current (number of ions bombarding the cathode) increases more than linearly

\[ I = k P^n \quad \text{where} \quad n = 1.05 \text{ to } 1.2 \]

• Initial pumping speed is higher, then the pumping at the cathode becomes negligible, and the gas is pumped at the anode only

• The nominal pumping speed is the maximum speed of a pump after saturation.

• The amount of gas needed to saturate a pump depends on pump size

• A bake out regenerates an Ion pump to the initial condition
Saturation

% of Nominal Pumping Speed

Pressure (mbar)

10^{-11} 10^{-10} 10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4}

50 100 150 200
Different types of pump for different applications - Diode, Noble Diode, StarCell
DIODE ION PUMP

Highest pumping speed for all getterable gases
(H₂, CO, CO₂, N₂, H₂O)

Highest pumping speed at low pressures

Limited speed and stability when pumping noble gases such as Argon, Helium and Methane

The only reason for different and more expensive ion pumps is to improve pumping speed and stability for Noble Gases
DIODE

Limited Argon stability means:
Maximum capacity of approx 20 hours at 1E-6 mbar of Argon
200 h at 1E-7 mbar
2,000 h at 1E-8 mbar
20,000 h at 1E-9 mbar ........

1% of air is Argon
200 h at 1E-5 mbar of Air (1E-7 mbar of Ar)
2,000 h at 1E-6 mbar of Air (1E-8 mbar of Ar)
20,000 h at 1E-7 mbar of Air (1E-9 mbar of Ar) ...........

DIODE are useless in applications where Argon flows are present or Air is pumped at high pressures
In UHV application, where:
Ion pumps are started below 1E-6 mbar
The system is rarely vented to air
There are no air leaks
The ion pump is used to pump the outgassing of the vacuum chamber
The Pressure is lower than 1E-8 mbar

Diode pumps can work for 20 years before showing Argon instability

Ion pumps with improved stability for noble gases may be a safer approach if they are cost competitive with diode
ION PUMPS for NOBLE GASES

One single working principle: improve the number of Noble Gas ions that are reflected when bombarding the cathode, and are physically buried into the anode (no chemical interaction)

Two different approaches to obtain it:

A) Change of material
B) Change of geometry
ION PUMPS FOR NOBLE GASES

A) Heavier cathode material (Tantalum vs. Titanium)
B) Different angle of incidence (Grazing vs. Normal )

A) Noble Diode
B) Triode / StarCell

Both solutions do improve the pumping speed and stability for noble gases
Ion Pump Technology

A) Noble Diode

Same design as Diode
Much more expensive material
Cost of Tantalum is much higher than cost of Titanium
Noble Diode is more expensive than Diode

B) Triode/Starcell

Same material as Diode
More complex (more expensive) geometry
Proper design and tooling allow to build them at similar cost of a standard diode
Noble Diode vs Diode
Lower capacity and speed for H2
Lower speed for all getterable gases (N2, CO, CO2)
Improved stability and speed for Noble Gases

Starcell vs Diode
Lower speed for all getterable gases (N2, CO, CO2)
Comparable speed for Hydrogen
Improved speed and stability for Noble Gases
Ion Pump Technology

StarCell vs. Noble Diode

Higher capacity for H2
Same speed for all getterable gases (N2, CO, CO2)
Higher capacity for Noble Gases
Higher stability and speed for Noble Gases
ION PUMP

SPECIFIC DESIGN FOR
SYNCHROTRON & PARTICLE
ACCELERATORS
Closed pump
Do not need any baking pump
No contamination from the roughing line
- No moving parts, no lubricant
Vibration free and contamination free
- Can withstand air inrush or improper use
Maintenance free, High reliability
Pumping speed is not the major concern…….

outgassing
contamination
vacuum leaks (corrosion)
safety hazard
resistance to radiation

……..may be more critical than pumping speed for Synchrotron
Pump designed to minimize outgassing/contamination
  Material choice
  Material cleaning
  Pump process

HV feedthrough and HV cable designed to be safe, radiation and corrosion proof

Pump designed to minimize stray magnetic field
Only UHV compatible materials: Metals and Ceramic

Body, Flange, Anode: Stainless Steel 304 or 316, L or LN
  L, low C precipitation, better corrosion resistance
  LN, Nitrogen for improved mechanical resistance

Cathode: Titanium grade A (Tantalum)
Insulators: Alumina Al2 O3
Material Cleaning

TITANIUM

Degreasing in Alkaline bath (NaOH-Na2CO3)
Ultrasonic degreasing in Alkaline bath
Cold rinsing
Cold rinsing with deionized water
Pickling, in Nitric and Fluoridric acid bath (HF-HNO3)
Cold rinsing
Cold rinsing with deionized water
Hot rinsing with deionized water
Oven drying at 150°C
The ion pump element must be the cleanest surface exposed to vacuum, because its outgassing is due to both thermal and bombardment induced effect. The surface will eventually be removed (sputtered): not only the surface, but the bulk too must be hydrogen free.

Ion pump element must be “vacuum fired”
2 hours @ 750 °C, at 1*E-5 mbar

Then, the complete pump is processed under vacuum at 450°C.
Pumps are individually processed
Residual gas analysis for each pump
Process is not “time driven” but “pressure driven”
Individual records of each pump (outgassing, spectra ...)
Pumps are processed in nitrogen atmosphere to prevent external oxidation (no more beadblasting needed)
Pumps can be leak-checked at high temperature (Helium instead of Nitrogen)
Vacuum performance are much more repeatable.
NEW ION PUMP OUTGASSING SYSTEM
Moved from passive to active safety

The control unit and HV cable connector must be intrinsically safe
No live parts can be touched
(passive safety)

Interlock on HV connection to ensure that HV is switched off whenever the HV cable is disconnected, either from the pump or from the controller (active safety)
Corrosion free feedthrough

HV feedthrough and connector are subjected to corrosion
Transition metal to Kovar (or similar) to ceramic is critical
Temperature cycling, humidity, high electric field gradient may cause corrosion
Water vapor trapped in between the connector and the feedthrough may cause oxidation
Specific design to minimize air trapping and critical surface exposed to air (vacuum side brazing)
Ion pumps must be radiation proof
HV connector, HV cable insulation, heaters must be specifically designed
PEEK, KAPTON or equivalent must be used as insulator
(250°C, 1E9 Rad)
No PVC, no TEFLON can be used
Electronic is not radiation proof
Power supply must be in a shielded location
Ion Pumps in Synchrotron & Particle Accelerators
Latest development in Ion Pump Technology

Ion Pump for UHV applications
Ion Pump with NEG coating
Round Ion Pump
NEG Deposition (Zr – V – Ti) plus an additional layer of a noble metal (Pd).

- Large amounts of H₂ can be pumped (and CO).
- NEG poisoning by heavier gases (O₂, CO₂, N₂) is prevented;
- for H₂ and CO **the pumping mechanism is thermally reversible.**
NEG coated Round Ion Pump
No activation or baking between measurements
Thank you !