ION Pumps for UHV Systems, Synchrotrons & Particle Accelerators

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ION Pumps
Agilent Technologies

1957-59

Varian Associates invents the first ION Pump

ION Pumps
Main choice for UHV systems, synchrotron & particle accelerators
Why?

1. Closed pump

   Do not need any baking pump

   No contamination from the roughing line

2. No moving parts

   There is no rotation or moving parts

3. No lubricant

   There are no oil or solvents and is fully contamination free

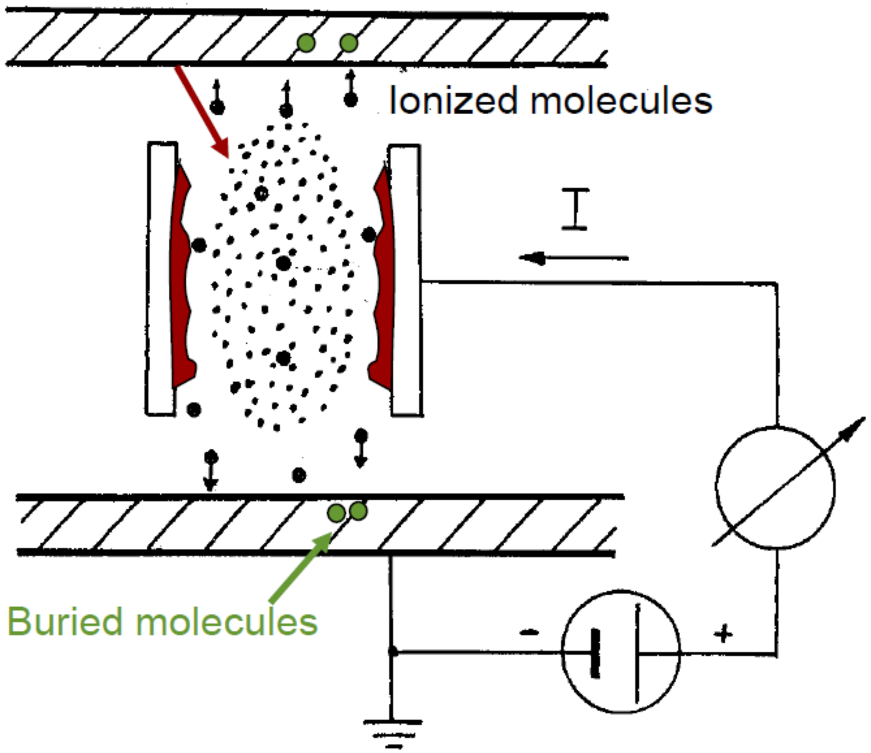
4. Can withstand air inrush or improper use

   Maintenance free, High reliability

ION Pumps
Basic Pumping Mechanism

Pumping principle:

- 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 (pumped)
- Sputtering of chemically active Ti film on anode
- Neutral Gas molecules stick to Ti film (chemisorption) and are buried in the anode (main pumping)
- Ion pumps do not pump ions at the cathode , but neutral molecules at the anode



ION Pumps
Basic Pumping Mechanism – Noble gases

- This works only for all active (getterable) gases
- Noble gases do not react with Ti film
- No chemisorption of neutral molecules
- Some ion bombarding the cathode are neutralized and reflected
- Some of them maintain enough energy to be physically implanted into the anode
- They will then be covered by the sputtered Ti film
- It is a physical burying, not a chemical reaction
- Pumping much less efficient than for getterable gases

ION Pumps

Diode Ion Pump

Highest pumping speed for all getterable gases (H_2, CO, CO_2, N_2, H_2O)

Highest pumping speed at low pressures

Limited speed (5 to 10%) and low capacity when pumping noble gases such as Argon, Helium

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

Limited Argon capacity means:

	Pure Argon	Air (1% Ar)
10 E-5 mbar		8 days
10 E-6 mbar	20 hours	3 months
10 E-7 mbar	8 days	2.5 years
10 E-8 mbar	3 months	25 years
10 E-9 mbar	2.5 years	

ION Pumps
Diode

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 Argon instability

Courtesy PSI SLS.

ION Pumps
Different types of pump: Diode, Noble Diode and StarCell

However, in real life…

- Air leaks may be present
- Venting to air may be more frequent than desired
- Working pressure may be higher than design values

…then more Argon than expected has to be pumped

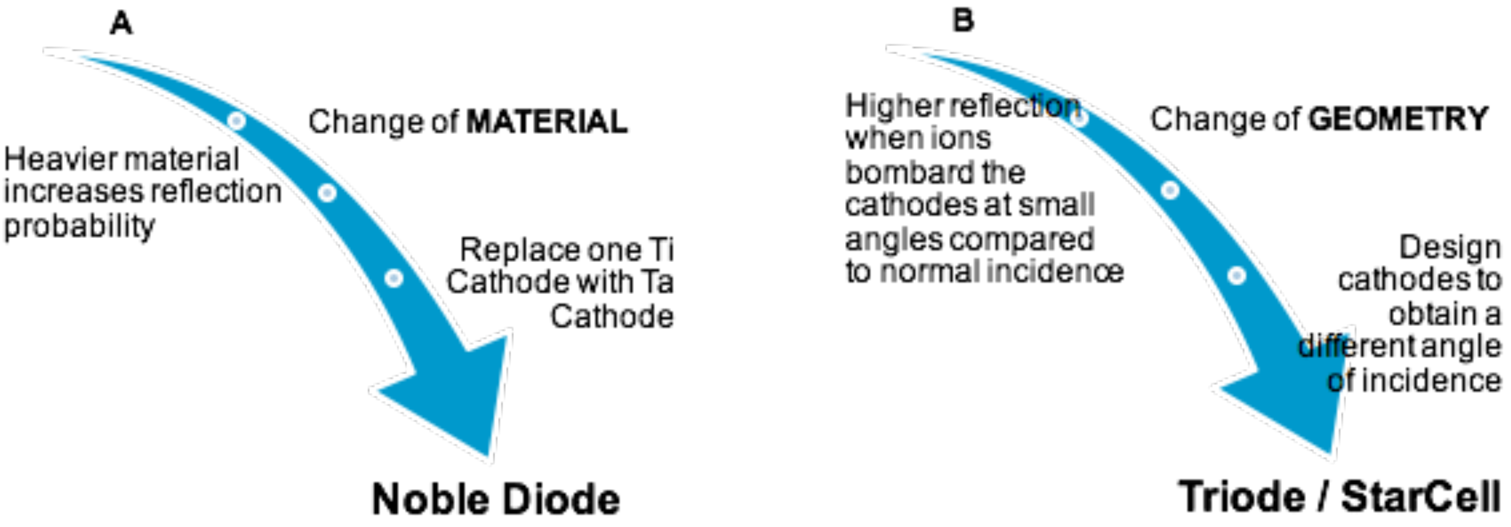
ION Pumps with improved stability for noble gases may be a safer approach

ION Pumps
Different Noble Diode & StarCell vs Diode

Ion Pumps for Noble Gases design

Improve the number/probability of Noble Gas ions reflection vs implantation after bombarding the catodo

After being reflected, they may be physically buried into the anode (no chemical interaction)
Two different approaches to modify Diode to obtain this result:

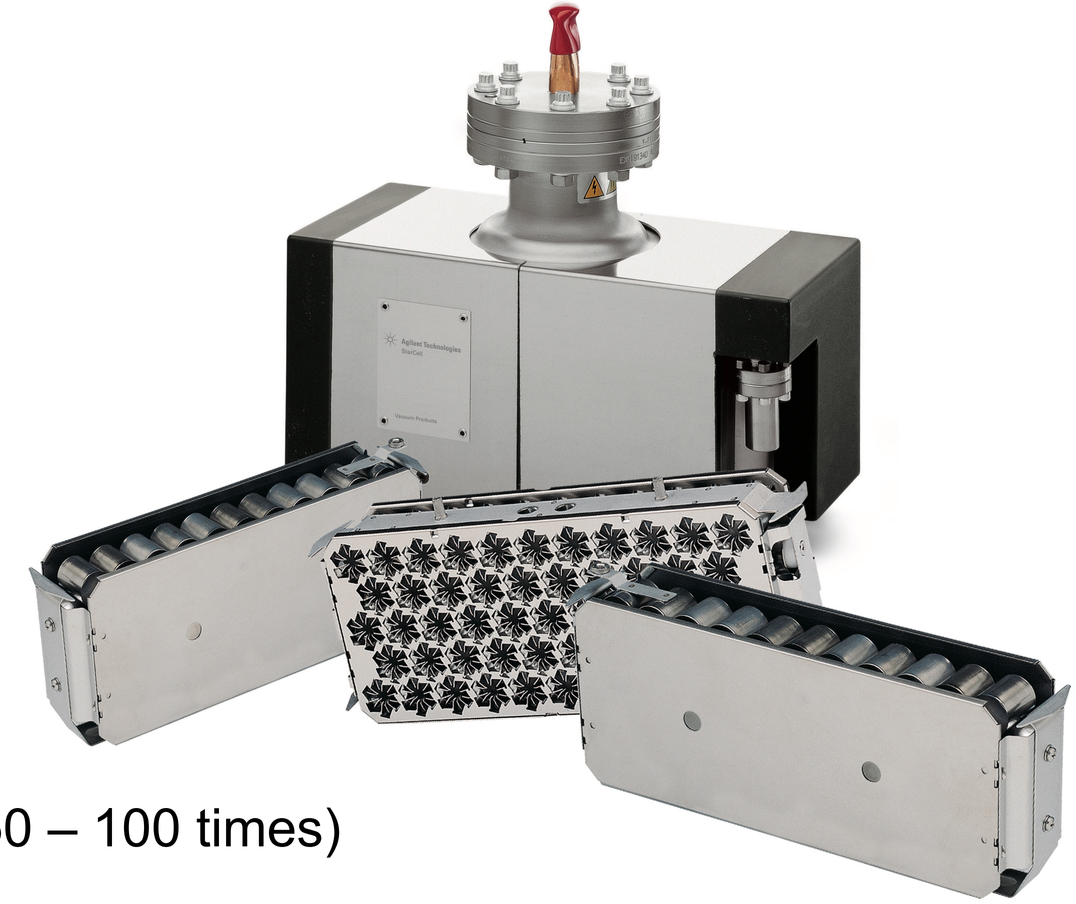


<u>Both solutions do improve the pumping speed and stability for noble gases</u>

ION Pumps
Noble Diode & StarCell vs Diode

Noble Diode vs Diode

- Much lower capacity and speed for H2
- Lower speed for all getterable gases (N2, CO, CO2)
- Improved stability and speed for Noble Gases (factor up to 10 - 20 times)
- Argon speed up to 15% 20% of Air Pumping speed

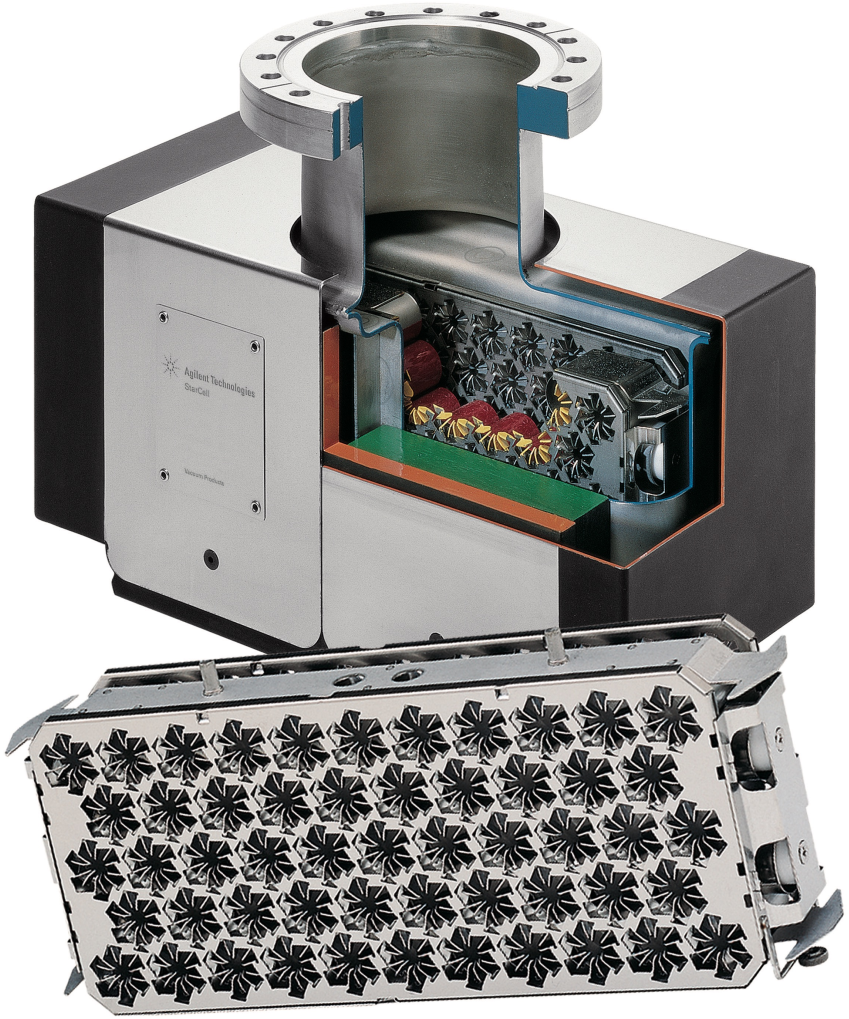


Starcell vs Diode

- Lower speed for all getterable gases (N2, CO, CO2)
- Comparable speed for Hydrogen
- Improved speed and stability for Noble Gases (up to 50 – 100 times)
- Argon speed up to 35% 40% of Air Pumping speed
- When only getterable gases must be pumped, Diode is still the best choice

ION Pumps
StarCell vs Noble Diode

- Much higher capacity for H_2 (one order of magnitude)
- Similar speed for all getterable gases (N_2, CO, CO_2)
- Higher stability for Noble Gases (factor of 5 to 10 times)
- Higher speed for Noble Gases (almost double , up to 40 % vs 20% of Air)
- When Noble gases must be pumped , StarCell is the proper choice



ION Pumps
How to choose the correct ion pump

Essential parameters of a UHV system

1. Operation mode
- Venting frequency
- Starting pressure (roughing pumps)

2. Gases
- Noble Gases (He, Ar, Kr, Xe...)
- Getterable Gases

3. Size of the chamber
- Surface exposed to vacuum
- Outgassing
- Conductance

4. Base Pressure
- Ion pump alone
- Combination with TSP or NEG

ION Pumps
Agilent Ion Pumps elements comparison table 1/2

	StarCell	Diode	Noble Diode	
HYDROGEN	2	3	1	The Diode element shows a higher pumping speed for H_2 than the Noble Diode since the H_2 solubility in the tantalum cathode is lower than in a titanium cathode. StarCell elements combine good performance at higher pressures with enhanced capacity for H_2. It is worth noticing that hydrogen is the main residual gas in UHV.
ARGON, HELIUM	4	1	3	See comments on other slides.
WATER	2	3	2	Not considering physisorption phenomena, water can be pumped when separated into hydrogen and oxygen.
METHANE	3	2	3	The methane molecule (as well as other hydrocarbon molecules) is cracked and transformed into smaller getterable compounds (C, CH_3,...H).
NITROGEN	2	3	3	Diode and Noble Diode elements show a higher pumping speed for N_2 at low pressure while StarCell elements perform better at higher pressure, because the Penning discharge is betterconfined inside the element.
O2, CO, CO2	2	3	3	As nitrogen, these are all getterable gases; same considerations as for N_2.

POOR 1 GOOD 2 EXCELLENT 3 OUTSTANDING 4

ION Pumps

Agilent Ion Pumps elements comparison table 2/2

	TSP
HYDROGEN	3
ARGON, HELIUM	0
WATER	3
METHANE	0
NITROGEN	3
O2, CO, CO2	4

Combination StarCell + TSP is outperforming any other combination and can satisfy nearly any need!

NULL	POOR	GOOD	EXCELLENT	OUTSTANDING
0	1	2	3	4

ION Pumps

Specific design for Large UHV Systems, Synchrotron & Particle Accelerator

Pumping speed is not the most important parameter to reach UHV

- outgassing
- contamination
- vacuum leaks (corrosion)

…may be more critical than pumping speed for large UHV systems, i.e. Synchrotron

ION Pumps
Specific design for Synchrotron & Particle Accelerator

Pump designed to minimize outgassing/contamination

1. Material choice
2. Material cleaning
3. Pump process

HV feedthrough and HV cable designed radiation and corrosion proof to avoid potential problems (leaks)

ION Pumps
Specific design for Synchrotron & Particle Accelerator

Material choice

- Only UHV compatible materials: Metals and Ceramic
- Body, Flange, Anode : Stainless Steel 304 or 316, L or LN
  1. L, low C precipitation, better corrosion resistance
  2. LN, Nitrogen for improved mechanical resistance
- Cathode: Titanium grade A (Tantalum)
- Insulators: Alumina Al_2O_3

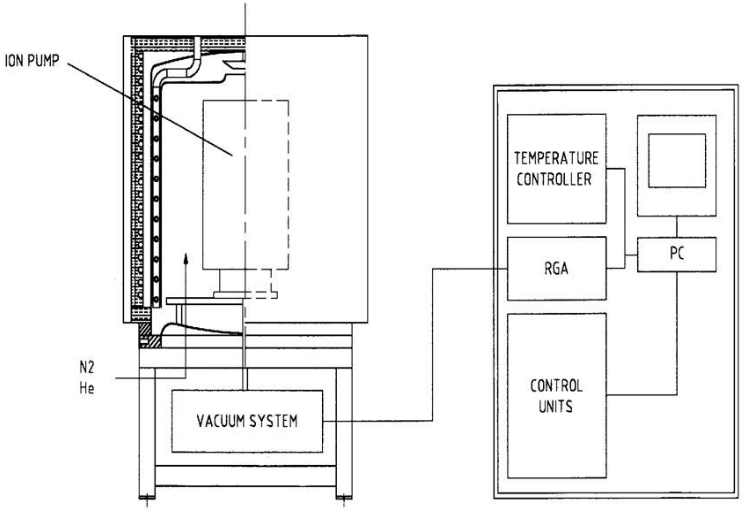
Material Cleaning

- Degreasing in Alkaline bath (NaOH-Na_2CO_3)
- Ultrasonic degreasing in Alkaline bath
- Cold rinsing
- Cold rinsing with deionized water
- Pickling, in Nitric and Fluoridric acid bath (HF-HNO_3)
- Cold rinsing
- Cold rinsing with deionized water
- Hot rinsing with deionized water
- Oven drying at 150°C

ION Pumps
Manufacturing

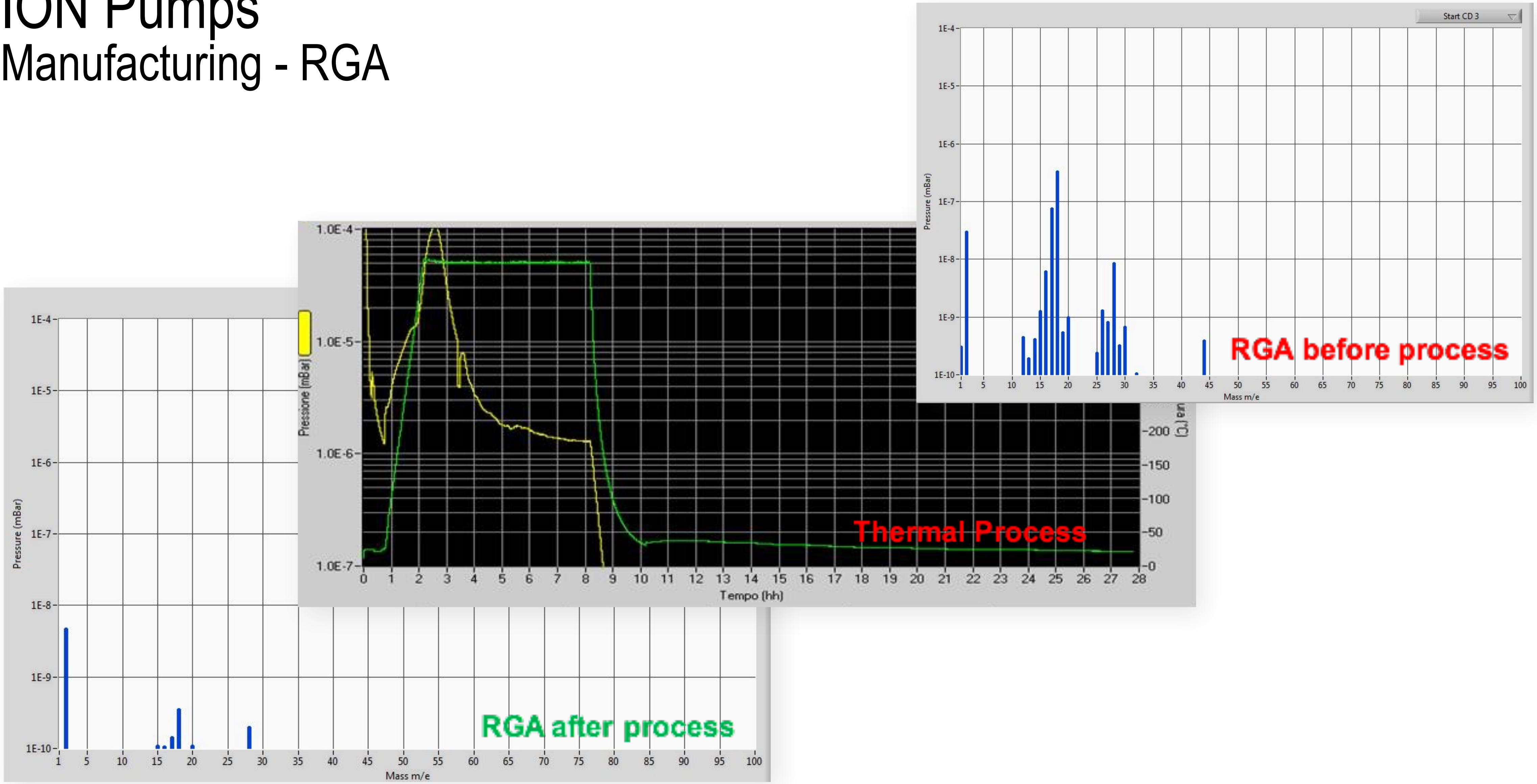
- The ion pump element must be the cleanest surface exposed to vacuum , because its outgassing is due to both thermal and bombardment induced effect
- The surface will eventually be removed (sputtered): not only the surface , but the bulk too must be hydrogen free
- Ion pump element is “vacuum fired” @ 950 °C
- Then, the complete pump is processed under vacuum at 450°C

ION Pumps
Manufacturing



- Pumps are individually processed
- Residual gas analysis for each pump
- 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

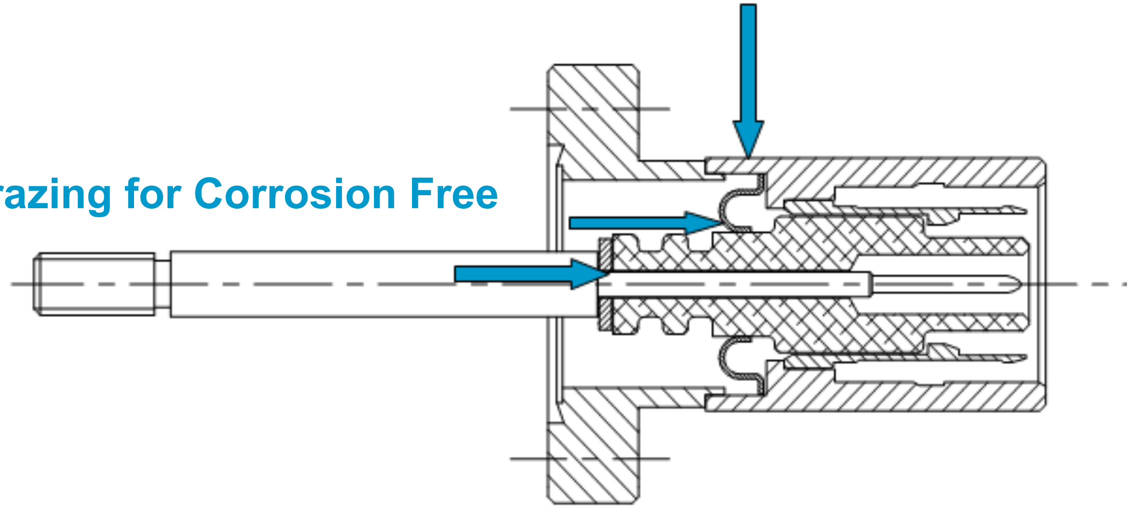
ION Pumps
Manufacturing - RGA



ION Pumps
Corrosion free

- 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)

Vacuum Side Brazing for Corrosion Free



ION Pumps
Safety Interlock

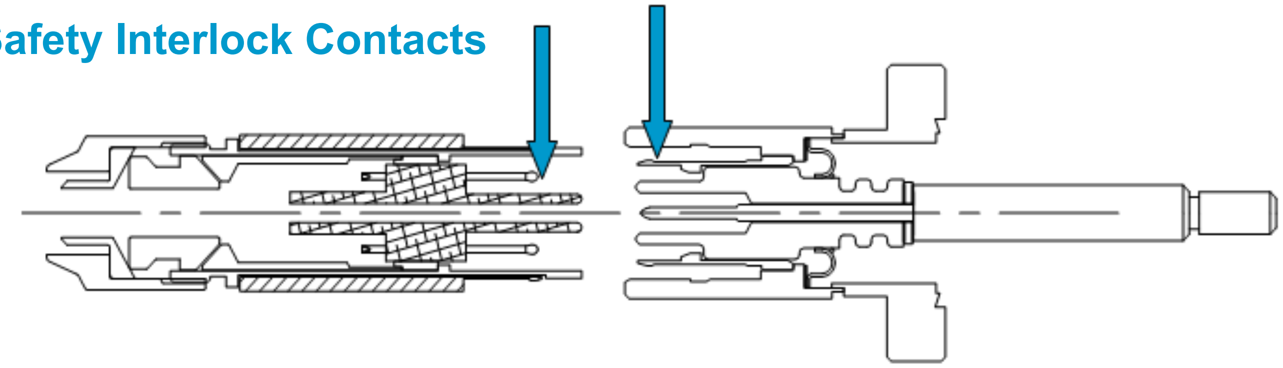
From passive to active safety

Passive Safety

- The control unit and HV cable connector must be intrinsically safe
- No live parts can be touched

Active 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



ION Pumps
Controller Design to Optimize Pump Performances in the Entire Operating Pressure Range
Summary

- Little efforts dedicated in the recent past to IP controller developments
- Properly Designed Ion Pump controller maximizes IP performances in the entire operating range
- Variable voltage maximizes pumping speed
- Variable voltage allows reliable pressure reading at low pressures
- Power control ensure starting at «high» pressure with limited power and low «aging» of the ion pump
- State of the art controllers incorporate all these functions in a compact and light design

Variable Voltage Optimizes Ion Pump Pumping Speed

Pumping Speed vs. Applied Voltage

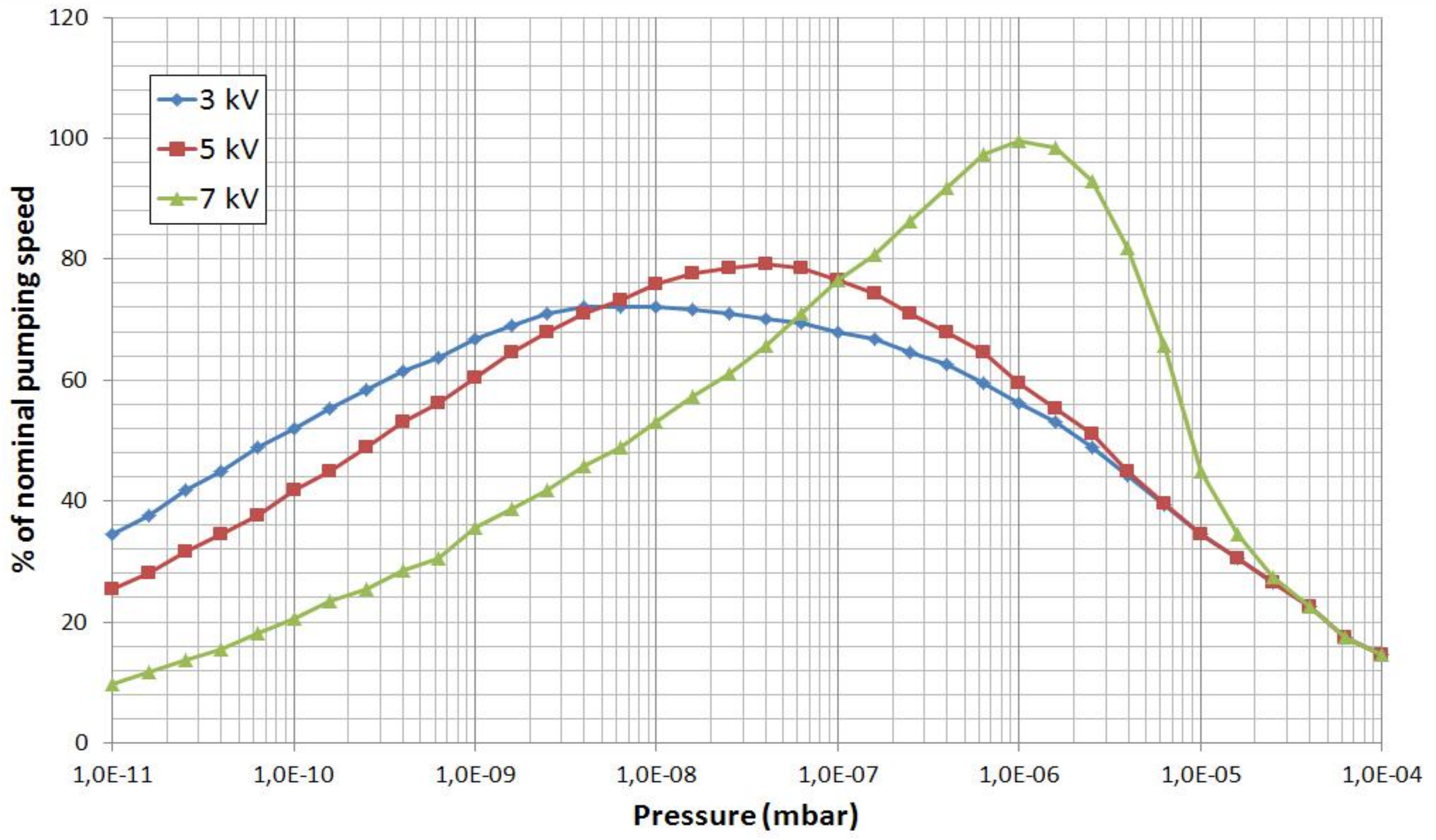
Ion bombarding energy of approx 3 keV ensure efficient sputtering

Space charge effect reduces ion energy

- Space charge effect is a function of pressure
- At «0» pressure ion energy equals applied voltage
- Marginal reduction at UHV condition , major effect at higher pressures
- In the 10^{-9} mbar range approx 3 kV are sufficient to ensure 3 keV of actual ion energy
- In the 10^{-5} mbar range approx 7 kV are needed to ensure 3 keV of actual ion energy

Variable Voltage Optimizes Ion Pump Pumping Speed

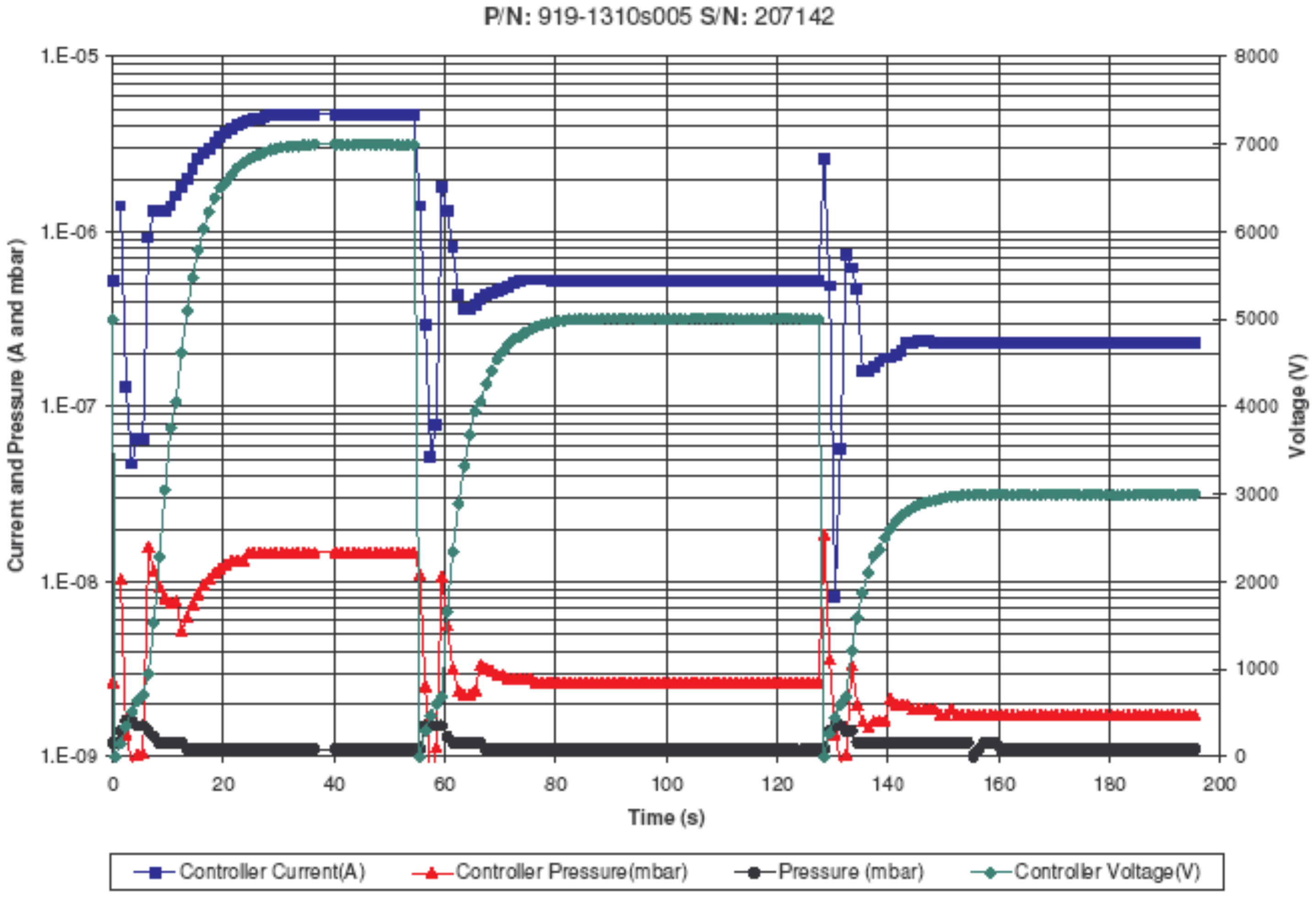
Pumping Speed vs. Applied Voltage



ION Pumps
Pressure measurement

- An Ion Pump is a Penning cell, Ion Current Proportional to Pressure
- IP Parameters (V , B , cell dimensions) optimized for pumping, not for pressure reading
- Current reading may be affected by Field Emission Current (independent of pressure)
- Total current (Ion + FE) conversion into pressure may be questionable
- FE current effect is dominant when Ion current is very low (Low p) and negligible when Ion current is high (High p)
- FE current is an exponential function of Voltage
- Lowering V at low pressures minimizes the FE current and allows a reilable current to pressure conversion

ION Pumps
Field Emission (leakage) current effect



ION Pumps
Field Emission (leakage) current effect