Extreme High Vacuum System of High Brightness Electron Source for ERL

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Outline

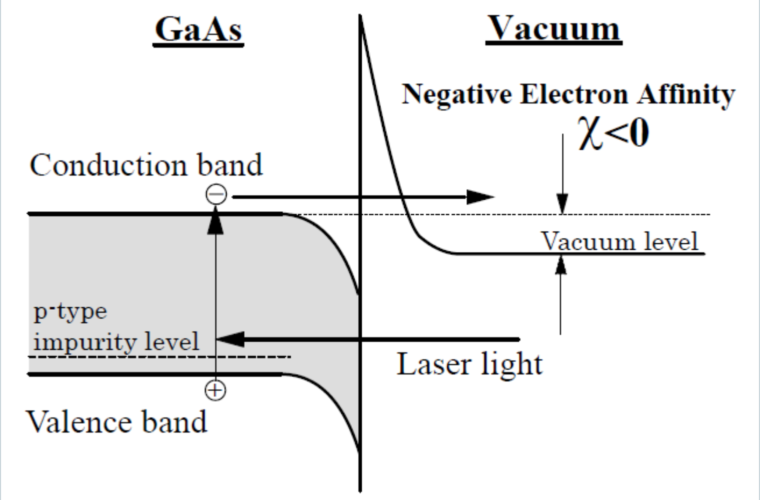
- Background
- Overview of the vacuum system for a 500 kV electron gun
- Total outgassing rate measurement
- Pumping speed measurement in UHV
- Summary

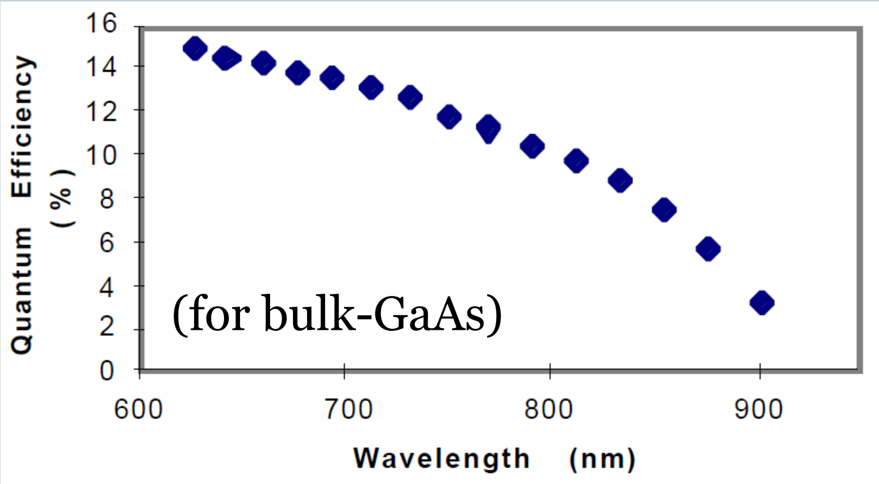
Simple formula of ultimate pressure

$$P\ [\mathrm{Pa}] = \frac{Q\ [\mathrm{Pa \cdot m^3/s}]}{S\ [\mathrm{m^3/s}]}$$

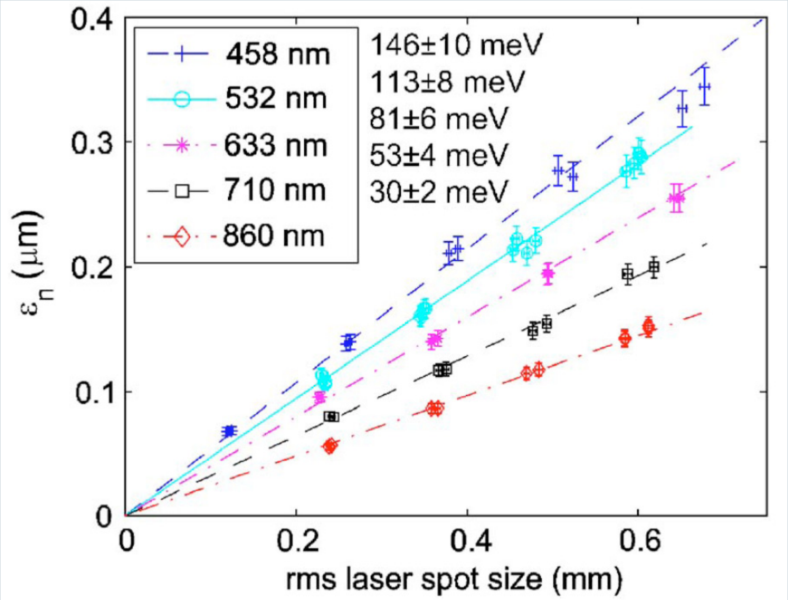
Background (1)

- GaAs-based high brightness DC-gun
  - A GaAs photocathode with negative electron affinity (NEA) surface can produce low emittance electron beams.
  - High quantum efficiency of > 10 % can be achieved.





Reference: C. K. Sinclair et al., Proceedings of PAC97 p.2864

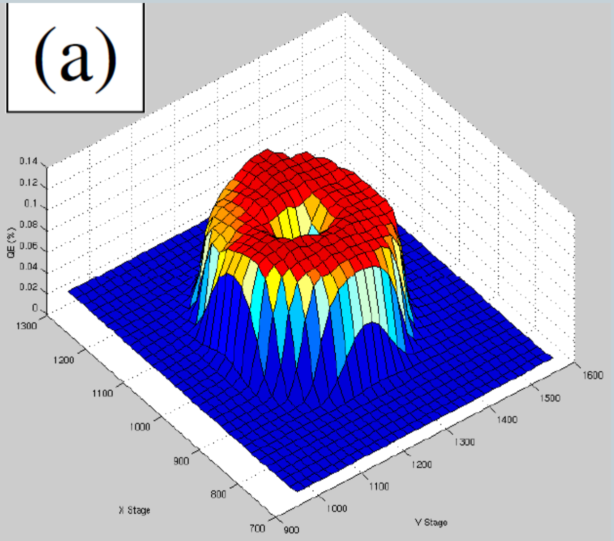


Reference: I. V. Bazarov et al., J. Appl. Phys. 103, (2008) 054901

Background (2)

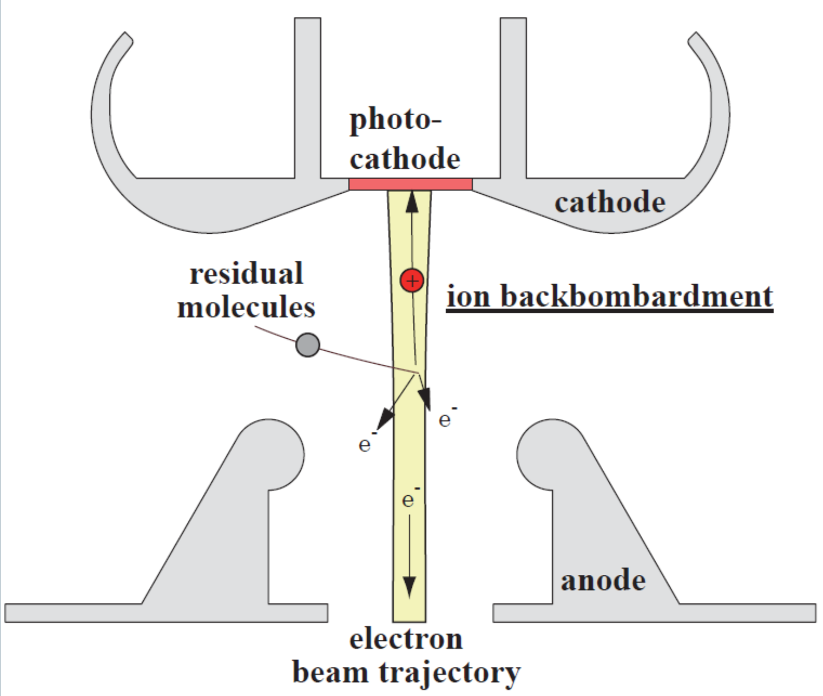
- Cathode lifetime problem

NEA surface is easily degrade by ion back-bombardment.



Reference: C. K. Sinclair et al., Phys. Rev. STAB 10, (2007) 023501

Charge lifetime is limited ~1000 Coulomb for 10 mA operation under the pressure range of ~10^{-9} Pa.



Lifetime τ is defined as

$$QE(t) = QE_0 \cdot e^{-\frac{t}{\tau}}$$

Charge lifetime Q_τ is defined as

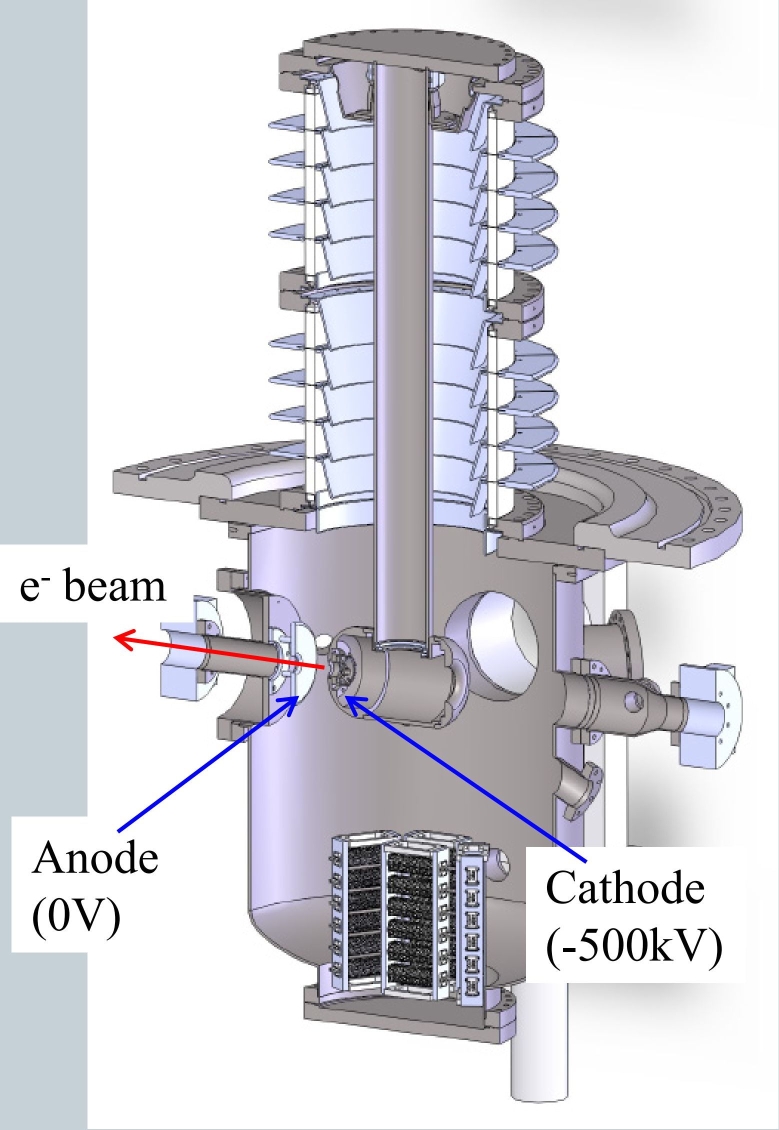
$$Q_\tau = \int_0^\tau I_{beam}(t)dt$$

Overview of electron source vacuum system

- High voltage insulator
  - Inner diameter of ϕ=360 mm
  - Segmented structure
- Low outgassing material
  - Large titanium vacuum chamber (ID~ϕ630 mm)
  - Titanium electrode, guard rings
- Main vacuum pump system
  - **Bakeable cryopump**
  - NEG pump (> $1x10^4$ L/s, for hydrogen)
- Large rough pumping system
  - 1000 L/s TMP & ICF253 Gate valve

Goal

Ultimate pressure : $1x10^{-10}$ Pa

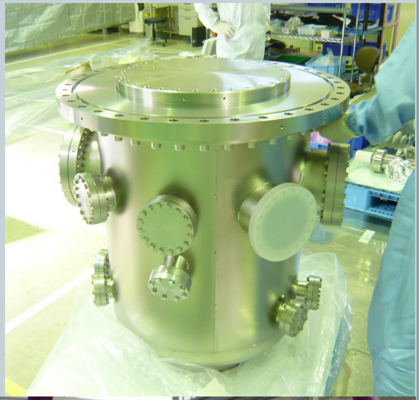


Total outgassing rate measurement (1)

- Method : Rate-of-Rise (RoR) measurement

$$\frac{dP}{dt} = \frac{Q\ [Pa \cdot m^3/s]}{V\ [m^3]}$$

Q: total outgassing rate
V: chamber volume

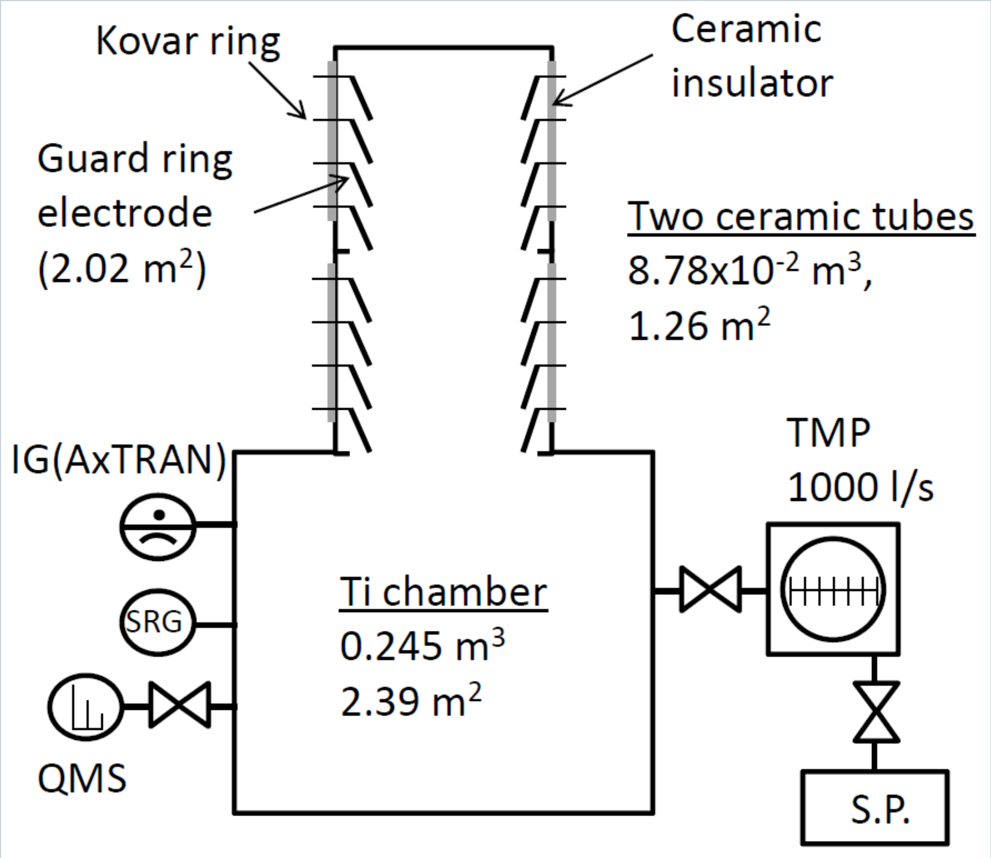


- Process of measurements

1. Individual bakeout & RoR measurement.
   - Titanium chamber (150 °C, 50 hrs)
   - Ceramic insulator tubes (200 °C, 100 hrs)
2. Assembled each part and guard ring electrodes.
3. Bakeout & measurement of the total system.

Total outgassing rate measurement (2)

- Assembled dc gun system



Spinning rotor gauge (SRG) was employed to suppress outgassing from the gauge.

Total outgassing rate measurement (3)

- Result of assembled RoR measurement (measured by SRG)

Baking condition
temperature: 150~200 °C
period: 100 hours

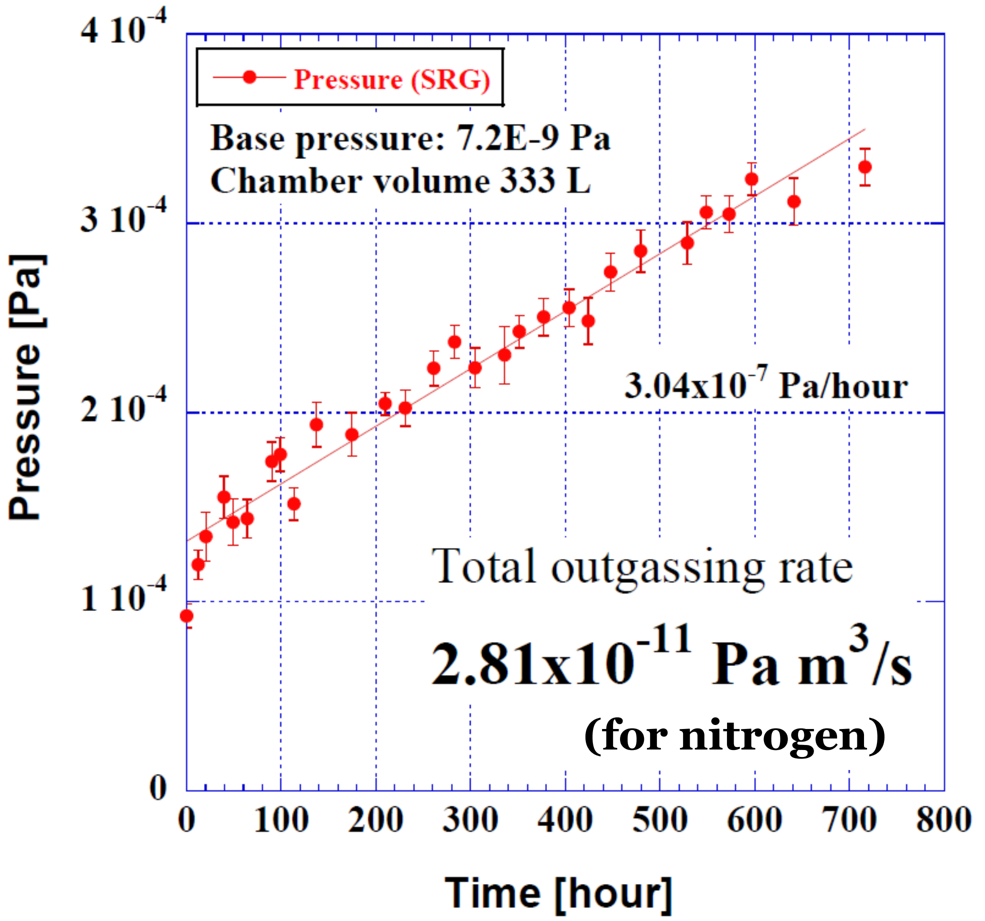
Compensation factor for SRG

$$P_{H_2} = \sqrt{\frac{M_{N_2}}{M_{H_2}}} \cdot P_{N_2}$$

Total outgassing rate

Q=1.05x10^{-10} Pa m^3/s

(for hydrogen)



Estimation of total outgassing rate from all system

Installed components	Surface area A [m^2]	Total outgassing Q [Pa·m^3/s] (**SRG**)
Gun chamber body	2.4	**1.1×10^{-10}** **(w/o viewports)**
Ceramic insulator tubes	1.6	
Guard ring electrodes	2	
Gate valves & View ports	~0.3	

Installation scheduled components		estimated total outgassing Q [Pa·m^3/s]
Cathode electrode & Support rod	~1.5	($\leq 1.5 \times 10^{-10}$)
Anode electrode	<0.3	($\sim 3.0 \times 10^{-11}$)
NEG cartriges support	<0.5	($\leq 2.5 \times 10^{-11}$)
Cryopump chamber	<0.5	($\leq 2.5 \times 10^{-11}$)

Total Q of the DC-gun	**Goal : $< 3 \times 10^{-10}$**

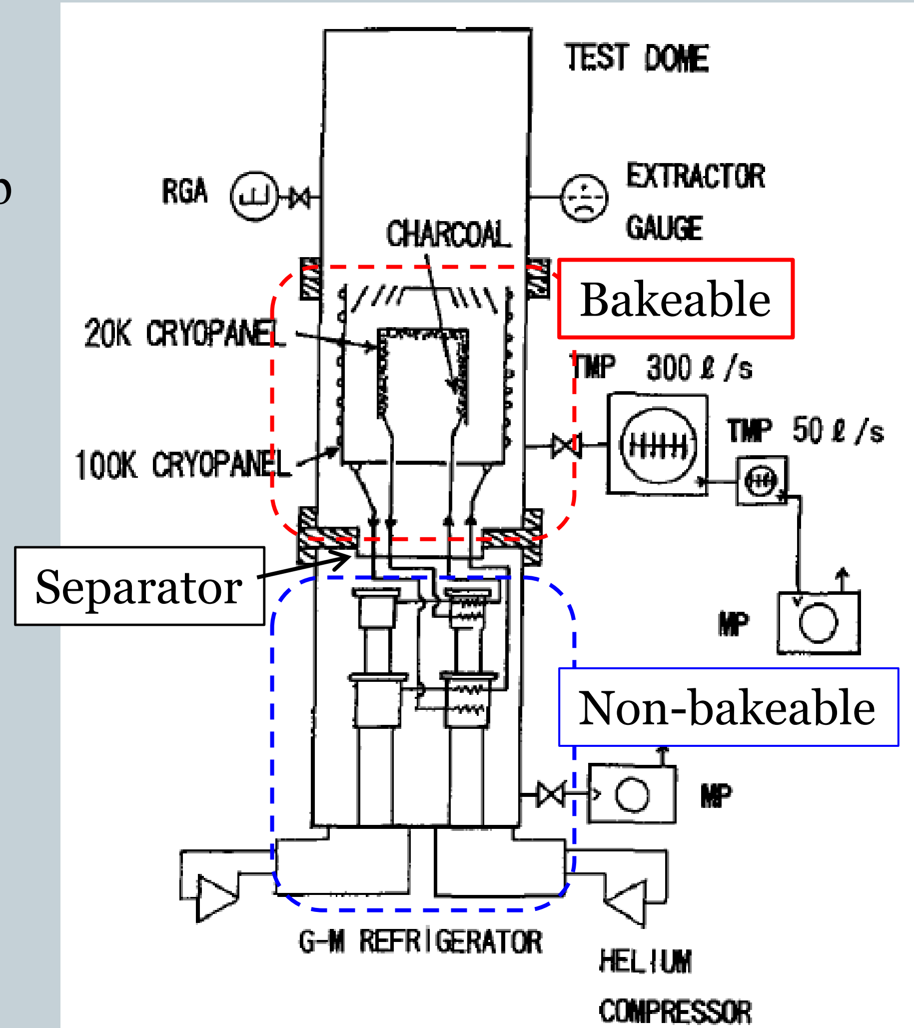
(The values of the total outgassing rate are equivalent for hydrogen.)

Bakeable Cryopump

- Features of the structure
  - G-M refrigerator system is separated spatially from cryopump housing.
  - Adsorbent is fixed on a cryopanel without resin.

Cryopump housing has a capability for baking over 150 °C including adsorbent. (high temperature regeneration of adsorbent is possible.)

Bakeable cryopump can achieve high performance for cryo-sorption under UHV condition.



Reference: H. Yamakawa, Vacuum 44, (1993) 675

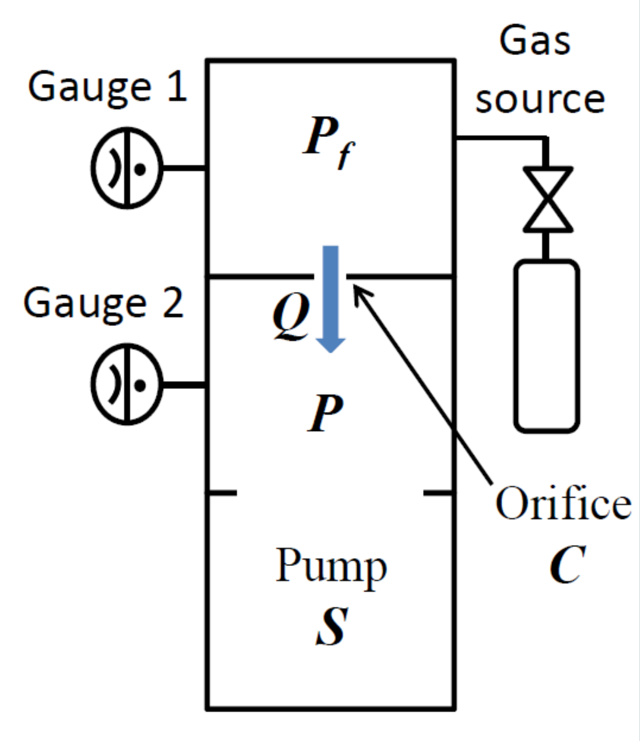
Pumping speed measurement

- Principle

$$S\ [m^3/s] = \frac{Q\ [Pa \cdot m^3/s]}{P\ [Pa]}$$

Basically, pumping speed (S) depend on the pressure (P) and gas species.

- Key issues
  - Precise measurement for pressure (P) and gas flow (Q)
  - Q is decided by conductance (C) and differential pressure ($\Delta P = P_f - P$) between pump test chamber and gas introduction system.



$$Q\ [Pa\ m^3/s]$$
$$= \Delta P\ [Pa] \cdot C\ [m^3/s]$$
$$= (P_f - P) \cdot C$$

Standard conductance element

- Special features
  - The element was made of sintered stainless steel with a pore size of less than 1 μm.
  - Molecular flow is realized at a pressure of $< 10^4$ Pa.
- Gas flow Q [Pa m³/s]

$$Q\,[\mathrm{Pa\cdot m^3/s}] = \underset{(P_f >> P)}{P_f\,[\mathrm{Pa}]} \cdot C\,[\mathrm{m^3/s}] \cdot \sqrt{\frac{28}{M_a}}\sqrt{\frac{T\,[\mathrm{K}]}{T_0}}$$

In this experiment, $C=3.03\times10^{-10}$ [m³/s] (T_0=T=300K, for nitrogen)

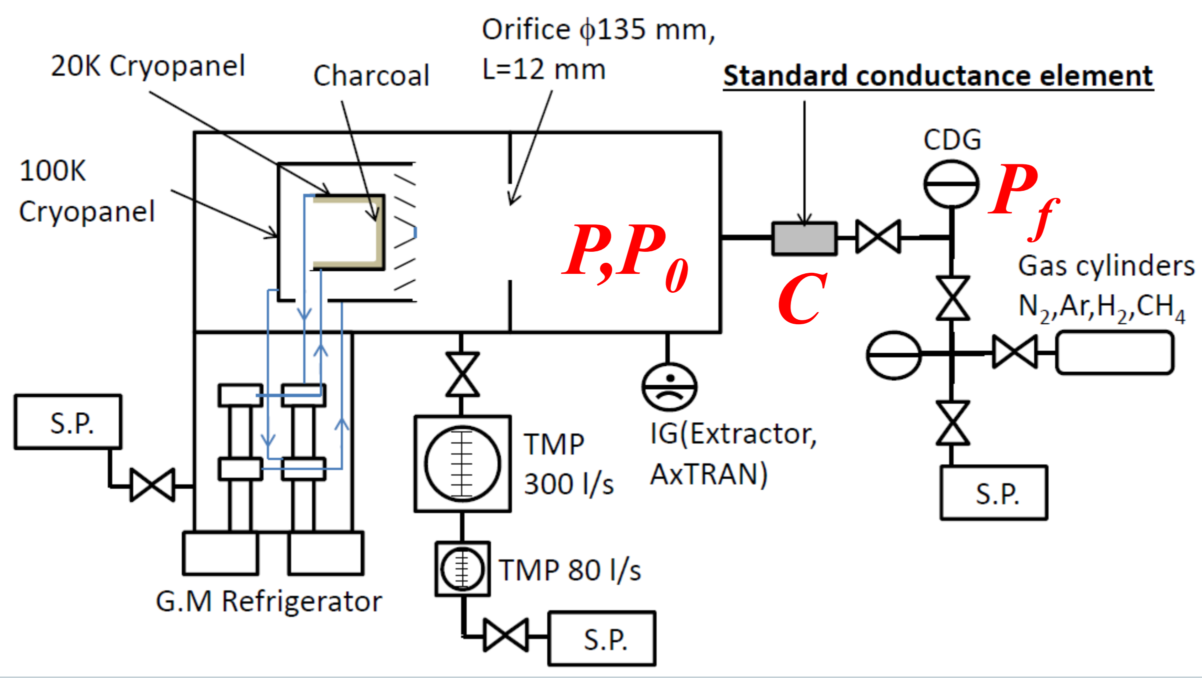
- Advantages
  - Conductance is easily compensated for gas species by the molecular mass.
  - Conductance is constant against changing in the upstream pressure of $< 10^4$ Pa.
  - Dependence of flow rate on the temperature is small in RT.

The calibrated element is commercially available from AIST.

Pumping speed measurement system

Pumping speed

$$S_{(P)} = \frac{Q_{(P_f)}}{(P - P_0)/\alpha}$$



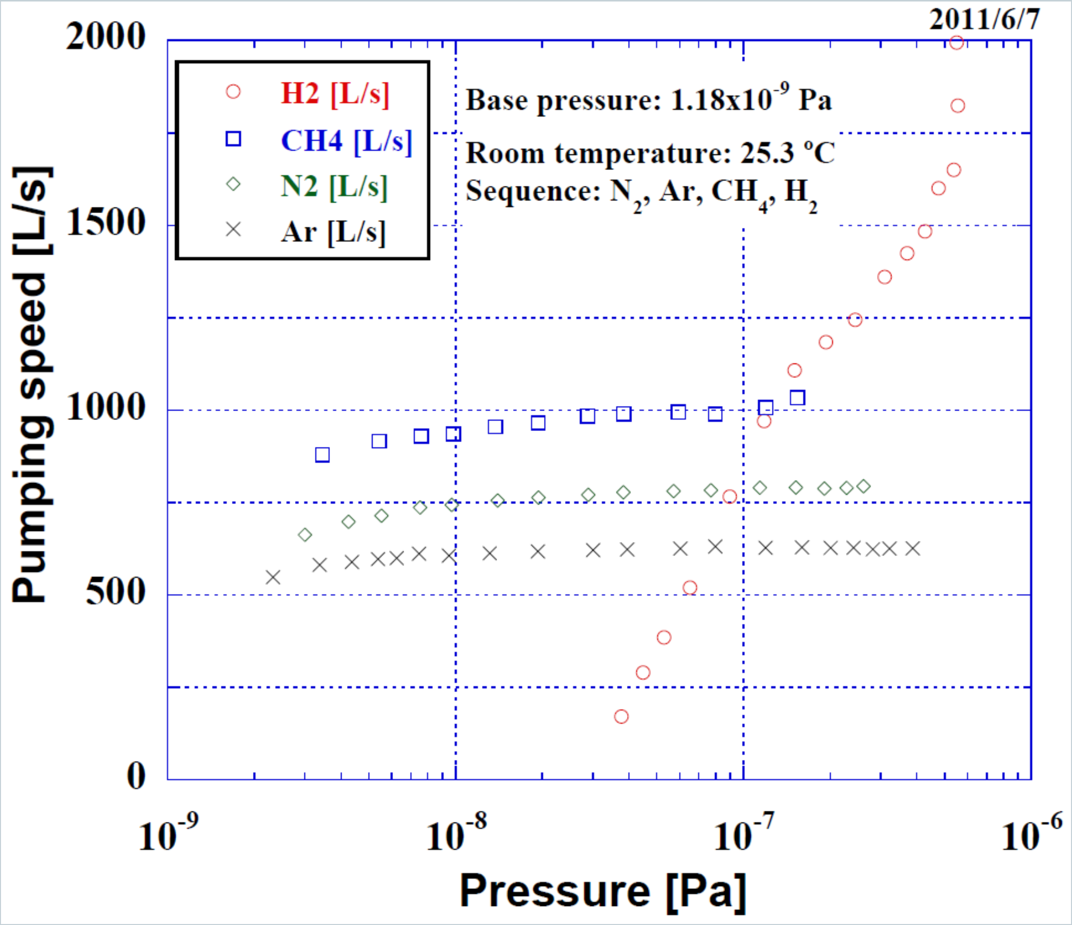
Relative sensitivity factor: α

	ATG	EXG
H2	0.48	0.45
CH4	1.69	1.56
Ar	1.43	1.41

$$Q\,[\mathrm{Pa \cdot m^3/s}] = P_f\,[\mathrm{Pa}] \cdot C\,[\mathrm{m^3/s}] \cdot \sqrt{\frac{28}{M_a}}\sqrt{\frac{T\,[\mathrm{K}]}{T_0}}$$

- Pressure measurement (***P***, P_0)
  - Axial Transmission Gauge (ATG)
  - Extractor Gauge (EXG)
- Gas flow control (***Q***)
  - Standard conductance element (***C***)
  - Capacitance Diaphragm Gauge (P_f)

Pumping speed of 20 K bakeable cryopump



Baking condition

temperature: 200~230 °C

period: 80 hours

Base pressure: 1.2x10^{-9} Pa

The result was calculated from the pressure data of ATG.

The result was almost the same tendency by using the data of EXG.

Pumping probability

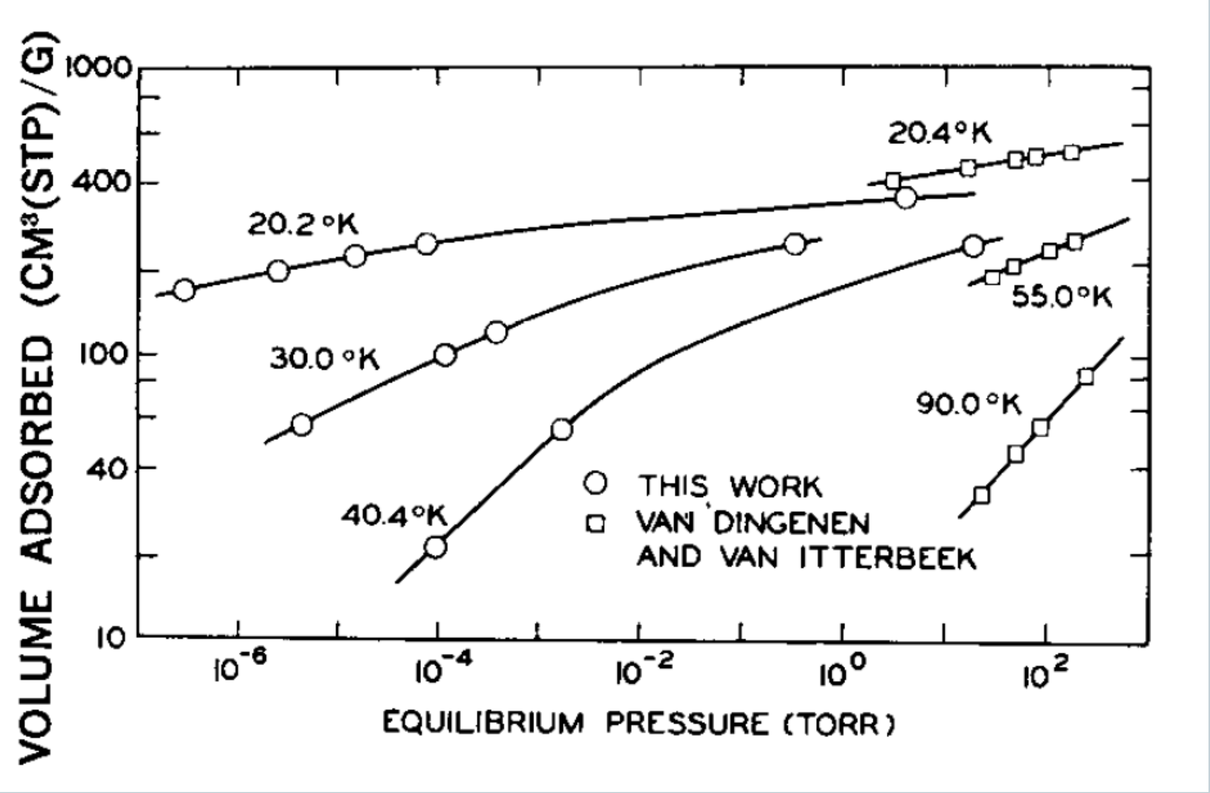
$$\frac{N_p}{N_0} \sim 0.5$$

For N_2, CH_4, Ar

Cryo-condensation or cryo-sorption is functioned well for N_2, CH_4 and Ar.
However, cryo-sorption is limited for H_2 under the pressure of < 10^{-6} Pa.

Adsorption Equilibrium

- Adsorption equilibrium of charcoal for hydrogen

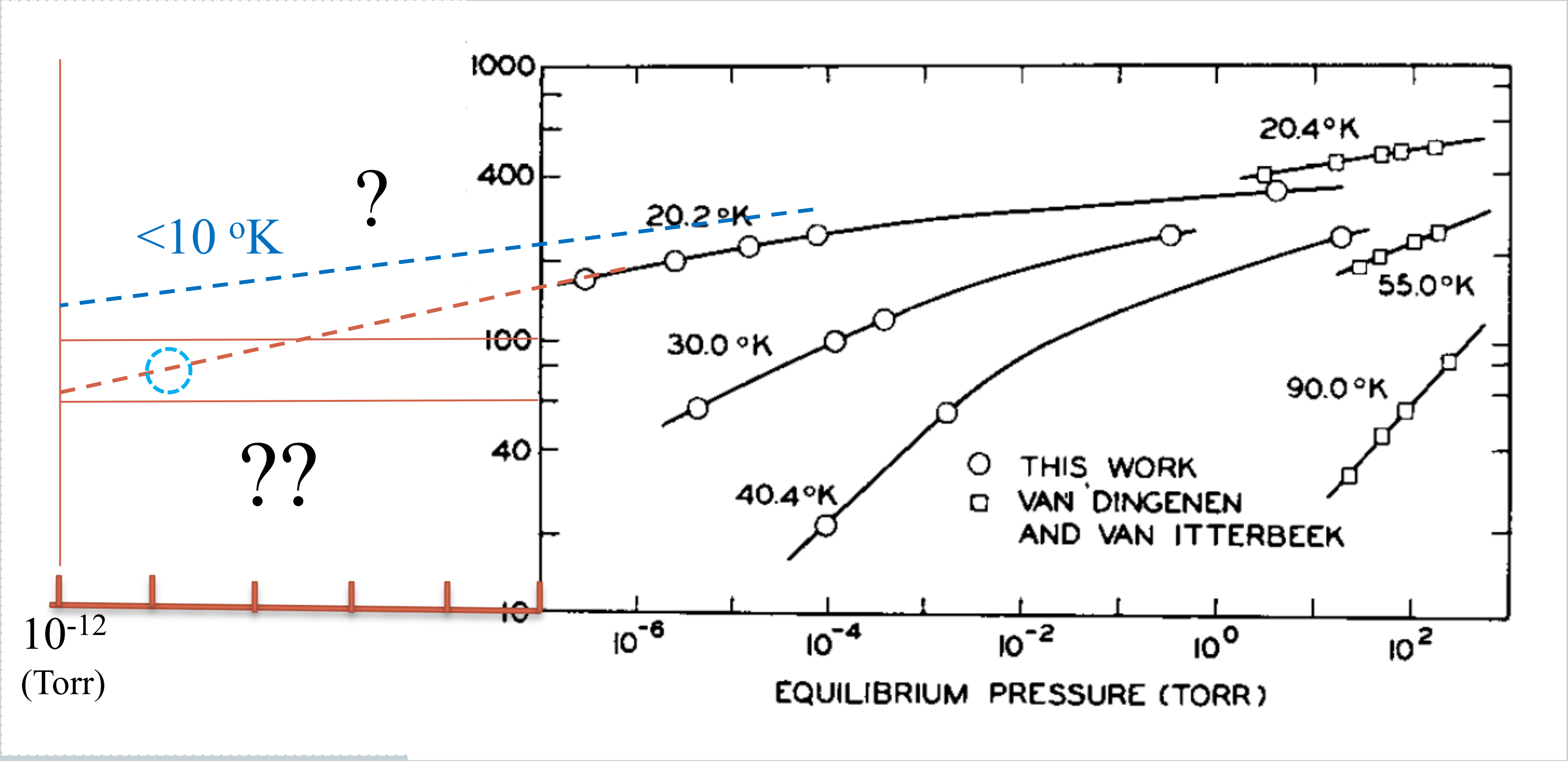


Ref. S. A. Stern, et al., J. Vac. Sci. Technol. 2, (1965) 165.

Cryo-sorption for hydrogen on a charcoal depends on the temperature of charcoal and the concentration of hydrogen in the charcoal.

Adsorption Equilibrium

- Adsorption equilibrium of charcoal for hydrogen



Ref. S. A. Stern, et al., J. Vac. Sci. Technol. 2, (1965) 165.

Cryo-sorption for hydrogen on a charcoal depends on the temperature of charcoal and the concentration of hydrogen in the charcoal.

Degassing by a long term baking or operation at low temperature is necessary.

Summary & Future

- The total outgassing rate of the dc gun with main components was suppressed to $Q \sim 1\times10^{-10}$ [Pa m^3/s].
  - Outgassing from the remaining components should be suppressed.
- The pumping speed of the 20 K bakeable cryopump was obtained for nitrogen, methane, argon, and hydrogen.
  - The ultimate pressure of the bakeable cryopump was limited by adsorption equilibrium of adsorbent for hydrogen.
  - A test about 4 K bakeable cryopump is in progress.

The possibility of generating extreme high vacuum of 1×10^{-10} Pa in the actual dc gun is still remained !