



Low-Cost, High-Performance Non-Evaporable Getter (NEG) Pumps Using NEG Pills

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Future plan of Photon Factory (PF), KEK in Japan

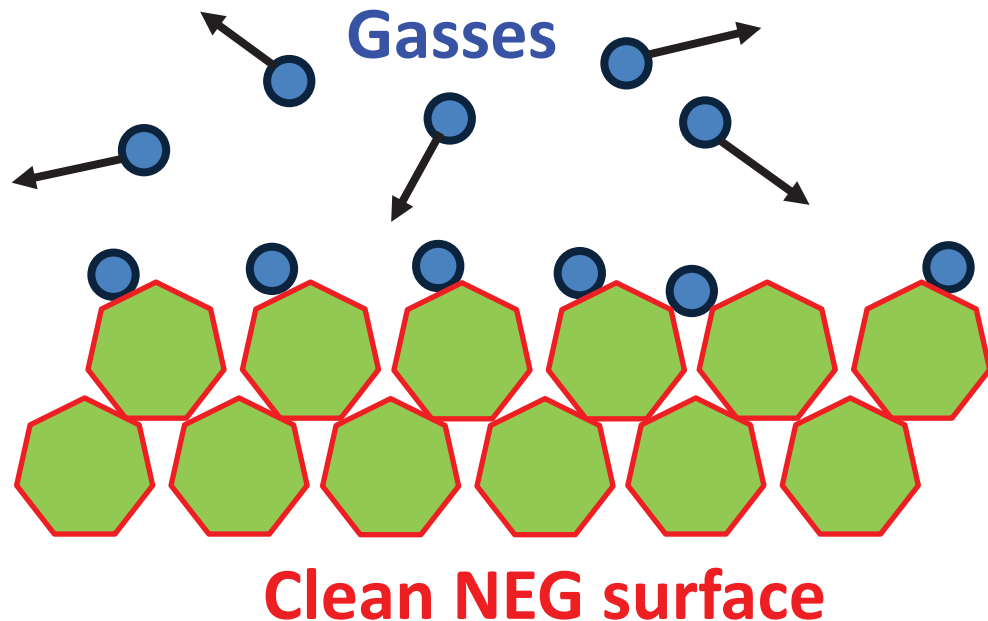
- ✓ PF is 34 years old but ~3400 researchers still uses PF per year.
- ✓ We have a plan to develop a **3 GeV storage ring light source with hybrid multi-bend achromat (KEK light source, KEK-LS)**
- ✓ Vacuum technology such as **Non-Evaporable Getter (NEG) Pumps and NEG coating** must be developed for KEK-LS.

エネルギー	Energy	E [GeV]	3GeV		
ラティスの型	Lattice		HMBA (Hybrid Multi-Bend Achromat)		
長周期数	# of SC	N_s	20		
周長	circumference	C [m]	570.721		
1.2m 短直線部数	# of 1.2-m ID		20		
5.6m 長直線部数	# of 5.6-m ID		20		
セル数	# of cells		20		
RF周波数	RF frequency	f_{RF} [MHz]	500.0735096		
ハーモニク数	Harmonic num.	h	952		
RF電圧	RF voltage	V_{RF} [MV]	2		
Bucket height		%	3.98		
Energy loss		MeV/rev	0.2984335		
モーメントムコンパクション		α	2.1893×10^{-4}		
ベータトロンチューン		ν_x, ν_y	48.58, 17.62		
damping turns x, y, z		[turns]	15364, 20105, 11887		
damping time x, y, z		[ms]	29.25, 38.28, 22.63		
beam current		[mA]	0	200	500
hor. emittance		[pmrad]	132.51	230.5	314.74
ver. emittance		[pmrad]		8.1	8.2

[http://www2.kek.jp/imss/notice/assets/2016/09/09/KEKLS_CDR_160909.pdf]

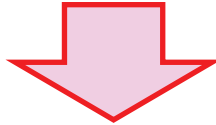
Non-evaporable getter (NEG) pumps

- ✓ The most popular NEG materials is an alloy comprising **70 wt% Zr, 24.6 wt% V, and 5.4 wt% Fe** developed and commercialized by SAES Getters under the trademark of **St 707®** [C. Boffito *et al.*, JVST 18, 1117 (1981)].
- ✓ St 707® NEG can be **fully activated by heating to 400 °C for 45 min** [C. Benvenuti and P. Chiggiato, JVST A 14, 3278 (1996).]
- ✓ After activation **residual gasses such as H₂, H₂O, CO, CO₂ can be pumped** by chemical adsorption on NEG surface.
- ✓ Advantages of NEG pumps are oil free, evaporation free, sputtering free, sublimation free, magnetic field free, vibration free, economical, compact, lightweight, and energy saving.



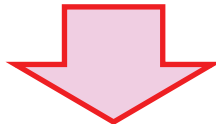
Disadvantages of NEG pumps

- ✓ Rare gasses can not be pumped.
- ✓ CH₄ can not be pumped at room temperature.
- ✓ Pumping speed decreases as pumped-quantity increases.
- ✓ NEG materials must be replaced after the lifetime.



These disadvantages are not serious in SR facilities, because vacuum systems are not vented frequently.

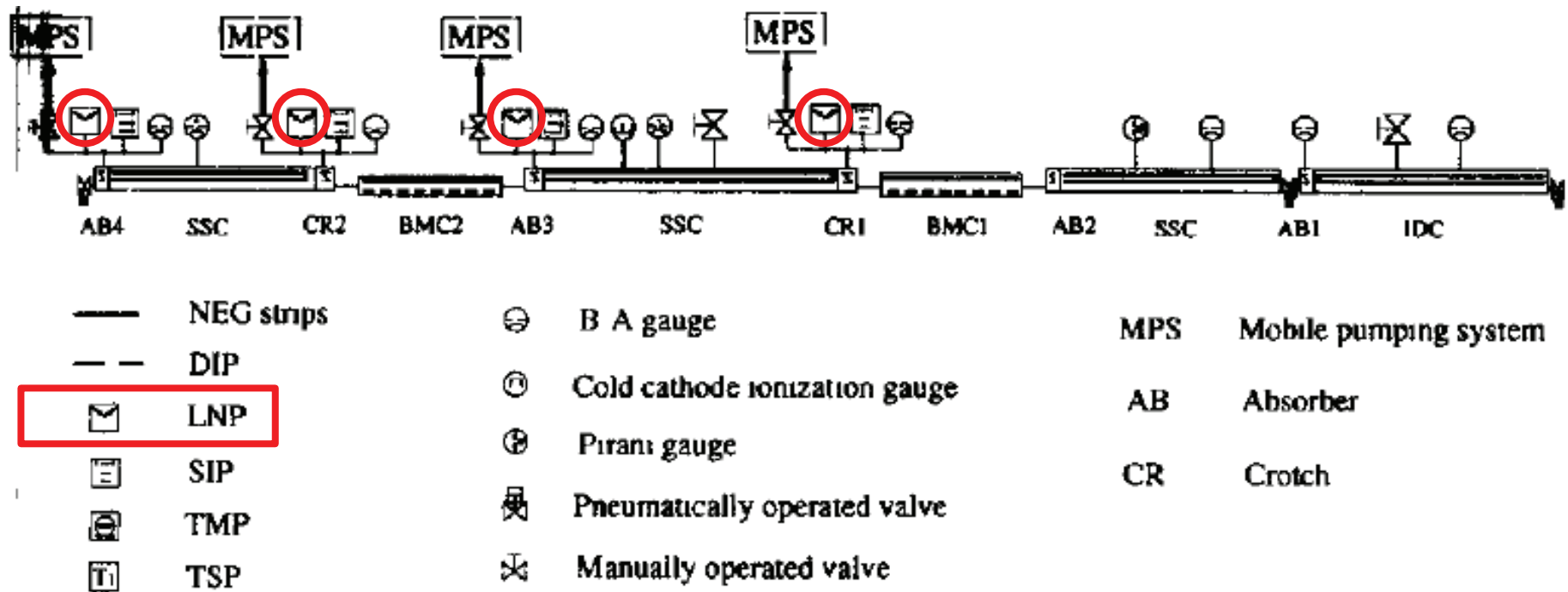
- ✓ Manufacturer of NEG pumps are quite limited.
- ✓ NEG pumps are expensive in some countries.



We often purchase NEG modules or NEG materials and construct NEG pumps. NEG strips are mainly used so far.

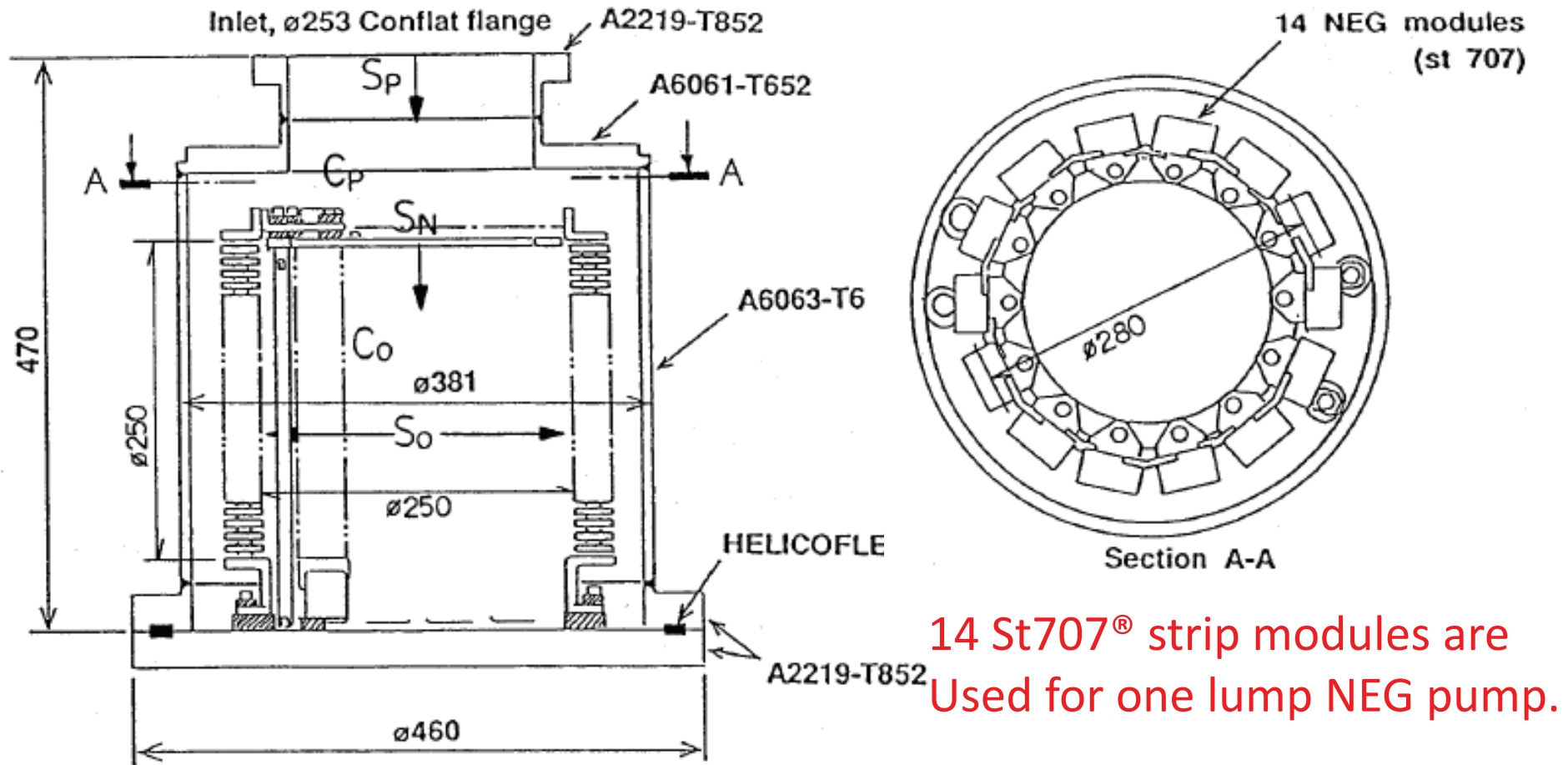
NEG pumps used at SPring-8 in Japan

Four Lumped NEG pumps (LNPs) are used in one cell of SPring-8 (4 LNPs $\times$ 44 cells = 176 LNPs). Straight and bending sections are pumped with St707[®] strips.



[Sakaue *et al.*, Vacuum **44**, 523 (1993).]

Lump NEG pump developed for SPring8

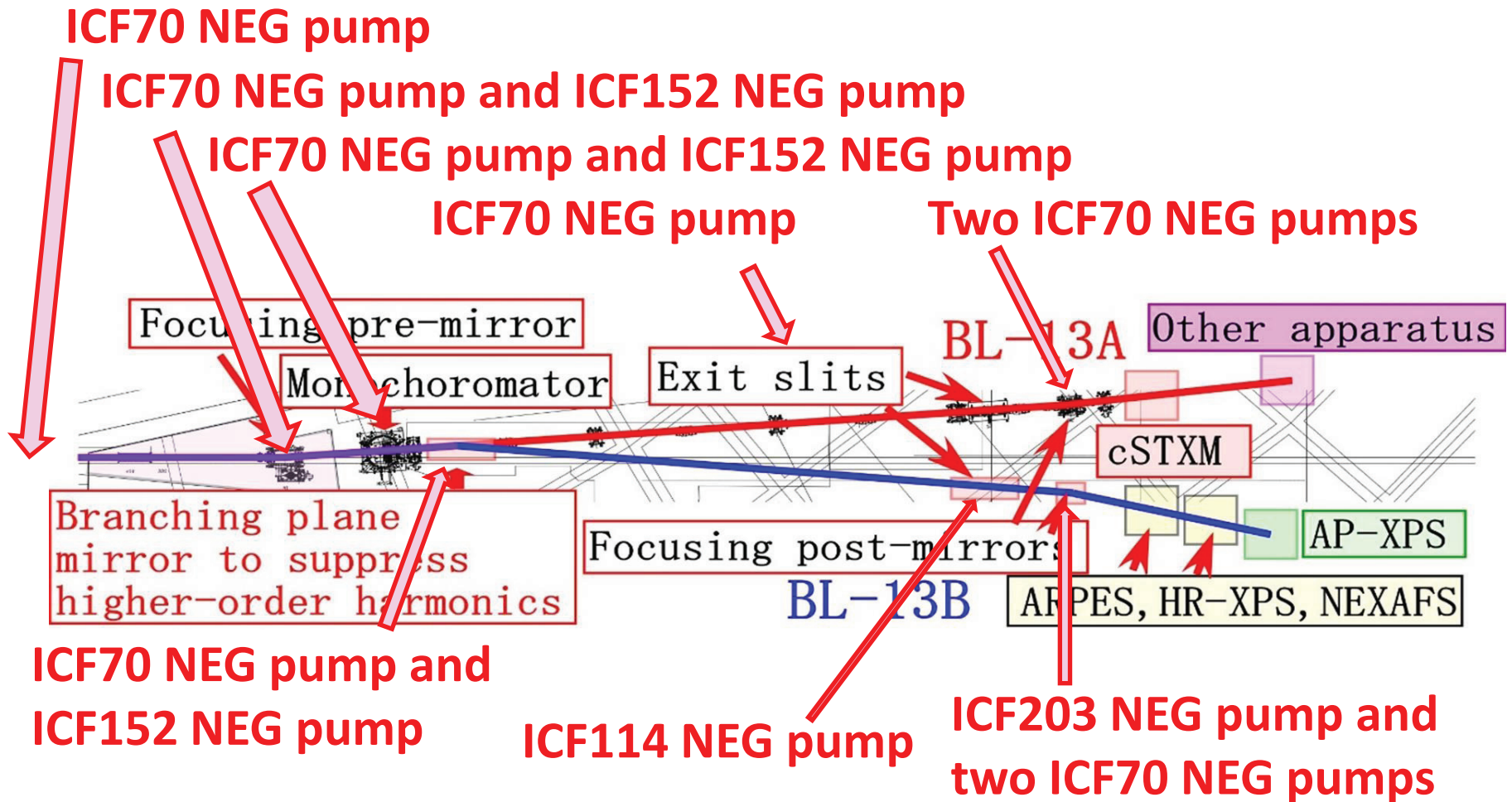


14 St707® strip modules are
Used for one lump NEG pump.

Flange	Number of St707® NEG strip modules	Pumping speed (L/s)			
		H2	N2	CO	CO2
ø253 CF	14	3000	1000	1700	1300

[S. R. In *et al.*, Shinku **34**, 882 (1991).]

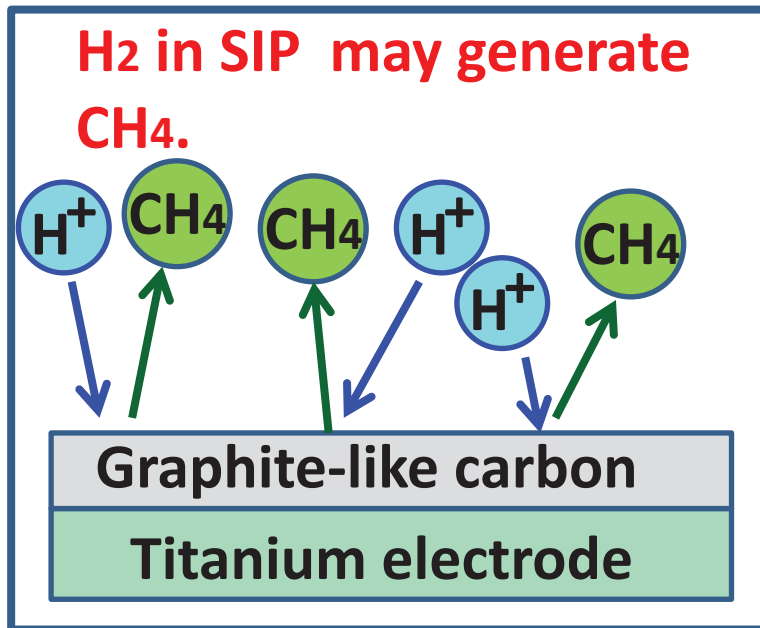
NEG pumps used in VSX beamlines, BL-13A/B at PF



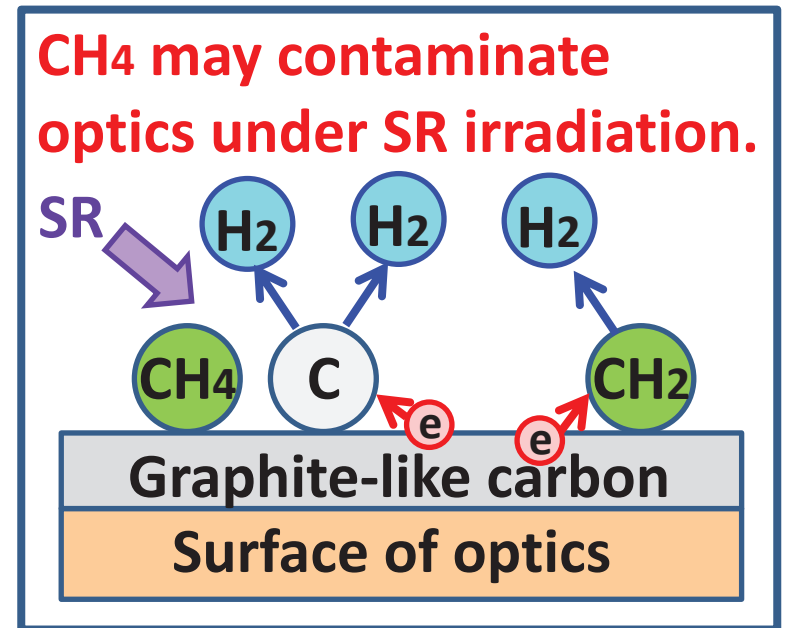
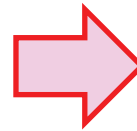
- ✓ More than 10 NEG pumps are required for one VSX beamline.
- ✓ Carbon-contamination on optics are almost completely removed by *in-situ* cleaning methods using activated oxygen under SR irradiation.

➡ Poster WEPE19.

Sputter ion pumps (SIPs) were not used in BL-13B because they may generate C_xH_y when the electrodes are contaminated with carbon. C_xH_y contaminate optics with carbon. **C_xH_y dissociated by photoelectrons are responsible for the carbon contamination of optics.**



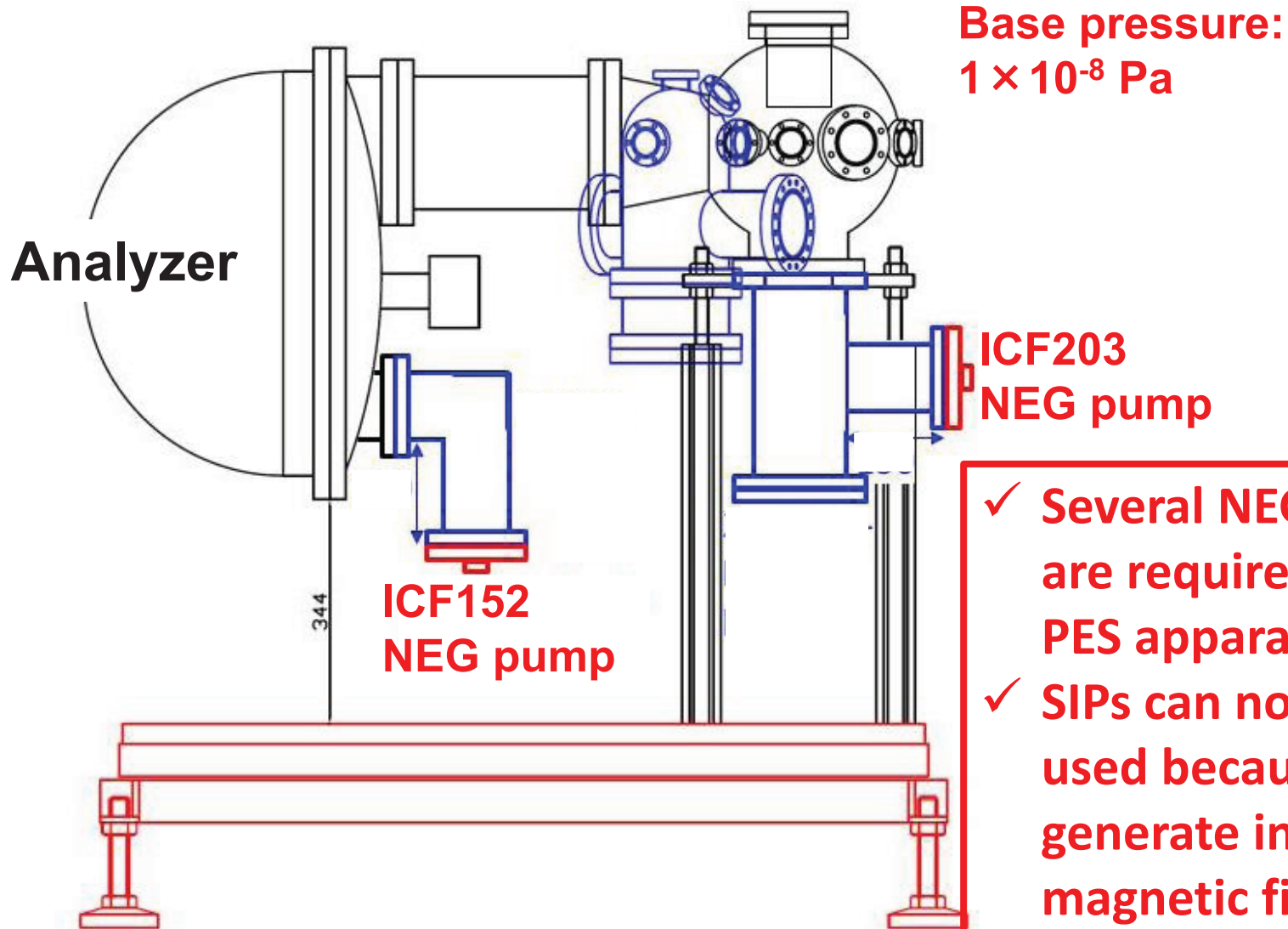
[Yamada *et al.*, J. Nucl. Mater. 111–112, 744 (1982).]



[K. Boller *et al.*, NIMPRA 208, 273 (1983).]

NEG pumps used in endstations

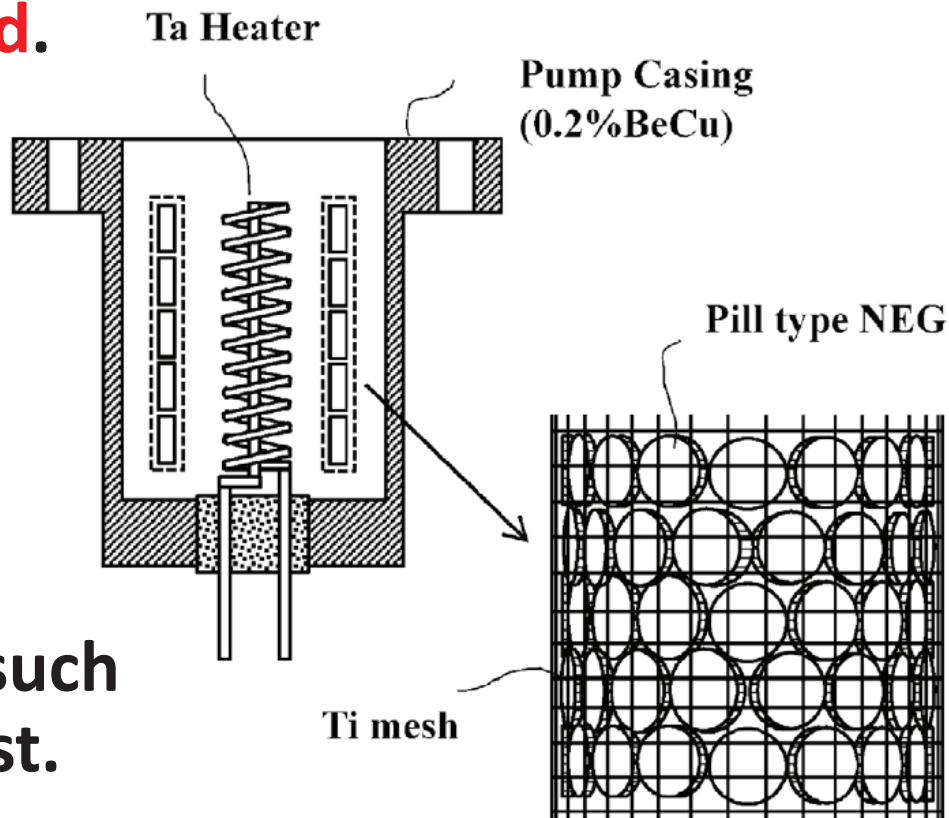
Photoelectron spectroscopy (PES) apparatus



- ✓ Several NEG pumps are required for PES apparatus.
- ✓ SIPs can not be used because they generate intense magnetic fields.

NEG pumps using NEG pills

- ✓ Since hundreds of NEG pumps will be used in KEK-LS, we decided to use **NEG pills**, which consist of compressed NEG powder, for NEG pumps.
- ✓ **NEG pills** are suitable for economical NEG pumps because they are **mass produced, easily available, and reasonably priced.**
- ✓ Pumping speed per NEG pill ($\phi 10\text{mm} \times t 3\text{ mm}$) is about 2 L/s for H₂ after activation.
- ✓ Outgassing from additional materials such as strips does not exist.



Previous NEG pumps using NEG pills

Low-cost NEG pumps using NEG pills (Alvatec Alkali

Vacuum Technologies

GmbH, APG-10-3-001-01;

same composition as SAES

Getters St 707®) [K. Mase

et al., AIP Conf. Proc. 1741,

030015 (2016)]. Measured

Pumping speeds (L/s) for

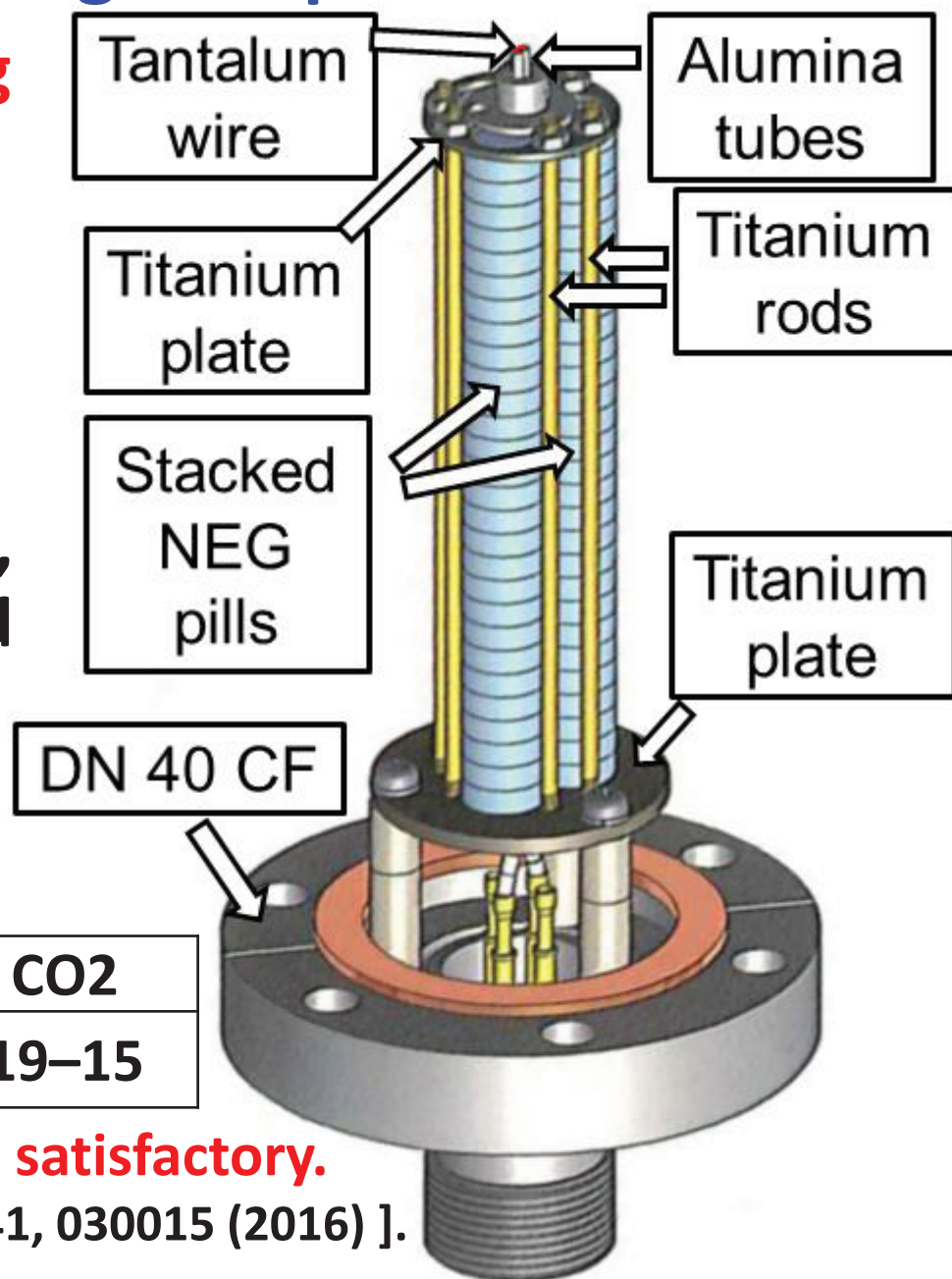
H₂, N₂, CO, and CO₂ after

activation are as follows.

H ₂	N ₂	CO	CO ₂
47–40	8–6	24–17	19–15

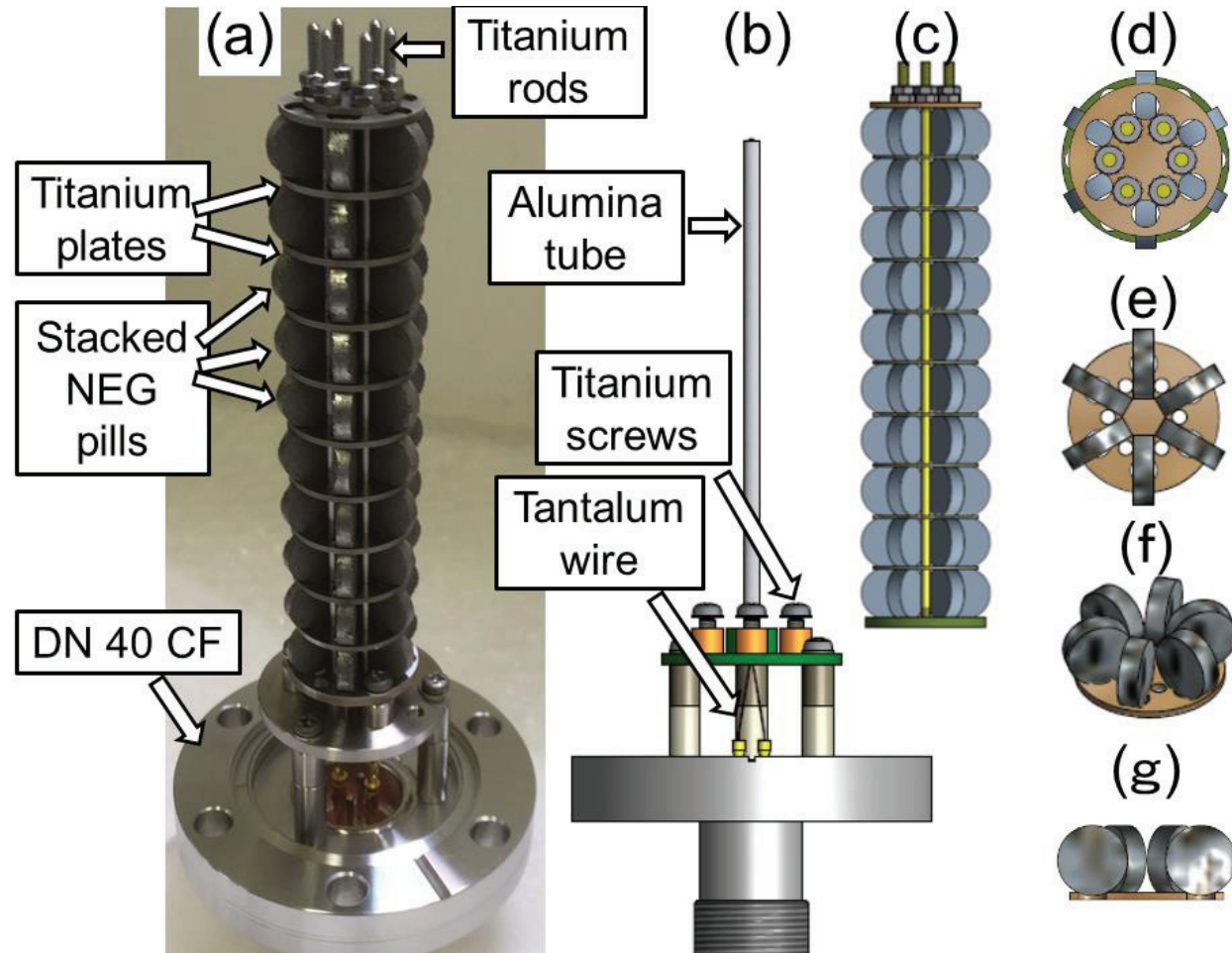
These pumping speeds are not satisfactory.

[K. Mase *et al.*, AIP Conf. Proc. 1741, 030015 (2016)].



New NEG pumps using NEG pills

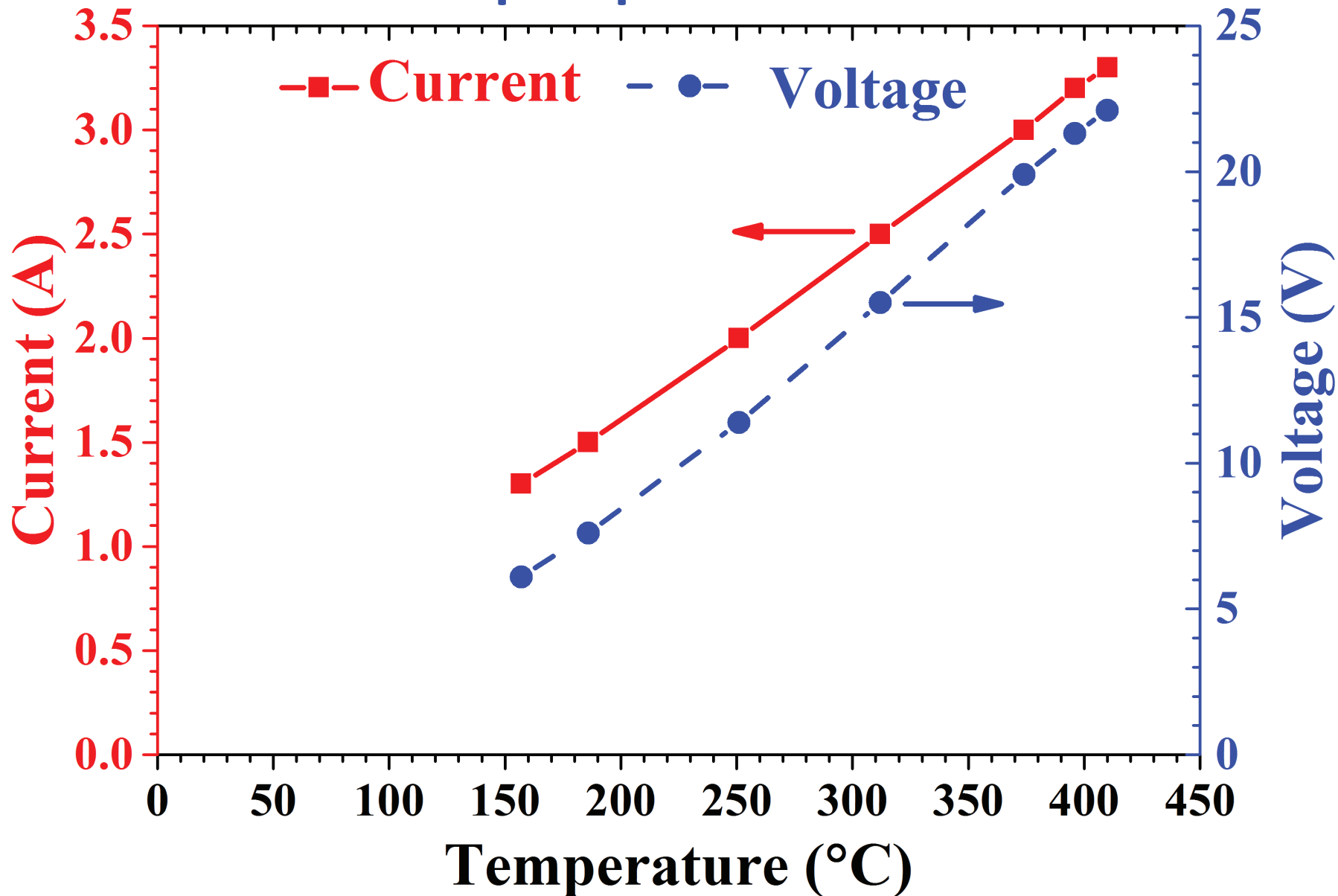
- ✓ 60 NEG pills ($\phi 10$ mm $\times$ $t 3$ mm, Nanjing Huadong Electronics Vacuum Material Co., Ltd) are used.
- ✓ Since effective surface area of NEG pills are increased, the pumping speeds are much improved (more than $\times 3$).



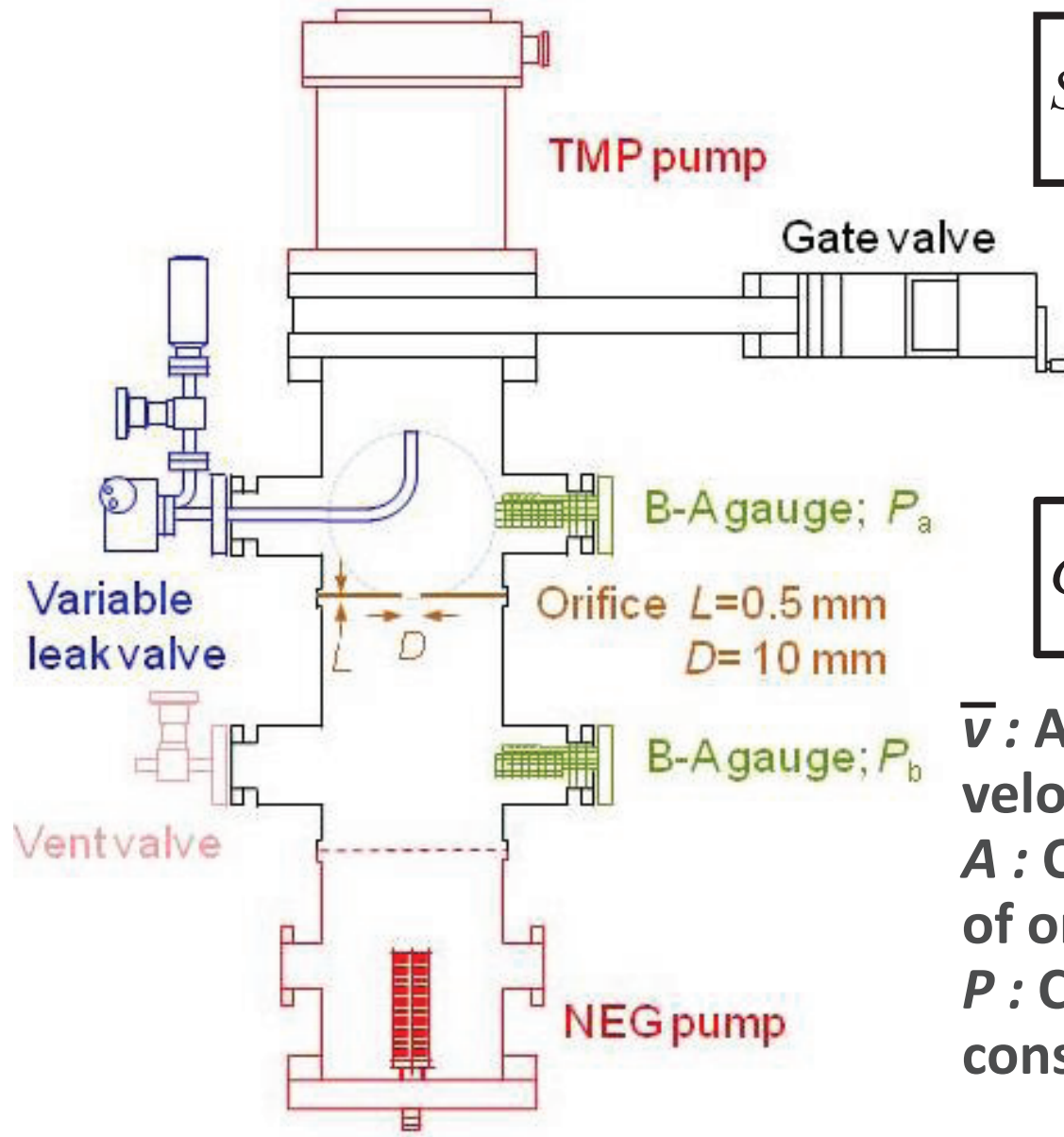
Gasses	H ₂	CO	CO ₂	N ₂
Pumping speed (L/s)	140–130	200–140	190–130	35–17

[H. Kodama *et al.*, J. Vac. Sci. Technol. A 34, 051601 (2016)].

Activation of NEG pump



Apparatus for pumping speed measurements of NEG pumps



$$S = C \left(\frac{P_a - P_{a0}}{P_b - P_{b0}} - 1 \right)$$

S : Pumping speed

C : Conductance

P : Pressure

P_0 : Base pressure

$$C = \frac{1}{4} \bar{v} A P$$

$\bar{v}$: Average velocity of gasses

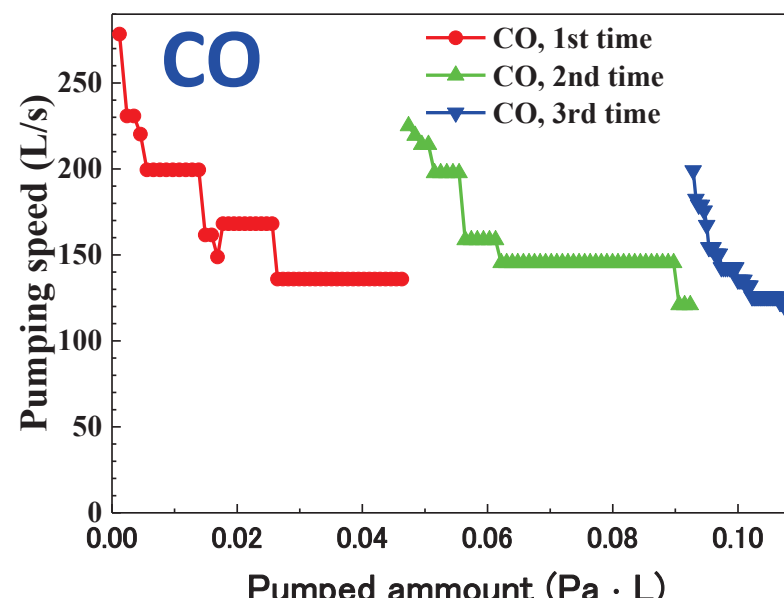
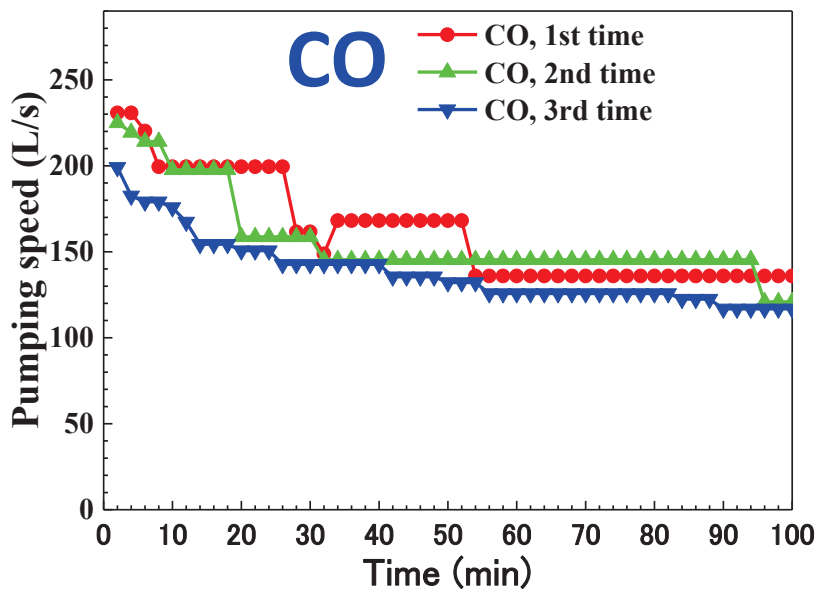
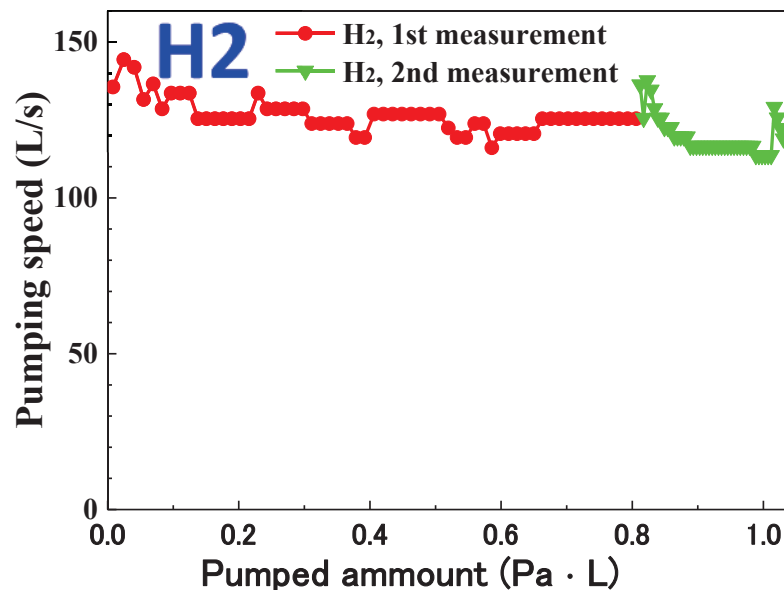
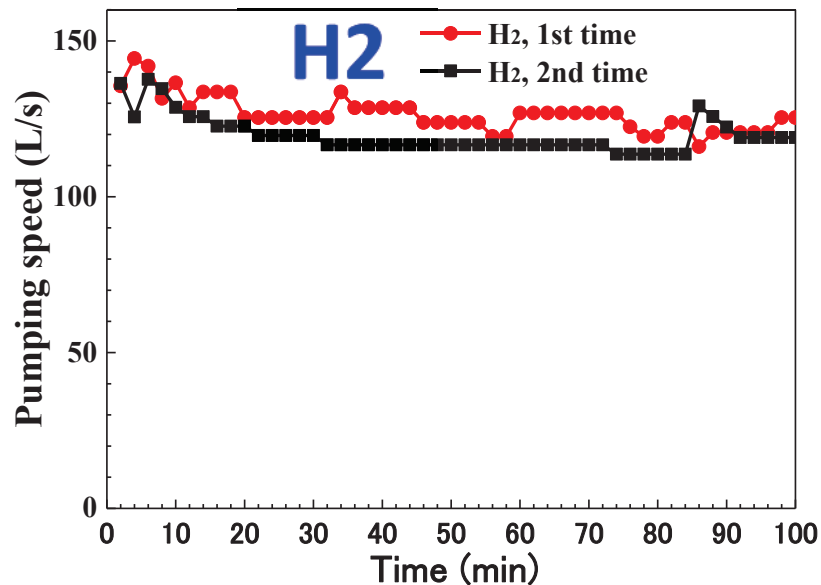
A : Cross section of orifice

P : Clausing constant

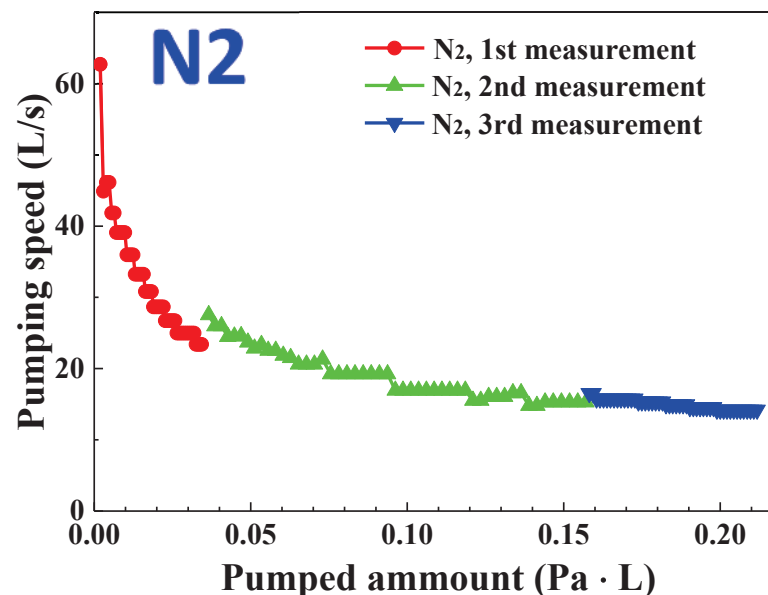
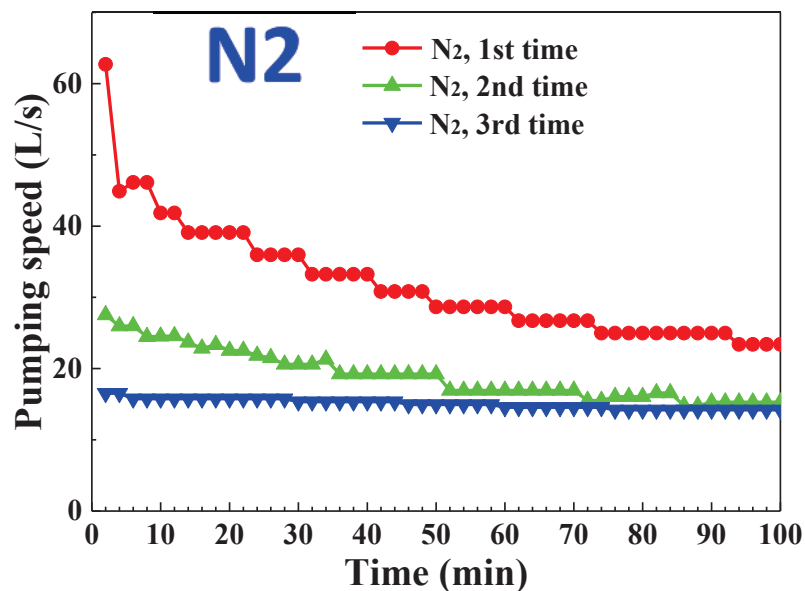
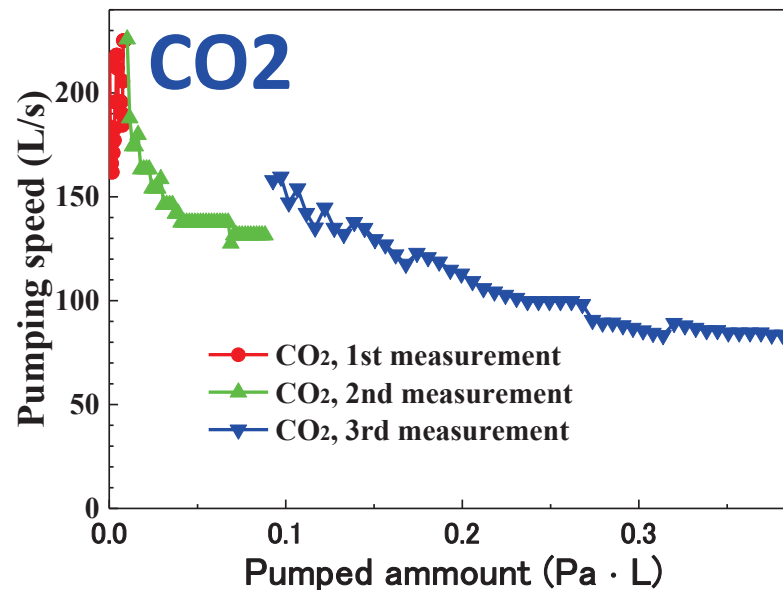
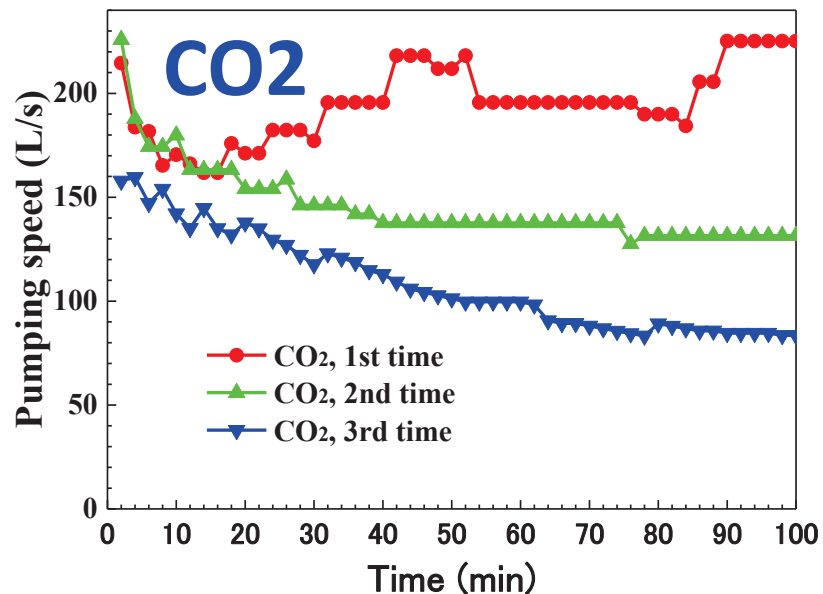
Gas ses	C at 26 °C (L/s)
H2	33.27
N2	8.89
O2	8.31
CO2	7.09
CO	8.89

[K. Mase *et al.*, AIP Conf. Proc. 1741, 030015 (2016)].

Pumping speed measurements for H₂ and CO

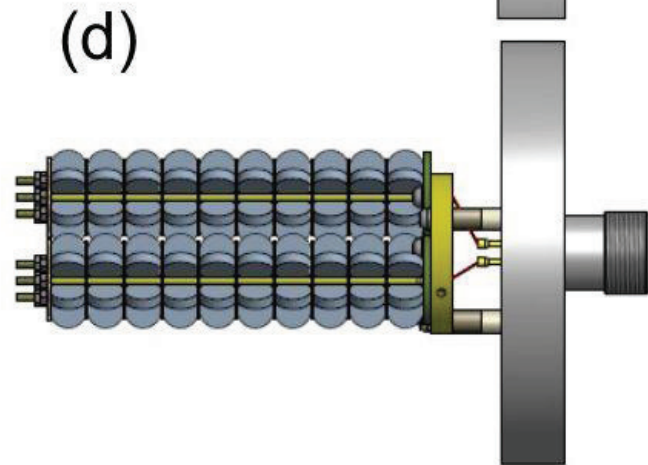
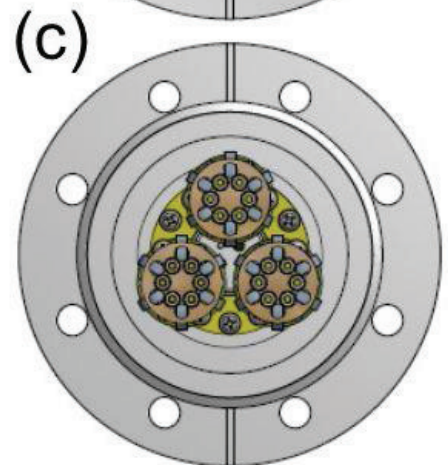
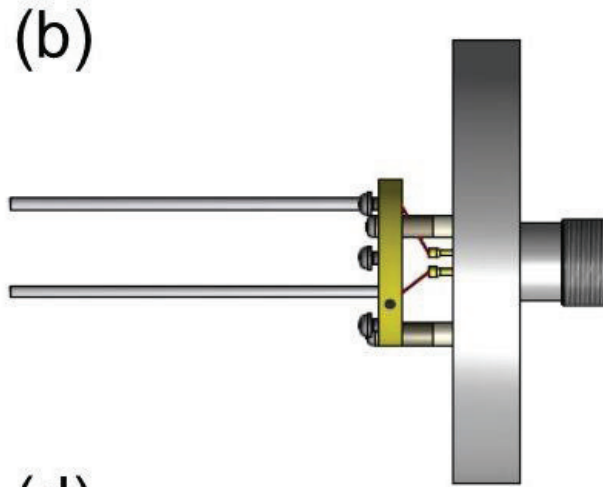
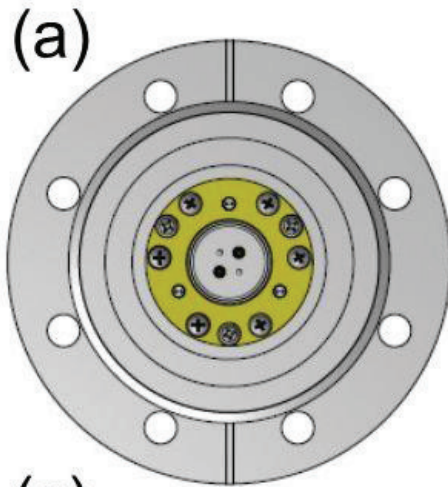


Pumping speed measurements for CO₂ and N₂



Larger NEG pumps using NEG pills

- ✓ Since the NEG pump is composed of a heating unit and a NEG module, the pumping speed can be improved by increasing the number of NEG modules.
- ✓ Various NEG pumps can be developed easily.



Summary

1. We have constructed a NEG pump using a DN 40 CF and 60 NEG pills comprising 70 wt% Zr, 24.6 wt% V, and 5.4 wt% Fe, which is the same composition as SAES Getters St 707®.
2. The pumping speeds of the NEG pump using 60 NEG pills were estimated to be 140–130, 200–140, 190–130, and 35–17 L/s for H₂, CO, CO₂, and N₂ gasses, respectively, in the pumped-quantity range of 0.01–0.1 Pa·L.
3. The pumping speed can be improved by increasing the number of NEG modules with a larger CF flange.
4. These NEG pumps will reduce the construction cost of SR facility because 1) NEG pills are economy, 2) Ti parts can be manufactured in the machine shop, and 3) non-specialist can construct them.

Acknowledgements

We are grateful to the staff of the PF and Mr. N. Ida for their invaluable support. Development of NEG pump is supported by Grant-in-Aid for Scientific Research 26390070.