



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

Hiraku Kodama,<sup>1</sup> Shinya Ohno,<sup>1</sup> Masatoshi Tanaka,<sup>1</sup> Masato Tanaka,<sup>2</sup>  
Koji K. Okudaira,<sup>2</sup> Kazuhiko Mase,<sup>3,4</sup> Takashi Kikuchi<sup>3</sup>

<sup>1</sup>Faculty of Engineering, Yokohama National University

<sup>2</sup>Faculty of Engineering, Chiba University

<sup>3</sup>Photon Factory, Institute of Materials Structure Science, KEK

<sup>4</sup>SOKENDAI (The Graduate University for Advanced Studies)

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

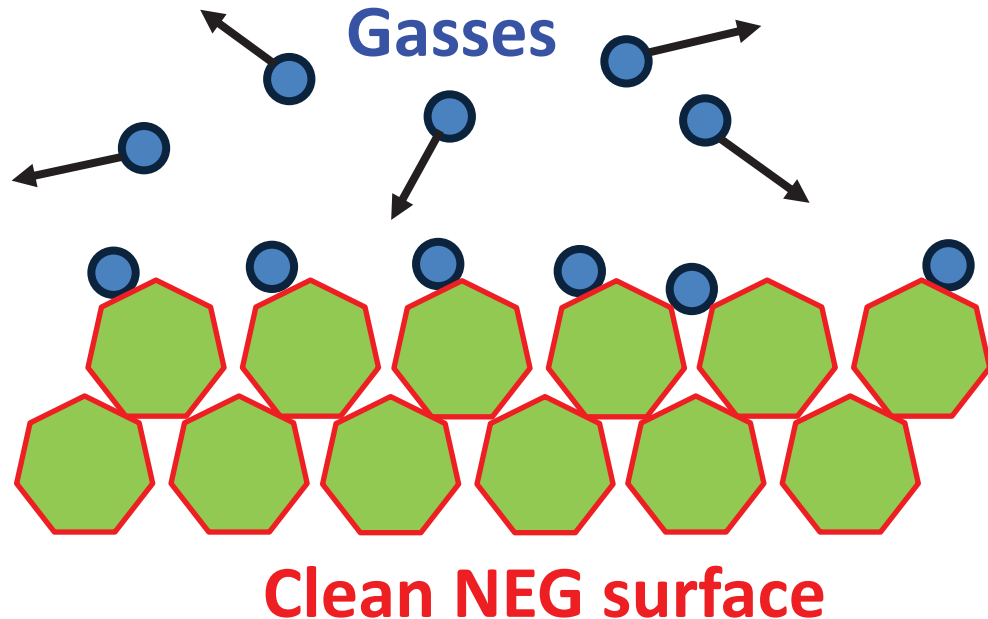
- ✓ PF is 34 years old but ~3400 researchers still uses PF per year.
- ✓ We have a plan to develop a **3 GeV storage ring light source with hybrid multi-bend achromat (KEK light source, KEK-LS)**
- ✓ Vacuum technology such as **Non-Evaporable Getter (NEG) Pumps and NEG coating** must be developed for 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		$\alpha$	$2.1893 \times 10^{-4}$		
ベータトロンチューン		$\nu_x, \nu_y$	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](http://www2.kek.jp/imss/notice/assets/2016/09/09/KEKLS_CDR_160909.pdf)]

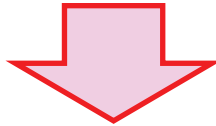
# Non-evaporable getter (NEG) pumps

- ✓ 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<sup>®</sup>** [C. Boffito *et al.*, JVST 18, 1117 (1981)].
- ✓ St 707<sup>®</sup> 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 H<sub>2</sub>, H<sub>2</sub>O, CO, CO<sub>2</sub> 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.



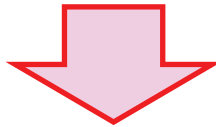
## Disadvantages of NEG pumps

- ✓ Rare gasses can not be pumped.
- ✓ CH<sub>4</sub> 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.**

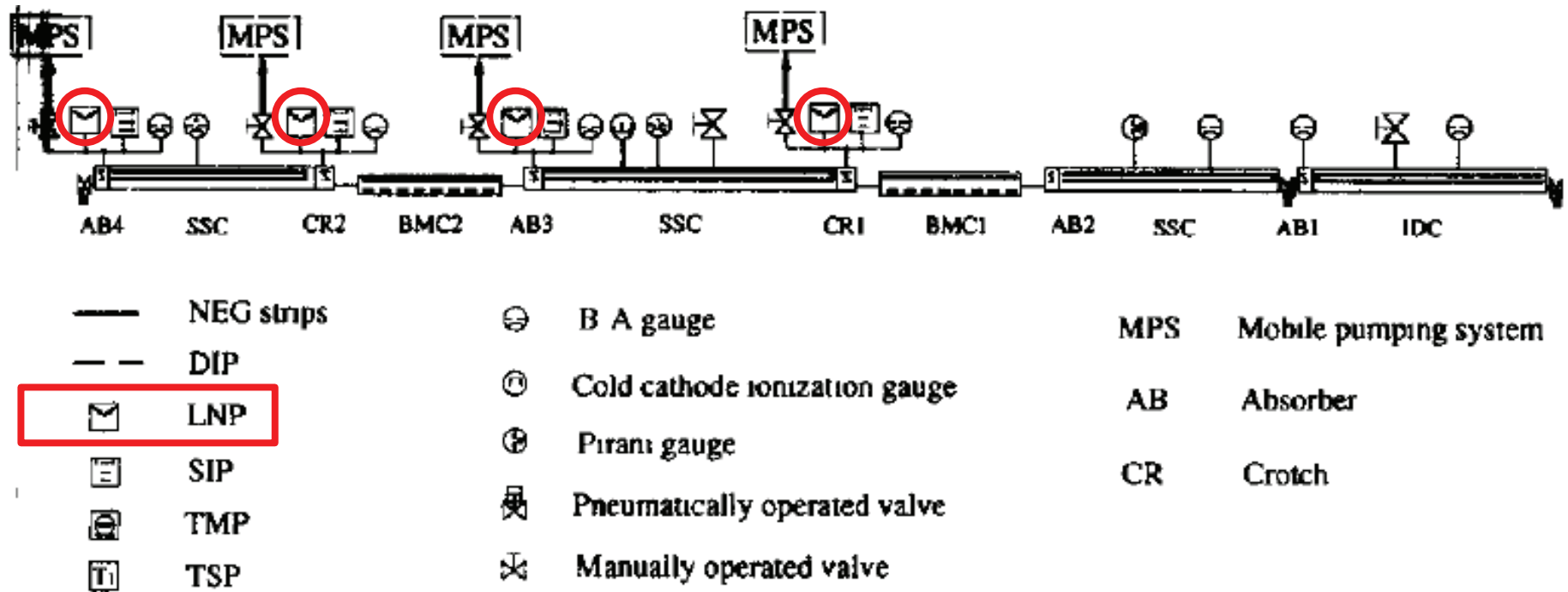
- ✓ Manufacturer of NEG pumps are quite limited.
- ✓ NEG pumps are expensive in some countries.



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

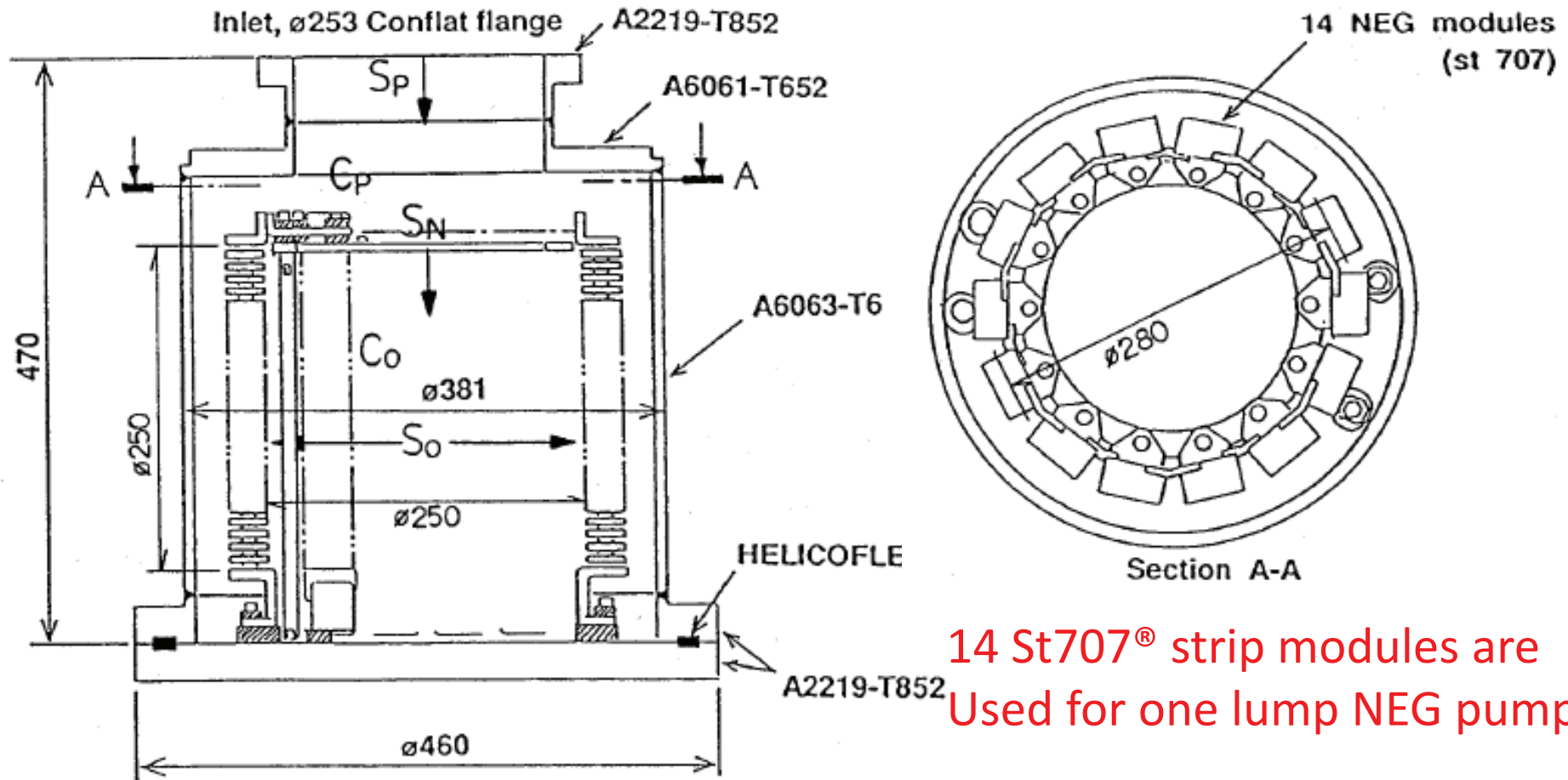
# NEG pumps used at SPring-8 in Japan

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<sup>®</sup> strips.



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

# Lump NEG pump developed for SPring8



14 St707<sup>®</sup> strip modules are Used for one lump NEG pump.

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

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

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

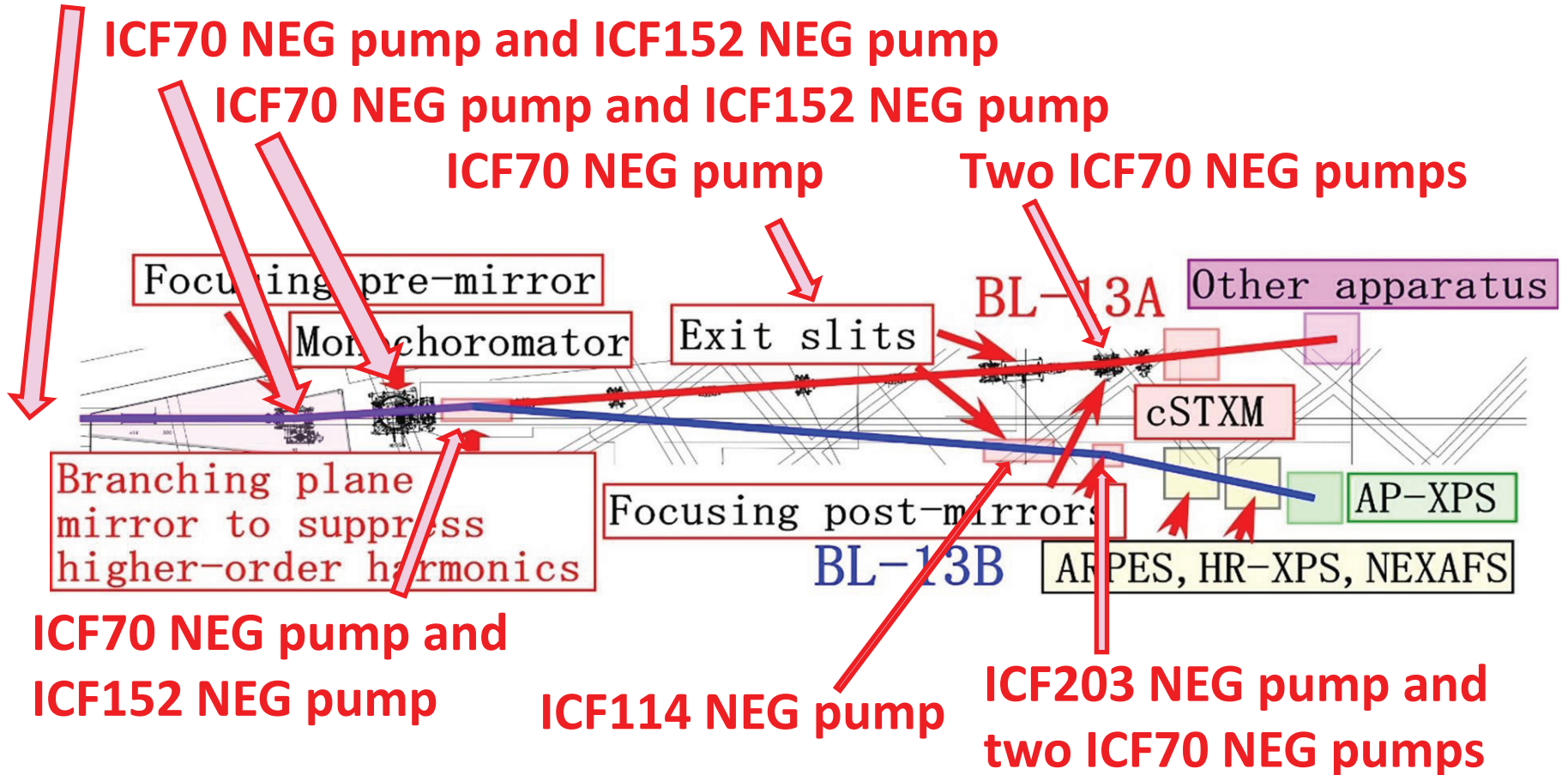
ICF70 NEG pump

ICF70 NEG pump and ICF152 NEG pump

ICF70 NEG pump and ICF152 NEG pump

ICF70 NEG pump

Two ICF70 NEG pumps



Branching plane mirror to suppress higher-order harmonics

Focusing post-mirrors

BL-13A

Other apparatus

cSTXM

AP-XPS

BL-13B

ARPES, HR-XPS, NEXAFS

ICF70 NEG pump and ICF152 NEG pump

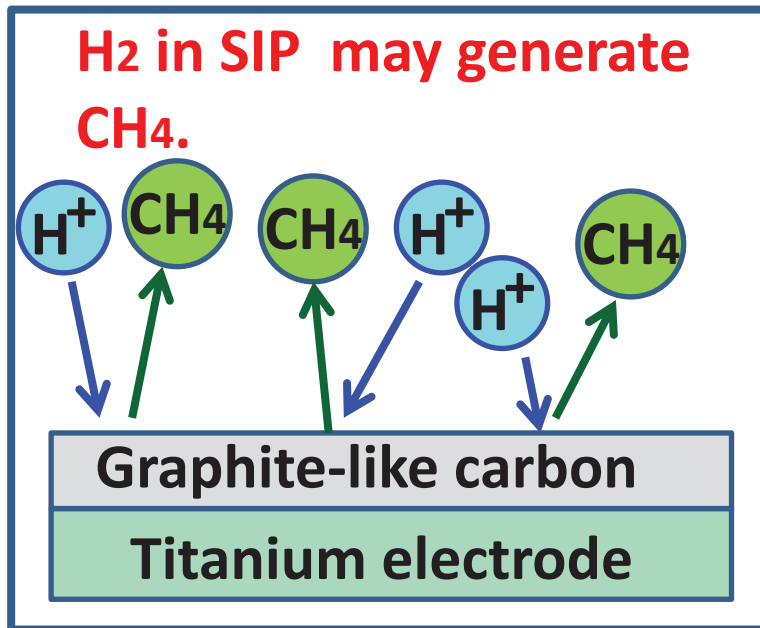
ICF114 NEG pump

ICF203 NEG pump and two ICF70 NEG pumps

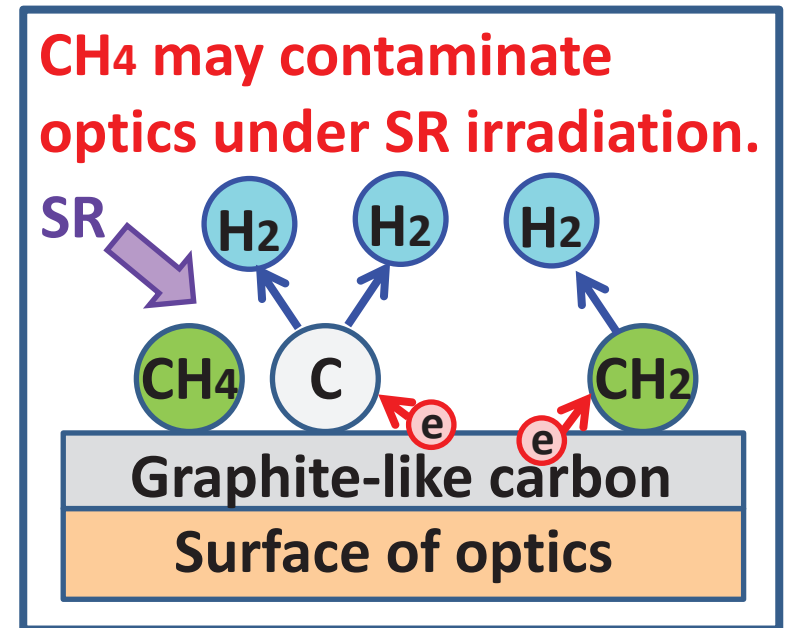
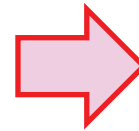
- ✓ More than 10 NEG pumps are required for one VSX beamline.
- ✓ Carbon-contamination on optics are almost completely removed by *in-situ* cleaning methods using activated oxygen under SR irradiation.

➔ 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).]

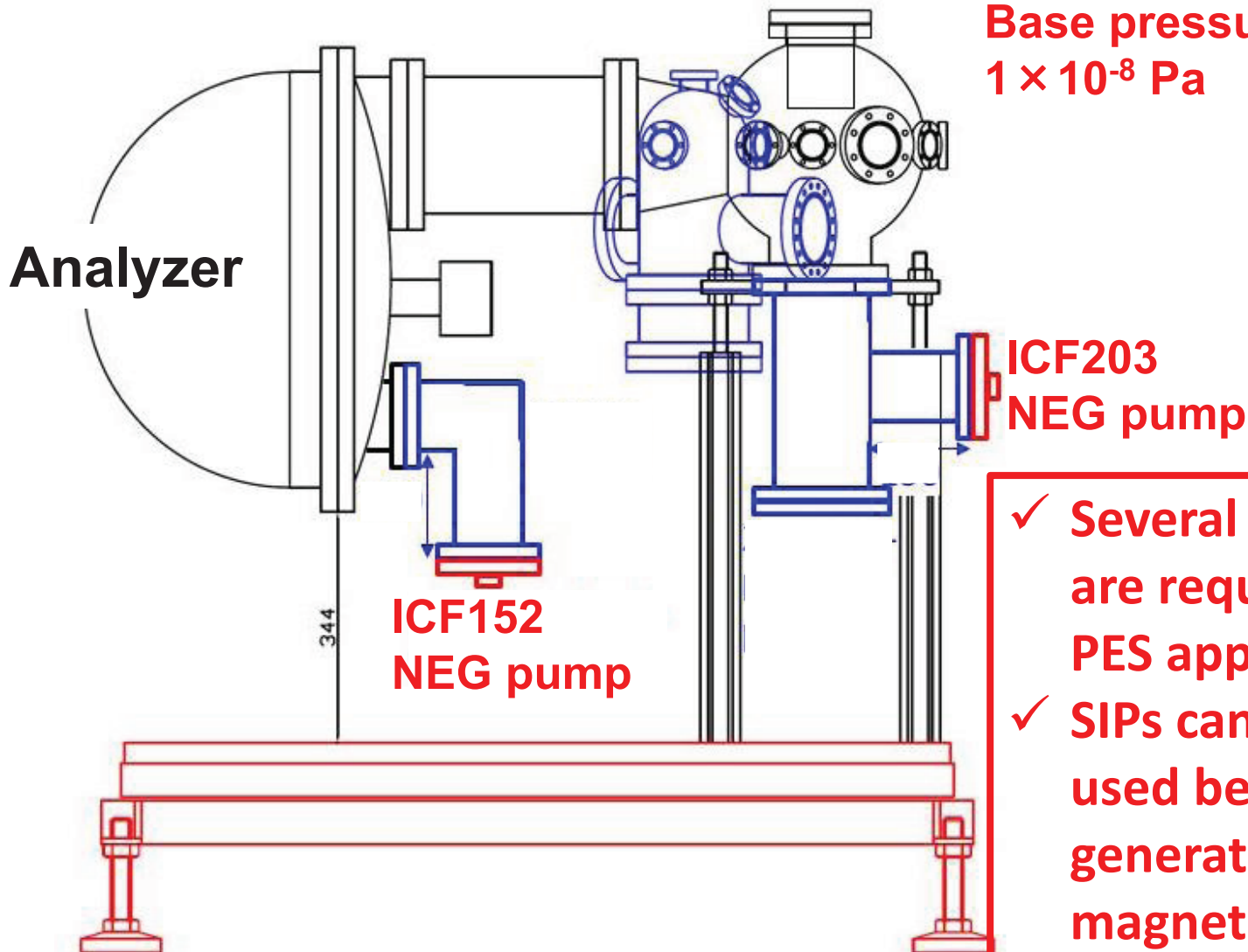


[K. Boller *et al.*, NIMPRA 208, 273 (1983).]



# NEG pumps used in endstations

## Photoelectron spectroscopy (PES) apparatus



Base pressure:  
 $1 \times 10^{-8}$  Pa

ICF203  
NEG pump

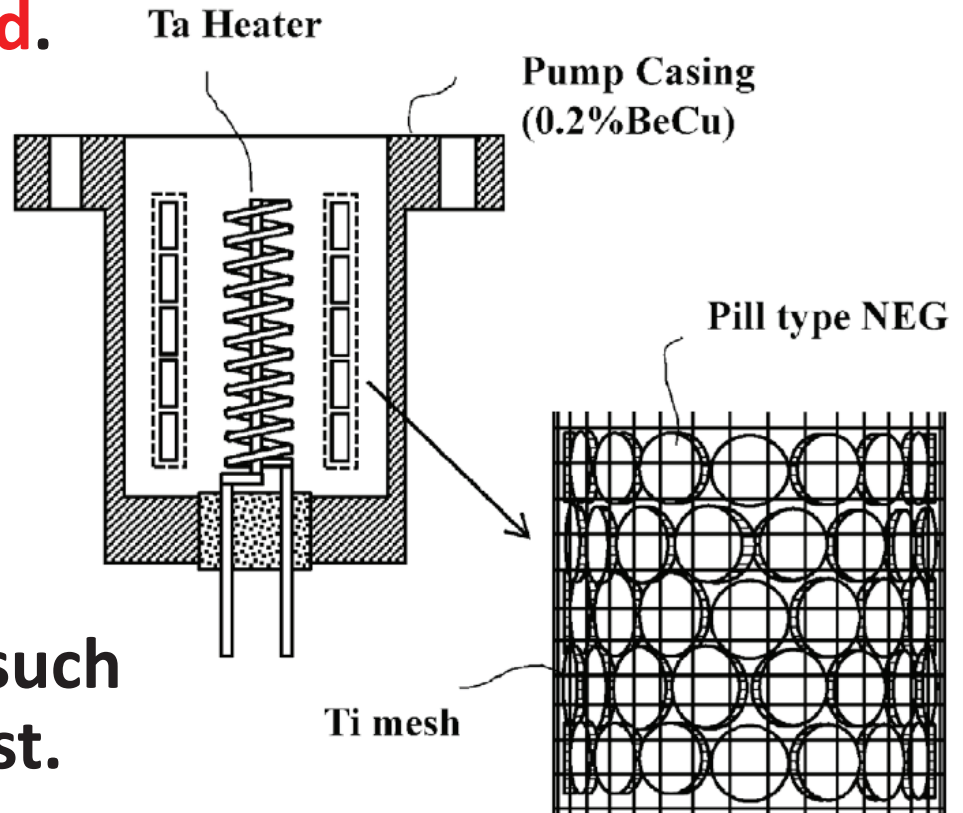
ICF152  
NEG pump

- ✓ 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 H<sub>2</sub> 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<sup>®</sup>) [K. Mase

*et al.*, AIP Conf. Proc. 1741,

030015 (2016) ]. Measured

Pumping speeds (L/s) for

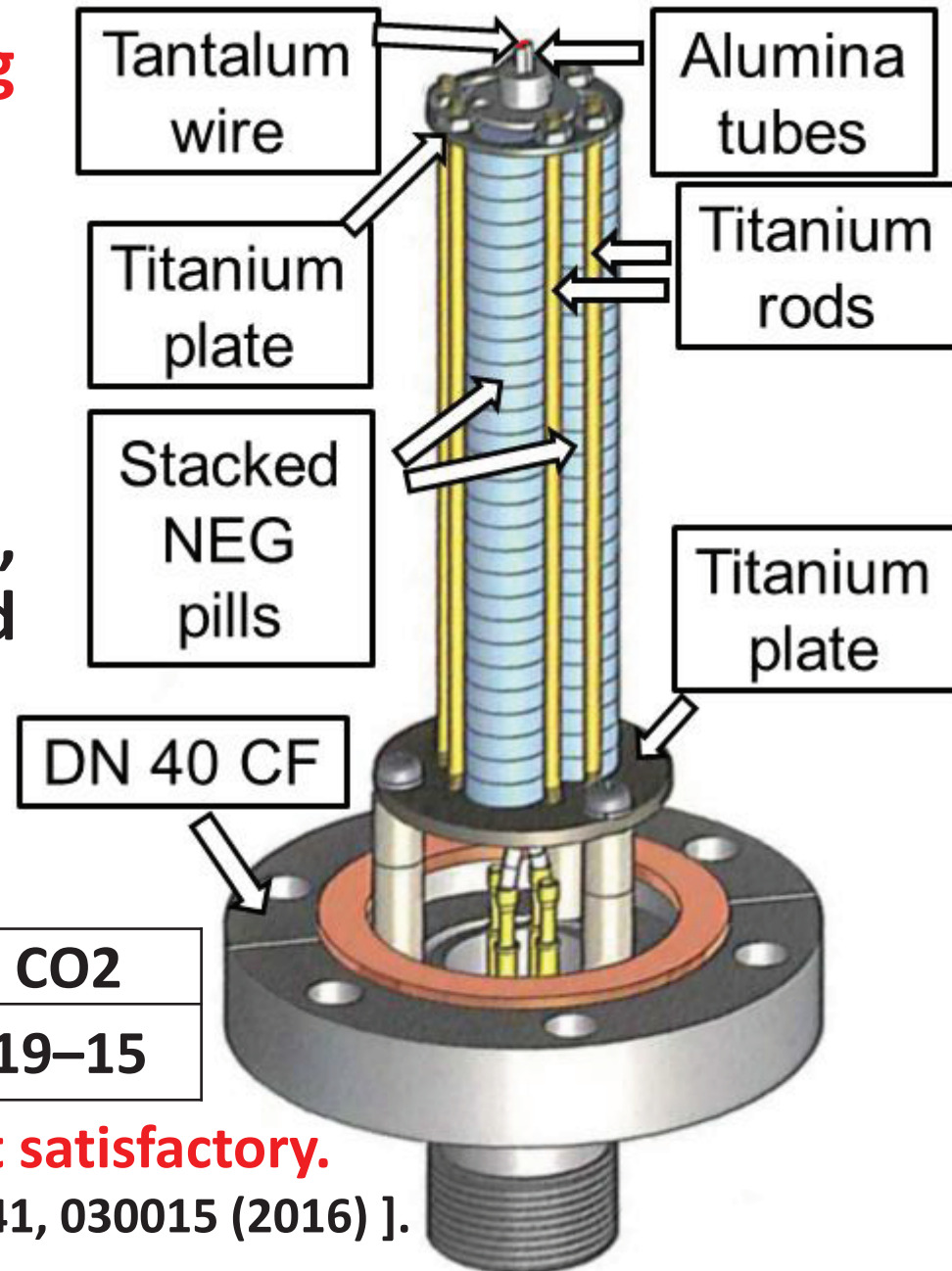
H<sub>2</sub>, N<sub>2</sub>, CO, and CO<sub>2</sub> after

activation are as follows.

H <sub>2</sub>	N <sub>2</sub>	CO	CO <sub>2</sub>
47–40	8–6	24–17	19–15

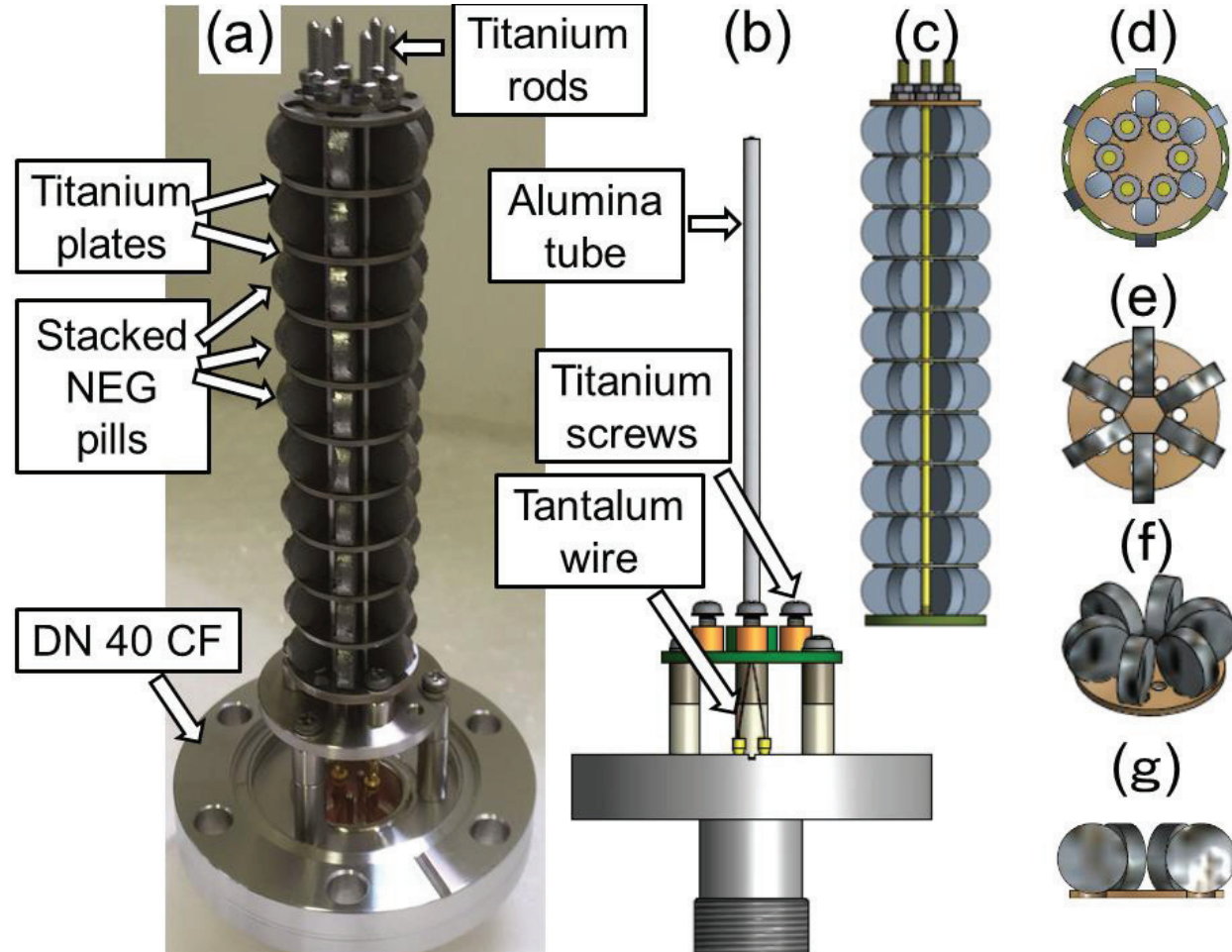
**These pumping speeds are not satisfactory.**

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



# New NEG pumps using NEG pills

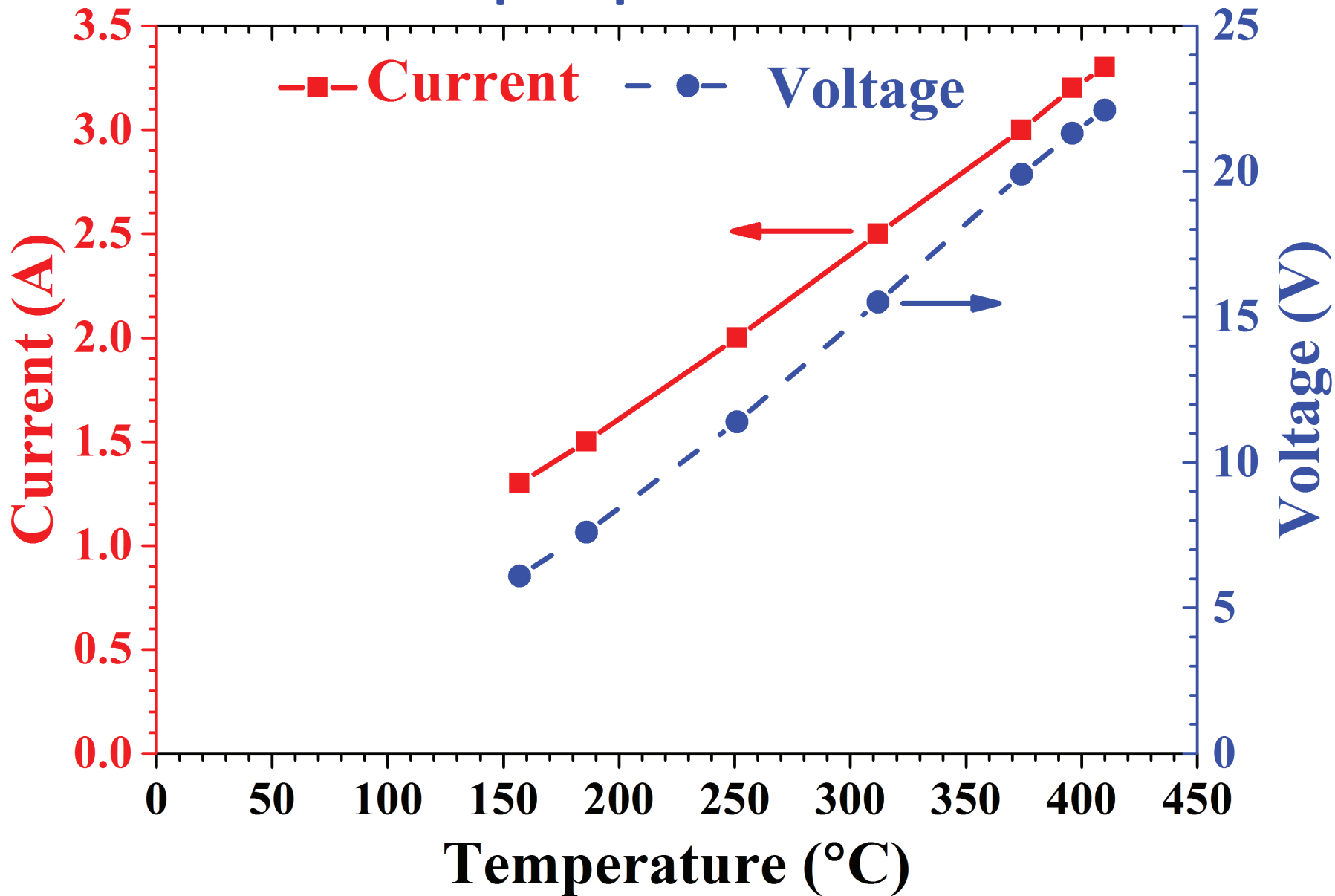
- ✓ 60 NEG pills ( $\phi 10$  mm  $\times$   $t 3$  mm, Nanjing Huadong Electronics Vacuum Material Co., Ltd) are used.
- ✓ Since effective surface area of NEG pills are increased, the pumping speeds are much improved (more than  $\times 3$ ).



Gasses	H2	CO	CO2	N2
Pumping speed (L/s)	<b>140–130</b>	<b>200–140</b>	<b>190–130</b>	<b>35–17</b>

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

# Activation of NEG pump



# Apparatus for pumping speed measurements of NEG pumps

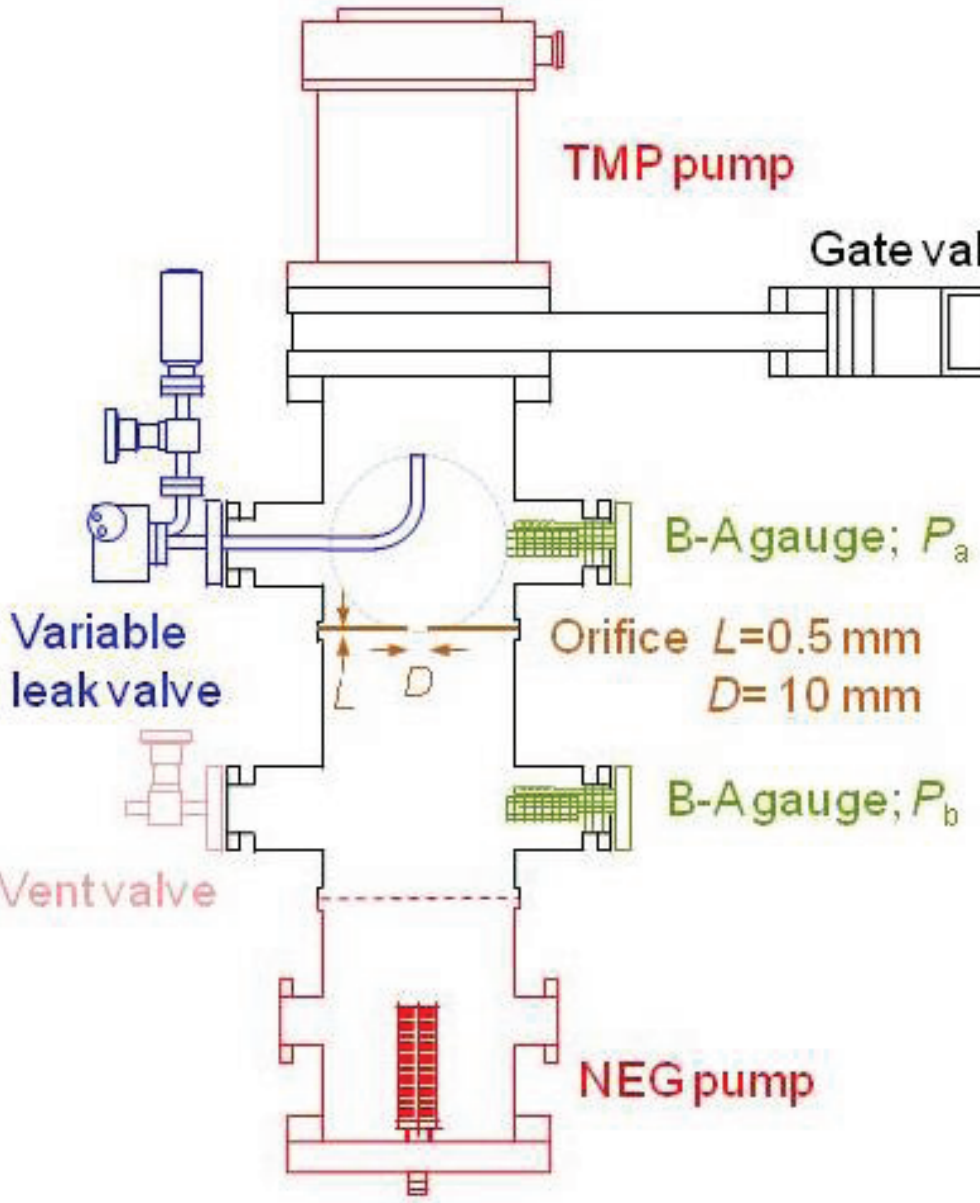
$$S = C \left( \frac{P_a - P_{a0}}{P_b - P_{b0}} - 1 \right)$$

**S** : Pumping speed  
**C** : Conductance  
**P** : Pressure  
**P<sub>0</sub>** : Base pressure

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

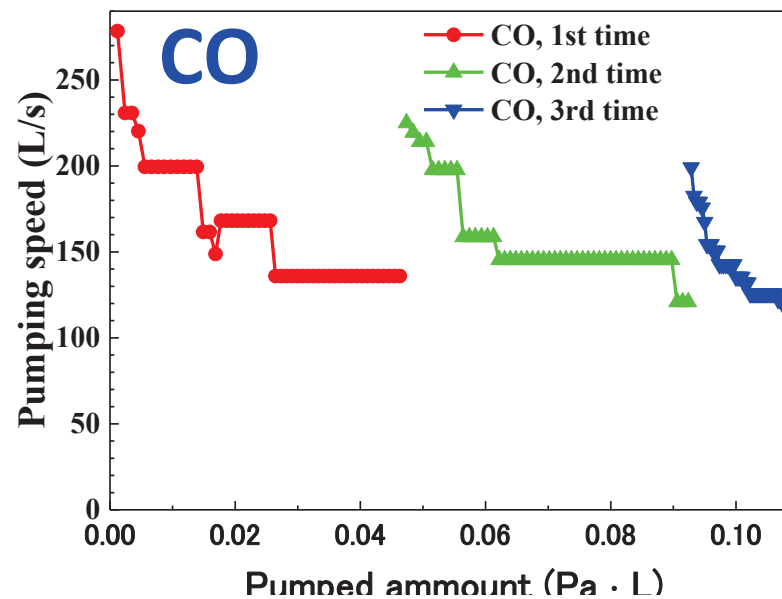
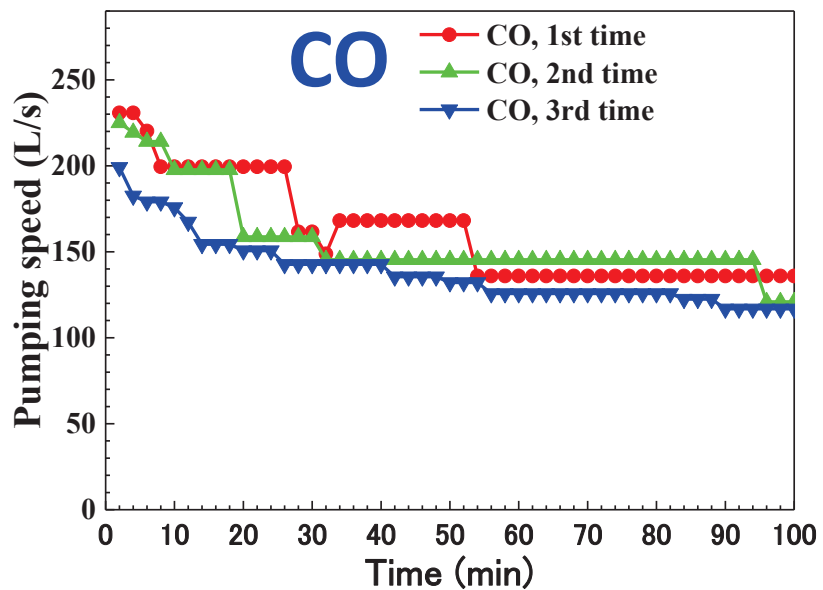
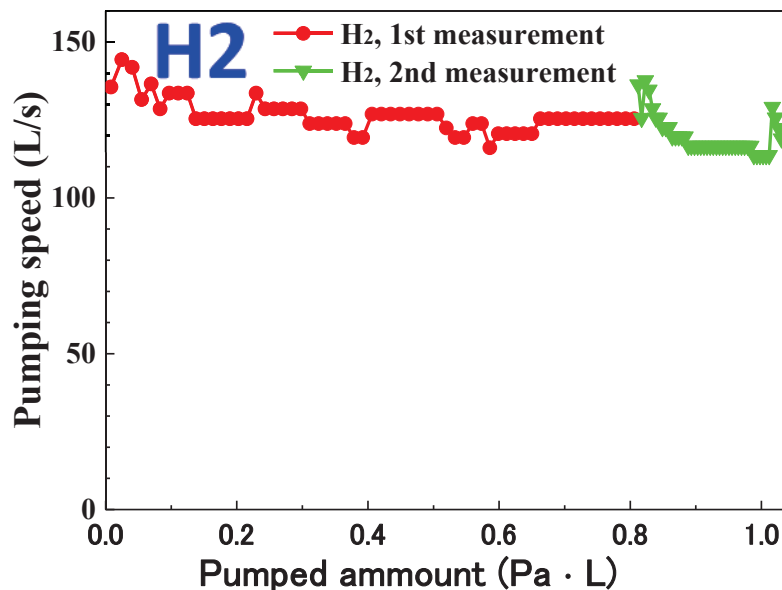
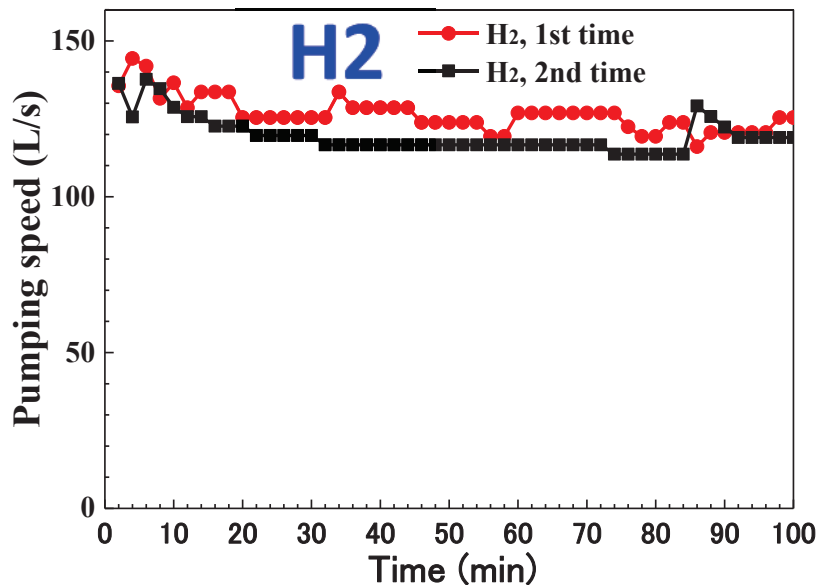
**$\bar{v}$**  : Average velocity of gasses  
**A** : Cross section of orifice  
**P** : Clausing constant

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

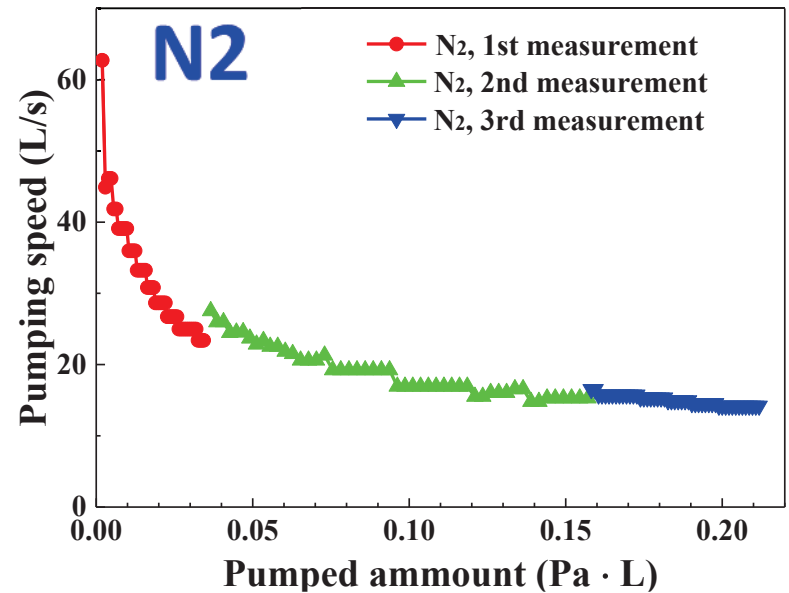
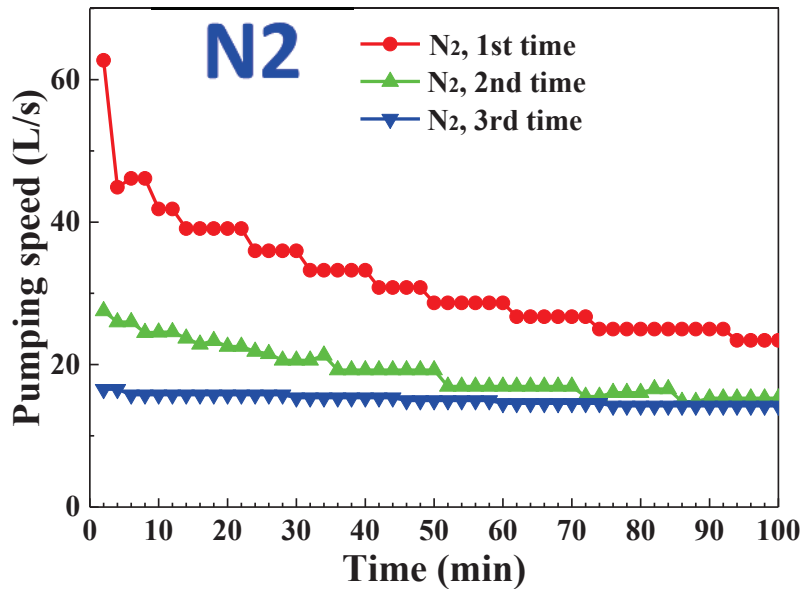
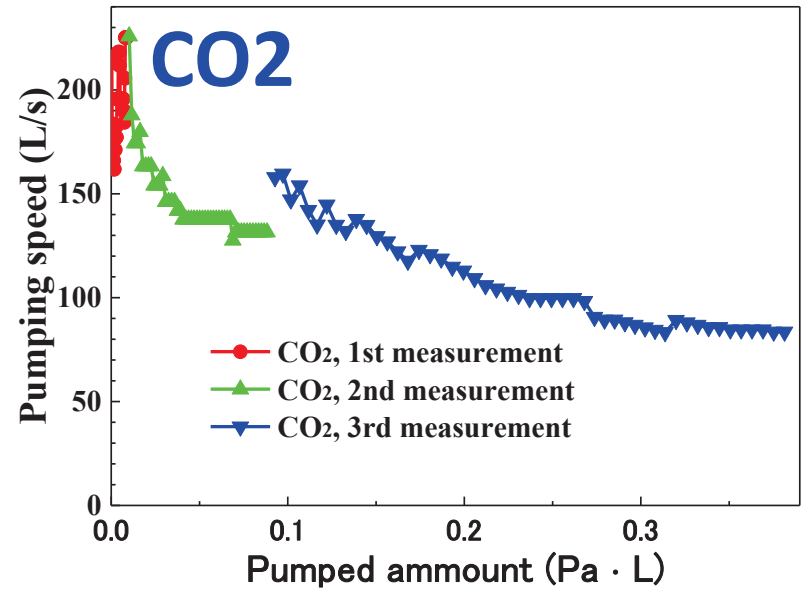
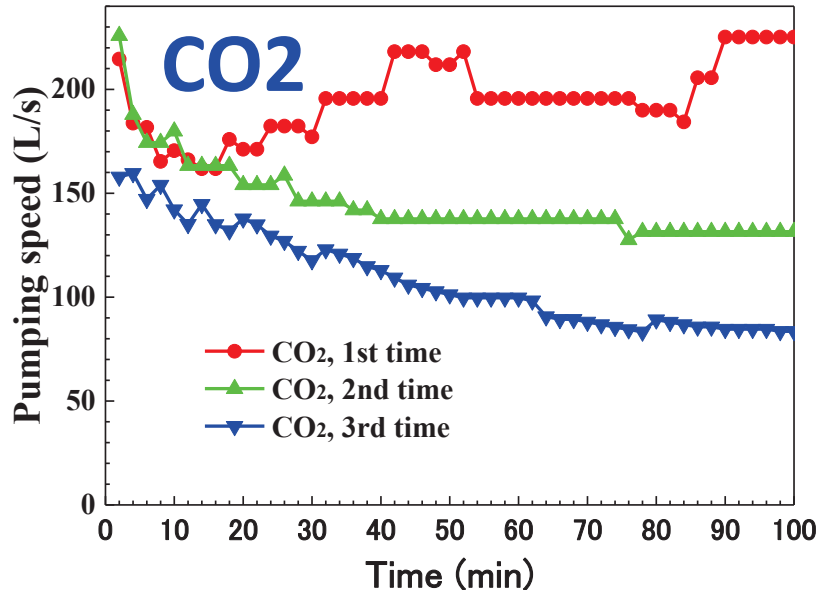


[K. Mase *et al.*, AIP Conf. Proc. 1741, 030015 (2016) ].

# Pumping speed measurements for H<sub>2</sub> and CO



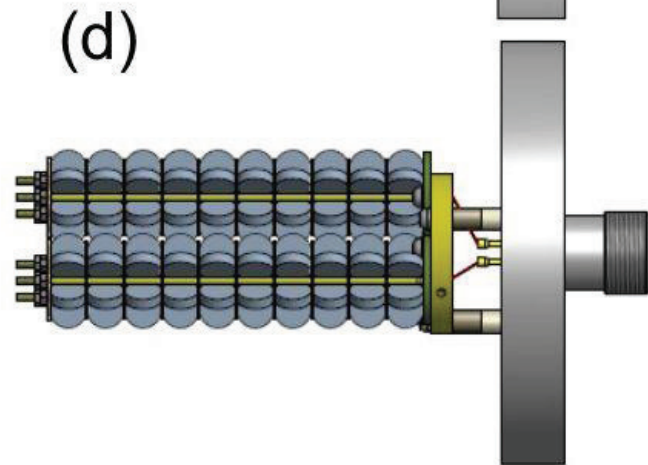
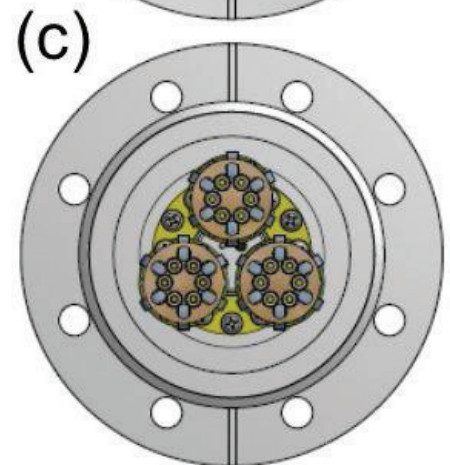
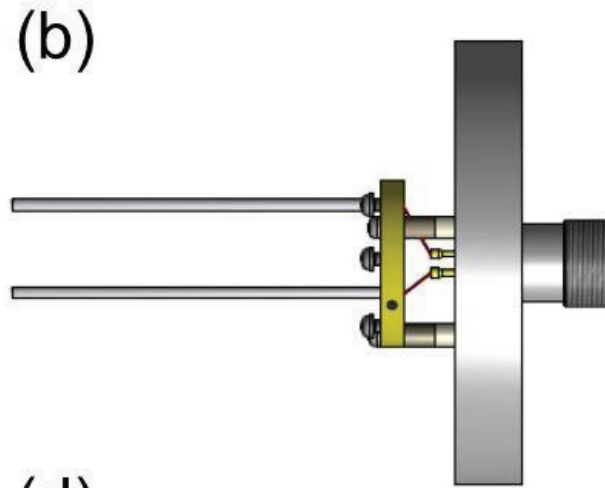
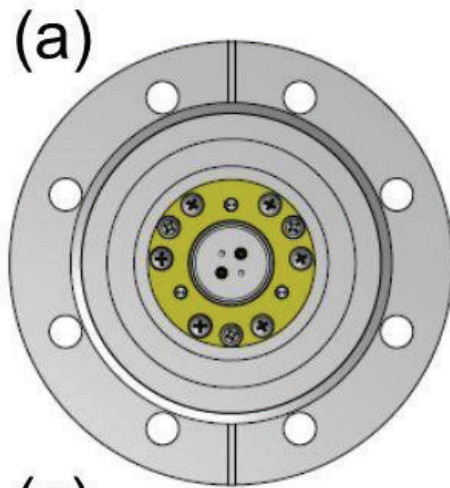
# Pumping speed measurements for CO<sub>2</sub> and N<sub>2</sub>





# 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<sup>®</sup>.
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 H<sub>2</sub>, CO, CO<sub>2</sub>, and N<sub>2</sub> 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.