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DEVELOPMENT OF A COMPACT LINEAR ZAO NEG PUMPING SYSTEM*

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Abstract

An upgrade of RHIC EBIS, the extended EBIS, is presently under development at Brookhaven National Laboratory to increase the intensity of the Au^{32+} ion beams by 40%–50% to $2.1 \cdot 10^9$ Au^{32+} ions/pulse at the booster ring entrance. Generation of intense beams of polarized $^3He^{2+}$ ions with up to $\sim 5 \cdot 10^{11}$ ions/pulse for the RHIC and the future electron–ion collider is a goal of the EBIS upgrade project as well. Ultra-high vacuum is extremely important for stable and reliable operation of EBIS/T devices. We have developed a linear pumping module based on the ZAO NEG unit commercially available from SAES Getters. This pumping system will be used for the Extended EBIS Upgrade which is presently under development at BNL. The new ZAO NEG material has a higher pumping speed and, more importantly, significantly higher sorption capacity for all active gasses compared to previously available types of getters. A ZAO NEG module has been modified to be heated up to 600 °C by passing up to 120 A of DC current through a stainless-steel cage for required NEG activation and reactivation temperature cycles. A method of pumping speed measurements using pulsed gas injection into the vacuum chamber has been developed and used for characterization of the ZAO NEG-based linear pumping system. The results of tests and design of the new ZAO NEG-based linear pumping system are presented and discussed.

DEVELOMENT OF A COMPACT LINEAR ZAO NEG MODULE

New so-called ZAO (Zr-V-Ti-Al) NEG material became commercially available from SAES Getters several years ago. According to SAES Getters, ZAO NEG has multiple advantages compared to previously used getters:

- Larger sorption capacity for all active gases
- Higher pumping speed for all active gases
- Ability to withstand more reactivation cycles
- More robust and has higher embrittlement limit
- Generates fewer micro particles.

The larger sorption capacity of the ZAO NEG is the most important advantage for EBIS applications. ZAO NEG can pump all active gases (especially hydrogen, which is the dominant species in ultra-high vacuum systems) for a year or longer even at a vacuum level of about 10^{-8} Torr without a significant decrease in pumping speed. Commercially available from SAES Getters, a linear ZAO NEG pumping unit with 470x28x8 mm^3 dimensions is shown in Fig. 1.

Figure 1: Photo of linear ZAO NEG pumping unit.

Fifty-four ZAO NEG discs are contained inside 316L stainless steel cage providing 500 l/s pumping speed for hydrogen. The pumping module can be activated by raising the temperature either to 500 ºC for 1 hour or to 450 ºC for more than 24 hours. In the latter case it can be done during high temperature bake-out of the vacuum chamber containing the ZAO NEG pumping module. From operational point of view and previous negative experience with high temperature bake-out (gate valves damage etc.) we strongly prefer ZAO NEG activation at 500 ºC temperature for 1 hour using heating of just pumping module and not the whole vacuum chamber for long period of time.

Activation of Linear ZAO NEG Pumping Unit by DC Current

To keep the ZAO NEG pump as compact as possible we decided to activate pumping module by passing DC current through the stainless-steel cage. The first heating test was done using the cage without ZAO NEG discs inside to prove that cage can transmit the current required to reach 500 ºC over the entire cage length without any damage. The cage has been mounted on high current vacuum feed-throughs with four thermocouples attached along the entire cage length in Fig. 2 (a). Dependence of electric power on transmitted current and dependences of temperatures along the cage on electric power are presented in Figs. 2 (b, c).

One can see that 550 W (85 A/6.5 V) electric power is required to reach temperatures in the range of 500 - 600 ºC along the cage. There was no damage to the cage under these conditions.

The second heating test was done using a pumping module containing ZAO NEG discs. A photo of the pumping module heated to 600 ºC in the middle of the cage inside of the vacuum chamber is presented in Fig. 3.

Pumping Speed Measurements

Schematic of experimental setup for pumping speed measurements is shown in Fig. 4.

A pulsed gas injection system has been assembled to allow injection of a small amount of gas of interest into the main vacuum chamber. It consists of a small buffer chamber with a volume of about 0.5 l, a needle valve, an electromagnetic pulse valve, and a turbomolecular pump (TMP)-based pumping station.

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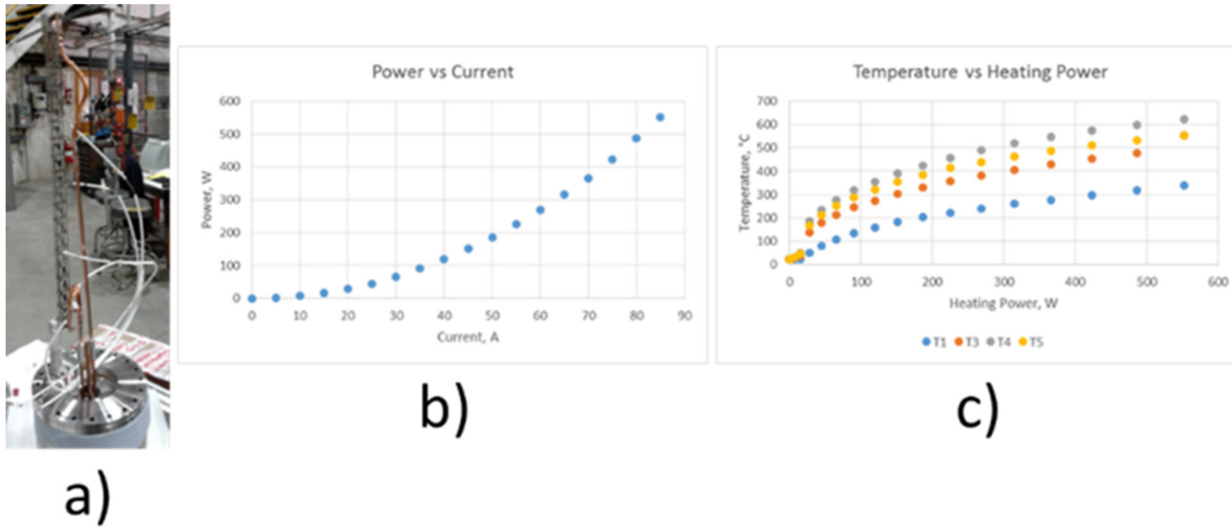

Figure 2 (a, b, c): Cage heating without NEG discs inside: a – cage mounted at high current vacuum feedthroughs with four thermocouples attached, b – dependence of electric power on transmitted current, c – dependences of temperatures along cage on electric power (blue dots – cage end, red dots – ¼ cage length, grey dots – ½ cage length, yellow dots – ¾ cage length).

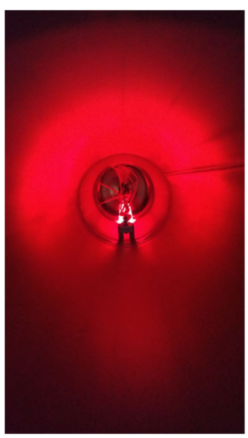

Figure 3: Pumping unit heated to 600 ºC in the middle of the cage.

At first, all gas lines were pumped by the TMP pumping station to about 10^{-3} Torr residual gas pressure. After that, the buffer chamber was filled by a gas of interest up to a pressure of about 100 Torr. The pulse duration of the electromagnetic valve controller was adjusted to drive the pressure in the main vacuum chamber up by about two orders of magnitude (typically from $2\text{-}5\cdot10^{-8}$ Torr up to $2\text{-}5\cdot10^{-6}$ Torr). In such a way, a wide enough dynamic range for measurements has been provided and the gas load on the pumps has been minimized.

The main vacuum chamber was pumped by the ZAO NEG pumping module and the TMP backed by a TMP pumping station to avoid pressure limits caused by low compression ratios of TMP for hydrogen and helium. An all-metal gate valve at the TMP input allowed to pump chamber either by TMP and ZAO NEG module when the valve was open or by only the ZAO NEG module when the valve was closed. The volume of the vacuum chamber was

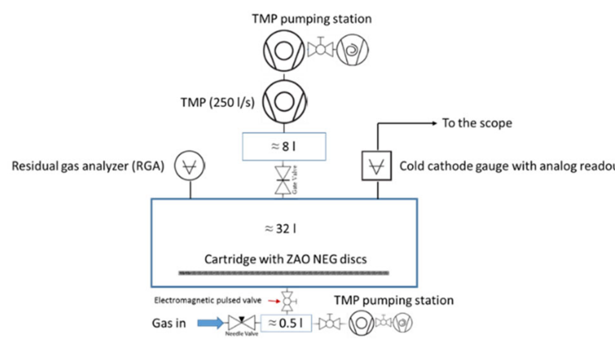

Figure 4: Schematic of experimental setup for pumping speed measurements.

equal to 40 l and 32 l respectively in these cases. An SRS RGA200 residual gas analyser and an MKS 421 cold cathode ion gauge with analog readout were attached to the vacuum chamber to record pressure time dynamics.

If some amount of gas is injected into vacuum chamber, the pressure inside the chamber will raise and then after the end of injection pulse will decrease exponentially (in molecular flow regime) according to following equation:

$$P(t) = P(t = 0) \cdot e^{-\frac{S}{V}\cdot t} \quad (1)$$

where $P(t)$ is pressure at the detector location (RGA or cold cathode (CC) gauge in our case) at time t, $t = 0$ is time right after the end of the injection pulse, S is pumping speed at the detector location, and V is the volume of vacuum chamber.

Time dynamics of hydrogen pressure recorded by the RGA when the chamber was pumped by the ZAO NEG module only (TMP gate valve closed) is presented in Fig. 5 (a, b, c, d) both in linear and logarithmic scale.

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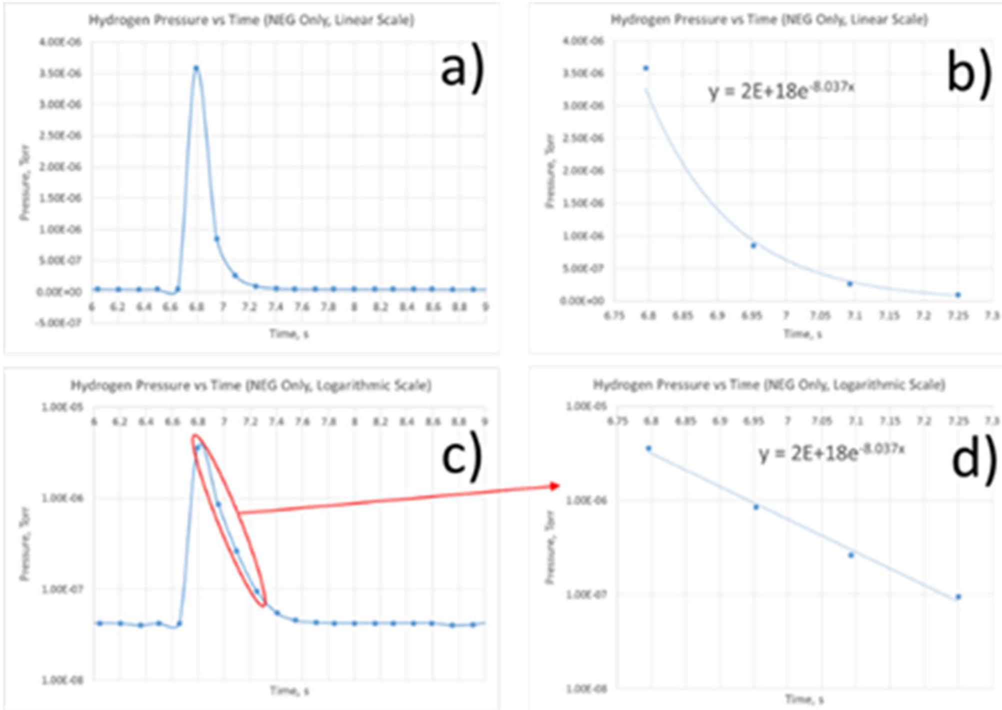

Figure 5 (a, b, c, d): Time dynamics of hydrogen pressure recorded by RGA when chamber was pumped by ZAO NEG module only (a – full pulse (linear scale), b – pressure decay part of pulse (linear scale), c - full pulse (logarithmic scale), d - pressure decay part of pulse (logarithmic scale)).

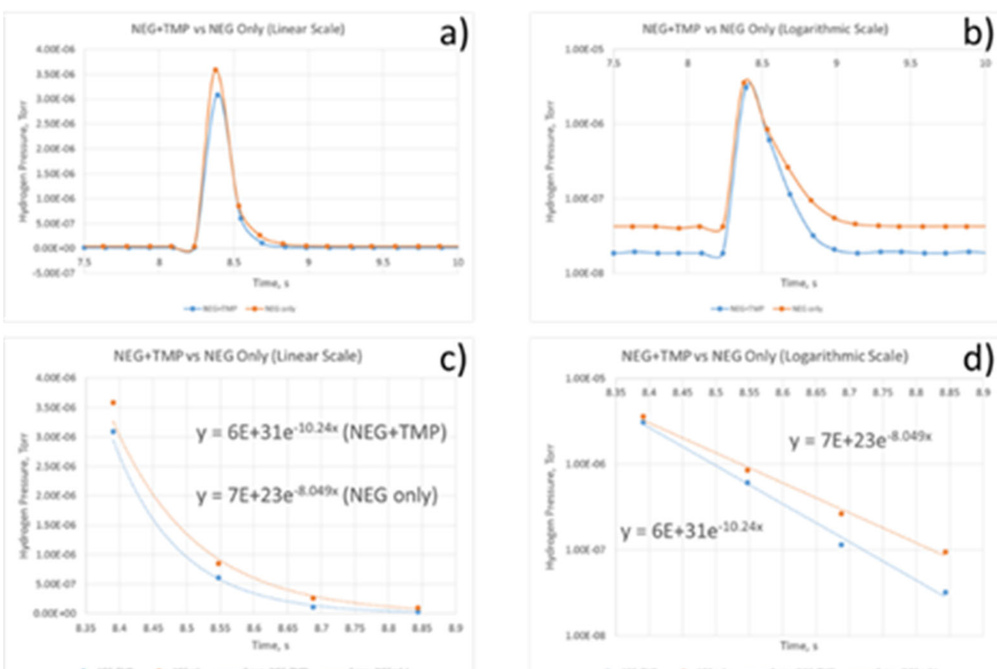

Figure 6 (a, b, c, d): Time dynamics of hydrogen pressure recorded by RGA when chamber was pumped by ZAO NEG module only (red dots and lines) and by ZAO NEG module together with TMP (blue dots and lines) (a – full pulse (linear scale), b – full pulse (logarithmic scale), c - pressure decay part of pulse (linear scale), d - pressure decay part of pulse (logarithmic scale)). Lines on lower plots are exponential fittings.

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RGA has been used at highest for this model recording rate (8 points/s) for all measurements described in this paper. Even in this case only 4 points were recorded for the pressure decay part of the pulse in Fig. 5 (b, d) because pressure decay time is quite short and just slightly exceeds 0.5 s. The purity of hydrogen gas injection was confirmed by recording RGA traces of atoms and molecules with other masses during injection pulse. The number of other atoms and molecules didn't exceed 1% compared to that of the injected hydrogen.

As one can see from Fig. 5, measured pressure decay is exponential with very high accuracy. The pumping speed of ZAO NEG module for hydrogen was found to be 257 l/s in this measurement since the vacuum chamber volume was equal to 32 litters. One should mention that pumping speed is measured at the RGA location and it is lower than the pumping speed inside the vacuum chamber because of limited vacuum conductance from the chamber to the RGA.

Comparison of pumping speed for hydrogen in case of pumping by both NEG module and TMP (TMP gate valve is opened) with pumping by NEG module only (TMP gate valve is closed) is illustrated in Fig. 6 (a, b, c, d).

Measured pumping speeds with hydrogen are 410 l/s for both NEG module and TMP, and 258 l/s for NEG module only. Average measured pumping speed for hydrogen is 259 l/s if chamber is pumped by NEG module only and 396 l/s if pumped by both NEG module and TMP. Statistical fluctuations of measured pumping speed are less than 6%.

Pumping speed has been measured for nitrogen as well. Average measured pumping speed for nitrogen is 87 l/s if the chamber is pumped by the NEG module only and 232 l/s if pumped by both the NEG module and TMP. Statistical fluctuations of measured pumping speed are less than 15%. The ratio of measured pumping speeds of NEG module for hydrogen (259 l/s) and nitrogen (87l/s) is in good agreement with the ratio of about factor three specified by SAES Getters.

Influence of Vacuum Conductance

The measured pumping speed for hydrogen (260 l/s) is significantly lower than pumping speed for hydrogen specified by SAES Getters (500 l/s). As was already mentioned above, pumping speed is measured at the RGA location which has limited vacuum conductance to the chamber where the NEG module is located. For this reason, pumping speed inside of the vacuum chamber can be significantly higher than measured pumping speed at a different location.

Pumping speed at the RGA location can be derived from following expression:

$$\frac{1}{S(RGA)} = \frac{1}{S(Ch)} + \frac{1}{C} \qquad (2)$$

where *S(RGA)* and *S(Ch)* are pumping speed at the RGA and at the NEG module locations, and *C* is vacuum conductance between the RGA and NEG module locations.

The RGA has been mounted on a pipe with a diameter of 31 mm and a length of 170 mm which is connected to the large vacuum chamber where the NEG module is located. Vacuum conductance of this pipe for hydrogen can be estimated to be about 374 l/s. There is always some uncertainty in the vacuum conductance value because real geometry is complex and should be somehow simplified for estimations. The dependence of the NEG module pumping speed inside the vacuum chamber on vacuum conductance between the RGA and NEG module locations is presented in Fig. 7 (using equation (2) and measured pumping speed of 259 l/s for hydrogen at the RGA location).

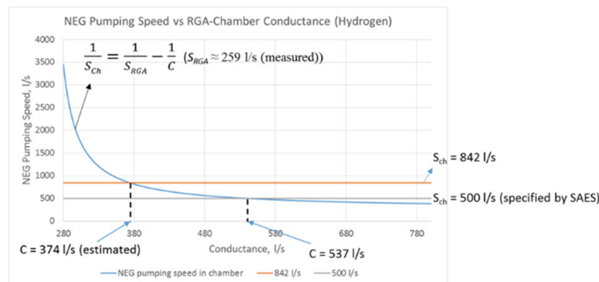

Figure 7: Dependence of NEG module pumping speed inside vacuum chamber on vacuum conductance between RGA and NEG module locations.

As one can see, any error in vacuum conductance estimation give significant uncertainty in re-calculated pumping speed. The main conclusion from this consideration is that pumping speed of the NEG module for hydrogen inside of the vacuum chamber is higher than 260 l/s and can be close to 500 l/s as specified by SAES Getters.

Can One Identify if the NEG is Saturated?

Pumping speed of NEG-based vacuum pumps can be reduced over their operation lifetime due to NEG saturation. There is always practical question exist: what is present pumping speed of NEG-based vacuum pumps after some period of operation? Pumping speed measurements using pulsed gas injection allow in situ monitoring of NEG-based pump conditions in EBIS or any other UHV device. Such an opportunity is illustrated by Fig. 8 where the pumping speed of the NEG module has been measured before and after NEG re-activation. As one can see, the degree of NEG saturation can be easily identified using this method.

Comparison of Pumping Speed Measurements by RGA and Ion Gauge

There is a significant practical interest to compare pumping speeds measured by RGA and ion gauge because RGA is not always part of UHV installation, but ion gauge is always there. MKS 421 cold cathode (CC) ion gauge with analog read-out was mounted right near RGA to cancel vacuum conductance issue and properly compare results of pumping speed measurements.

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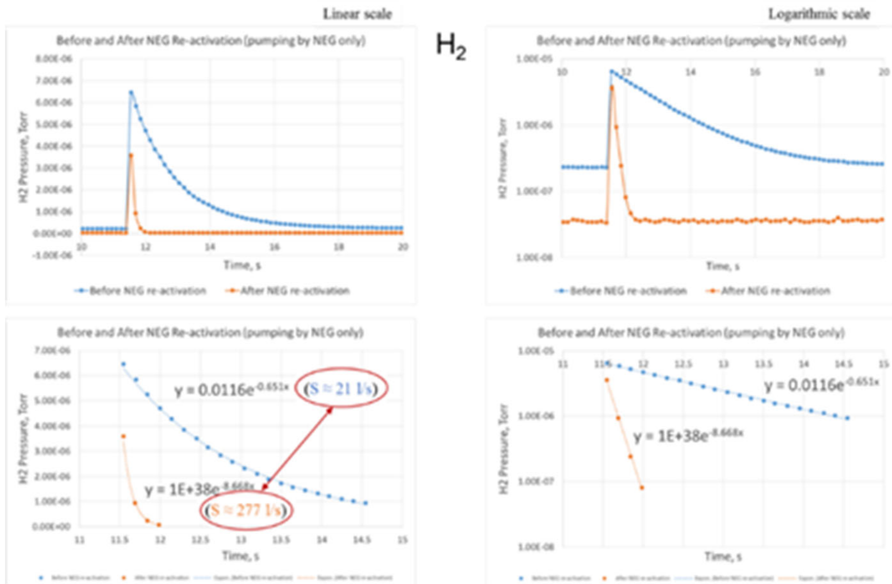

Figure 8: Pumping speed of ZAO NEG module for hydrogen before (blue dots and lines) and after (red dots and lines) re-activation.

Time dynamics of nitrogen pressure recorded by RGA and CC gauge is presented in Fig. 9 in linear and logarithmic scales. Vacuum chamber was pumped by TMP only because NEG was not activated yet.

One can see that time dynamics of pressure recorded by RGA and CC gauge are in good agreement. Some discrepancy at rising slope can be explained by limited time resolution of RGA (only 8 points per second). Comparison of pumping speed measured by RGA and CC gauge for conditions mentioned above is presented in Fig. 10. One can see that results of pumping speed measurements by RGA and CC gauge are in good agreement with each other and with specified pumping speed corrected by vacuum conductance for TMP model used. One should conclude that ion gauge can be used for pumping speed measurements although RGA would be preferable choice because it records time dynamics for gas specie of interest only thus providing more transparent results.

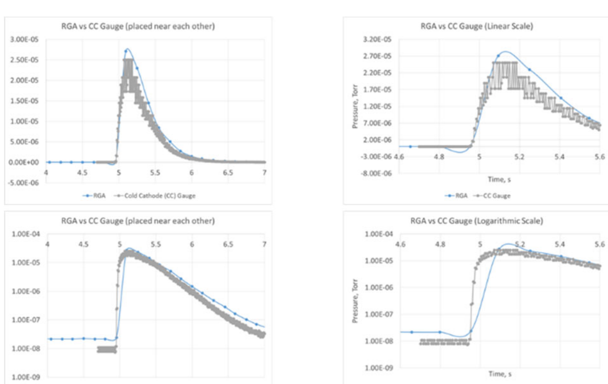

Figure 9: Time dynamics of nitrogen pressure recorded by RGA (blue dots and lines) and CC gauge (grey lines) in linear and logarithmic scales (right side plots are zoomed to show better time resolution of rising pressure slope).

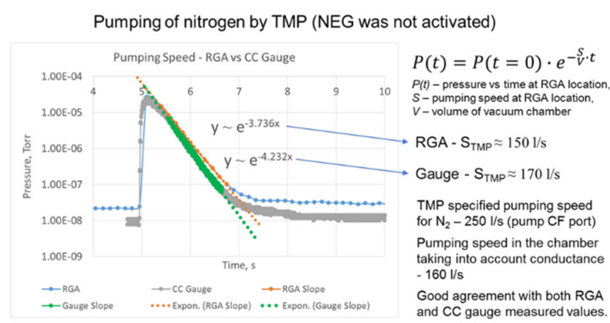

Figure 10: Pumping speed of nitrogen by TMP measured by RGA (blue dots and line, red line – approximation by exponential function) and CC gauge (grey line, green line – approximation by exponential function).

CONCLUSION

Recently introduced by SAES Getters ZAO NEG linear module is very attractive for EBIS applications due to large sorption capacity, high pumping speed and transverse compactness. It has been shown that module can be activated and regenerated by DC (or AC) current passing through the cage which contain ZAO NEG discs. We have developed in-situ method of pumping measurements using injection of limited amount of gas into vacuum chamber. Either residual gas analyzer or ion gauge can be used to record time dynamics of pressure. High pumping speed of the module for hydrogen and nitrogen has been measured. Developed method of pumping speed measurements can be used to monitor in situ NEG saturation level in EBIS or any other UHV device.