

## Improving Fast Ejecting System of Targeted Sample (FESTA) and Gas Calibration

YUE, Qilin  
Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

<https://doi.org/10.5109/4738571>

---

出版情報 : Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 7, pp.71-76, 2021-10-21. Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

バージョン :

権利関係 :



# Improving Fast Ejecting System of Targeted Sample (FESTA) and Gas Calibration

Qilin YUE<sup>1\*</sup>

<sup>1</sup>Interdisciplinary Graduate School of Engineering Sciences, Kyushu University

\*Corresponding author email: k.gaku@triam.kyushu-u.ac.jp

**Abstract:** To realize fusion power generation, the storage of hydrogen and its isotopes in plasma facing walls (PFWs) is a significant problem to maintain steady-state operation, in which wall retention is divided by static and dynamic retention. In QUEST, Fast Ejecting System of Targeted sAmple named FESTA has been developed to measure the local dynamic retention by exposing a specimen. Such a retention is evaluated by hydrogen gas pressure released from the plasma-exposed specimen, so it is necessary to perform a gas calibration of data before analysis. On the other hand, considering the future work of calculating fuel particles' reflection rate on specimen, measurement of static retention after exposure should also be carried out simultaneously. Therefore, we have drawn up a project on improving the test chamber of FESTA.

**Keywords:** FESTA; wall retention; gas calibration; quadrupole mass spectrometer; thermal desorption spectrometry

## 1. INTRODUCTION

Steady state operations (SSO) are important for a magnetic confinement nuclear fusion power plant, and static and dynamic retention of fuel particles, hydrogen and its isotopes deuterium and tritium in plasma facing walls (PFWs), must be investigated to achieve SSOs. Lately, due to the introduction of metallic wall, a dramatic reduction of wall-stored fuel particles after plasma discharges was reported at Joint European Torus during ITER-like wall (ILW) experiments [1 - 4], indicating that dynamic retention has become dominant and played a crucial role in the fuel particle balance.

In QUEST (Q-shu University Experiment with Steady Spherical Tokamak) which is equipped with all metallic walls [5 - 7], static retention in PFWs has been quantitatively measured until now [8], while dynamic retention was only measured by nuclear reaction analysis [9], where the conditions are completely different from the real high temperature and density plasma in Tokamak, though. Furthermore, such a measurement is limited after plasma discharges and only global retention is measured. Therefore, a device called FESTA (Fast Ejecting System of Targeted sAmple) has been newly developed [10]. With FESTA system, a plasma-exposed specimen can be extracted from QUEST plasma to a mechanically isolated test chamber, so the measurement of dynamic retention can be carried out immediately soon after one plasma exposure. Through measuring the hydrogen gas released from the specimen by a quadrupole mass spectrometer (QMS) dynamic retention can be evaluated directly. In this research, a calibration method of the raw data obtained by QMS is introduced in section 3.

On the other hand, in QUEST the vacuum is exhausted using cryopumps, so their exhausting speed should also be calibrated every experimental day due to the deterioration, which is described in section 3.

The static retention is always measured by thermal desorption spectrometry (TDS) conventionally, while the plasma-exposed specimen will be exposed to the air once. Therefore, the contamination risk of specimen is unavoidable, to some extent. In this research, with the help of the independence between the test chamber of FESTA

and the QUEST vacuum vessel, it is convenient to measure static retention soon after FESTA experiments without taking the specimen out. In section 5, we gave a project to improve and change the test chamber for the purpose of the future work on static retention.

## 2. EXPERIMENTAL SET-UP

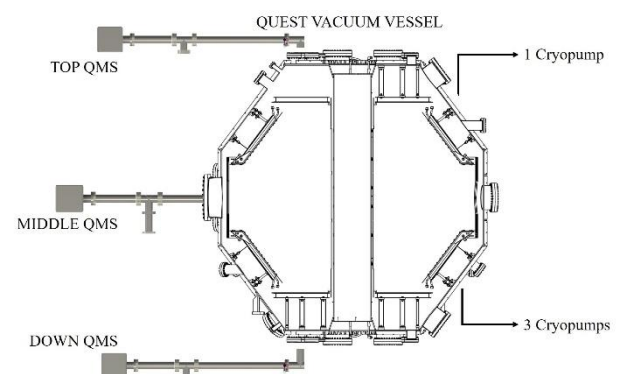


Fig.1 Schematic of QUEST

There are three QMSs in total installed on top, middle and down position of QUEST.

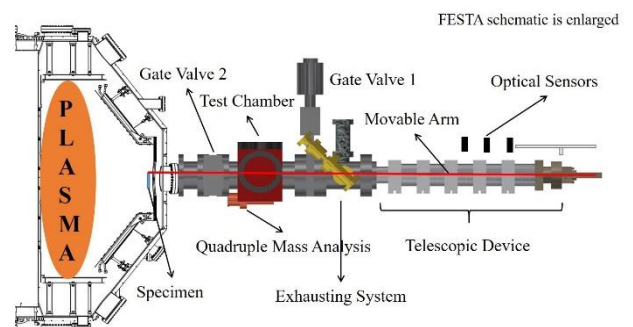


Fig.2 Schematic of FESTA [10]

As shown in Fig. 1, hydrogen (fuel particles in QUEST) pressure in QUEST is measured by three QMSs installed

on QUEST vacuum vessel. There is one cryopump on the top of QUEST vacuum vessel and three cryopumps on the bottom of QUEST, 4 in total, to exhaust vacuum. FESTA is set on the mid-plane of QUEST and the partial hydrogen pressure in FESTA test chamber is measured by one QMS which is the same altitude as the middle QMS on QUEST as shown Fig. 2. The ion current measured by the QMS is calibrated and converted into particle flux using a calibrated flowmeter with different flows on QUEST and such a calibration is carried out every campaign [5, 9]. In order to perform gas calibration on FESTA, a standard leak is also installed on its test chamber.

As shown in Fig.2, FESTA consists of a test chamber and a telescopic device. A movable arm is connected in the telescopic device helping to expose the specimen to QUEST plasma and extract it rapidly. The test chamber can be isolated by two gate valves whose opening and closing are controlled by optical sensors monitoring the tip position of the movable arm. All the FESTA motion has been pre-programmed using Lab-VIEW and FESTA experiments were successfully carried out [10].

### 3. GAS CALIBRATION IN QUEST AND FESTA

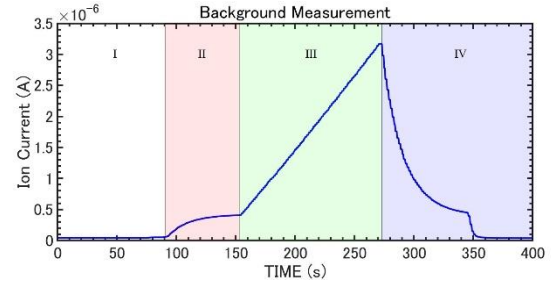
As mentioned above, the pressure in the vacuum vessel is always being measured by QMS whose measurable range is  $10^{-8} \sim 10^{-2}$  Pa. The QMS is mainly composed of an ion source, a filter, and a detection unit [11]. At the ion source, neutral particles collide with thermo electrons emitted from the filament and are ionized. Those generated ions are sent to the quadrupole part in the filter using an electric field. By applying a voltage to the quadrupole portion, ions who have the specific mass-to-charge ratio can pass through due to the different particle orbits. The detection unit can detect such ions, those corresponding neutral particles can be measured as the ion current value, as a result. The partial pressure of the neutral particles can be measured owing to calibrating the obtained ion current value to pressure. In the next session, the calibration method will be introduced.

#### 3.1 Gas calibration in QUEST

As noted above, since the measured value of QMS is obtained by the ion current value, it is necessary to calibrate it in order to convert it into pressure. In addition, as shown in Fig. 1, the measured values of QMSs installed in the top, middle, and down part are different even when the QUEST vacuum vessel is isolated without pumping, so each QMS sensitivity must be calibrated, either. Therefore, in QUEST a certain amount of hydrogen was injected by mass flow, and the calibration is performed from using the measured value of QMS at that time. The details are shown below.

Step 1. With the closing of all the exhausting system's gate valves on QUEST, measuring the background in such an isolation state with QMS begins. Since there is always a

certain amount of outgas from the PFWs, the outgas can be evaluated due to the proportionally rise of the partial pressure in the isolated the vacuum vessel as shown in Fig.



3. The exhausting equation is shown in eq (1) when vacuum

Fig.3 Time evolution of measured ion current in QUEST by middle QMS

In area I, QUEST vacuum vessel is under vacuum exhausted. In area II, the gate valves of cryopumps are closed and QUEST is pumped only by the turbomolecular pump. In area III, all the vacuum pumps' gate valves are closed so that the QUEST vacuum vessel is isolated, and the measurement begins. During area III, ion current is increasing due to the outgas from the PFWs. In area IV, after 2-minute-isolation, vacuum pumps are open again on sequence.

pumps are on work,

$$V_Q \frac{dp}{dt} = -S \cdot p + q_{wall} \quad (1)$$

in which  $V_Q$  in  $[m^3]$  is the volume of QUEST vacuum vessel that is about 14  $[m^3]$ ,  $p$  in pascal is the vacuum pressure in QUEST,  $S$  in  $[m^3/s]$  is the effective exhausting speed of vacuum pumps and  $q_{wall}$  in  $[Pa \cdot m^3/sec]$  means the outgas released from the QUEST walls. In the status of isolating the vacuum vessel, all the gate valves of vacuum pumps are closed meaning  $S$  is equal to zero, so the exhausting equation will be changed to eq (2).

$$V_Q \frac{dp}{dt} = q_{wall} \quad (2)$$

The gas pressure  $p$  is proportional to the ion current  $I$  measured by QMS, defined as  $p = kI$ . Therefore, eq (2) can be given as follows,

$$V_Q k \frac{dI_{bg}}{dt} = q_{wall} \quad (3)$$

in which  $I_{bg}$  in  $[A]$  is the ion current measured by QMS at the end of the background measurement and  $k$  is the proportionality factor. In this gas calibration experiment, the duration of isolation last 2 min.

Step 2. With all the gate valves closed again, a certain amount of hydrogen gas (0.5 ml / min for 10 seconds) is injected into QUEST by the flowmeter, and the hydrogen partial pressure is measured by QMS simultaneously. Fig. 4 shows the change in hydrogen partial pressure when such

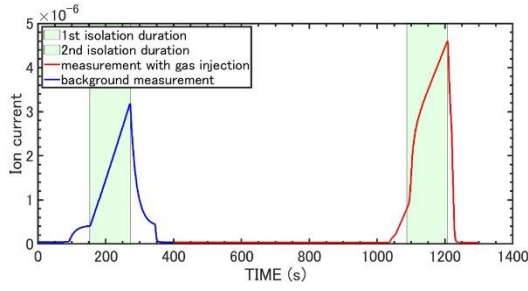


Fig. 4 Time evolution of measured ion current in QUEST by middle QMS

Hatched areas show the duration (2 minutes) of isolation of QUEST vacuum vessel. In the second isolation the hydrogen gas was injected at 0.5 ml / min for 10 s.

an amount of hydrogen was injected at that time, and the exhausting equation is shown below,

$$V_Q \frac{dp}{dt} = q_{MF} + q_{wall} \quad (4)$$

in which  $q_{MF}$  in  $[Pa \cdot m^3/sec]$  means the injected hydrogen flux.

Since the hydrogen amount supplied by the flowmeter is in the dimension of  $[ml / min]$ , it is necessary to convert it to  $[number / sec]$  in order to perform the gas calibration. According to the calibration of flowmeter with a manometer the flow 1 ml / min is obtained as  $1.36 \times 10^{18} s^{-1}$ [9]. Therefore, the amount of injected hydrogen gas at 0.5 ml / min for 10s is about  $0.5 [ml / min] \times 10 [s] \times 1.36 \times 10^{18} s^{-1} = 6.8 \times 10^{18}$ . According to the ideal gas law,  $pV = nkT$ , the pressure change in QUEST due to such a gas injection can be calculated as

$$\Delta p = \frac{nkT}{V_Q} = 2.5 \times 10^{-3} Pa \quad (5)$$

in which  $n$  is the injected hydrogen amount,  $k$  is the Boltzmann constant, and  $T$  is the temperature of QUEST vacuum vessel during the gas calibration that was 100 °C. Step 3. In order to know the ion current change that is only related to the injected hydrogen gas, it is necessary to

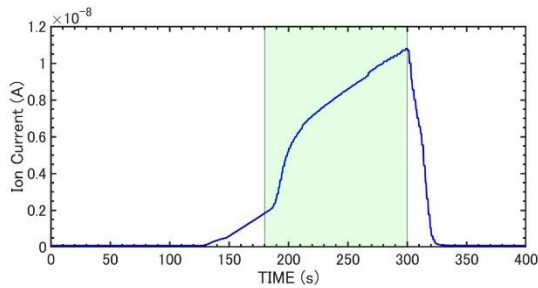


Fig. 5 Time evolution of measured ion current in QUEST by top QMS

The hatched area shows the duration (2 minutes) of isolation of QUEST vacuum vessel, during which hydrogen gas was injected at 0.5 ml / min for 10 s, in which  $I_{qms}$  is about  $1.1 \times 10^{-8} A$ .

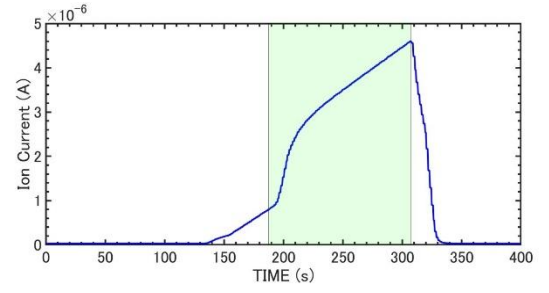


Fig. 6 Time evolution of measured ion current in QUEST by middle QMS

The hatched area shows the duration (2 minutes) of isolation of QUEST vacuum vessel, during which hydrogen gas was injected at 0.5 ml / min for 10 s, in which,  $I_{qms}$  is about  $4.6 \times 10^{-6} A$ .

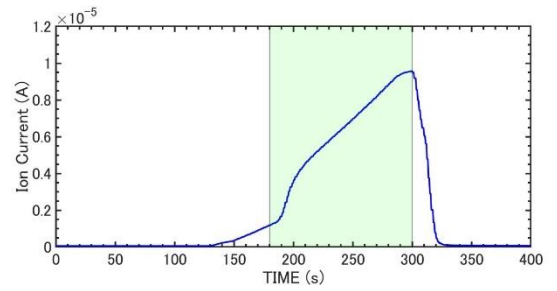


Fig. 7 Time evolution of measured ion current in QUEST by down QMS

The hatched area shows the duration (2 minutes) of isolation of QUEST vacuum vessel, during which hydrogen gas was injected at 0.5 ml / min for 10 s, in which,  $I_{qms}$  is about  $9.6 \times 10^{-6} A$ .

subtract the background content shown in Fig. 3, and the  $I_{bg}$  is about  $3.2 \times 10^{-6} A$ . The proportionality factor  $k$  is given as

$$k = \frac{\Delta p}{I_{qms} - I_{bg}} \quad (6)$$

in which  $I_{qms} = 4.6 \times 10^{-6}$  A, is the ion current measured by middle QMS at the end of isolation when hydrogen gas was injected into isolated QUEST vacuum vessel for 10 s at 0.5 ml/min. Accordingly, the proportionality factor  $k$  of those three QMSs can be obtained as  $k_{TOP} = 1.0 \times 10^6$  Pa / A,  $k_{MID} = 2.4 \times 10^3$  Pa / A, and  $k_{DWN} = 7.8 \times 10^2$  Pa / A, respectively, from Fig. 5-7.

### 3.2 Gas calibration in FESTA

As shown in Fig. 2, the hydrogen gas released from the plasma-exposed specimen is measured by the QMS set on FESTA test chamber. Therefore, it is necessary to calibrate

it using the same method mentioned above. However, due to the background temperature difference between the QUEST vacuum vessel and FESTA test chamber, hydrogen molecules and pressure in those two vessels are different to each other. Because FESTA is independent to QUEST vacuum vessel, so the background temperature is almost room temperature as  $T_R = 27$  °C. When hydrogen gas was injected into QUEST vacuum vessel at 0.5 ml/min for 10 s. The change of pressure in the test chamber can be obtained as  $\Delta p \times T_R/T = 2.0 \times 10^{-3}$  Pa referred to eq. (5). Fig. 8 shows

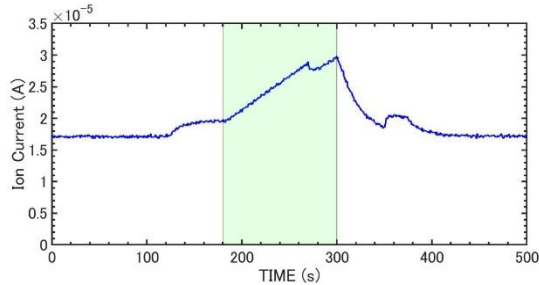


Fig. 8 Time evolution of measured ion current in FESTA test chamber by QMS

The hatched area shows the duration (2 minutes) of isolation of the test chamber, in which,  $I_{qms}$  is about  $3.0 \times 10^{-5}$  A.

the pressure change using ion current measured by QMS in the test chamber during two-minute isolation. The same to the condition in QUEST, when hydrogen gas is injected into QUEST vacuum vessel at 0.5 ml/min for 10 s, due to the connection between QUEST and FESTA, the pressure in the test chamber also increase as shown in Fig.9. In consequence, according to eq. (6), the proportionality factor of FESTA QMS  $k_{FESTA}$  can be obtained as  $1.7 \times 10^2$  Pa/A.

Above all, all the QMSs have been calibrated during one

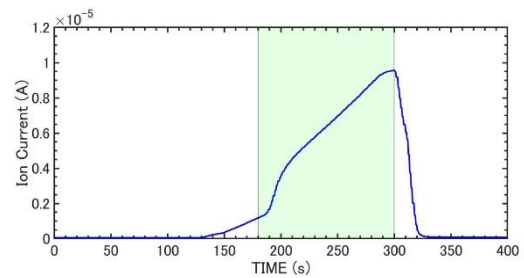


Fig. 9 Time evolution of measured ion current in FESTA test chamber by QMS

The hatched area shows the duration (2 minutes) of isolation of test chamber, during which hydrogen gas was injected at 0.5 ml / min for 10 s, in which,  $I_{qms}$  is about  $4.2 \times 10^{-5}$  A.

campaign.

### 4. Calibration of Gas Balance

The exhausting speed of cryopumps on QUEST are under change depending on experimental conditions. Therefore, in order to evaluate the exhausted flux accurately, QUEST QMSs are used at the begin and the end of each experimental day, and the method is denoted below.

Step.1 As shown in Fig. 10, ten-step hydrogen flux is

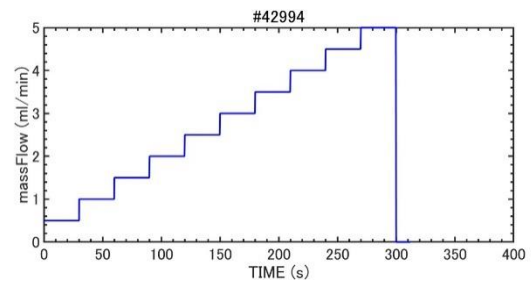


Fig. 10 Time evolution of ten-step mass flow value (injected hydrogen flux) due to calibrated flow meter

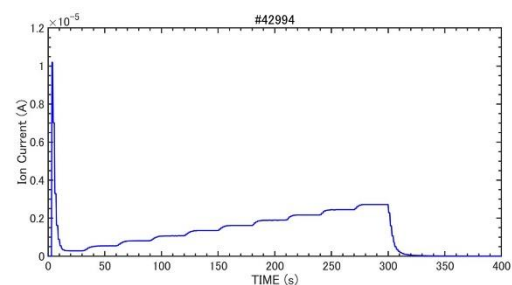


Fig. 11 Time evolution of hydrogen ion current measured by QUEST QMS, which is used to evaluate hydrogen pressure mentioned in the previous section



injected into QUEST vacuum vessel by flowmeter mentioned above.

Step. 2 The hydrogen pressure in the vessel is being measured using QMSs simultaneously. As shown in Fig. 11 when the particle supplied flux is balanced with exhausted flux the pressure becomes constant. In consequence, it can be considered that exhausted flux can be evaluated by the particle supplied flux. The time evaluation until the partial pressure becomes constant is considered to be caused by the movement of particles in the pipes, diffusion in the QUEST vacuum vessel, surface adsorption, etc. Since the particle exhaust flux is proportional to the partial pressure, the exhaust flux can be evaluated by measuring the partial pressure under the steady state.

Step. 3 By taking each flux at which the hydrogen partial pressure becomes flat and the hydrogen ion current on the horizontal axis and the vertical axis, the exhausted flux calibration figure is obtained as shown in Fig. 12.

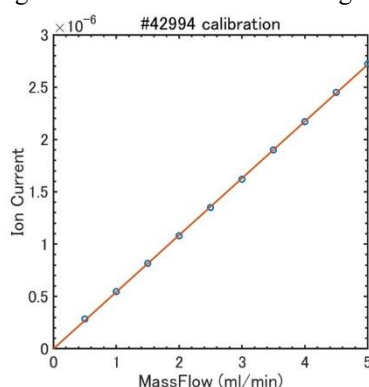


Fig. 12 Calibration of exhaust flux by measured QMS value

According to the calibration, exhausted flux can be obtained from the slope  $k_c = 5.4 \times 10^{-7} \text{ A/(ml/min)}$ . As mentioned in the previous section, 1 ml/min flow is obtained as  $1.36 \times 10^{18} \text{ s}^{-1}$  supplied by flowmeter. Taking ideal gas law,  $1.36 \times 10^{18} \text{ s}^{-1} = 4.66 \times 10^{-3} \text{ Pa-m}^3/\text{s}$ . Therefore, the exhausting speed of cryopumps on QUEST can be expressed as  $4.66 \times 10^{-3} \text{ Pa-m}^3/\text{s} / (k_c k_{MD}) \text{ m}^3/\text{s}$ .

## 5. Project to Improve FESTA and the Test Chamber

Hydrogen recycling involves reflection and surface recombination, but reflection only occur in the presence of particle flux from the plasma. As shown in Fig. 13, by attaching a TDS device to FESTA, the amount of static retention in the plasma-exposed specimen can also be evaluated. Since the particle flux from the plasma can be measured with the existing permeation probe [12], the reflection can be measured by the difference between the total recycling and retention.

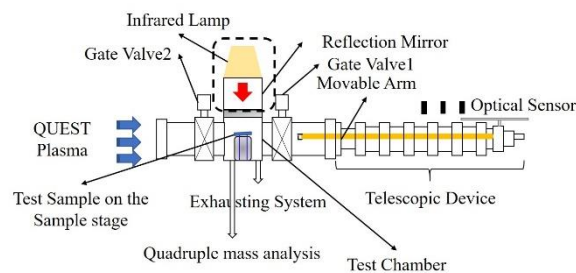


Fig. 13 Schematic of FESTA

The dotted frame shows the infrared lamp and reflection mirror of the TDS device.

Furthermore, the effect of induced desorption of helium (He) cannot be evaluated unless the temperature is over 2000 K at least, so a new heating device is being designed and the test chamber shall be upgraded as shown in Fig. 14.

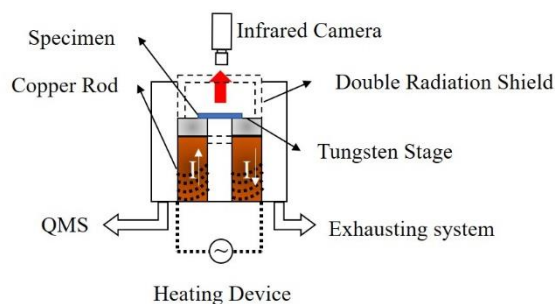


Fig. 14 Schematic of heating device in the test chamber

A specimen in which He is pre-occluded inside is exposed to hydrogen plasma to QUEST of 473 K wall temperature using FESTA. The He-induced desorption effect of hydrogen plasma is predicted to be quantitatively measured by measuring the remaining He after plasma discharge, and the surface condition of the exposed specimen will be confirmed with an electron microscope before and after exposure to QUEST plasma.

## 6. Summary

In the data analysis, the ion currents measured by QMSs have been calibrated accurately both on QUEST and FESTA due to the use of flowmeter. The exhausting system on QUEST is also under calibration according to the proportional relationship between mass flow injected into the QUEST vacuum vessel and the ion current value measured by QMSs.

In the future work, FESTA will be installed a TDS device to measure the amount of static retention without being contaminated, so that the reflection rate can also be measured. With the help of new project of improving the test chamber, the plasma-exposed sample can be heated up to over 2000 K. The influence of He on the PFWs will be deeply understood using FESTA.

## 7. Acknowledgement

This work was supported by QUEST team. This work was also supported by a Grant-in-Aid for JSPS Fellows (KAKENHI Grant Number 16H02441, 19H05526, 21J21782) and the NIFS Collaboration Research Program (NIFS05KUTRO14, NIFS19KUTR136). This work was also supported in part by a Grant-in-Aid for JSPS Fellows (KAKENHI Grant Number 19H05526), the Collaborative Research Program of the Research Institute for Applied Mechanics, Kyushu University and the JSPS-NRF-NSFC A3 Foresight Pro-gram in the field of Plasma Physics (NSFC: No. 11261140328). This work has also been hinted by the papers published on the previous conferences [13-15].

## References

- [1] S. Brezinsek, et al 2013 Nucl. Fusion 53 083023
- [2] S. Brezinsek, 2015 J. Nucl. Mater. 463 11–21
- [3] T. Loarer, et al 2007 Nucl. Fusion 47 1112–20
- [4] V. Philipps, et al 2013 J. Nucl. Mater. 438 S1067
- [5] K. Hanada, et al 2017 Nucl. Fusion 57 126061
- [6] K. Hanada, et al 2010 Plasma Fusion Res. 5 S1007
- [7] K. Hanada, et al 2016 Plasma Sci. Technol. 18 1069–75
- [8] Y. Oya et al. 2019 Fusion Eng. Des. 146, 1480-1484
- [9] K. Hanada, et al., Nucl. Fusion 59 (2019) 076007
- [10] Q. Yue et al. 2020 Plasma Fusion Res. 15 240201
- [11] T. Wauter et al., Plasma Phys. Control. Fusion 53 (2011). 125003 (20pp).
- [12] A. Kuzmin et al., Nucl. Mater. and Energy. 12 (2017) 627-632
- [13] M. Khalid Hossain et al., Proceedings of Inter. Exchange and Innovation Conference on Eng. & Sci. (IEICES) 6 (2020) 1-6
- [14] W. Mohamed, Proceedings of Inter. Exchange and Innovation Conference on Eng. & Sci. (IEICES) 6 (2020) 19-20
- [15] K. Hashizume, Proceedings of Inter. Exchange and Innovation Conference on Eng. & Sci. (IEICES) 6 (2020) 34-39