PLASMA-WALL INTERACTION FACILITIES IN KOREA

K.-S. Chung[1,2,*], H.-J. Woo[1,2], S.-G. Cho[1,2] , Y.-S. Choi[3], S.-H. Han[7], B.-G. Hong[4] , S.-H. Hong[6] , H.-S. Kim[5], S.-J. Noh[5], T. Lho[3], S.-J. Park[1,2], and H.-J. You[3]

[1]*Dept. of Electrical Engineering, Hanyang University, Seoul 133-791, Republic of Korea*
[2] *Center for Edge Plasma Science (cEps), Hanyang University, Seoul 133-791, Republic of Korea*
[3]*Plasma Technology Research Center, National Fusion Research Institute, Daejeon 305-333, Republic of Korea*
[4]*High Enthalpy Plasma Research Center, Chonbuk National University, Jeonju, Jeollabuk 561-756, Republic of Korea*
[5]*Dept. of Applied Physics, Dankook University, Yongin, Gyeonggi 448-701, Republic of Korea*
[6]*KSTAR Team, National Fusion Research Institute, Daejeon 305-333, Republic of Korea*
[7]*Korea Institute of Science and Technology, Seoul, Republic of Korea*
*kschung@hanyang.ac.kr

Although the research of plasma-material interaction (PMI) is rather immature comparing the recent success of Korean fusion program, there are several facilities and programs of PMI research in Korea. DiPS (Divertor Plasma Simulator)-2 is a linear device with a four-inch-LaB_6 cathode at the Center for Edge Plasma Science (cEps), concentrating on the development of various diagnostics for divertor and scrape-off plasmas, and for PMI research such as tungsten and graphite related phenomena. This is modified from DiPS-1, which were for the simulations of divertor, space and processing plasmas using LaB_6 and helicon plasma sources. MP^2 (Multi-Purpose Plasma) is a linear device with an eight-inch-LaB_6 cathode for PMI in National Fusion Research Institute (NFRI), and will be merged with molten salt (FLiNaK) experiment by using an Electron Cyclotron Resonance (ECR) plasma source. High power plasma torch facilities have been developed at the High-Enthalpy Plasma Research Center in ChonBuk National University, aiming for the development of new materials of the aero-space-, nano-, and automobile-industries, yet recently they have interest in fusion materials. Plasma Immersion Ion Implantation & Deposition (PIIID) facility has been utilized for the research of processing materials in Korean Institute of Science and Technology (KIST), and is to be used for fusion material researches with high energy ions (~70 keV). Electron beam irradiation has been tried for the research of graphite and tungsten at DanKook university. These facilities are to be utilized for the application to KSTAR, ITER and/or Korean DEMO fusion devices. Dust as the by-product of PMI in fusion device is to be characterized and removed in TReD (Transport & Removal experiment of Dust) device in Hanyang University. Plasma sources, diagnostics, and surface analyses of these programs will be explained with design philosophies and basic parameters of plasmas.

I. INTRODUCTION

Plasma-material interaction in fusion devices is one of the key issues for the success of ITER and DEMO, which is complex and coherent[1], one needs to understand the edge plasma state, material damage, and their mutual interactions. Generally, the plasma-material interactions should be analyzed by studying the plasma properties in the scape-off layer and divertor (limiter) regions[2-4], material erosion and deposition[5,6], impurity transport[7], fuel retention[8], dust production and detection[9-11]. This indicates that the laboratory simulations of PMI are necessary to quantify the long-term results of plasma-beam illuminations on the plasma facing components, and to repeat a tedious and multiple procedures. For these, various PMI facilities have been developed recently in Korea, such as DiPS, MP2, ECR plasma, a segmented plasma torch system, e-beam accelerator, and the TReD (Transport & Removal experiment of Dust) device. In this paper, these devices are briefly to be explained in terms of objective and specifications along with initial experimental results.

II. PMI FACILITIES

II.A. DiPS-2 Linear Plasma Facility

DiPS (Divertor Plasma Simulator)-2 has been modified from the DiPS-1 [12] to focus the edge plasma simulation and plasma-material interaction research with diagnostics developments, while the latter had wide range of applications : fusion, space and processing plasma simulations. DiPS-2 generates the plasma a LaB_6 cathode like DiPS-1. The main objective of DiPS-2 is the development of plasma diagnostics for the fusion edge plasmas, edge plasma simulations such as the effect of atomic processes in the scrape-off layer (SOL) and divertor regions, and material test of the plasma facing components (PFCs).

Four-inch LaB_6 disk is heated by a graphite heater cooled by water, and it has a central hole for the passage of LIF(laser induced fluorescence) system. Figure 1 shows the schematic diagram of DiPS-2. DiPS-2 is separated by 5 regions, such as source region (A), 1st differential pumping (DP) stage (B), 2nd DP stage (C), magnetic nozzle (D), and test region (E) by adapting highly differential pumping to control the test region plasma strongly independent from the source plasma. Typical magnetic field shape is shown in Figure 2, which varies 0 – 3.5 kG.

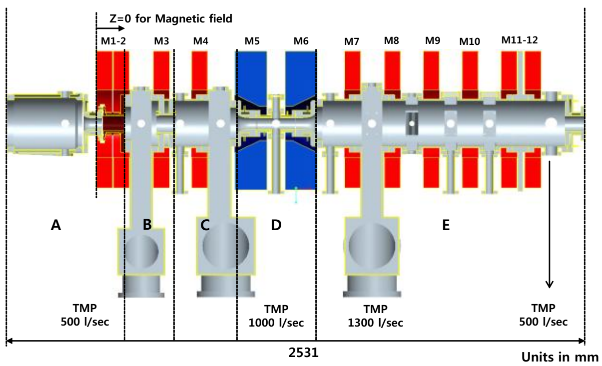

Figure 1: *Schematic diagram of DiPS-2: Labels of A, B, C, D, E, and M1-12 are source region, 1st differential pumping stage, 2nd differential pumping stage, magnetic nozzle, test region, and electromagnets.(Hanyang University)*

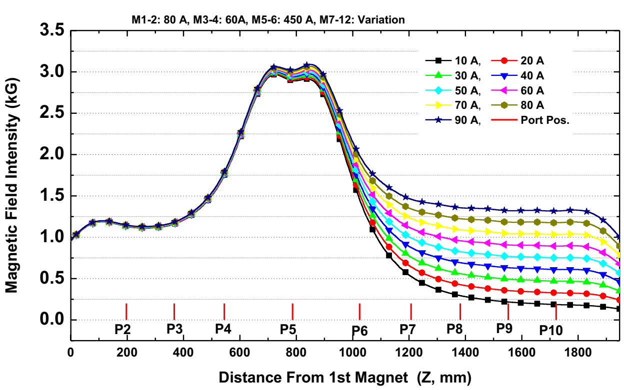

Figure 2: *Typical magnetic field intensity in DiPS-2: Labels of P2-10 are the port number from source chamber. P1 and P11 are not shown.*

DiPS-2 is generally operated with the following conditions: discharge voltage (V_d) = 0 - 200 V, discharge current (I_d) = 0 - 150 A, operating pressure (P_n) = 20 mTorr (source region), 3 mTorr (2nd differential pumping (DP) stage) and 1-100 mTorr (test region) within less than variations of 20% of 2nd DP pressure and 5% of source region, plasma density (n_p) = upto 5´ 10^{13} cm^{-3} at test region, electron temperature (T_e) = 2-3 eV for Ar plasma and 5-7 eV for He plasma, and ion temperature (T_i) ~ 0.1 eV for Ar ions.

DiPS-2 has the four main plasma diagnostics, such as probe systems (four fast scanning probes and one fixed probes) [12], two laser-induced fluorescence systems for Ar ion diagnostics [13], optical emission spectroscopy [14] and one laser Thomson scattering (LTS) system which is recently installed while others are already developed for DiPS-1.

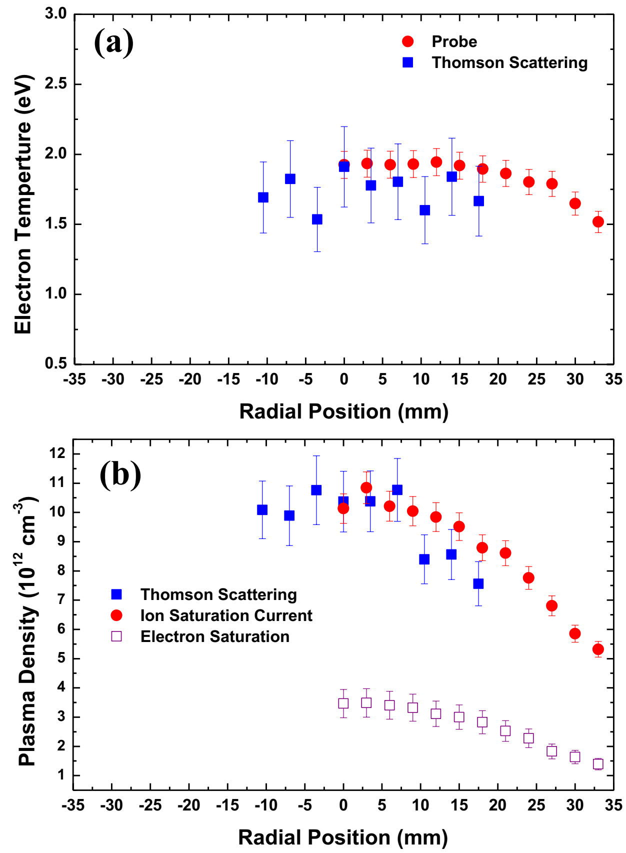

Figure 3: *Initial data of LTS diagnostics comparing with probes – electron temperature (a) and plasma density (b).*

Initial data of LTS diagnostics is shown in Figure 3, comparing with those by a single electric probe. The electron temperatures and plasma density measured by LTS agree well to those of electric probe deduced by ion saturation currents, while the plasma density by electron saturation current is not matched to those by LTS due to reduction factor by the magnetic field, which is related cross- and parallel diffusions and sheath impedance. The details of LTS system will be discussed later.

II B. MP^2 Linear Plasma Facility [15]

MP^2 plasma facility was developed from former Hanbit mirror device at NFRI with similar concept of DiPS-1, but with a larger plasma source and a higher particle flux plasmas. For larger plasma generation, MP^2 has adapted honeycomlike large area LaB6 cathode (HLA-LaB6) with 4 inch diameter (center, one disk) and

2 inch diameter (outer, 6 disks) LaB_6 plates along the peripheral side, which becomes about 8 inch of total source diameter. The plasma shape or density controls can be possible by separately heating center and outer cathode in MP^2. The MP^2 is now idling since it will be moved to a separated branch institution in Kunsan site of the NFRI (at Daejeon), but it will be resumed soon.

II C. ECR Plasma Facility [16]

During resting phase of MP^2, a complimentary machine has been developed with small size ECR plasma for the test liquid PFCs materials, especially molten salts (FLiNaK). This is to be incorporated with MP^2 after resuming at Kunsan site. Figure 4 shows the schematic diagram of ECR device and its diagnostics systems. The plasma is produced by 2.45 GHz Magnetron upto 2 kW of Power. Typical plasma density and electron temperatures are 5´ 10^{10} cm^{-3} and 10 eV from probe measurements, respectively. The magnetic field at molten salt surface is about 200 G. The typical heating temperature is about 540 ºC for liquid FLiNaK.

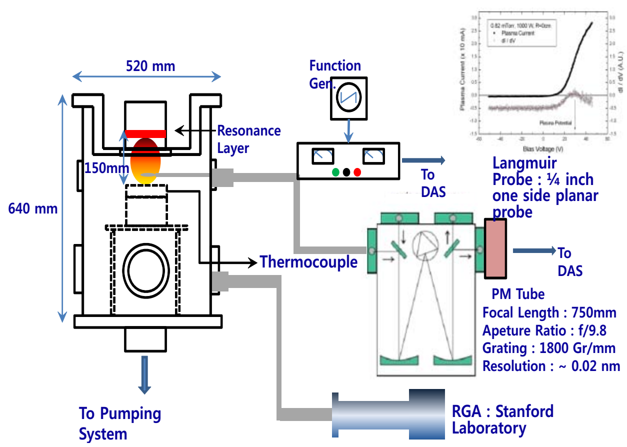

Figure 4: *ECR plasma facility with diagnostics systems for liquid PFCs tests.(NFRI)*

Figure 5 shows the initial results of H_2 retention in FLiNaK versus plasma irradiation time. One uses the outgassing rate of H_2 without plasma irradiation as the reference value. The integrated amount of the difference between measured one with plasma and the reference with the time gives the total about of the retention of H_2 molecules in FLiNaK at a given pressure. The main mechanism of H_2 retention would be caused by the ion bombardment on material surface accelerated by the sheath potential, and it will be discussed more detail in a separated report.

II D. E-beam Test Facility

High energy electron beam facility was developed for thermal heat load experiments at Dankook University. The electron beam energy and beam current are 70 keV (maximum) and 100 mA (maximum) within 40 x 40 mm^2 of target size. This means that the maximum heat load over 4-5 MW/m^2, which is acceptable for fusion material tests of KSTAR and even parts of ITER.

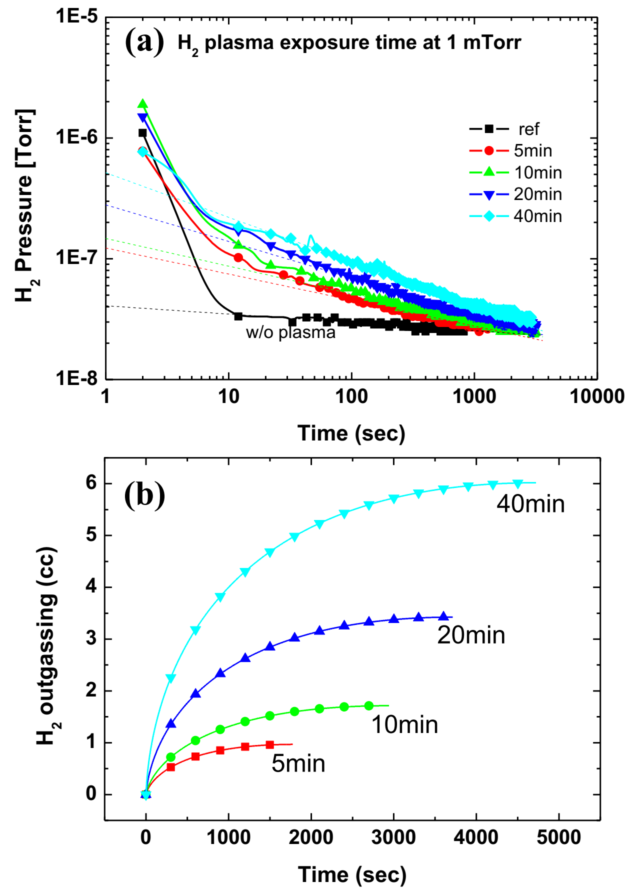

Figure 5: *H2 retention in FLiNaK versus plasma irradiation time at 1 mTorr.*

II E. Torch Plasma Facility

The high power plasma torch has been developed in Chonbuk National University for the material tests at the extreme environments, such as material erosions by aerodynamic heating, thermal protection at extremely high temperature condition, heat load tests for fusion and space plasmas. Figure 6 shows the cross-sectional view of a segmented plasma torch, which will be operated with the following conditions: arc heating power = 400 kW, voltage = 800 – 2200 V (normal 1000 V), maximum current per cathode = 250 A (total 500 A, double cathode), pressure = 0.2 – 1 Torr, plasma velocity at nozzle = 1-4 Mach numbers. Diagnostic systems include enthalpy probe with mass spectrometer for measurement of enthalpy, plasma composition and plasma temperatures, and heat flux probe for measurement of heat flux.

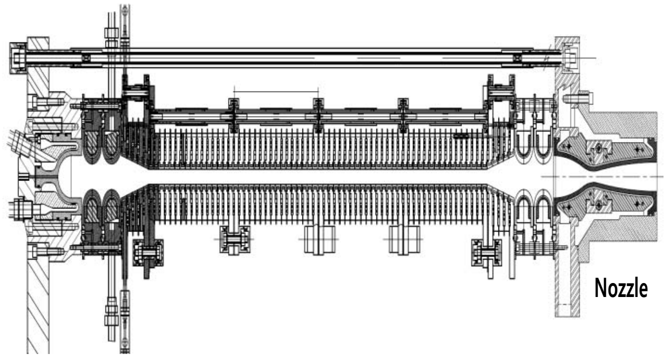

Figure 6: *Drawing view of segmented plasma torches.* (Chonbuk National University)

Visualization systems such as a pyrometer, a fast camera and an emission spectroscopy are installed to monitor the surface temperature of the substrate, plasma density, flow pattern etc. Measured performance data of the segmented arc plasma torch is shown in Table 1. This torch can produce the high heat flux above 10 MW/m^2 to target area of ~ 100 cm^2.

II. F. PIIID Plasma Facility

The plasma immersion ion implantation and deposition (PIIID) device was developed at KIST for the test of various material and surface modifications with high energy ions. Figure 7 shows the schematic diagram of PIIID system equipped with high-power pulsed magnetron sputtering system along with plasma immersion ion implantation capability. The intense pulse power to the magnetron can increase the ionization rate of sputtered atoms and can be implanted with the use of negative high-voltage pulse bias to the sample. The specifications of PIIID system are as follows; implantation energy = up to 70 keV, peak current = up to 10 A, peak power density = 100 MW/m^2, averaged power density = 0.5 MW/m^2, and maximum sample size = 50 x 50 mm^2.

II. G. TReD Facility [17]

TReD (Transport & Removal experiment of Dust) device has been developed for the tests of dust particle transport, removal and its diagnostics. Figure 8 shows the drawing view of TReD, which is adapted the method of electrostatic curtain with tripolar grid and three phase alternative current (AC) operation. For versatile experiments, the chamber is designed as a rectangular shape with dimension of 0.5 (W) x 1.2 (L) x 0.5 (H) m^3 and equipped large rectangular view ports for dust monitoring. The total 100 traveling electrode was located bottom of the chamber with dimensions of 9 (W) x 450 (L) mm^2 and gap spacing is of 1 mm. The plasma is generated by inductively coupled plasma (ICP) source with the frequency of 13.56 MHz and 3 kW of maximum RF power (typically, < 50 W operation). One uses four linear antennas with ladder shape for uniform plasma generation from the upper region of the rectangular chamber.

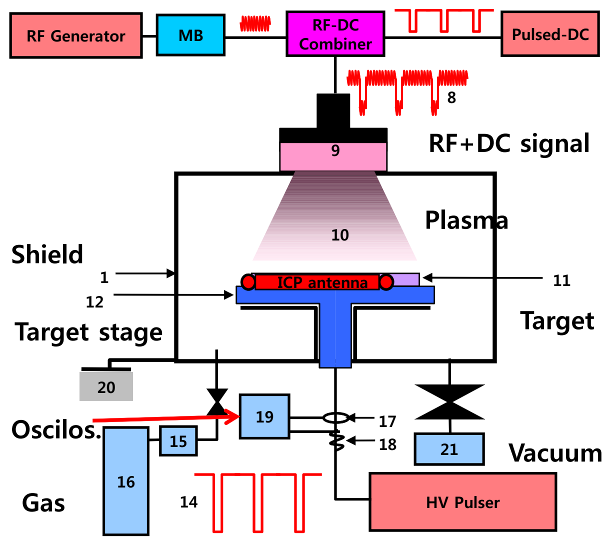

Figure 7: *Schematic diagram of plasma immersion ion implantation and deposition (PIIID) system, which is equipped with high-power pulsed magnetron sputtering along with plasma immersion ion implantation capability.* (KIST)

In the first phase, one tries to test the dust particle detector based upon capacitive diaphragm gauge (CDG), which will be used KSTAR and ITER. Figure 9 shows the CDG assembly and calibration results. One uses the dust tray with aluminum ball(2.1 g) for centering the weight position since the response of CDG is dependent on the position. The CDG gauge will be checked at KSTAR during the 2012 campaign.

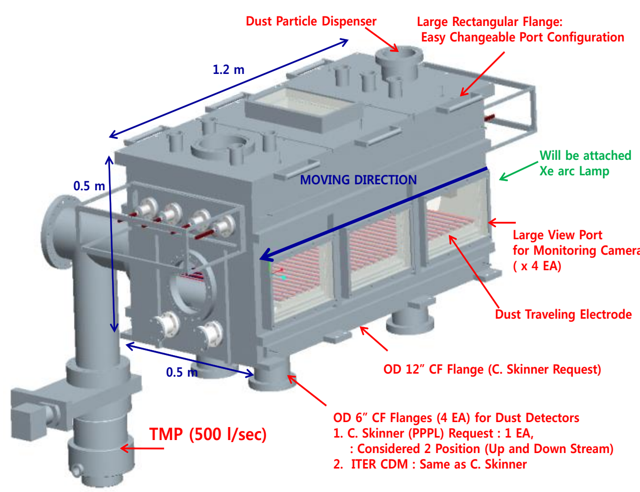

Figure 8: Drawing view of TReD device.

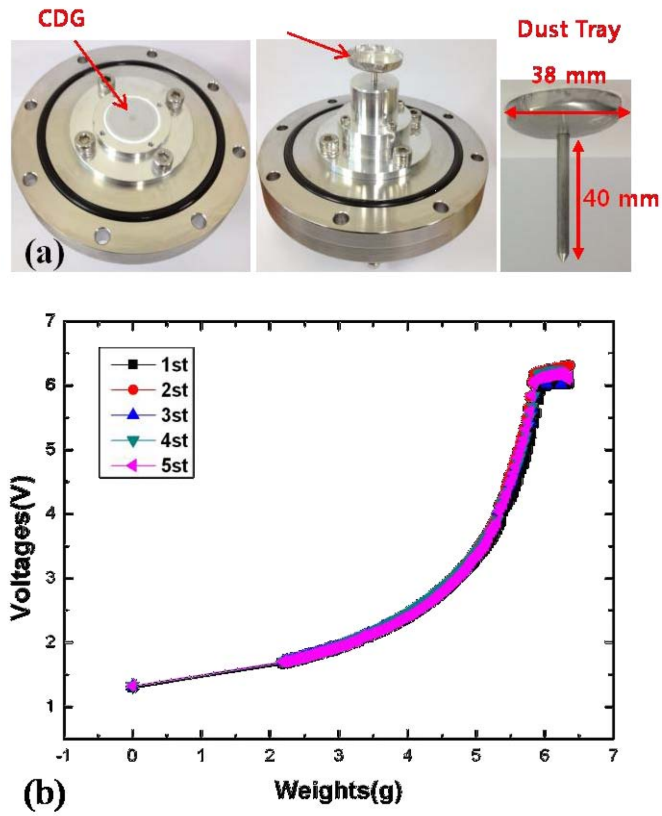

Figure 9: Test of CDG dust particle detector – CDG detector assembly (a) and calibration results (b).

II. CONCLUSIONS

Recently, the various plasma devices have been developed in Korea for the plasma-material interaction (PMI) researches. These can be categorized by the followings; (1) edge plasma simulator - DiPS-2 (HYU), MP2 (NFRI) (2) plasma diagnostics developments - DiPS-2 (HYU) and MP2 (NFRI), (3) material test by plasma - DiPS-2 (HYU), MP2 (NFRI), ECR plasma facility (NFRI), by ion beam – PIIID (KIST), (4) thermal heat load test by electron beam (e-beam facility: DKU), by high heat flux plasma (segmented plasma torch: CBNU) and (5) dust particle transport and removal (TReD: HYU).

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