Development of Radiative Divertor Simulator Using Magnetic Mirror Device at KAIST

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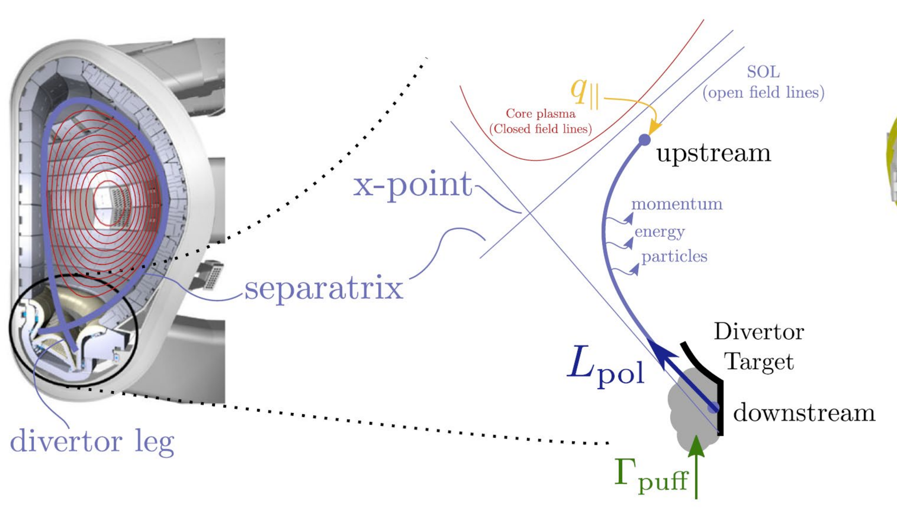
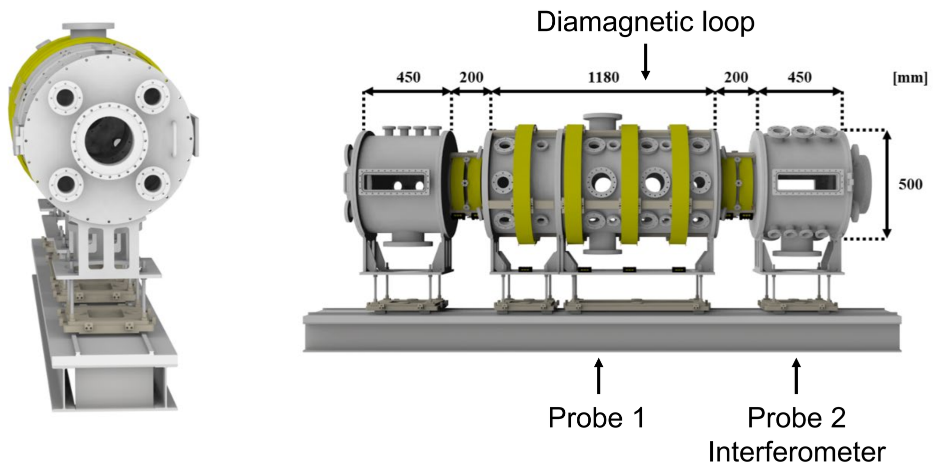
Introduction



Diverted plasma configuration in a tokamak and schematics showing mitigation of heat flux with gas puffing [1]

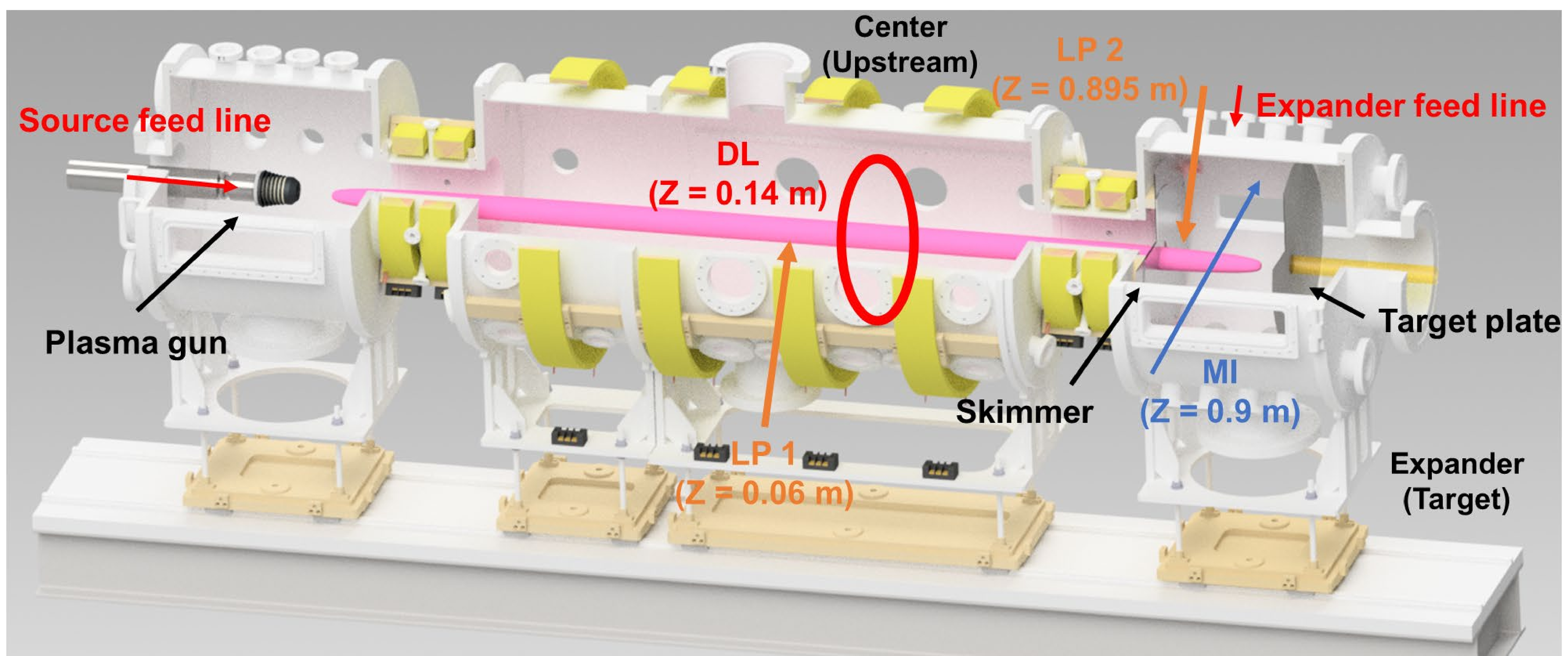


Computer-aided design model of the KAIMIR chamber

- Divertor component is utilized to protect plasma facing material and control impurities from the wall in closed field systems
- A comprehensive understanding of the divertor region is required to satisfy the thermo-engineering limits of the plate, preventing damages caused by high heat and particle flux
  - Since the magnetic field in divertor region is open, simulation in open field device can be more efficient than in overall system, which is much more complex
- Heat flux on the divertor can be reduced by puffing main ion or impurity species near the target in the **radiative divertor**, which induces **radiative power dissipation**
- **Magnetic mirror device** (KAIMIR) [2] was employed to simulate radiative divertor
  - Valid for test bed of divertor region to study divertor physics with low cost and similar geometry
  - Produces **~4–6 eV, ~$10^{18–20}$ m^{-3} Helium plasma** for **~12 ms** using a plasma gun [3]

Development of Radiative Divertor Simulator

Independent control of each chamber pressure is required to induce **radiative loss** at the target region without **disturbing upstream plasma**

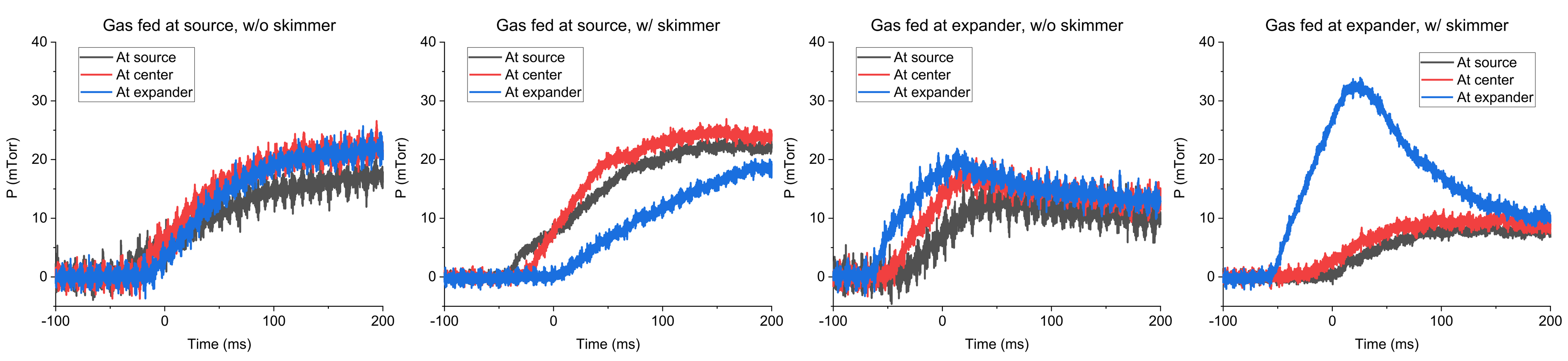


LP = Langmuir probe, DL = Diamagnetic loop [4], MI = Microwave interferometer,
Z = 0 m is referenced to the center of the chamber

Skimmer at the entrance of expander blocks gas flow between chambers
→ **Sustain the pressure difference** during the discharge

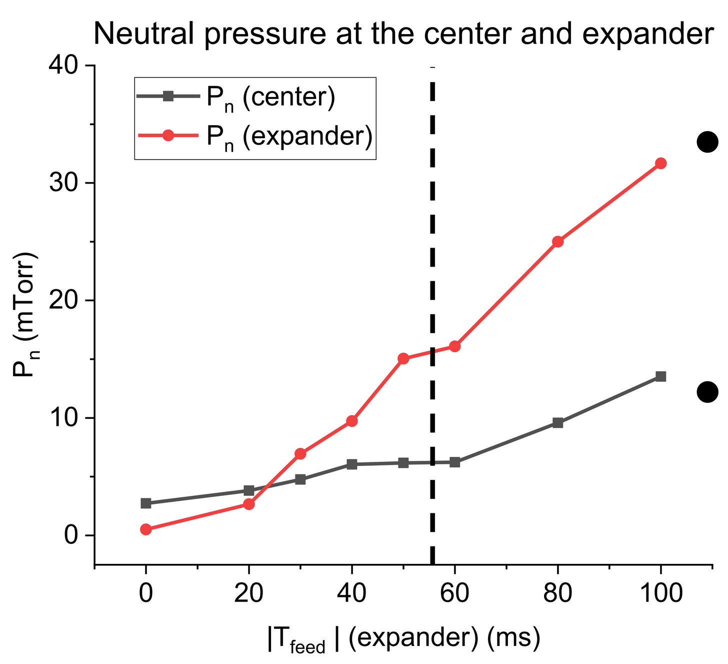
Verification of the independent pressure control of each chamber

$T_{inj.} = -100\text{~}0$ ms, $Q_{inj.} = 13$ slm (Dataset low-pass filtered by f_c = 10 kHz)



- **Differential pressure** between the chambers was observed **with the skimmer**
  - Generates **~60 ms time delay** of the pressure evolution in the chambers that gas was not fed
    - P_{source} < ~9 mTorr & $P_{expander}$ < ~30 mTorr while pressure at the other chamber < 1 mTorr
    - The increase was stronger when the gas was fed at the expander, since overall volume is smaller
- Confirmed that the **pressure difference** was **sustained** during the discharge (0 – 12 ms)

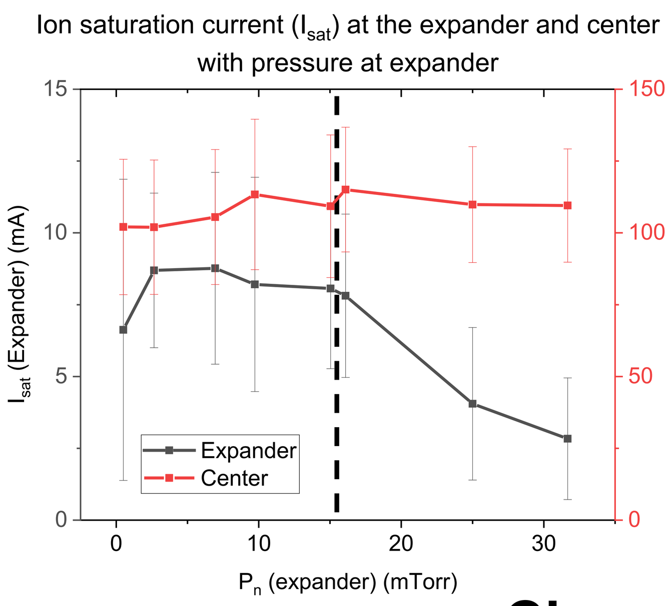
Expander gas feeding with the differential pumping system



- Increase of neutral pressure was ~3.5 mTorr at the center, much smaller than the expander, ~16 mTorr by the feed time ($|T_{feed}|$) < 60 ms
- $|T_{feed}|$ > 60 ms → P_n (center) increased significantly
  - $|T_{feed}|$ larger than the time delay by the differential pumping system affects the P_n (center)

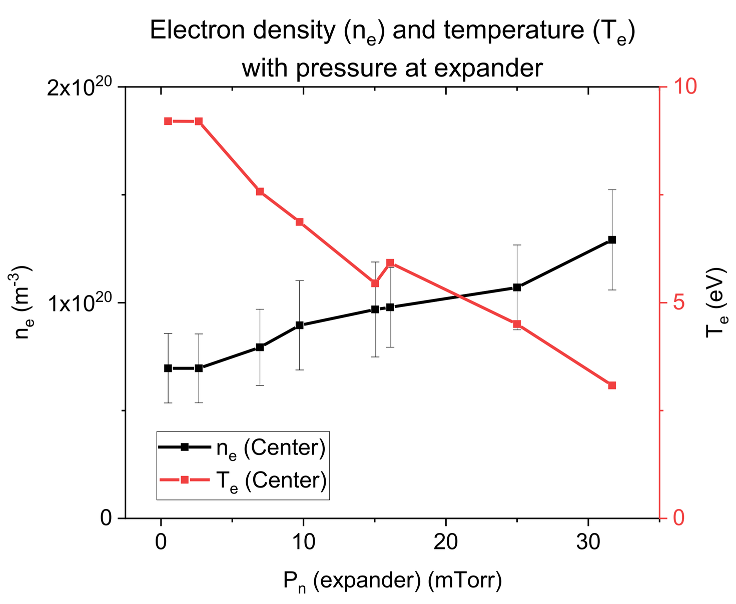
Effects of expander gas feed

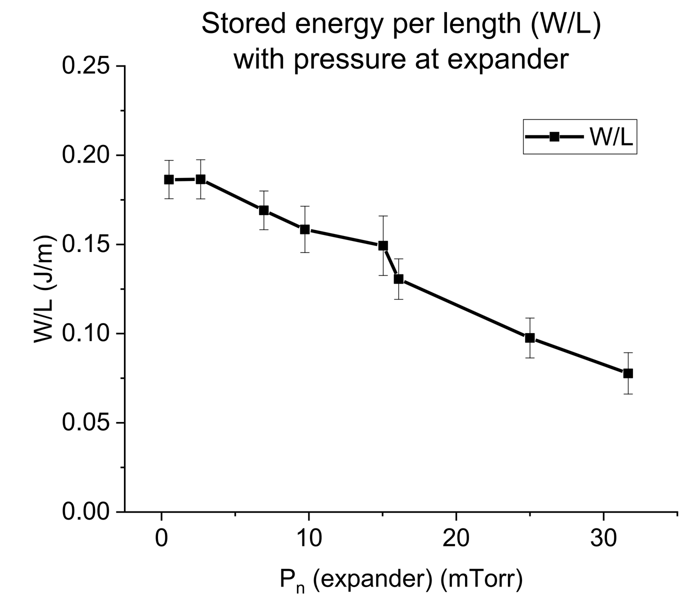
Effects to the particle flux



- Variations in the I_{sat} at the center were negligible (<10%), while I_{sat} at the expander region slightly increased (~30%) until P_n = 16 mTorr
- I_{sat} at the expander decreased with increasing pressure when P_n > 16 mTorr
- I_{sat} at the center stayed at similar level despite the increased neutral pressure at the center chamber

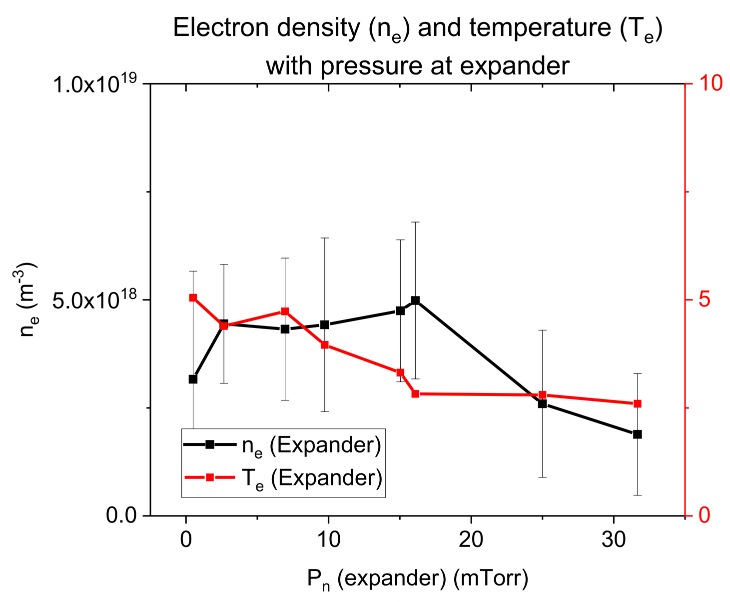
Changes at the central region

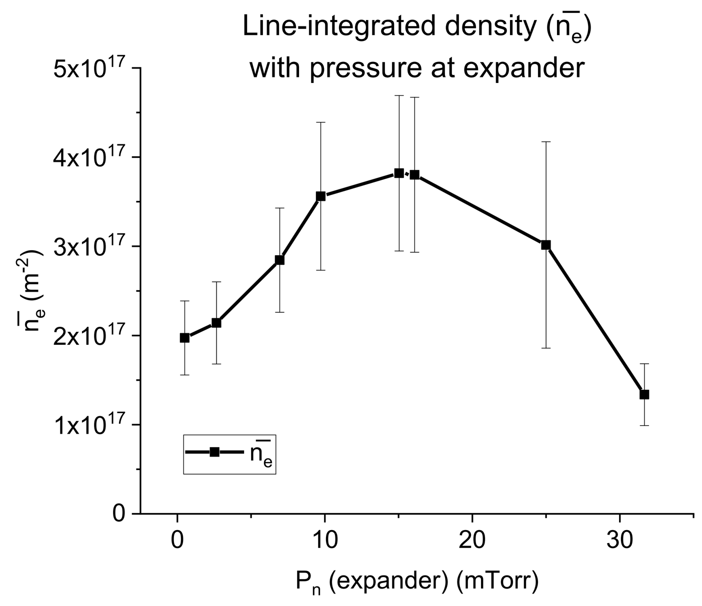




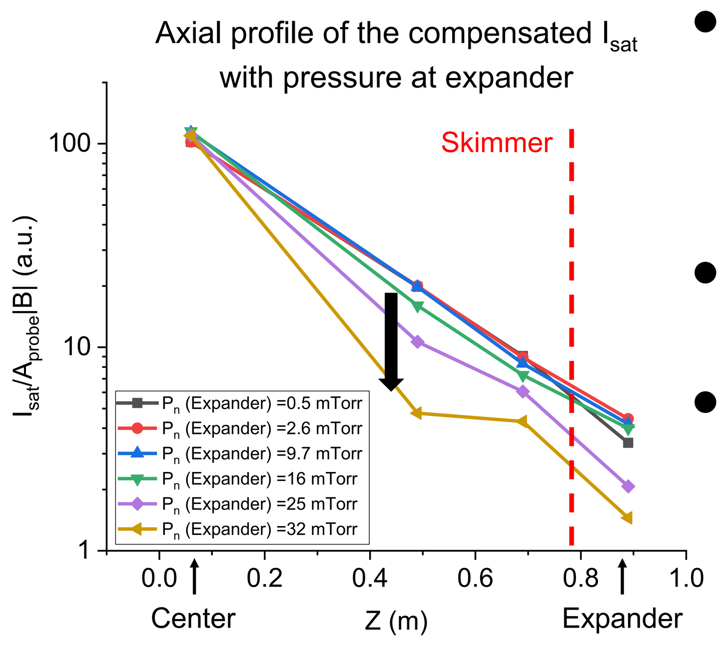
- Gradual decrease of T_e and increase of n_e were observed with the steady particle flux
- Reduction in the stored energy per length, measured by DL, was also consistent
- Cooling of the expander can reduce energy at the center and degrade the energy confinement at the central region, which should be investigated in the future

Changes at the expander region





- Increased n_e observed from both probe and interferometry in P_n < 16 mTorr at expander
  - The density increased due to higher ionization rate with the increased neutral density
  - Frequent collisions with neutrals may reduce the electron temperature as observed
- Reduced flux when P_n > 16 mTorr will be the result from the increased neutral pressure in both expander and center chambers



- Change of the cross-section area of the plasma (A_{pl}) compensated by dividing the field intensity ($|B|$)
  - Particle flux, Γ can increase even with constant particle flow rate, S, due to BA_{pl} = Const. ($\Gamma \sim SA_{pl} \propto I_{sat}/|B|$)
- In P_n < 16 mTorr, little change in axial profile of $I_{sat}/A_{probe}|B|$
- As P_n is higher than 16mTorr, decrease of the particle flux was observed between center and expander
  - Can be a main contributor to the reduced particle flux in the expander

Summary

- We are developing a radiative divertor simulator using KAIMIR
  - Independent control of the pressure in each chamber in KAIMIR was verified
- The particle flux at the center was sustained while adjusting the pressure at the expander
- Two different regimes were observed depending on neutral pressure at the center
  - n_e ↑, T_e ↓ in both region when the low center pressure was sustained, results in steady flux
    → The interaction b/w the center (upstream) and the expander (target) may alter the plasma parameters at the center, despite the center neutral pressure being constrained
  - The particle flux between center and expander decreases with higher center pressure

Future work

- Develop additional diagnostic, which can quantitatively measure radiative loss along the axis induced by the gas feeding (e.g. bolometer, filterscope)
- Analyze factors influencing electron density and temperature changes utilizing a spectrometer and the Electron Energy Distribution Function (EEDF) at different pressure
- Conduct experiments under various conditions related to the radiative divertor

Reference.
[1] Ravensbergen, Timo, et al. "Real-time feedback control of the impurity emission front in tokamak divertor plasmas." *Nature communications* 12.1 (2021).
[2] Oh, D., et al. "Development of a new magnetic mirror device at the Korea Advanced Institute of Science and Technology." Journal of Plasma Physics 90.2 (2024).
[3] Park, JongYoon, et al. "Design and development of the helicity injection system in Versatile Experiment Spherical Torus." *Fusion Engineering and Design* 96 (2015).
[4] Choe, M., et al. "Development of a diamagnetic loop in KAIMIR." *Review of Scientific Instruments* 95.7 (2024).
This work was supported by the National Research Foundation of Korea (NRF) funded by the Korea government (Ministry of Science and ICT) (RS 2023 00212124, RS 2022 00155956).