9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

A new approach to solve divertor heat and particle issues – RF plugging using a toroidally localized electrodes –

Ryuya Ikezoe[1], Wooran Fumikawa[2], Satoshi Togo[3], Takumi Onchi[1], Makoto Hasegawa[1], Toshiki Kinoshita[1], Hiroshi Idei[1], Kazuaki Hanada[1], Takeshi Ido[1], Yoshihiko Nagashima[1]

[1] Research Institute for Applied Mechanics, Kyushu University,

[2] Interdisciplinary Graduate School of Engineering Sciences, Kyushu University,

[3] Plasma Research Center, the University of Tsukuba

e-mail (speaker): ikezoe@triam.kyushu-u.ac.jp

The major unresolved issues in anticipation of a magnetic confinement fusion reactor include dealing with the extensive divertor heat load and particle control in a burning condition. Most current reactor designs rely on dissipating most of the heat energy at the divertor through impurity-induced radiation, but there is no clear evidence that this can be maintained stably for long periods of time in a high-power reactor environment, or that it is compatible with core confinement. In addition, it is important to maintain the mixing ratio of fuel ion species to sustain the burning state. The fusion output is a strong function of temperature and fuel particle fraction, and thus, fuel dilution and radiative power loss due to impurity accumulation have a crucial impact. However, whether the maintenance of fuel fraction is feasible while handling a finite amount of tritium remains to be seen. To solve these anticipated major issues, we are aiming to pioneer innovative technologies by using an old but new RF plugging.

RF plugging has been intensively studied in the past to suppress the leakage of the plasma flow in an open magnetic system [1]. A 95% reduction in end-loss ion flux at a line cusp has been achieved [1]. The ponderomotive potential that a charged particle of charge q and mass m subjects under the influence of an RF field in a magnetic field is described in the following expression,

$$\Psi_{\mathrm{RF}} = \frac{q^2 E_\perp^2}{4m(\omega^2-\omega_c^2)} + \frac{q^2 E_\parallel^2}{4m\omega^2}\ , \qquad (1)$$

where ω_c, $E_\perp$ and $E_\parallel$ are the angular cyclotron frequency, perpendicular and parallel RF electric fields, respectively. The first term in eq. (1) becomes effective for ions when the RF angular frequency ω is close to ω_{ci}, which means that Ψ_{RF} has a selectivity for the charge to mass ratio. By using this fascinating advantage, selective pumping of He ions have been demonstrated in linear devices [1,2]. Also in a toroidal system, RF limiter employing second term in eq. (1) has achieved the reduction in the limiter heat load [3], and preferential removal of helium was also achieved by using a pump limiter configuration in TEXTOR [4]. An RF divertor concept was proposed based on LHD helical divertor to create high density scrape-off plasma that screens the penetration of neutral atoms into core plasma, and to create positive electrostatic potential to suppress the penetration of impurity ions from divertor rooms [5].

We propose to use RF plugging in a divertor leg of toroidal system with a compact local electrode. By placing a toroidally local RF electrode across the divertor leg and applying a ponderomotive potential that selectively acts on ions, following functions would be expected.

- Selective ion species confinement (or selective pumping), which brings active control knob of ion species mixing ratio.
- SOL plasma confinement, which leads to SOL width expansion and formation of a high-density impurity barrier.
- Radiative detachment that is compatible with core confinement by suppressing the backflow of radiative impurity ions. This may accompany extra functions like stabilization and improved efficiency of radiative detachment.

As a first step to demonstrate the scientific and technological feasibility of implementing these attractive features, it is necessary to demonstrate RF plugging by a local RF electrode in a toroidal system. While a large ring electrode that circles the toroidal direction would be impractical for implementation in a reactor, a local compact electrode is easy to be implemented and allows simultaneous implementation of multiple functions using several different frequencies. In a toroidal system, ions transported to the SOL reach the divertor while orbiting in the toroidal direction along the magnetic field lines. Therefore, such ions will always pass in front of the toroidally localized electrode, which is a major difference from a line cusp and has the potential to bring advantages unique to toroidal systems. A simple experiment to test above effects has been performed on QUEST, where annular ECR slab plasma was generated to simulate a long divertor leg in a stable manner and a toroidally local electrode pair was installed just below the top divertor plate. In the first experiment, the downstream proton saturation current was reduced by 24% at most by applying RF plugging to proton, demonstrating the possibility of RF plugging in a toroidal system with a compact electrode. More practical RF plugging in the divertor configuration is planned on QUEST, where SOL width broadening and selective pumping will be studied. As for the control of radiative detachment, RF plugging of impurity ions is ongoing using the GAMMA 10/PDX tandem mirror machine.

This study was partly funded by NIFS24KUTR191, NIFS24KUGM192, and NIFS25KSPM007.

[1] T. Sato and K. Takayama, Project Report of IPP, Nagoya University, IPPJ-REV-5 (1989).
[2] Y. Ohara *et al.*, JPFR SERIES (2009).
[3] J.A. Boedo, T. Shoji *et al.*, JNM 241-243 (1997) 857.
[4] T. Shoji *et al.*, JNM 313-316 (2003) 1262.
[5] T. Watanabe *et al.*, FST, 27 (1995) 515.