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Compatibility of RMP-driven ELM Control with Divertor Detachment in KSTAR

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1. Introduction

Nuclear fusion power faces scientific challenges such as high confinement and controlled heat loads, and one key challenge is controlling edge-localized modes (ELMs) that can damage divertor materials. To address this issue, various ELM control techniques have been proposed, with resonant magnetic perturbations (RMPs) considered the most promising [1]. However, the compatibility of RMP-induced ELM control with detachment to control divertor heat loads in high-performance tokamaks like ITER is unclear.

In this study, we demonstrate argon-seeded discharges that exhibit a detachment during the ELM suppression and mitigation by an ITER-like, three-row RMP configuration in KSTAR [2]. The results suggest that argon seeding may be a suitable technique for impurity-seeded detachment in ITER operations. Furthermore, in the small ELM phase, which is considered a favorable regime for impurity exhaust, additional reduction in heat and particle fluxes on the targets was observed compared with the ELM suppression phase.

2. Argon-seeded Discharge with RMP-driven ELM Control

In this section, we present the details of the experimental setup experimental results with various diagnostics.

2.1 Experimental Setup

We investigate the compatibility of argon-seeded divertor detachment and RMP-driven ELM control in KSTAR plasmas. The target discharge was an H-mode plasma with an I_p of 0.5 MA and a B_T of 1.8 T in the clockwise direction. Neutral beam injection (NBI) was used as the primary heating source and injected in a stepwise way, reaching a maximum power level of 5 MW at 1.5 s. RMP coil currents I_{RMP} started to ramp up at 4.0 s, and reached the maximum current of 2.0 kA/turn on 3-rows with a n = 1, +90 degrees phasing configuration for ELM control. During the discharge, we injected argon gas at a constant rate from 6.0 s through the gas pipeline connected to the midplane and introduced prefilled and additional deuterium fuel gases into the plasma from the midplane and divertor, respectively.

2.2 Experimental Results

As RMP was applied, ELM was fully suppressed from 4.5 s to 6.6 s, and mitigated from then to the end of discharge. During the RMP-driven ELM suppression phase, the argon-seeded detachment was successfully achieved. During the ELM suppression phase, the heat flux was continuously reduced by 70% compared to the pre-argon seeding case (see Fig. 1 at 5.8 s versus 6.6 s). At 6.6 s, the ELM suppression phase abruptly changed to the ELM mitigation phase. The RMP suppression condition is known to be sensitive to the plasma density, and in this case, the density increase due to argon injection may have triggered the change to the ELM mitigation phase. During the ELM mitigation phase, the heat flux was significantly reduced by approximately 90% compared to the pre-argon seeding case.

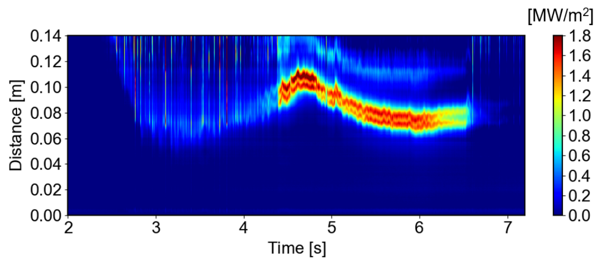

Fig. 1. Thermal loading on the outer divertor measured by the divertor IRTV [3].

The behavior of ion saturation current density (j_{sat}) during argon seeding showed a similar trend as that of the heat flux. Fig. 2 shows the inter-ELM target j_{sat} profiles at the targets measured using the Langmuir probe arrays, with the strike point position being controlled to be located on the divertor target where the Langmuir probe array was installed. During the ELM suppression phase, the particle flux decreased continuously by approximately 50% compared to that before argon seeding (5.8 s). When the ELM suppression phase changed to the ELM mitigation phase, j_{sat} on both targets decreased by approximately 60% compared to that of the before argon seeding case.

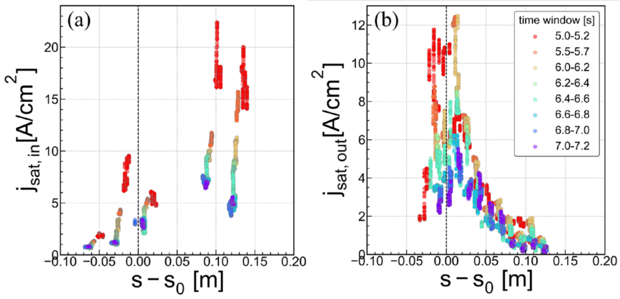

Fig. 2. Inter-ELM target j_{sat} profiles at (a) the inner and (b) outer targets measured by the Langmuir probe arrays.

Clear evidence of detachment was observed in the 2-D radiation distribution. Before the argon seeding (see Fig. 3 (a)), the radiation was concentrated near both targets, indicating an attached state. After argon seeding (see Fig. 3 (b)), the strongest radiation zone shifted gradually from the inner target plate towards the X-point at 7 s. The radiation near both targets decreased significantly, while the strongest radiation was inside the X-point. This suggests that the temperature near the targets dropped, indicating successful detachment due to argon seeding.

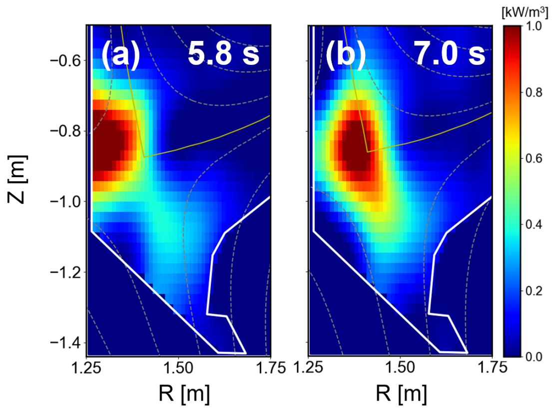

Fig. 3. Tangentially reconstructed 2-D radiated power profiles in the divertor region: (a) before and (b) after argon seeding.

3. Summary and Conclusions

In this study, we explore the compatibility of argon impurity-seeded detachment with RMP-induced ELM control in KSTAR. Argon-seeded detachment during the RMP-driven ELM suppression phase was successfully achieved and also a further reduction in heat and particle fluxes on the divertor targets was observed when the ELM suppression phase changed to the mitigation phase. During the divertor detachment, the most intense radiation zone moved from the inner divertor region to the X-point. The results suggest the possibility of a compatible discharge with mid-Z impurity-seeded detachment and RMP-driven ELM control, which is essential in future tokamaks with high performance, including ITER.

REFERENCES

[1] T.E. Evans *et al.*, Edge stability and transport control with resonant magnetic perturbations in collisionless tokamak plasmas, Nuclear Fusion, Vol.58, 126010, 2018.
[2] H. Shin, J. Hwang, Y. Han, G. Shin, H. Lee, K.-B. Chai and Wonho Choe, Argon-seeded Detachment during ELM Control by RMPs in KSTAR, Nuclear Fusion (accepted).
[3] H.H. Lee *et al.*, Thermographic studies of outer target heat fluxes on KSTAR, Nuclear Materials and Energy, Vol.12, pp. 541-547, 2017.