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Mitigation of edge-localized mode enabled by control of neutral recycling with new EAST divertor

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A key challenge currently encountered in the development of tokamak fusion energy is the erosion of plasma-facing materials due to excessive transient heat load from large-amplitude ELMs, characterized by quasi-periodic relaxations of an edge transport barrier, accompanying H-mode plasmas. Small grassy ELM regime is a promising method for ELM control in future devices [1]. Recent studies indicate that a low pedestal density gradient is a key for access to small-ELM regimes [1, 2, 3].

The pedestal density gradient can be actively reduced by controlling divertor recycling and pedestal fueling with a new tungsten lower divertor on EAST, featured by a right-angled closed corner joining the vertical and horizontal target plates [4]. Mitigation of large ELMs is observed as the outer strike point moves from the vertical target to the horizontal target with a significant reduction of the pedestal density gradient, as shown in figure 1. This phenomenon has been observed in a q_{95} range of 4.9-6.4 with both B_t direction, different heating power levels and heating schemes.

Linear analyses of pedestal stability indicates that the plasma of large ELMs with strike point on the vertical target is located right on the peeling boundary, while the small ELMs with strike point on the horizontal target are mainly triggered by high-n ballooning modes. Nonlinear simulation has reproduced the ELM crash processes of large and small ELMs. Overall, the linear and nonlinear analyses of pedestal stability confirm that the ELM behavior change is mainly induced by the profile change, especially the density profile change.

SOLPS-ITER simulations indicate that when the strike point is located on the horizontal target most particles from the upstream SOL flow into the outer divertor slot and hit the horizontal target plate and the ionization source appears to concentrate in the vicinity of the horizontal target, due to the trapping of the recycled particles in the closed corner area, leading to a reduced pedestal fueling from the lower divertor, thus reducing the pedestal density gradient and elevating the SOL density. In contrast, when the strike point is located on the vertical target, a much stronger ionization source appears in the vicinity of the X-point, especially inside the separatrix. The vertical target plate reflects recycled neutral particles towards the private region where the electron density and temperature are much lower than the SOL. Therefore, the neutrals cannot be fully re-ionized in the vicinity of the X-point and tend to diffuse into the pedestal. Furthermore, as the baffle area is closer to the divertor strike point for the vertical target case, much more particles from the upstream SOL hit the baffle, which also enhance the pedestal fueling. This results in a much steeper density gradient and a lower density in the SOL for the strike point on the vertical target.

This paves a new path in ELM mitigation through tailoring pedestal structure with divertor condition control. The results presented here may have strong implications for future fusion reactors where a low pedestal density gradient is anticipated due to much higher neutral opacity and lower pedestal fuelling.

References
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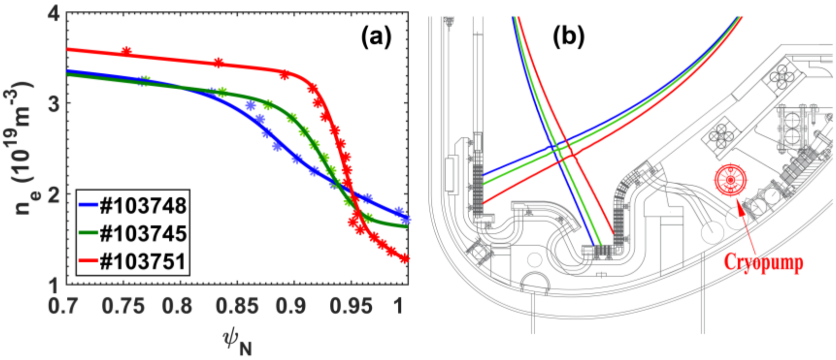

Figure 1. (a) Pedestal electron density profiles for different strike point locations as shown in (b).