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A promising grassy ELM regime for high-performance steady-state operations with metal wall in EAST and CFETR

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A highly reproducible stationary grassy ELM regime has been achieved in the EAST superconducting tokamak with water-cooled metal wall, exhibiting good energy confinement, H_98y2~1.1, strong tungsten impurity exhaust, and compatibility with low rotation, high density and fully non-inductive operations. It offers thus a highly promising operational regime in EAST, potentially applicable to future steady-state tokamak fusion reactors, such as the Chinese Fusion Engineering Test Reactor (CFETR). Recent linear and nonlinear simulations using ELITE and BOUT++ codes have uncovered, for the first time, the underlying physics of this grassy ELM regime. Both grassy and type-I ELMs are triggered by the marginally unstable intermediate-n peeling-ballooning modes (PBMs). However, the radial width of the linear mode structures cannot explain the small ELM size. The nonlinear simulations indicate that the pedestal current-profile relaxation is much slower than the pressure-gradient collapse. For the type-I ELMs, the high current density and gradient can still drive the kink/peeling-dominated low-n PBMs unstable even when the pressure gradient is significantly reduced, thus the collapsing front propagates radially inward, leading to large ELMs, as observed by Lithium BES on EAST. In contrast, for grassy ELMs, the pedestal current density and gradient are inherently lower and the operational parameter space can intrinsically improve the pedestal stability against the low-n PBMs. Hence, the instabilities quickly die away when the pressure gradient is just slightly reduced, leading to small ELMs. Some important features of the EAST grassy ELM regime are expected in future steady-state reactor-level plasmas, such as the relatively lower pedestal density gradient, higher SOL density and wider pedestal at high betap and low rotation. The desired edge density profile can be self-consistently generated by the strong cross-field particle transport driven by the high-frequency grassy ELMs. In particular, the pedestal density gradient in reactor-level plasmas could be even lower, since the plasma temperature and density at the separatrix are high so that the penetration of recycling neutrals into the pedestal is almost negligible. This may facilitate access to the grassy ELM regime in future devices, thus opening a potentially new avenue for next-step steady-state fusion development.

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