ELM pacing with high frequency multi-species impurity granule injection in NSTX-U H-Mode discharges

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We report on ELM triggering and pacing experiments in NSTX-U, including comparisons to pellet ablation models. Multiple sizes and types of solid impurity granules are injected into the low field side of the plasma to determine their ELM triggering and pacing capability. Examining the penetration depths, mass deposition locations, and ELM triggering efficiencies of sub-millimeter lithium, boron carbide (B_4C) and carbon granules, we assess the optimal size and composition for minimally perturbative high frequency ELM pacing. By utilizing a neutral gas shielding model, benchmarked with lithium granule ablation experiments performed on DIII-D, the pedestal atomic deposition characteristics for the three different species of granule have been modelled for NSTX H-mode discharges with low natural ELM frequencies. Variations in the depositional barycenter can range from 5 cm for lithium to 17 cm for the same size and velocity carbon granule. We estimate that these penetration depths will be reduced by a factor proportional to $q_s \sim n_e T_e^{3/2}$ as the full NSTX-U capabilities are realized. In addition, by reducing the rotation speed of the impeller, the mass deposition location is translated closer to the top of the pedestal allowing further tuning of the pressure perturbation. At this location the pressure profile generated by the granule can be added to the preexisting pedestal pressure gradient, leading to a set of characteristics advantageous for ELM triggering while affecting a minimal perturbation to the core plasma. Using multiple high-speed cameras to precisely track the granule injections and monitor the ablation duration and penetration depths in NSTX-U, a fractional mass deposition location can be extrapolated. Fast infrared camera measurements are used to characterize the variations between triggered ELMs and the inter-ELM period. In addition, comparisons are also made between stimulated and spontaneously occurring ELMs. These measurements provide a comparison of the ELM peak heat flux mitigation factor, as well as variations in the ELM footprint due to the triggering mechanism. The results of ELM pacing and comparisons with the constructed ablation model in NSTX-U will be reported.

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