Real-time impurity injection for wall conditioning, ELM and H-mode pedestal control, and divertor exhaust enhancement

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Impurities are injected into magnetic fusion devices for a number of reasons, e.g. wall conditioning, control of edge-localized modes (ELMs), and power and particle exhaust. A new device designed to inject a wide range of impurity species was developed by staff at the Princeton Plasma Physics Laboratory (PPPL) and is now deployed on the ASDEX-Upgrade, DIII-D, EAST, and KSTAR devices. This seminar describes both the device and first results.

The original device injected spherical, non-sticky impurities through an aperture on a vibrating piezoelectric disk driven at resonant frequencies; the injected impurities accelerated via gravity into a drop tube and into the boundary plasma[1]. The new device uses piezoelectric crystals for a horizontal drive off the edge of a surface into a drop tube, and is compatible with a wide range of impurity species and particle sizes, including boron-based compounds[2].

Results from ASDEX-Upgrade include injection of boron nitride and pure boron powders into plasma discharges that improved wall conditions in subsequent H-mode plasmas[3]. Specifically, pure boron injection appeared to improve wall conditions qualitatively similar to boronization, and enabled access to low collisionality plasmas needed to study ELM control with magnetic perturbations. In addition, boron nitride injection was dominated by the effects of the nitrogen, including up to a 20% confinement improvement as also observed with nitrogen gas puffing. Moreover, it appears that solid boron nitride injection produced much less ammonia than observed with nitrogen gas injection, which would simplify tritium separation requirements for future devices that may generate tritiated ammonia.

In DIII-D, boron injection was used to improve wall conditions prior to a boronization by reducing recycling during the plasma current rampup[4]. Impurities (lithium, boron, and boron nitride) were also injected into a closed upper divertor configuration and increased power dissipation. Lithium injection destabilized a pedestal-localized mode that transiently increased pedestal pressure and improved confinement[5], mirroring easrlier results in NSTX[6] and EAST[7]. Finally, the effect of lithium and boron injection on equilibrium carbon concentration, which is the dominant intrinsic impurity in DIII-D, is being examined.

In EAST, real-time lithium injection with the original dropper design eliminated ELMs in long pulse discharges with the carbon divertor[7], and short pulse discharges with the tungsten divertor[8]. The new dropper allowed injection of trace boron for transport experiments, and large lithium granules to confirm ELM elimination and recycling reduction[9], perhaps more effectively than lithium powder. The first experiments on KSTAR in November 2018 focused on boron and boron nitride injection for recycling control and ELM mitigation. Supported in part by U.S. Dept. of Energy under contract DE-AC02-09CH11466.

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