§51. Active Particle Control in the Compact Spherical Tokamak: CPD by a Li-gettered Rotating Limiter

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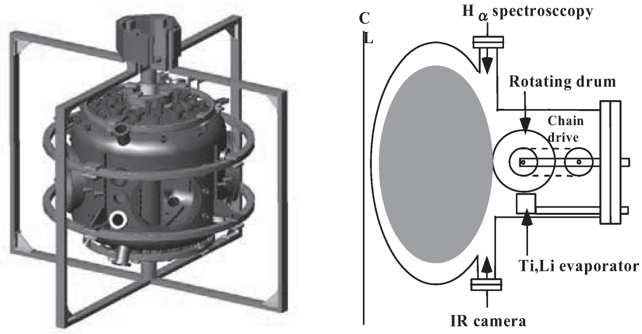
Reduced wall recycling has widely been recognized as a key condition to obtain high-performance core plasmas in the magnetic fusion community. First of a kind experiment was conducted in TFTR almost two decades ago, leading to the discovery of "Supershot". In this experiment, the inboard graphite bumper limiter was first depleted of hydrogenic particles with helium plasma conditioning, which then provided implantation-reduced recycling, i.e. "passive" wall pumping, during subsequent confinement discharges. Since then, a number of wall conditioning techniques such as boronization have been developed for reduced wall recycling as well as impurity control in major confinement experiments.

Among these wall conditioning techniques, lithium pellet injection followed by the formation of lithium-coatings on the bumper limiter was found to be particularly effective in improving the core plasma performance, again, in TFTR during the final DT-campaign, having resulted in a record-long energy confinement time reaching 0.35s. Since then, lithium has been adopted as a PFM (for plasma-facing material) or as coatings to cover PFCs (for plasma-facing components) in other confinement devices as well, including DIII-D, TdeV, FTU, TJ-II, CDX-U and NSTX. However, due to the surface saturation with implanted or adsorbed particles, the efficacy of any wall conditioning technique has a finite lifetime which, therefore, necessitates re-conditioning. Clearly, this is not desirable from the point of view of operating steady state fusion reactors.

To resolve this steady state particle control issue, a variety of innovative PFC concepts have been proposed over the past decade. Essentially, all of these concepts employ some self-replenishing surface component, either made of a solid or liquid, avoiding saturation. One such concept proposed in 1997 by Hirooka et al. [1] features a moving-belt made of SiC-SiC fiber fabrics with an in-line getter film deposition system, intended for "active" wall pumping. A series of proof-of-principle experiments have been conducted on this concept with the moving-belt simplified by a lithium-gettered rotating drum in a laboratory-scale steady state plasma device [2]. Results indicate that not only hydrogen but also helium recycling can be reduced to levels significantly lower than 100% even at steady state, so long as lithium gettering continues.

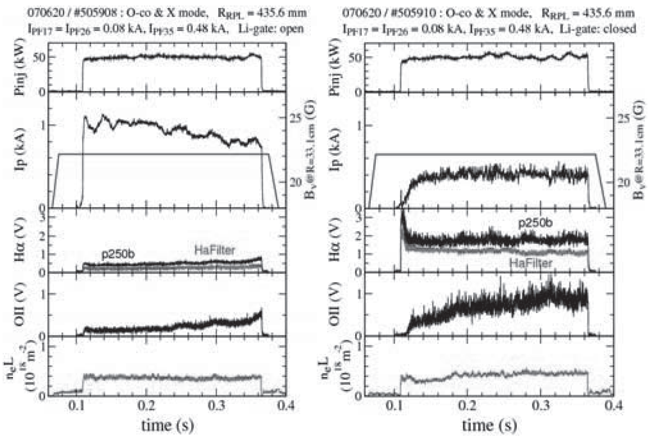
Encouraged by these successful laboratory experiments, a similar but custom-designed rotating drum limiter has been constructed for the next-step experiments in the CPD compact spherical tokamak, shown in Fig. 1, where plasma discharges are produced by a 50kW RF-current drive. The pulse length is typically ~400ms with a flat-top of ~350ms during which the core plasma density is of the order of 10^{12} cm^{-3} and the core plasma temperature is around 20eV. T

As shown in Fig. 2, it has reproducibly been observed that, as soon as the rotating surface is gettered with lithium at the deposition rate of the order of 10^{15} atoms $cm^{-2}s^{-1}$, hydrogen recycling measured with H_α spectroscopy decreases by about a factor of 3 not only near the gettered surface but also in the center stack bumper limiter region. This clearly indicates that active control over edge recycling can lead to a global effect on plasma confinement. Along with reduced edge recycling, the core oxygen impurity level measured with O-II spectroscopy is reduced by about a factor of 3 as well. Meanwhile, the core plasma electron temperature is found to increase nearly by a factor of 2 and the flat-top toroidal plasma current increases up to about a factor of 2, suggestive of current drive efficiency. Also, taking into the effect of active particle control by lithium gettering, zero-dimensional 5-reservoir particle balance modeling analysis has successfully been conducted to corroborate these experimental data.



(a) (b)

Fig. 1 A bird-eye view of the CPD-tokamak with a major radius of 30cm and a minor radius of 20cm (a); and a schematic diagram of the rotating drum limiter in a poloidal section of CPD (b).



(a) (b)

Fig. 2 Wave forms of the RF input power, toroidal current, vertical field, H_α intensity, O-II intensity, and line-averaged density measured during CPD discharges with (a) and without (b) Li-gettering.

1) Hirooka, Y. et al., Proc. 17th IEEE-SOFE, San Diego, Oct. 6th -10th , 1997, pp.906.
2) Hirooka, Y. et al., Fusion Sci. & Technol. **47**(2005)703.