A Review of the Applications of Liquid Metals for Plasma-Facing Components in Magnetic Fusion Experiments

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It has widely been recognized in the magnetic fusion research community that plasma-wall boundary control plays an important role in determining core plasma performance in confinement experiments [1]. For the boundary control in fusion experiments, a variety of wall conditioning techniques have been developed to improve plasma confinement. Among all these techniques, lithium coating on plasma-facing components (PFCs) has been found to be most effective in improving plasma cleanliness as well as energy confinement. Unfortunately, it is also true that, as plasma operation proceeds, lithium coatings become saturated with implanted hydrogen isotopes, forming lithium hydride, which necessitates plasma shutdown for wall re-conditioning. Needless to say, this is not desirable for the operation of steady state fusion reactors.

To avoid the surface saturation over lithium-coated PFCs, several innovative concepts have been developed over the past decade. One such concept implemented recently is a liquid lithium divertor (LLD) in NSTX [2] with the hope that surface saturation be mitigated, so that the boundary controlled condition would be longer lasting. However, results are not as good as expected in that both implanted hydrogen isotopes and oxygen-containing impurity films, buoying over LLD, seem to accelerate the surface de-conditioning process. In a related study [3], the effects of liquid stirring to simulate forced convection have been investigated on the behavior of hydrogen and helium recycling from molten lithium. Data indicate that liquid lithium stirring reactivates hydrogen pumping via surface de-saturation and/or uncovering impurity films, but can also induce helium release via surface temperature change. This suggests the need for a flowing liquid divertor with forced convection which, however, would require another innovative concept.

As such, the application of liquid metals as PFCs continues to expand and improve. Most recently, however, it has been pointed out that in fusion reactors beyond ITER the divertor heat flux profile can peak, as narrowly as a few mm, reaching ~50MW/m^2 [4], a new challenge. Clearly, further improvement is necessary for liquid metal PFCs performance to handle such tremendous amount of power and particles. This paper reviews some of the important findings in recent confinement and laboratory experiments on the interactions between liquid metal PFCs and edge plasmas, intended to provide a future perspective of the plasma-wall boundary control by innovative concepts of liquid metal applications to fusion power reactors.

References:

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