Topic: MPT

High-temperature, liquid metal plasma-facing component research and development for the NSTX-U*

M.A. Jaworski[1,a], A. Brooks[1], P. Rindt[2], K. Tresemer[1], J.-P. Allain[3], R.J. Goldston[1], T.K. Gray[4], R. Kaita[1], N. Lopes-Cardozo[2], J. Nichols[1], J. Menard[1], M. Ono[1], D.N. Ruzic[3], J. Schwartz[1], and the NSTX-U Team

[1]*Princeton Plasma Physics Laboratory, Princeton, NJ 08543, USA*
[2]*Technological University of Eindhoven, Eindhoven, The Netherlands*
[3]*Department of Nuclear, Plasma and Radiological Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 60181, USA*
[4]*Oak Ridge National Laboratory, Oak Ridge, TN, USA*
[a]*Email correspondence to mjaworsk@pppl.gov*

Liquid metal plasma-facing components are actively studied as a possible plasma-facing component (PFC) material in current and future fusion experiments. Liquid metals provide a self-healing material that has the potential to eliminate net erosion and damage due to local melting of the plasma-facing surfaces, and separate neutron damage from the plasma-induced damage at the surface. In addition, liquid lithium PFCs have the potential to provide control of the fuel inventory through simultaneous control of the liquid metal inventory, and provide a low-Z material surface[1]. The high vapor pressure of liquid lithium further raises the possibility of intercepting significant plasma-based heat flux into a gaseous target when operating at an elevated temperature (T>500°C). With the innovative use of multiple, differentially pumped chambers, the condensable nature of lithium vapor can be exploited to separate high-neutral pressure regions from the plasma main-chamber such as in the lithium vapor-box scheme[2]. These benefits, if realized, would solve several issues associated with the leading solid material, tungsten, and potentially improve reactor economics.

The NSTX-U team has developed a program for transitioning the machine from its current PFCs to surfaces that can provide a comparative assessment between the high-Z and low-Z, liquid approaches. The ultimate goal is the realization of a flowing liquid lithium divertor target within the confinement device. The progressive steps include the implementation of high-Z divertor targets, shown in figure 1, in order to establish a metallic PFC that can absorb reactor-relevant heat fluxes of the order 10MW/m^2. These divertor targets with an evaporated lithium coating will provide a mass-limited, confinement-device analogue of recent experiments on high-temperature lithium targets in the Magnum-PSI linear plasma device[3]. Pre-filled liquid metal targets will next be implemented as a means of introducing larger quantities of lithium into the confinement device without the need for evaporations[4]. These targets will

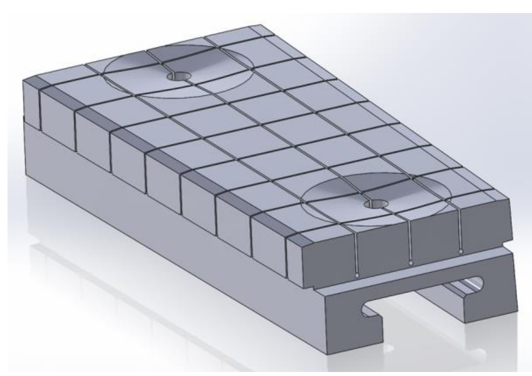

Figure 1: Render of NSTX-U high-Z divertor tile target. The PFC target is fabricated from a monolithic block of molybdenum (TZM-alloy) with a combination of wire-EDM and traditional machining. The top surface includes chamfered features to mitigate leading edges between tiles and those introduced due to the NSTX-U legacy mounting scheme.

feature a porous surface which is passively fed by capillary forces to maintain the liquid surface allowing tests of liquid maintenance and recovery from transients. Finally, actively-supplied liquid metal PFCs will be implemented based on the results of the pre-filled target testing integrating liquid lithium pump technologies with the torus.

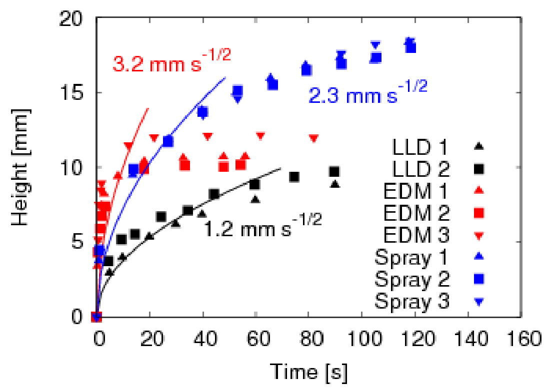

Figure 2: Wicking speed testing of multiple candidate surfaces including two types of flame-sprayed molybdenum (“LLD” and “Spray”) and a micro-textured, molybdenum surface (“EDM”). Numbers for each label indicated repeated tests. Wicking height as a function of time indicates a speed where faster wicking indicates improved performance. The sorptivity of each material is calculated with this data and are shown for the initial period of liquid imbibition for each material. A surrogate fluid is used for these tests.

Each of the three steps described above represent significant technological challenges. The design shown in figure 1 includes geometry allowing for 1-for-1 replacement with the existing graphite targets to facilitate a rapid transition and implements a castellated surface to shift peak material stresses away from the surface. Edge chamfering will mitigate the impact of leading edges. The vapor pressure of lithium is an exponential function of temperature which will allow for a wide range of lithium fluxes to be tested with this design.

The practical realization of experiments with pre-filled targets and the development of porous substrates is also a significant challenge. Technological aspects include the choice of porous substrate, methods of fabrication, and maintenance of the liquid and its chemical composition during and between experiments. Development of pre-filled targets has included the use of flame-sprayed materials as well as micro-textured surfaces. Figure 2 shows a wicking test comparing several different materials. Wicking rates are similar to those observed with laser-textured surfaces[5]. Previous experiments conducted on the Magnum-PSI linear plasma device utilized protective foils to prevent excessive surface contamination. Such pre-filling of the targets avoids issues of achieving acceptable wetting of the PFC *in-situ*. An alternative strategy to physically removed macro-foils is the use of a nanoscale foil. In this scheme, a thin foil of chemically-compatible metal is deposited directly onto the lithium. The foil has sufficient strength to maintain cohesion during liquefaction of the lithium beneath but is thin enough to be eroded by specifically tailored plasma discharges when experiments are to be conducted. Laboratory testing of this scheme will be presented. Previous theory development of MHD-enhanced porous wicking phenomena indicate rapid recovery from depletion events is possible at a rate commensurate with typical ELM times[4]. Laboratory experiments examining reflow and recovery will also be described.

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