*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-1.009 (2008)*

Improvement in Plasma Performance with Lithium Coatings in NSTX*

R. Kaita[a], H. Kugel[a], J-W. Ahn[b], J. P. Allain[g], M. G. Bell[a], R. Bell[a], J. Boedo[b], C. Bush[c],
D. Gates[a], T. Gray[a], J. Kallman[a], S. Kaye[a], B. LeBlanc[a], R, Majeski[a], R. Maingi[c],
D. Mansfield[a], J. Menard[a], D. Mueller[a], M. Ono[a], S. Paul[a], R. Raman[d], A. L. Roquemore[a],
P. W. Ross[a], S. Sabbagh[e], H. Schneider[a], C. H. Skinner[a], V. Soukhanovskii[f], T. Stevenson[a],
D. Stotler[a], J. Timberlake[a], W. R. Wampler[h], J. B. Wilgen[c], L. Zakharov[a]

[a] Princeton Plasma Physics Laboratory, Princeton, NJ 08543
[b] University of California at San Diego, La Jolla, CA 92093
[c] Oak Ridge National Laboratory, Oak Ridge, TN 37831 USA
[d] University of Washington, Seattle, WA 98195 USA
[e] Columbia University, New York, NY 10027 USA
[f] Lawrence Livermore National Laboratory, Livermore, CA 94551 USA
[g] Purdue University, School of Nuclear Engineering, West Lafayette, IN 47907 USA
[h] Sandia National Laboratories, Albuquerque, NM 87185 USA

I. Introduction

Lithium as a plasma-facing material has attractive features, including a reduction in the recycling of hydrogenic species and the potential for withstanding high heat and neutron fluxes in fusion reactors. Dramatic effects on plasma performance with lithium-coated plasma-facing components (PFC's) have been demonstrated on many fusion devices, including TFTR,[1] T-11M,[2] and FT-U.[3] Using a liquid-lithium-filled tray as a limiter, the CDX-U device achieved very significant enhancement in the confinement time of ohmically heated plasmas.[4] The recent NSTX experiments reported here have demonstrated, for the first time, significant and recurring benefits of lithium PFC coatings on divertor plasma performance in both L- and H- mode regimes heated by neutral beams.

II. Description of NSTX and Lithium Evaporation System

The NSTX[5] device is a large spherical tokamak with plasma major and minor radii 0.85 m and up to 0.67 m, respectively. Auxiliary heating capabilities include 7 MW of deuterium neutral beam injection (NBI) and 6 MW of RF power for high-harmonic fast-wave (HHFW) heating and current drive. Discharges in excess of 1 MA can be sustained for more than 1 s. The present PFC's are primarily ATJ graphite and carbon fiber composite tiles.

During NSTX experiments in 2008, lithium coatings of the PFC's were applied with two ovens mounted on the upper dome of the vacuum vessel.[6] Each LIThium EvaporatoR (or LITER) directed a collimated stream of lithium vapor downwards toward the tiles on the lower center stack and divertor. The two LITERs were separated by 150° toroidally to coat the entire divertor area. The evaporation rate from each LITER was varied between 10 and 70 mg/min by adjusting its temperature. A typical sequence prior to a plasma shot would be to conduct helium glow discharge cleaning (HeGDC) for up to 9.5 min, followed by lithium evaporation onto the PFC's for up to 10 min. It took several minutes for the oven temperature to drop sufficiently for lithium evaporation to cease. For this reason, each LITER was withdrawn behind a movable shutter that prevented lithium from entering the vacuum vessel during the HeGDC and plasma shots.

III. Effects of Lithium Coatings on Plasma-Facing Components

Experiments before 2008, which were conducted with a single LITER, indicated that lithium deposition prior to a NBI-heated plasma shot decreased the plasma density, inductive flux consumption, and ELM frequency and increased the average electron temperature, ion temperature, energy confinement time, and DD neutron rate. In addition, extended periods of MHD quiescence were observed.

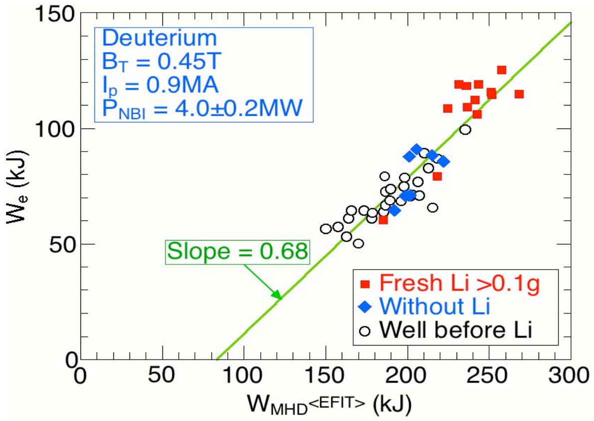

Fig. 1 Demonstration of stored energy (W_{MHD}) increase after lithium deposition

These features were again observed with two LITER evaporators, but were more pronounced and reproducible. An example of this is the increase in stored energy after lithium deposition (Fig. 1). Plasma parameters as a function of time are compared for discharges before and after lithium evaporation in Fig. 2. Comparing one and two LITER operation, the maximum plasma stored energy (W_{MHD}) rises from about 0.2 MJ to almost 0.3 MJ when lithium is applied, and ELM-free periods appear. The most conspicuous difference is in the larger percentage increase in pulse duration after lithium is deposited with the two LITERs. This suggests more efficient flux consumption, and one potential mechanism is the change in conductivity as the temperature profile broadens in the presence of lithium-coated PFC's.

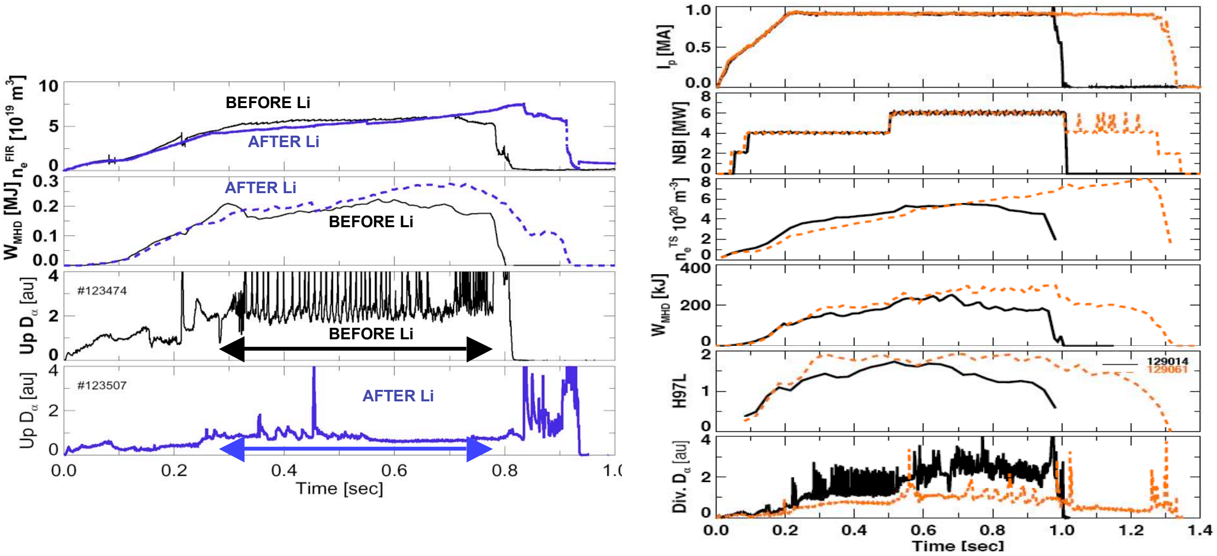

Fig. 2 Time evolution of plasma parameters before and after lithium evaporation with (a) one LITER and (b) two LITERs.

An expectation for lithium-coated PFC's is a reduction in edge recycling. To determine if this could be related changes in the density profile in the scrapeoff layer (SOL), measurements were performed with a broadband swept X-mode reflectometer, covering a frequency range of 6 to 27 GHz. By sweeping the frequency, average density profiles were obtained at 1.8 ms intervals.[7] Fig. 3 compares the SOL density profiles from shots at about 0.36 s into discharges with two LITERs operating. The evaporation rate was 17.9 mg/s prior to shot 129024 when the profile labeled (a) in Fig. 3 was obtained, and ELM's were still present. The evaporation rate was 83.2 mg/s prior to shot 129038 when the profile labeled (b) in Fig. 3 was measured, and the ELM's were suppressed. At the lower lithium evaporation rate, the density

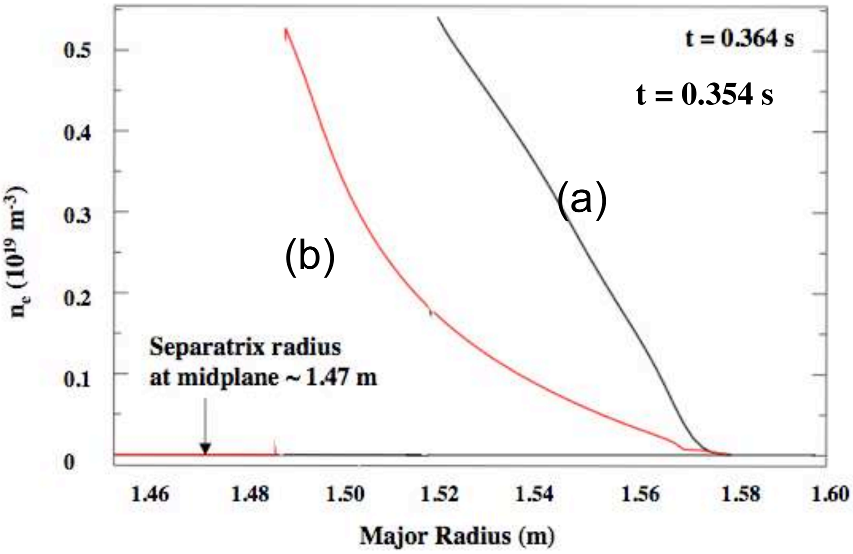

Fig. 3. SOL density profiles at (a) low and (b) high lithium coating rates from two LITER evaporators.

rise is almost linear with radius. The density reaches the same value at a significantly smaller major radius at the higher evaporation rate, and the shape of the profile has markedly changed.

Detailed edge plasma modeling has begun with the UEDGE transport code to simulate the effects of reduced recycling expected from the liquid lithium divertor module (LLD) that will be installed in NSTX.[8] The simulations start with adjusting the transport coefficients until the edge temperatures and densities match the data from the multipoint Thomson scattering diagnostic for existing NSTX plasmas. New profiles are then generated for a variety of recycling coefficients. They have the same nonlinear radial dependence as the SOL measurements during high lithium evaporation. The simulations do not show the linear density rise observed at the low lithium evaporation rate, so more work needs to be done on the transport model before drawing conclusions about recycling from the UEDGE calculations.

IV. Discussion

Two lithium evaporators have been used successfully to increase lithium coating rates for NSTX PFC's. As in earlier experiments with one evaporator, plasma performance improved. Significantly reduced inductive flux consumption was achieved with two-LITER operation, reminiscent of the decrease in loop voltage that was observed with large-area liquid lithium limiter experiments on CDX-U.[9] While further analysis is required to understand the relationship between the effects of lithium-coated PFC's on impurities and recycling and plasma performance, higher lithium evaporation rates appear to be advantageous.

In the light of these results, a liquid lithium divertor (LLD) will be installed on NSTX this year to provide the first complete liquid metal divertor target in a high-power device. Experiments with the LLD can inform on the behavior of metallic ITER PFC's should they liquefy during high-power operation. The NSTX lithium coating and LLD experiments are important near-term steps in demonstrating the potential of liquid lithium as a solution to the first-wall problem for both magnetic and inertial fusion reactors.

*This work supported by USDOE contract No. DE-AC02-76CH03073.

[1] D. K. Mansfield *et al.*, Nucl. Fusion **41,** 1823 (2001)
[2] S. V. Mirnov *et al.,* Fus. Eng. Design **65,** 455 (2003)
[3] M. L. Apicella *et al.,* J. Nucl. Materials **363-365,** 1346 (2007)
[4] R. Majeski *et al.,* Phys. Rev. Lett. **97,** 075002 (2006)
[5] M. Ono *et al.*, Nucl. Fusion **40,** 557 (2000)
[6] H. Kugel *et al.,* 18th Int. Conf. on Plasma-Surface Interactions, Toledo, Spain (2008)
[7] J. B. Wilgen *et al.,* Rev. Sci. Instrum. **77,** 10E933 (2006)
[8] D. Stotler *et al.,* 18th Int. Conf. on Plasma-Surface Interactions, Toledo, Spain (2008)
[9] R. Majeski *et al.,* Nucl. Fusion **45,** 519 (2005)