Edge plasma transport and microstability analysis with lithium-coated plasma-facing components in NSTX

J.M. Canik[1], W. Guttenfelder[2], R. Maingi[1], T.H. Osborne[3], S. Kubota[4], Y. Ren[2], R.E. Bell[2], H.W. Kugel[2], B.P. LeBlanc[2], V.A. Soukhanovskii[5]
(email: canikjm@ornl.gov)

[1] Oak Ridge National Laboratory, Oak Ridge, TN 37831
[2] Princeton Plasma Physics Laboratory, Princeton University, Princeton, NJ 08543
[3]General Atomics, San Diego, CA, USA 92186
[4]University of California-Los Angeles, Los Angeles, CA, USA 90095
[5]Lawrence Livermore National Laboratory, Livermore, CA 94551

The application of lithium coatings to the plasma-facing components (PFCs) of the National Spherical Torus Experiment (NSTX) has been shown to strongly impact plasma performance, improving energy confinement[1] and eliminating ELMs[2,3]; these effects are promising for future large fusion devices, which must simultaneously achieve high confinement while avoiding large ELMs. In NSTX discharges with lithium coatings, a widening of the pressure pedestal is observed that leads to an overall increase in the pedestal-top pressure, contributing to the observed improvement in energy confinement. Here we present analysis of the edge transport properties of NSTX discharges as a function of the coatings applied. This is comprised of 1) interpretive 2-D plasma/neutral modeling of the edge transport, and 2) calculations of the linear microstability as lithium coatings are varied.

2-D modeling of pre-lithium and with-lithium discharges has been performed using the SOLPS suite of codes[4], which solves a set of coupled fluid plasma and kinetic neutral transport equations. The modeling is performed in an interpretive sense, with the “anomalous” cross-field transport coefficients adjusted until agreement is obtained between the measured and modeled midplane density and temperature profiles (divertor heat flux and D_α measurements also constrain the modeling). The power flowing from the core into the edge is input as a boundary condition, and the sources due to neutral recycling are calculated self-consistently. This technique yields “effective” cross-field diffusivities (no attempt is made to capture any convective particle transport), along with the particle recycling coefficient R at the PFC surfaces[5].

The modeling indicates that the application of lithium to the PFC surfaces reduces R from ~0.98

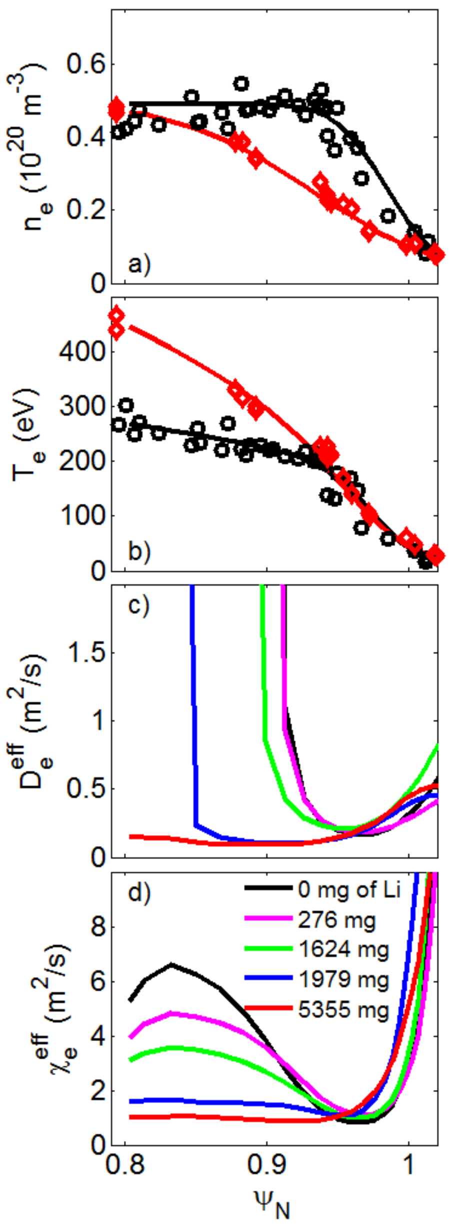

Figure 1: Profiles of a) n_e, b) T_e, without (black) and with 5355 mg of lithium (red), and change in c) D_e^{eff} and d) χ_e^{eff} as amount of lithium is varied

to 0.9[5]. The modeled and measured pedestal profiles (Figure 1) show that, with lithium coatings, the electron density (n_e) gradient within the pedestal is reduced by ~50%, which is consistent with the reduction in particle source with lithium[6]. The width of the n_e pedestal increases, however, so that the pedestal-top n_e is comparable in the two cases. The electron temperature (T_e) profile is similar pre- and with-lithium in the region $\psi_N > 0.95$, while the T_e gradient is stronger inside this radius for the with-lithium case. The interpretive effective electron thermal (χ_e^{eff}) and particle (D_e^{eff}) profiles reflect these profile changes: χ_e^{eff} is similar outside ψ_N ~0.95, and is reduced in the region $\psi_N < 0.95$ as the amount of lithium increases. The D_e^{eff} profile shows a broadening of the region with low diffusivity with lithium, while the minimum value within the steep gradient region is comparable in the various cases. These changes reflect the strong widening of the pressure pedestal observed with lithium.

The 2-D modeling highlights two regions with differing behavior as lithium is applied: the far edge region outside ψ_N~0.95 characterized by ~constant T_e gradients, and the pedestal-top region ψ_N~0.8-0.95 with transport coefficients that decrease in the with-lithium case. The linear microstability properties in these two regions are analyzed using the initial value GS2 code[7]. At ψ_N=0.88, low-k ($k_\theta\rho_s < 1$) microinstabilities are unstable, with the dominant modes being ITG-like in the pre-lithium case and TEM-like with lithium. For both discharges analyzed, ETG modes are calculated to be stable at this radius. In the with-lithium case, an increase in flow shear results in a larger E_r shearing rate γ_E with lithium, so that γ_E becomes significant compared to the linear growth rate (Figure 2a). This suggests that changes to E_r may be contributing to the decreased diffusivities inferred in this region. In the region ψ_N>0.95, both the pre- and with-lithium cases are calculated to be strongly unstable to ETG modes, which may play a role in the stiffness of the T_e profile observed near the separatrix; the two discharges are also both found to lie near the onset (Figure 2b) for kinetic ballooning modes, which also may contribute to the residual transport within the pedestal.

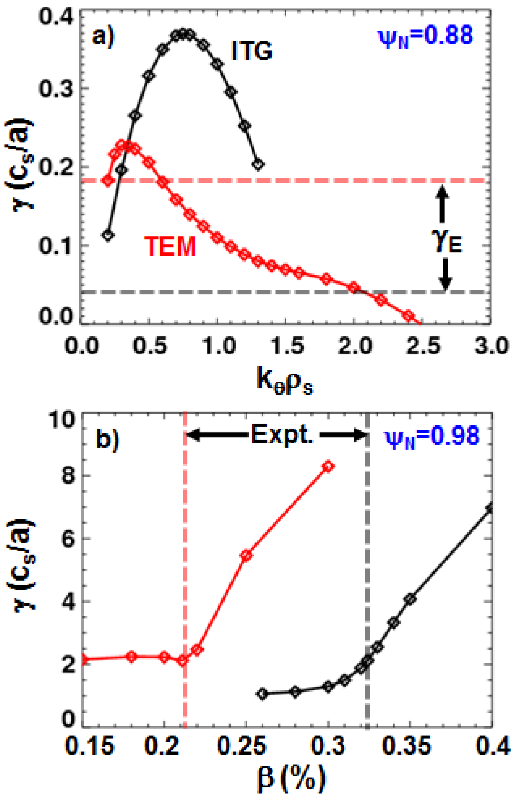

Figure 2: a) Spectra of growth rates at ψ_N=0.88 and b) variation in growth rates with β at ψ_N=0.98 for pre- (black) and with-lithium (red) cases

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