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Surrounding a Tokamak Plasma With Lithium Improves Its Disposition

PRINCETON, New Jersey, November 13, 2008 – In a series of contributed papers to be given at the 50th Annual Meeting of the Division of Plasma Physics of the American Physical Society in Dallas TX, November 17-21, scientists from the Princeton Plasma Physics Laboratory (PPPL) will describe how a coating of metallic lithium on surfaces facing the very hot plasma in the National Spherical Torus Experiment (NSTX) was used to suppress the return of ions which have escaped from the plasma. This coating improved plasma performance significantly.

The NSTX is a tokamak which confines hot ionized gas, called plasma, inside a large vacuum chamber using magnetic fields to insulate and form the plasma into a fat doughnut shape. The interior surface of the NSTX is covered by tiles made of graphite, chosen because it can withstand very high heat flows from the plasma as it is heated by up to six million watts (6 MW) of power by injected beams of energetic atoms of deuterium, an isotope of the element hydrogen. After becoming ionized inside the plasma, some of this deuterium can escape to the walls as quite energetic ions. At the graphite surface, these positively charged ions lose their energy and capture an electron, becoming neutral once again. Some of these neutrals return to the plasma, but this time with much less energy than they had when they left. Controlling this return of cool atoms, called "recycling", has been found to be crucial in determining how well the magnetic field insulates the plasma so that its central core becomes heated to a very high temperature.

Beginning in the 1990s, scientists at PPPL working on an earlier tokamak had shown that reducing plasma recycling by coating its interior with very small amounts of lithium could substantially improve plasma confinement. Lithium, which is the lightest metallic element, has a strong chemical affinity for hydrogen and deuterium, and when deposited on the plasma facing surface effectively suppresses their recycling. However, when lithium coating was initially tried in experiments on other tokamaks employing a magnetic field structure called a "divertor" at the plasma edge, similar benefits were not obtained. The divertor is included in most modern tokamaks and the design for the large international project ITER includes a magnetic divertor.

Now scientists working on NSTX have demonstrated significant benefits from lithium coating in a divertor tokamak for the first time. In NSTX, the lithium was evaporated onto the walls by two ovens mounted inside the main vacuum chamber of NSTX. The ovens were electrically heated to about 600°C (1100°F), at which temperature lithium evaporates. Between plasma pulses, these ovens directed two streams of lithium vapor onto the graphite surfaces of the divertor at the bottom of the vacuum chamber where the lithium condensed into a thin solid film.

When plasma discharges were run after the lithium coating was applied, there was a significant increase in the plasma stored energy compared to discharges run under the same conditions but without a fresh layer of lithium applied. This increase in plasma energy indicates an improvement in the effectiveness of the magnetic insulation of the plasma as a result of the lithium coating. Most striking was the improvement in the temperature of the electrons in the plasma. The central electron temperature increased and its profile across the plasma column became much broader with lithium, as shown in Fig. 1. Fig. 2 compares the average total stored energy and the electron stored energy for two groups of about 20 discharges each with and without lithium. The improvement in the total energy by about 20% and particularly that of the electrons, by 44%, is apparent.

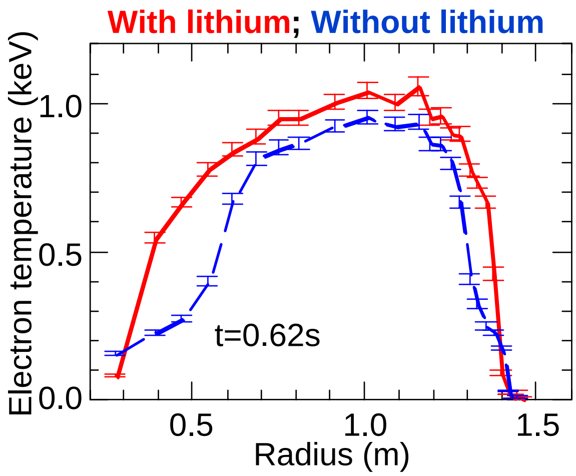

Fig. 1. Measured profile of the plasma electron temperature in similar NSTX discharges with (red) and without (blue) lithium coating.

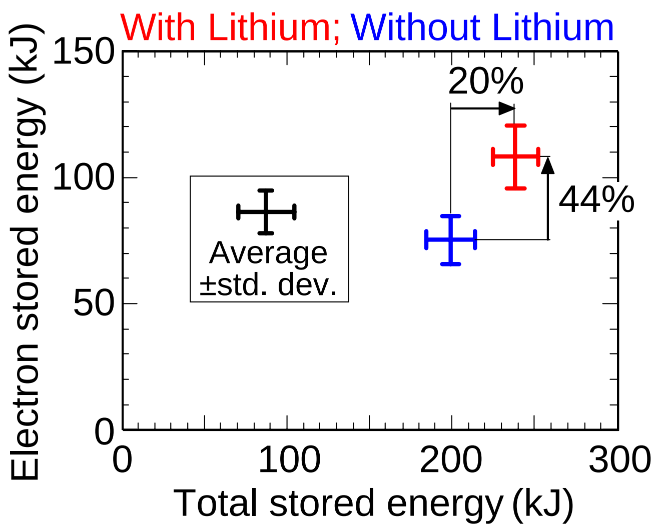

Fig. 2. The average energy stored in electrons vs. *the total plasma stored energy for two groups of about 20 similar NSTX discharges with (red) and without (blue) lithium coating.*

The NSTX results are significant because the success of future tokamaks, such as ITER, in reaching "fusion ignition" where a self-sustaining energy-producing plasma is created, depends on achieving good electron confinement since the energetic alpha-particles produced by the fusion reactions will heat the background plasma by transferring their energy to electrons initially. Inadequate electron confinement would thwart that process.

The success of these experiments has motivated the NSTX project to install, for experiments next year, a new divertor module which will use a heated liquid lithium surface, rather than the solid coating. The liquid lithium has the potential to sequester much larger amounts of hydrogen isotopes than the solid, the surface of which becomes saturated with hydrogen after a few seconds of plasma operation. The liquid surface offers potential for use in ITER and other next-generation tokamaks which are planned to operate for periods up to a thousand seconds.

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Related presentations at the 50th Annual Meeting of the Division of Plasma Physics of the American Physical Society, Hyatt Regency Hotel, Dallas TX, November 17–21, 2008:
R. Kaita "Effects of Lithium-Coated Plasma-Facing Components on NSTX Discharges" (talk CO3.5, Monday, 2:45pm, Reunion A) and **H. Kugel** "NSTX Experiments with Lithium Plasma-Facing Components" (poster NP6.84, Wednesday, 9:45am - 12:45pm, Marsalis A/B).