Plasma facing surface composition during Li evaporation on NSTX and LTX

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Astract:

- Evaporated lithium coatings react with residual water in the tokamak vacuum to produce lithium hydroxide and hydrogen:

  $2 Li + 2 H_2O \rightarrow 2 LiOH + H_2$

- Since tokamaks typically do not have ultra-high vacuum (UHV) conditions, this process can occur in the time interval between lithium evaporation and the next discharge.
- The resulting PFC surface should be considered as a mixed material rather than a pure 'lithium coating'.
- We present calculations of the flux of water from the residual vacuum to PFCs in NSTX and LTX under various conditions.
- To avoid reactions with residual vacuum gasses an ultra-high vacuum (≤1e-8 Torr) is required and may be achievable by a large-scale lithium getter pump.

Li deposition rate:

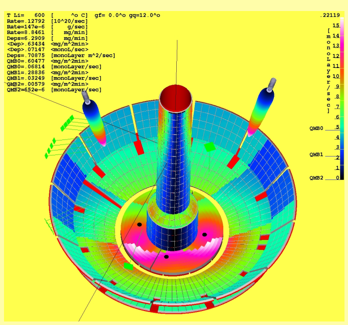
Q. How does the time scale to deliver a monolayer of lithium via evaporation compare to the time scale for the residual vacuum to deliver a monolayer of water to PFCs in LTX and NSTX?

One mole of lithium = 6.94 g and 6.02e23 atoms.

Using the Li density = 0.534 g/cm^3 a Li monolayer with cubic atom spacing has 1.29e15 atoms /cm^2 or 1.3e20 atoms or 1.5 mg over the NSTX deposition area of ~ 10 m^2.

At a typical LiTER evaporation rate of 20 mg/min depositing a Li monolayer would take 4.5 s.

(note this is for an flat mirror-like surface - coating a more realistic rough surface with a monolayer of Li would take longer.)



Calculation by Cbebm code of lithium deposition from the LITER-1 lithium evaporator.
[L. Zakharov et al., PPPL report PPPL-4187 Nov. 2006]

H_2O flux from base vacuum.

The flux of impinging gas molecules on a surface is given by kinetic theory[1]:

flux = 3.513e22 [P/√(M*T)] molec/cm^2/s

where P is in Torr, M is in amu, and T is in K.

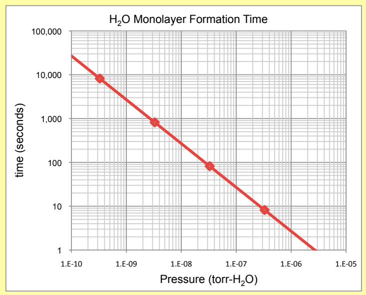
For water M=18, and using T=300K and P=1e-6 Torr

Flux (H_2O) = 4.78e14 molec/cm^2/s.

The reaction probability for incident H_2O molecules and surface Li atoms is near unity.

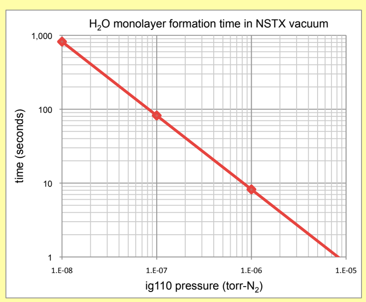
[1] A. Roth 'Vacuum Technology' 3rd ed. P. 3 table 1.2 and P. 36

Time to supply one molecule of water to every Li atom on a flat surface



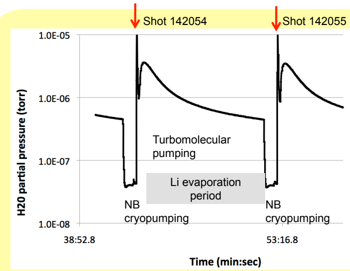
From NSTX ionization gauge and RGA calibrations:

Water pressure (Torr) = IG110 reading (N_2 calibration) x 0.33



Time to supply one molecule of water to every Li atom on a flat surface as a function of ig110 reading on NSTX

NSTX water base pressure



Between shots the water monolayer formation time (6s) is similar to the Li monolayer impingement time (4.5 – 11.3 s) at 20 mg/min.

1 minute before shot, LiTER was withdrawn and NB cryopump opened giving ~ 25 sec with water flux lower than the Li flux on flat surface.

Oxygen segregation to Li surface

Q. The majority of sputtered atoms originate at the surface. Can fresh lithium evaporation restore a pure Li surface over an oxidized lithium surface ?

- Materials with a low surface tension such as LiOH tend to segregate to the top of liquid lithium surfaces leading to a large difference between surface and bulk compositions.
- Buried or dissolved LiOH (or Li_2O) may resurface when Li melts.

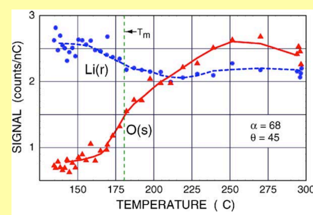


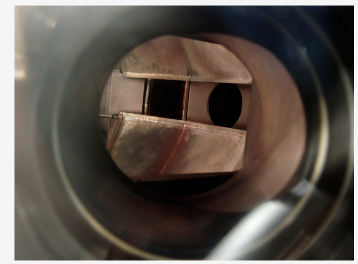
Fig. 3. Variation in oxygen signal intensity on a lithium surface as a function of temperature. The intensity of ion scattering from O and recoil emission from Li were monitored while the sample was bombarded with a 500 eV He^+ beam. Oxygen atoms appear more abundant on the liquid surface.

[Bastasz and Whaley, Fus. Eng. Des., (2004) 111]

- In a tokamak non-thermal mechanisms such as ion-induced diffusion and the formation of other lithium compounds may complicate this process.

LTX operated with a Li-coated 300 °C shell :

- First full high temperature, high Z wall operation of a tokamak
  - Lithium evaporated into 5 mTorr helium fill to disperse coating



- Deposition rate ~0.75 g/hour/evaporator
  - 3 hour duration, plasma operations follow 1 ¼ h later
  - Estimated 1.6 micron average Li thickness.
  - Partial pressure of water estimated to be in 1e-8 Torr range
- Lithium coating darkens rapidly.
- No visual evidence of shiny metallic surface
  - Indicative of LiOH formation at the surface.
- Li evaporation onto cold walls produced large effect on peak Ip and discharge duration.
- With hot walls - no significant improvement so far over uncoated walls or walls with passivated Li coatings.

Conclusions:

- At typical tokamak residual H_2O pressures of 1e-6 – 1e-8 Torr after a discharge, evaporated lithium coatings will react with residual water to form LiOH at the surface on a time scale of 3 - 300 seconds.
- Buried oxygen-containing lithium compounds can segregate to surface of molten Li
- The resulting PFC surface should be considered as a mixed material rather than a pure 'lithium coating'.
- To avoid reactions with residual vacuum gasses an ultra-high vacuum (≤1e-8 Torr) is required.

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