Temperature-dependence of Sn Sputtering Studied in IIAX

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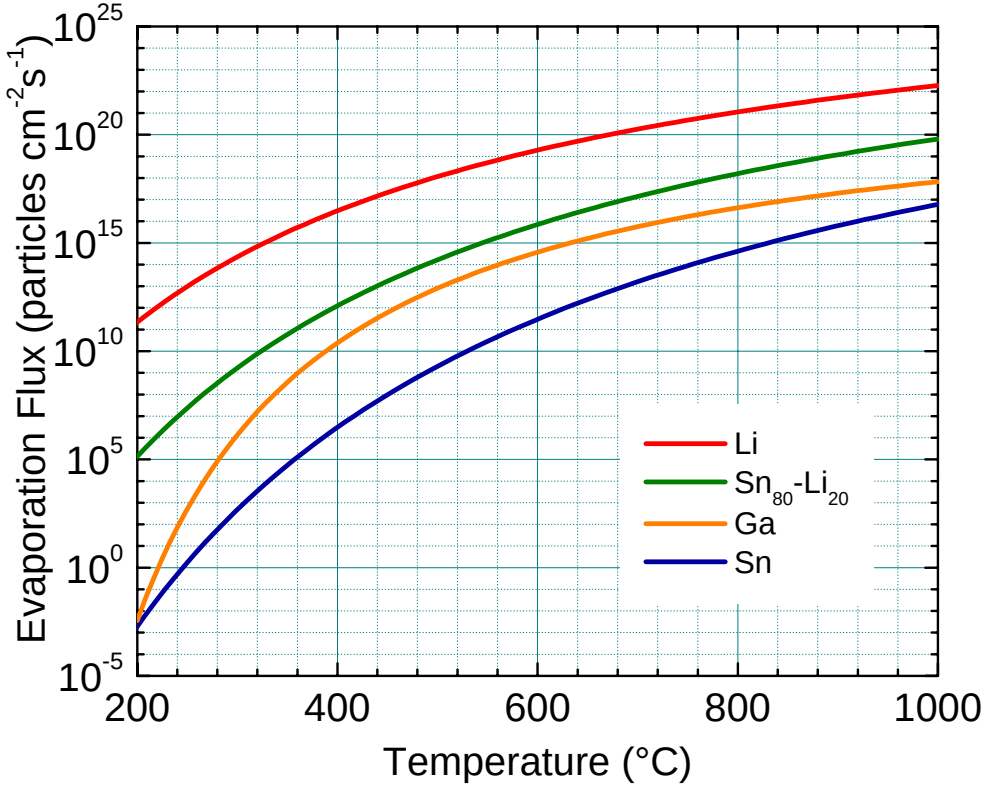
Outline of Talk

- Quick reminder why Sn is in consideration
- IIAX, DCU-QCM Technique
- Parameter space coverage
- Measurements of temperature-enhanced solid and liquid Sn sputtering
- Summary
- Future Work Options – Request for Feedback
- Questions

Advantages of using liquid Sn

- Sn has an evaporative flux many orders of magnitude lower than Li
- Also, *liquid* Sn does not seem to retain hydrogen isotopes[1], minimizing tritium inventory in a D-T machine
- Evaporation curves based on theory by [2] and fits from [3] and [4].



[1] R. Bastasz and J. Whaley, *Analysis of Liquid Tin Surfaces*, APEX/ALPS Meeting, PPPL, Nov. 4-8, 2002.

[2] Y. Waseda, S. Ueno, K.T. Jacob, J. Mat. Sci. Let, 8, (1989) 857-861.

[3] M.A. Abdou, A. Ying, N.B. Morley et al., APEX Interim Report Report No. UCLA-ENG-99-206, (1999).

[4] I.A. Sheka, I.S. Chaus, T.T. Mityureva, *The Chemistry of Gallium*, (1966), Elsevier, Amsterdam.

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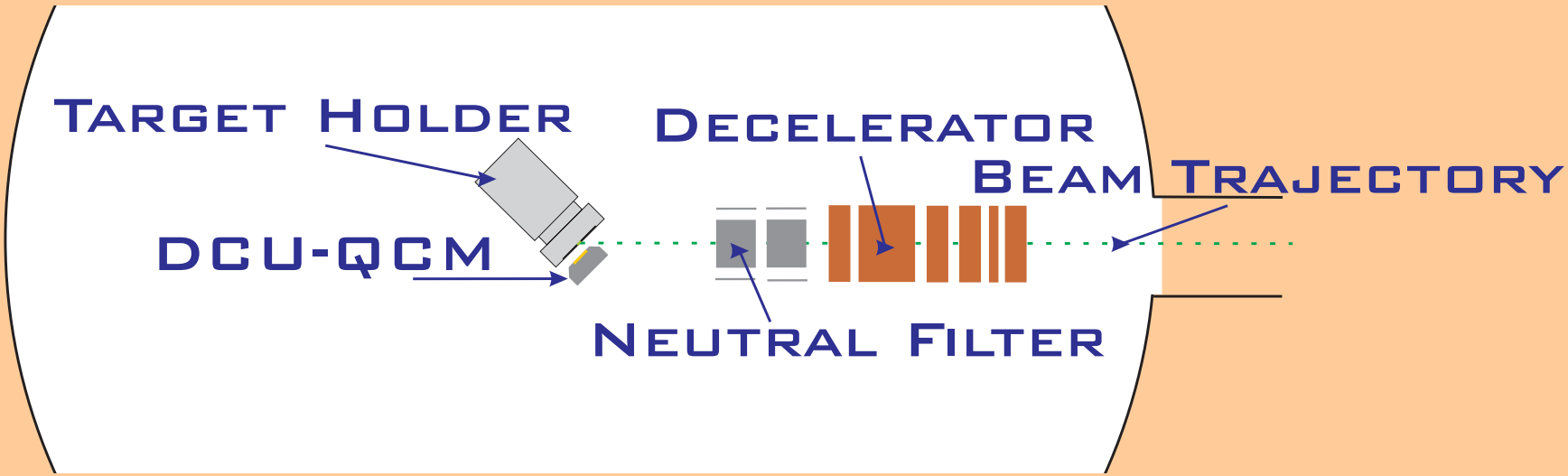
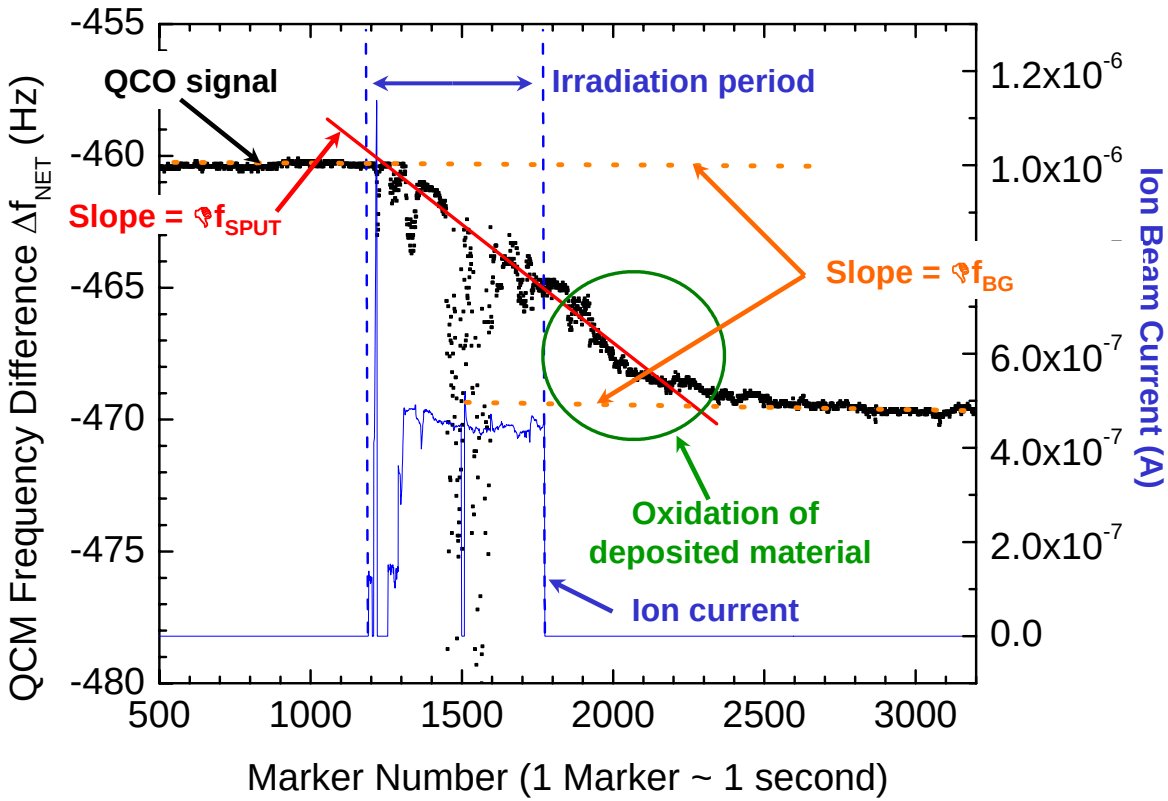
IIAX:
Sample Chamber



Determination of deposited mass via QCO frequency and beam current vs. time plot

- Before liquid target is irradiated with ion beam, a background flux measurement is completed
- QCM frequency difference slope increases when beam hits target measuring the sputtering flux
- When beam is off, some oxidation follows until original background flux is obtained



$$-\delta f_{sput} = \left| \delta f_{sput+backg} - \delta f_{backg} \right|$$

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Scope of Experimental Work in IIAX with Solid and Liquid Sn

Incident Ion Energy

Sample Temperature

	300 eV	500 eV	700 eV	1000 eV
380°C	He, D	He, D	He, D	He, D
370°C	He	He	He	He
335°C	He	He, D	D	
305°C	He, D	He, D	He, D	He, D
240°C	He		D	D
205°C		He	He	He
25°C	He, D	He, D	He, D	He, D

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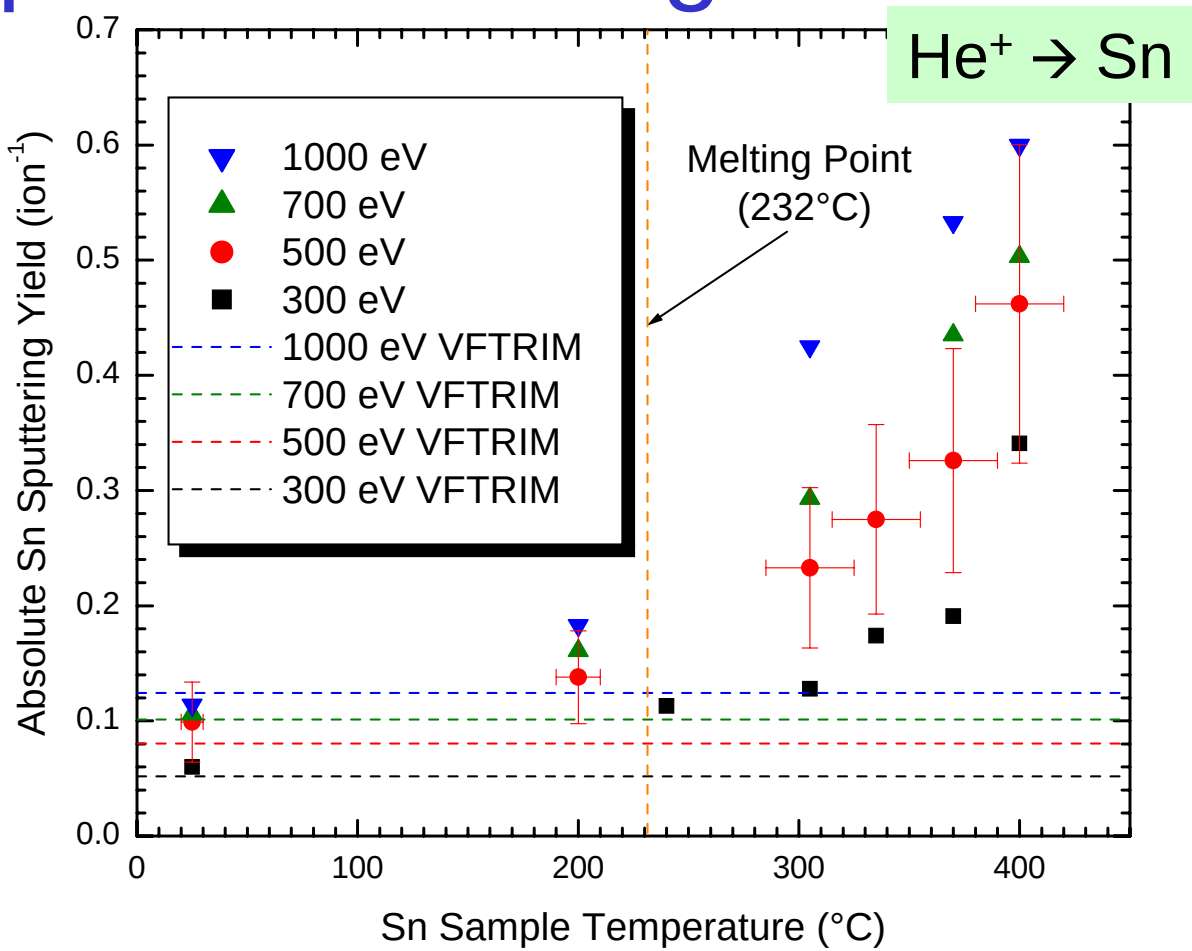
Sn sputtering yield vs. Sn sample temperature during He^+ irradiation



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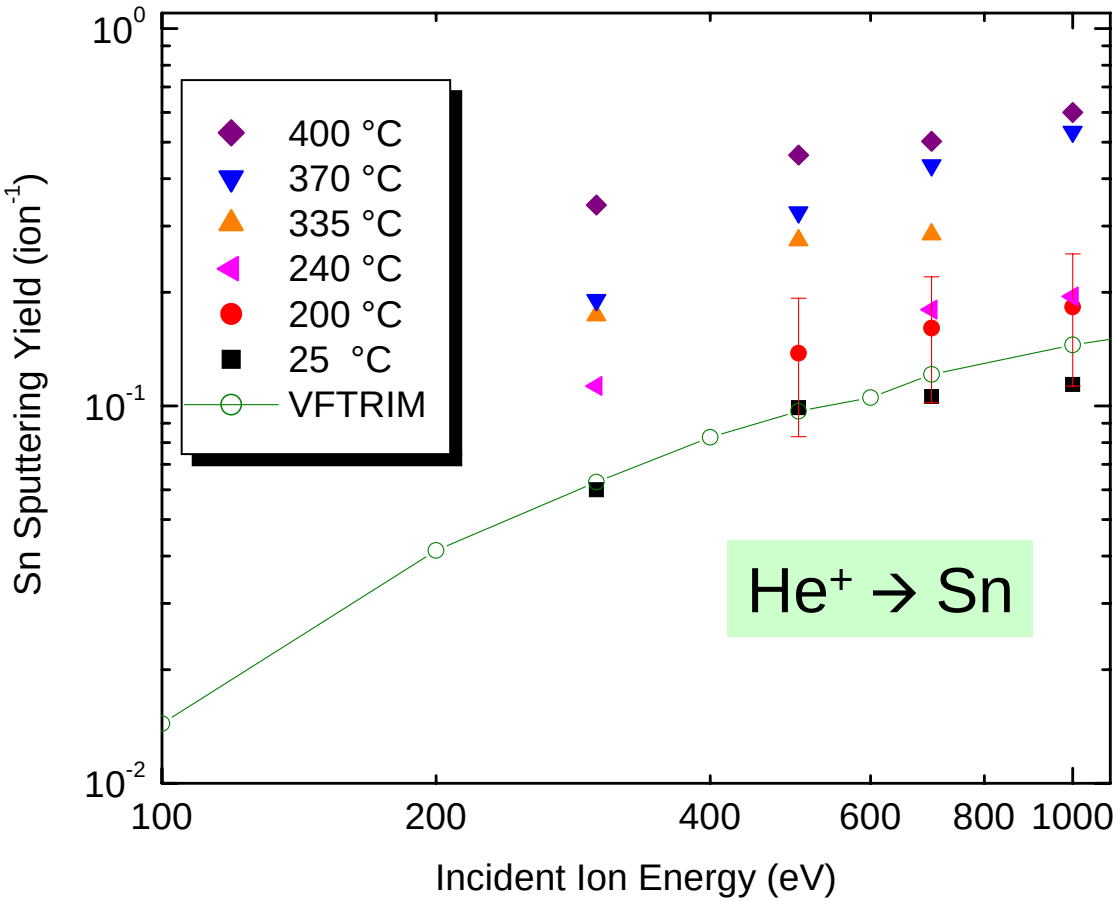
Sputtering yield of Sn as a function of incident He^+ energy



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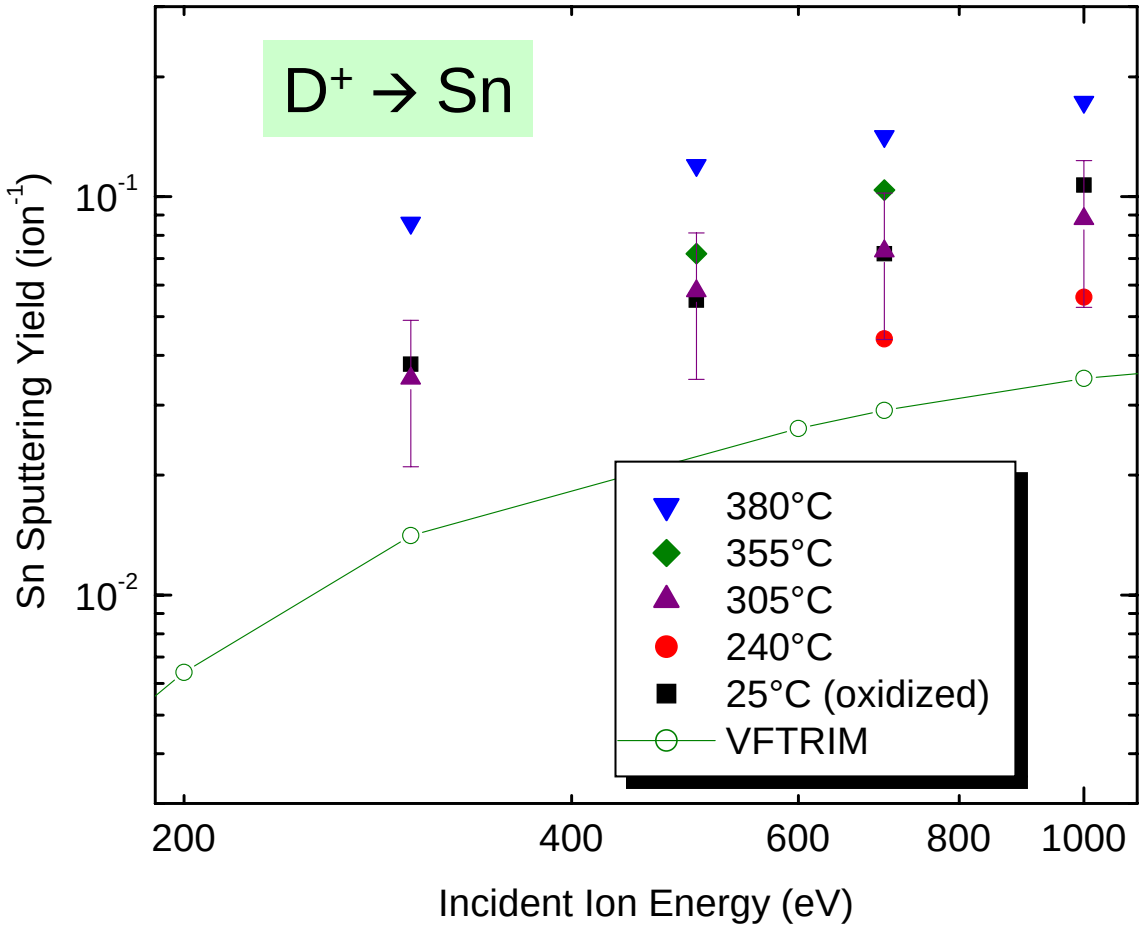
Physical mechanism behind temperature-enhanced sputtering

- Energy transfer efficiency
- Scattering angle increase

- The combination of the two mechanisms has been shown via a combination of MD/MC simulations to explain the temperature-enhancement phenomena (Paper on MD-TRIM already submitted) in liquid lithium self-sputtering. These mechanisms are assumed to play a similar role in other liquid materials for other irradiating species.

Sputtering yield of Sn as a function of incident D^+ energy



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Results

- Using direct monitoring of both the incident ion beam and the sputtered material, absolute sputtering yields of both solid and liquid Sn have been recorded.

- Like those of Li, Sn-Li, and Ga, the sputtering yield of liquid Sn has been found to have a strong dependence upon temperature.

- While Sn's total sputtering yield is much less than that of lithium, the *net* sputtering of Sn is marginally higher once the high level of ionization of sputtered lithium particles is taken into consideration for high incident particle energies.

Future *Lithium* Work Possibilities

- We would <u>greatly</u> appreciate feedback / suggestions so we can maximize the utility of the study to the community
  (Note: This will also be my PhD work)
- Ion-induced electron/ion emission
  - Yield
  - Energy spectrum
  - Emission angle spectrum
- Effects on electronic properties (IIEE / IIIE) due to presence of dopant impurities
  - Example contaminants: C, D/H, O, Be, W, …
  - Make extensive use of Materials Research Lab to characterize samples
  - Coupled experimental and computational/analytical studies

General Future Work on Sputtering

- *Extend Energy Range:* Studies of physical sputtering of Sn due to *lower* energy incident ions to explore ion energies that are associated with high recycling regimes (or alternatively higher ion energies).

- *Extend Temperature Range:* Similar Sn studies at *higher* temperatures to allow predictions at higher-end temperatures (taking advantage of Sn's low vapor pressure).

- *Additional Materials:* e.g. Ga to complement data reported by UCSD.

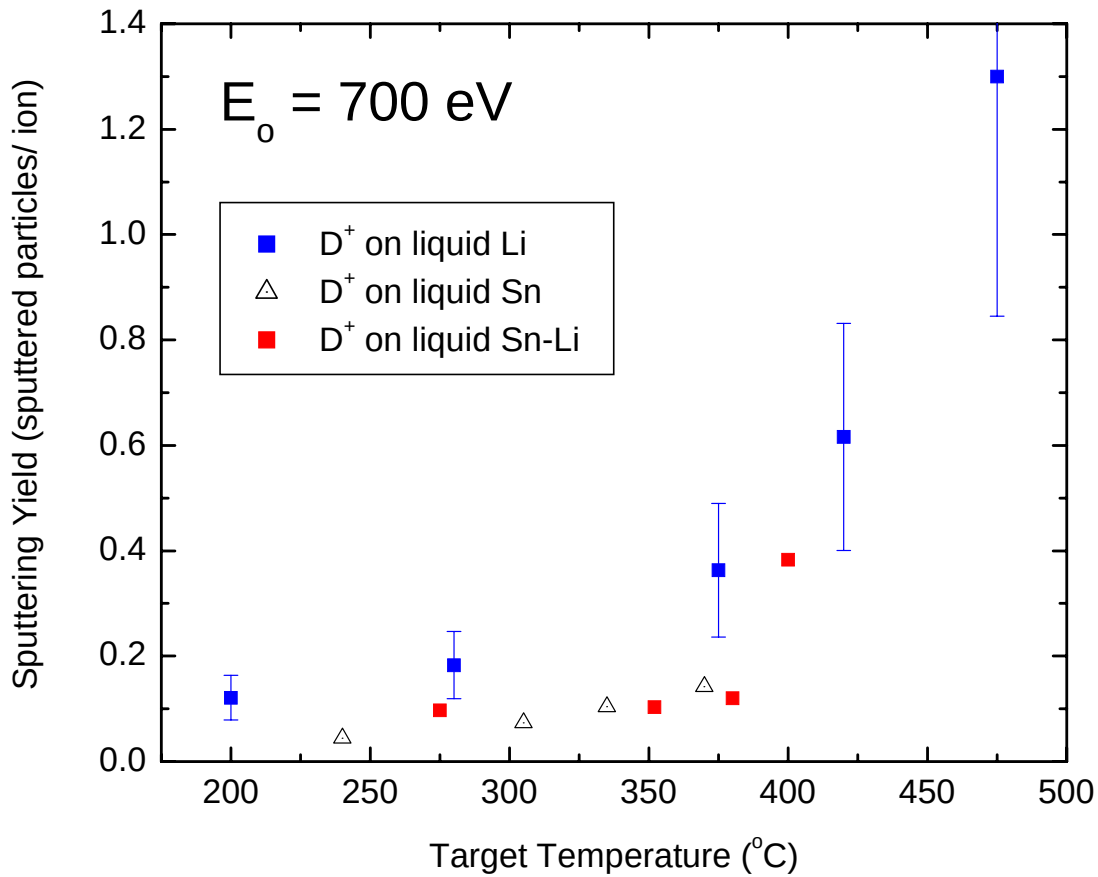
Thank you

Questions/Discussion???

My email: coventry@uiuc.edu

Comparison of Sn sputtering with SnLi and Lithium from D^+ bombardment

- The temperature enhancement of *lithium* sputtering shown here resembles that found by PISCES-B[1]
- That for liquid *tin* sputtering closer resembles that found for liquid *gallium*, again by PISCES-B[2]



[1]RP Doerner, et al., J. Nucl. Mater. **290-293**, 2001, 166.

[2]RW Conn, et al., Nucl. Fusion **42**, 2002, 1060.

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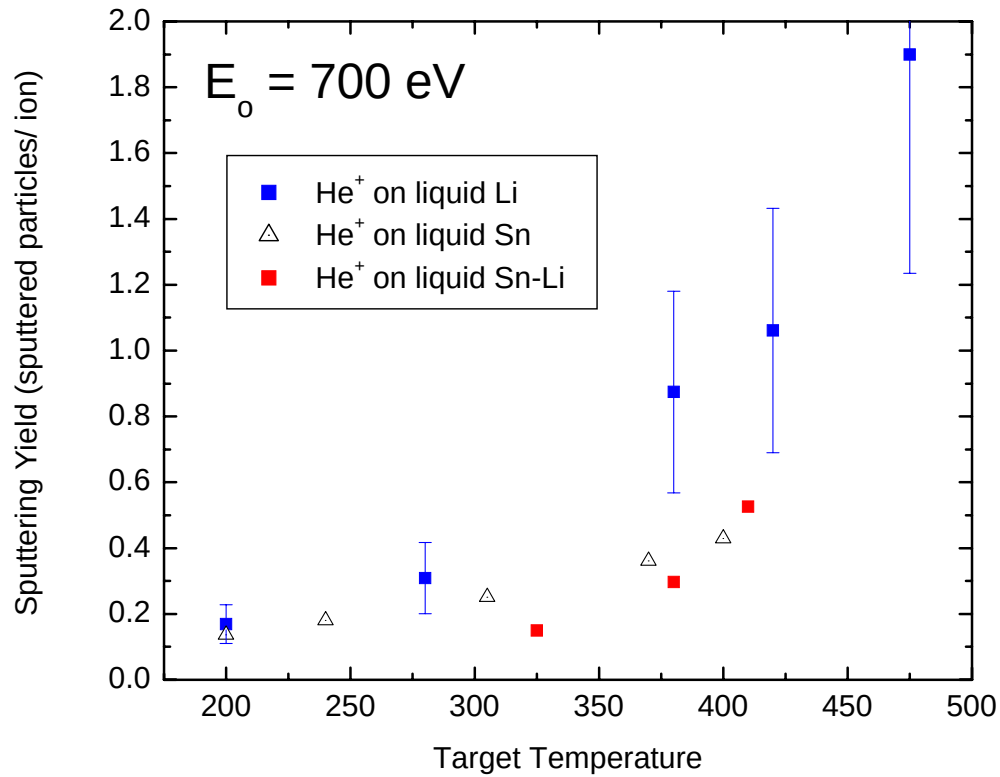
Comparison of Sn sputtering with SnLi and Lithium from He^+ bombardment

- The Sn-Li sample used here was easily machined and there were no reactions observed
- Both the Li and Sn-Li data shown here were measured on IIAX
- The fraction of sputtered Sn from the solid state that comes off ionized has been found to be negligible (✪ 5%, easily absorbed by error bars)
- Thus, if one considers the *net* erosion in the presence of a sheath that would return all ions emitted, the high charge fraction of sputtered lithium particles (2/3)[1] actually puts its *net* sputtering yield below that of Sn



[1]Allain, J.P., Ruzic, D.N., et al. (2001). J. Nucl. Mater. 290-293: p33-37.

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Implications of liquid Sn PFC's in tokamak fusion devices

- Line radiation losses set limit on the maximum impurity levels of Sn and other high-Z materials (while dilution is the limiting process for lower Z materials)
- Evaporation-imposed operation temperature limitation for Sn is estimated to be ~ 1500°C based on erosion/redeposition models[1]

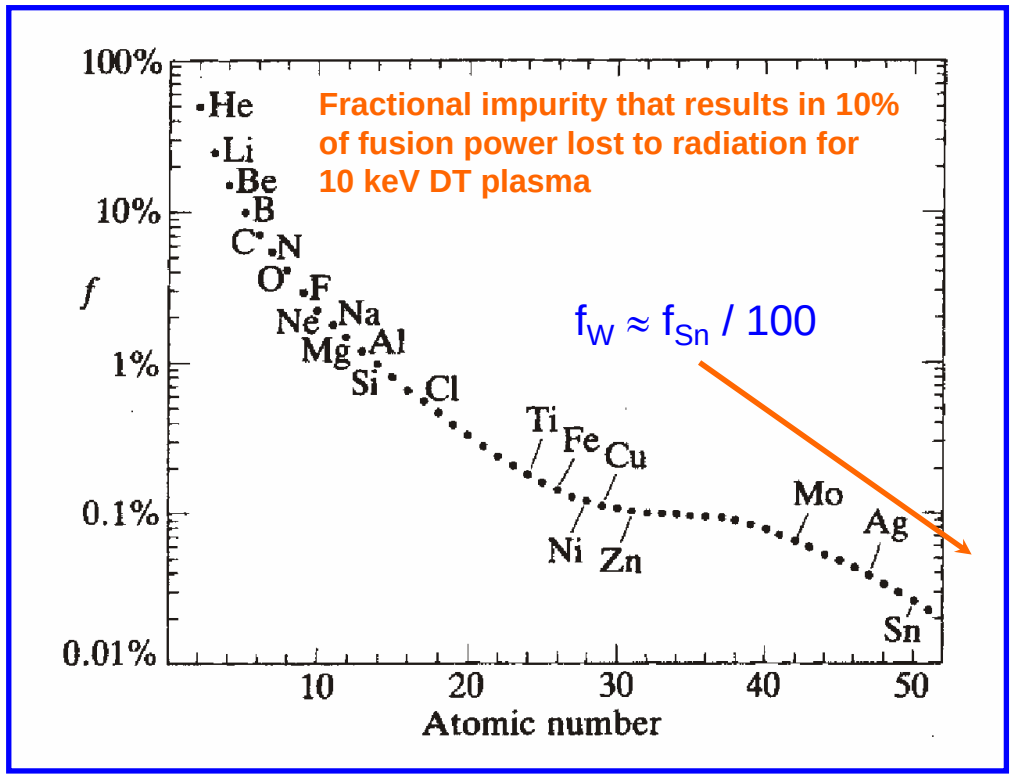

Figure from: J. Wesson, Tokamaks, 2nd Ed. Oxford University Press, Oxford, 1997.

[1]J.N. Brooks, Fusion Eng. Des. V60, (2002) p515.

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