PRD-LMD kick-off meeting 2021: CIEMAT

Eider Oyarzabal, Daniel Alegre, Francisco Tabarés, David Tafalla and Alfonso De Castro.

Fusion National Laboratory. CIEMAT. Madrid. Spain

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 and 2019-2020 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

Tasks involved and resources allocated

P2: IMPURITY CONTROL (Li and Sn transport/contamination). 9PM Completed

- ✓ Insertion of CPS samples (Li, Sn and LiSn) into the edge of TJ-II plasmas. Studies of sputtering/evaporation and penetration into the plasma vs T_{sample} with radial and poloidal emission profiles.
- ✓ E_0 Sn: 3.2 eV, E_0 Li: 1.68 eV → Overestimate of ioniz rates for Sn?

(Tabares 2nd Vapour Shielding CRP. Oct. 2020/ Tabares el al. ISLA-6 Urbana Illi. Oct-2019)

P3: POROUS MEDIA AND MATERIALS (Plasma &Laser texturing) 8PM+30k€ Completed

- ✓ Use of SS substrates with different roughness grades to achieve different columnar structures (University of Sevilla) and samples manufactured at the University Complutense of Madrid by Laser micro-texturing.
- ✓ Study the wetting properties of the different microstructures for CPS design optimization purposes.
- ✓ Lateral movement of Li is favored for smaller channel width (40μm) and inter-channel width (400 μm) and it is hindered with respect to non treated material for wider channels (above 200μm)

(S. Muñoz-Piña et al. Nuclear Fusion, Volume 60, Number 12)

S1: TRITIUM RETENTION (LiSn and Sn at high T) 5PM Completed

P1: POWER HANDLING (OLMAT). 9PM+ 16k€ (2PM+2K€ to 2021)

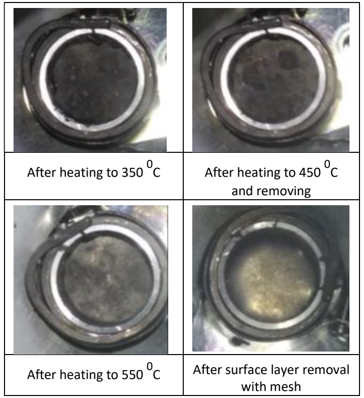
P4: PROTOTYPE DEVELOPMENT (Tests of CPS in OLMAT) 10PM +10 k€ (10PM +10 k€ to 2021)

S1: TRITIUM RETENTION: LiSn and Sn at high T

- Study of H retention in Sn and SnLi at high temperatures.
- SnLi and Sn wetted CPS electrodes have been manufactured in order to expose them to D_2 plasmas (5mTorr and around 4 x10^{19} D atoms/m^2.s flux) at different temperatures from RT to 700 ^{0}C and to obtain the D_2 retention by TDS.
- Publication in NF (Under Eurofusion clearence process)

SnLi target manufacturing

Sn and Li mixing procedure



After heating to 350 ^{0}C | After heating to 450 ^{0}C and removing | After heating to 550 ^{0}C | After surface layer removal with mesh

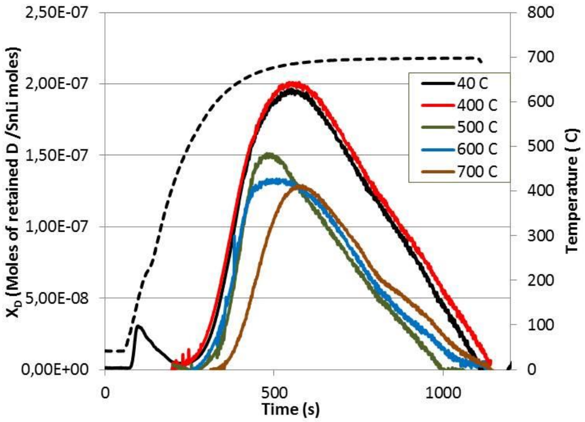
Electrode with W mesh (three windings → 50µm effective porous size) is wetted with the mixture at around 850 ^{0}C.

Sn target manufacturing

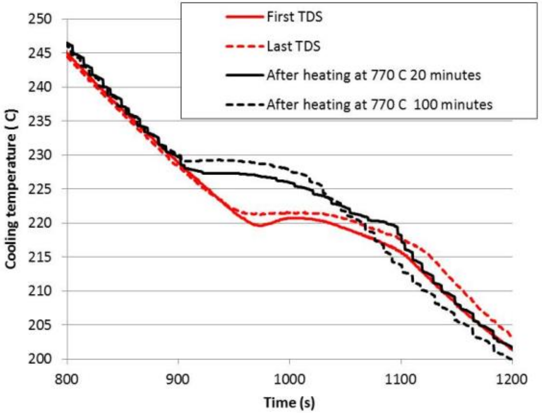
Wetting at a vacuum oven reaching 1150 ^{0}C. No diffusion upwards observed in this case, only the part that is inserted in the liquid tin is wetted.

S1: TRITIUM RETENTION: LiSn and Sn at high T

LiSn main results



- Saturation already reached at 5 minutes absorption, total fluence 1,2 x10^{22} D atoms/m^2
- Main peak around 650 ^{0}C for all absorption temperatures.
- For absorption at 40 ^{0}C additional peak at around 200 ^{0}C
- Small decrease of total amount retained with temperature.



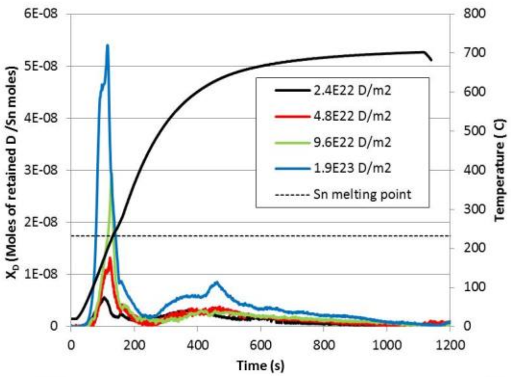
Continuous bubble formation during D_2 absorption and sometimes during TDS.

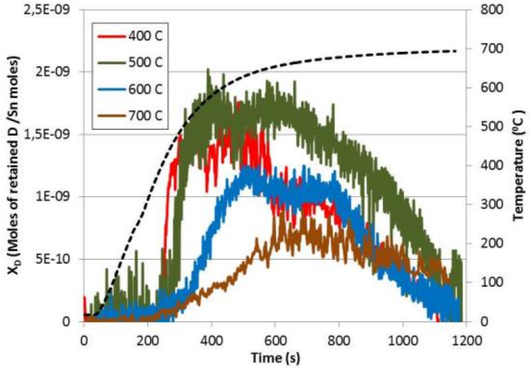
- TDS experiments(temperatures under 700 ^{0}C):
  - No appreciable change in cooling characteristics (related to alloy composition).
- Heating at 770 ^{0}C for 100 minutes:
  - Cooling characteristic of a Sn sample→ Preferencial evaporation of Li.
  - Obtained evaporative fluxes in the order of 1x10^{17} atoms/cm^2.s dependent on Li content.

S1: TRITIUM RETENTION: LiSn and Sn at high T

Sn main results:

Very low values of retention → Retention of W mesh not negligible anymore.





Absorption at 40 ^{0}C:

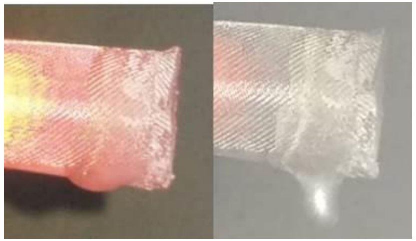
- Peaks at around 200 ^{0}C, melting point and 600 ^{0}C,
- No saturation even after 80 minutes.

Absorption from 400 ^{0}C to 700 ^{0}C:

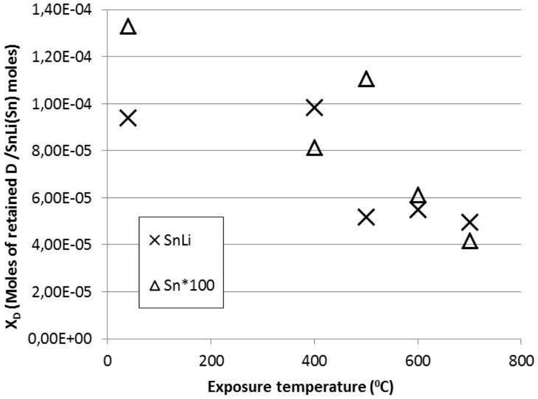
- Saturation after 5 minutes.
- Peak between 550 ^{0}C and 650 ^{0}C
- Retention decreases for the highest temperatures.

W mesh retention represents 50 % of the total amount for the case of 40 ^{0}C exposure and around a 5% of the total amount for the case of exposure at 500 ^{0}C.

No bubbling observed for Sn but drop formation.

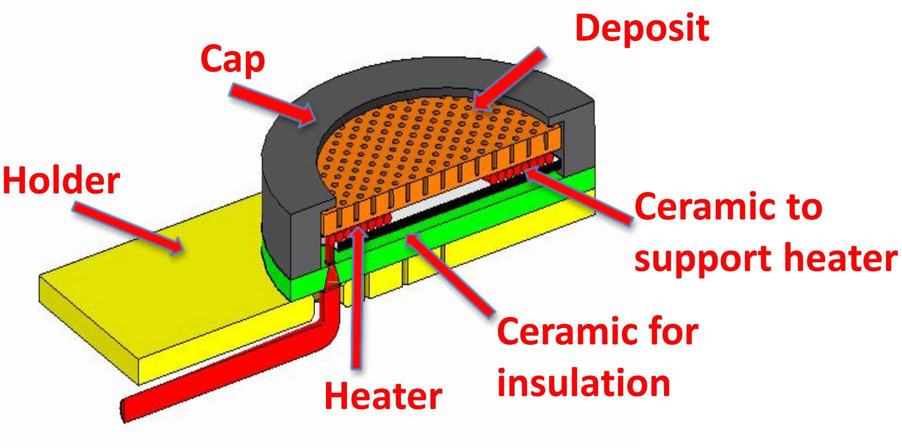


100 times higher retention for SnLi in our conditions.

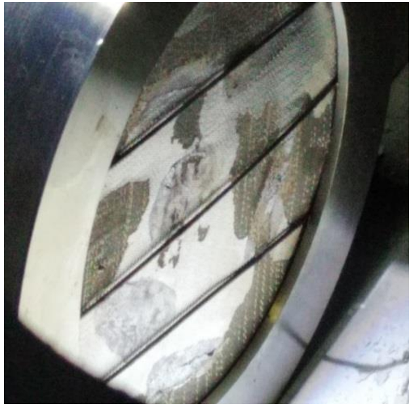


P4: PROTOTYPE DEVELOPMENT: target design

- Testing in small ovens for other experiments (LIBS for refilling time) indicated big issues with the mesh if a (relatively) deep liquid metal pool is used.
- To reduce mesh bending the mesh support is a sheet perforated with 2 mm diameter, 4 mm depth holes.
  - ➢ A firm mesh support is achieved and has sufficient liquid metal volume for replenishment.
- The target may be insulated easily to measure current or for bias experiments



Li wetted target (Mo wires to avoid mesh bending)



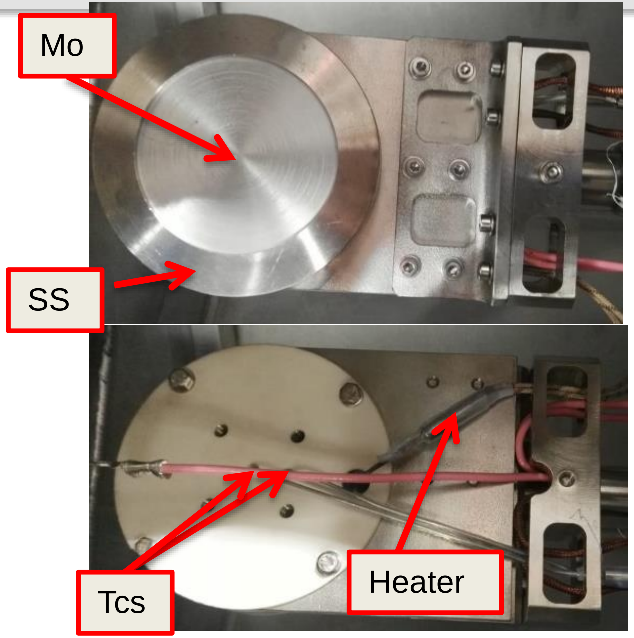
Mo deposit and cap almost ready for Sn wetting under vacuum.

P1. POWER HANDLING: OLMAT FIRST TESTS

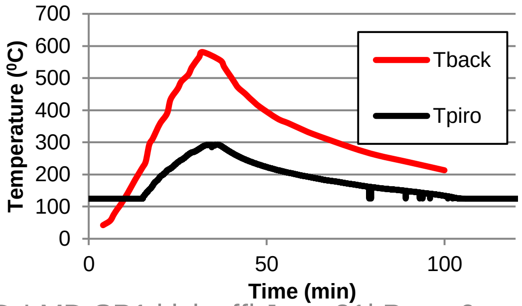
- OLMAT fabrication, assembly, control system and security tests finished.

- 4 operational days in April (27-30 of April):

  - 7mm thick Mo (TZM) target in order to characterize the NBI pulses.
  - Frontal part (Mo+SS) thermically and electrically isolated with ceramic plates (5 mm Macor plate).
  - Resistive heater behind Mo target.
  - Two thermocouples, one of them controlling the power supply for the resistive heater.



100 kW-330 kW 20ms-100ms (With and without bending magnet)
Series of 10 pulses every 70 s at 200 KW and 50 ms
Series of 5 pulses every 70 s at 200 KW and 100ms (<u>Target surface at 250 ^{0}C</u>)
200kW 100ms at 70/45/30 inclination degrees (<u>Target surface at 250 ^{0}C</u>)

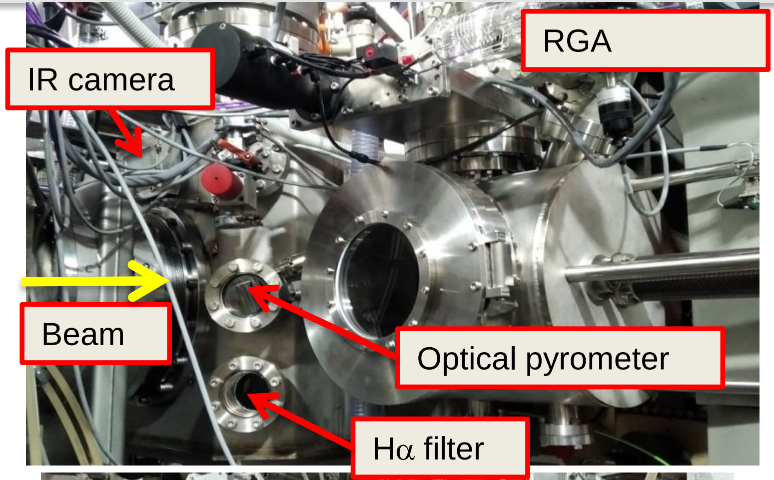


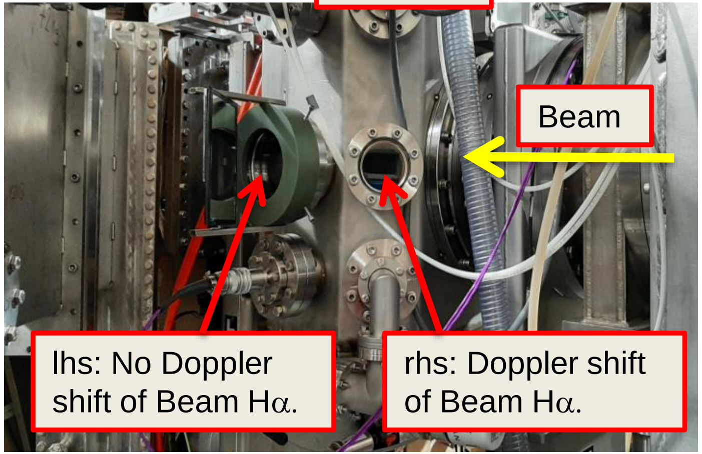
P1. POWER HANDLING: OLMAT FIRST TESTS

- Infrared camera: Not available in these experiments.
- Optical pyrometer measuring the superficial temperature at the center of the Mo target→ Calibrated in the laboratory.
- RGA in the pre-chamber.
- Hα filter

OLMAT spectroscopy:

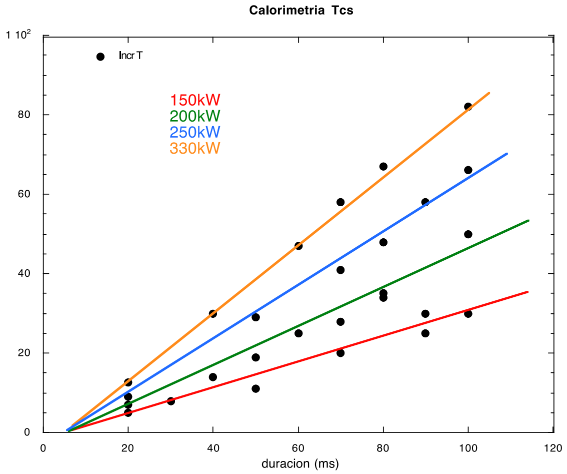
- Two viewport available to collect spectra of beam/target interaction (lhs & rhs).
- We use the rhs viewport as it allows us to separate beam Hα, Hβ emissions from target surface emissions.

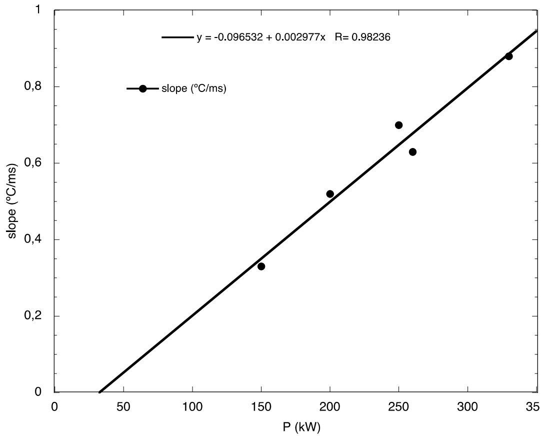




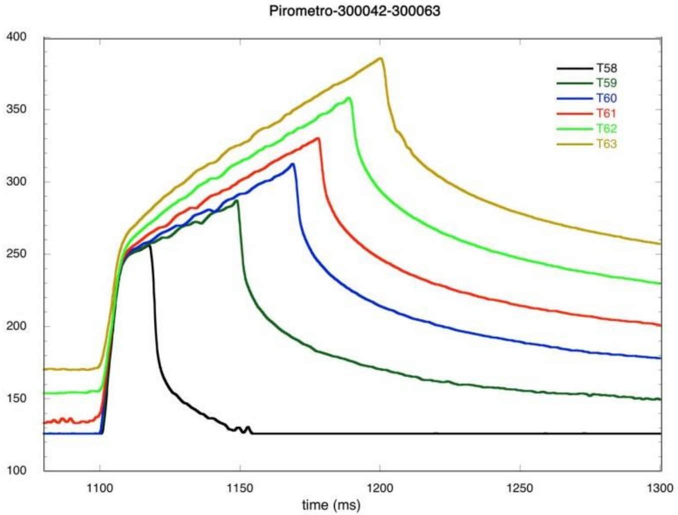
P1. POWER HANDLING: OLMAT FIRST TESTS

Heat flux from calorimetry:





P= 250 kW (with ions)



Target: 351g SS+332g Mo = 255 J/K

Assuming thermal decoupling of Mo-SS:

$A_{Mo}=7.5^2.\pi/4= 44\ cm^2$

At 200kW, R heat= 0.55 K/ms **Q= 10.5 MW/m2**

At 330kW, R heat= 0.90 k/ms. **Q= 17.2 MW/m²**

With thermal coupling → Higher heat fluxes (Q values).

Calibrated in the laboratory only up to 300 ^{0}C.

Upgrade to a multi-wavelength pyrometer .

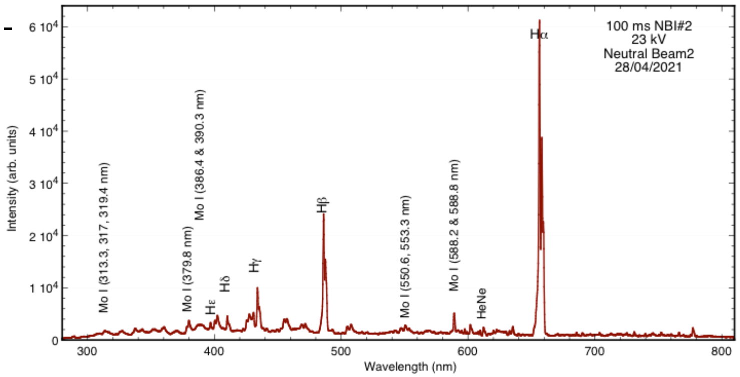
P1. POWER HANDLING: OLMAT FIRST TESTS

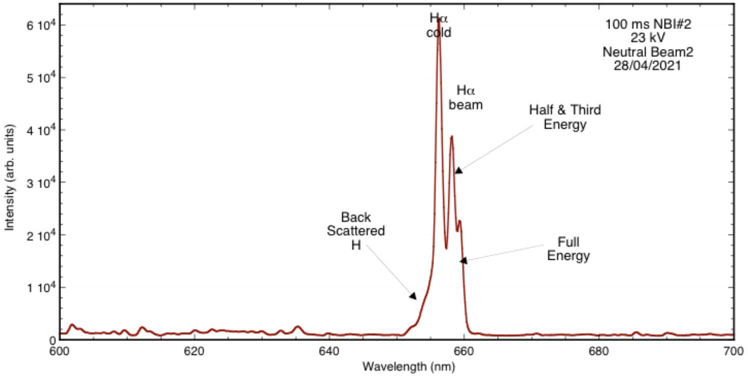
Optical spectroscopy:

-MoI lines detected.

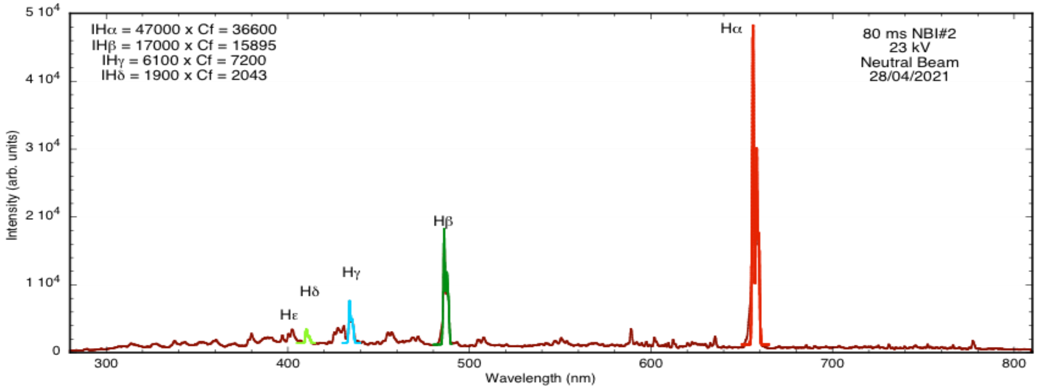
-H beam, cold H & back-scattered H

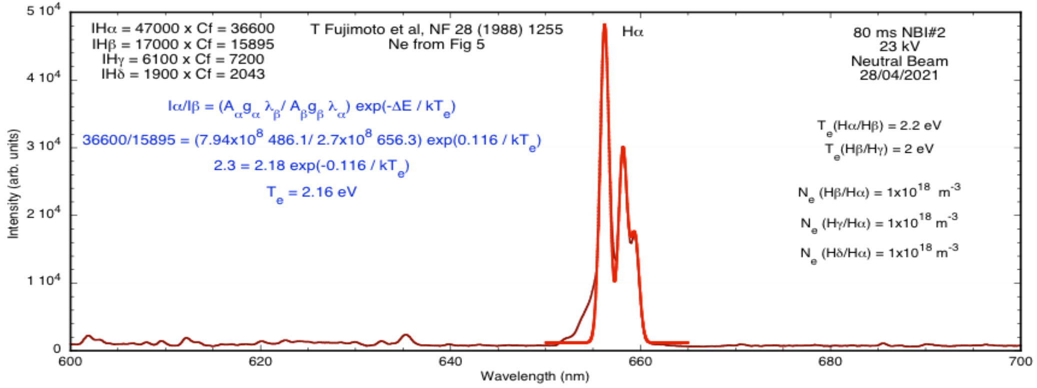
-





-Temperature from H lines fitting around 2 eV.





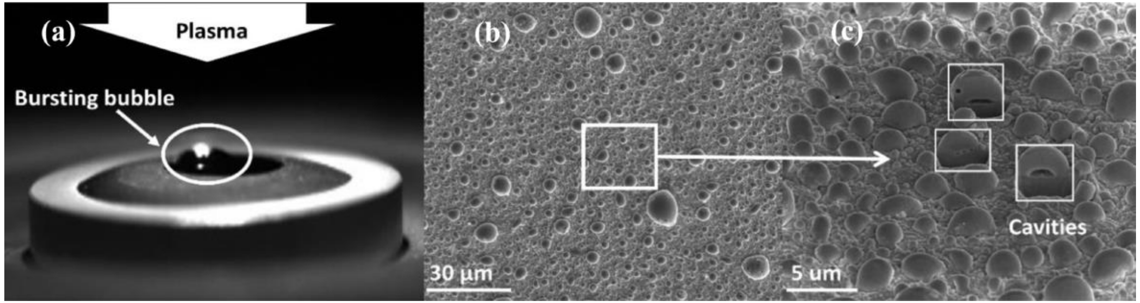
Outlook at the future

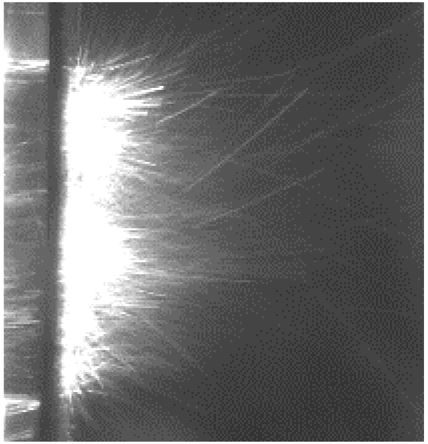
FUTURE EXPERIMENTS: OLMAT 2021

- **General**
  - Increase power to maximum (about 40-50 MW/m^2)
  - Higher repetition rate: 10-20 s? (skipping data acquisition)
  - Install refrigeration in beam dump and manipulator.
  - Damage and melt TZM sample to compare with LM

FUTURE EXPERIMENTS: OLMAT 2021

- **General**
  - Increase power, Higher repetition rate, Damage TZM
- **Tin**
  - First test at end of June.
  - *Issues:* Splashing, dry-out, vapor shielding, SnH_4, etc.





General

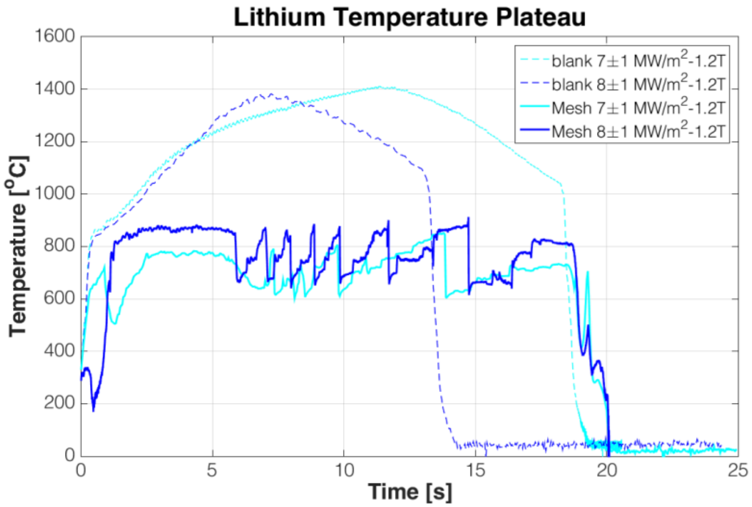
- Increase power, Higher repetition rate, Damage TZM

Tin

- Splashing, dry-out, vapor shielding, SnH_4, etc.

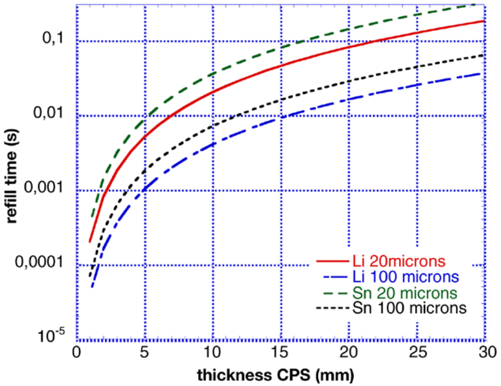
Lithium

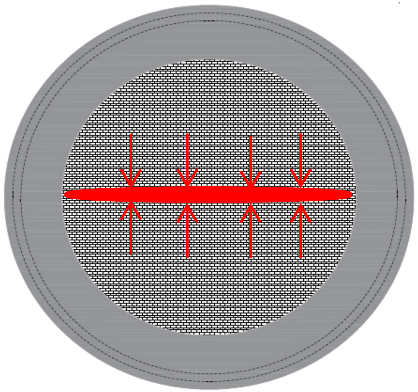
- Late 2021.
- H retention (w. preloading)
- Erosion
- Vapor shielding
- Solve Li condensation!



FUTURE EXPERIMENTS: OLMAT 2022 and beyond

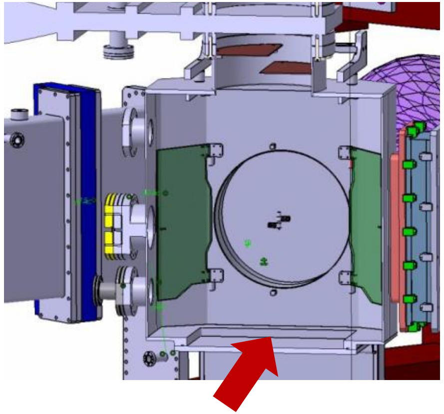
- **CW laser**
  - Installation expected late 2021.
  - Simulate type I & III ELMs. Synergies with *longer* OLMAT beam
  - Allows faster fatigue and cracking experiments.
  - In-situ refilling time, partial damage of CPS…
  - Strike point shape (10 MW/m^2): long experiments, lateral refilling time…





FUTURE EXPERIMENTS: OLMAT 2022 and beyond

- **CW laser**
  - Simulate type I & III ELMs. Synergies with “long” OLMAT beam
- **CPS Prototypes**
  - Mesh, Laser-textured, 3D-print: 80 x 5 mm (or 30-150 x 0.1-0.8 mm)
  - Small prototypes on manipulator: up to 200x40 mm.
  - Large prototypes at bottom: 300x300 mm



FUTURE EXPERIMENTS: laboratory 2021 and beyond

- **General**
  - Test refilling time of different samples by LIBS.
  - Refilling studies from LM pool
- **Tin**
  - Continue with H retention
  - Estannane production?: RGA and surface analysis techniques during/after H-Sn GD-plasma exposure. Use cryotrap or pyrolysis.
  - Use the high temperature vacuum oven to study wetting.
- **Lithium and LiSn**
  - Collaborations with Illinois/PPPL.
  - Li partial evaporation in SnLi; LiMIT/CPS mixes; etc.

SUMMARY

- **Most 2020 work finished**

- **H retention in Sn very low.** Moderate for SnLi.

- **First experiments in OLMAT were very successful.** No issues at half maximum power density.

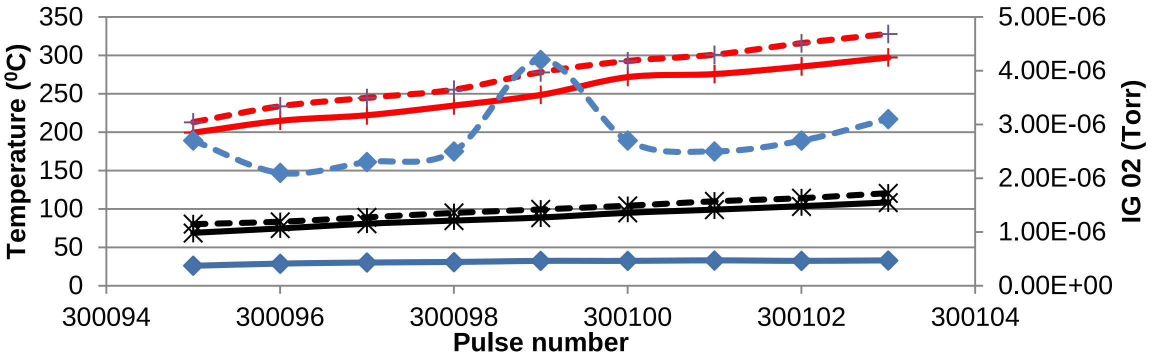
- **Start experiments this year in OLMAT with Sn, Li (CW laser?).** Verify CPS resilience against heavy heat loads.

- **Continue with experiments for Sn transport, wetting, SnH_4, etc.**

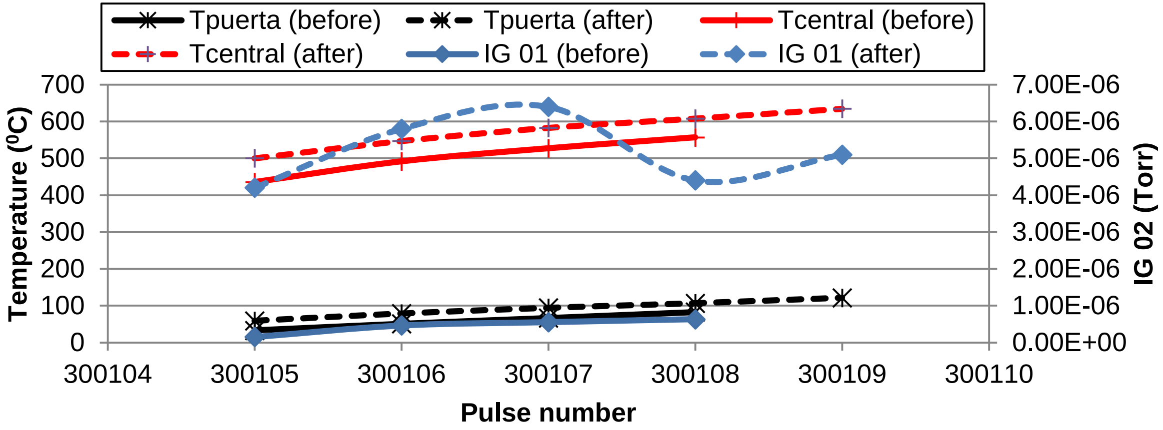
Reserve slides

Reserve slide

10 pulses of 200kW and 50 ms every 70 s



5 pulses of 200kW and 100 ms every 70 s (250 ⁰C T superficial)

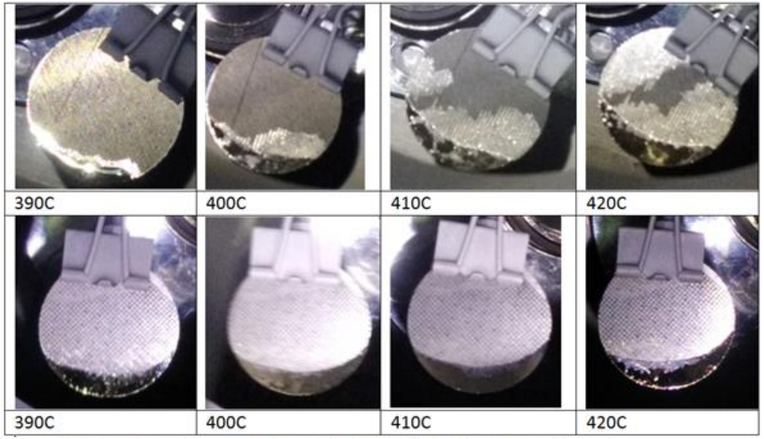


- Very small increase in pressure → Not a limiting factor in these conditions.
- Temperature of the target and Mo doors increases, no constant value reached with this number of pulses..
- Maximum surface temperature reached 450 ^{0}C.

Laser micro-texturized samples:

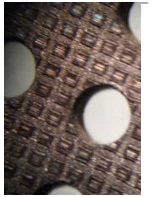
Holes: 200 μm
Inter-channel width:400 μm
Channel width: 40μm

Holes: 400 μm
Inter-channel width:800 μm
Channel width: 40μm

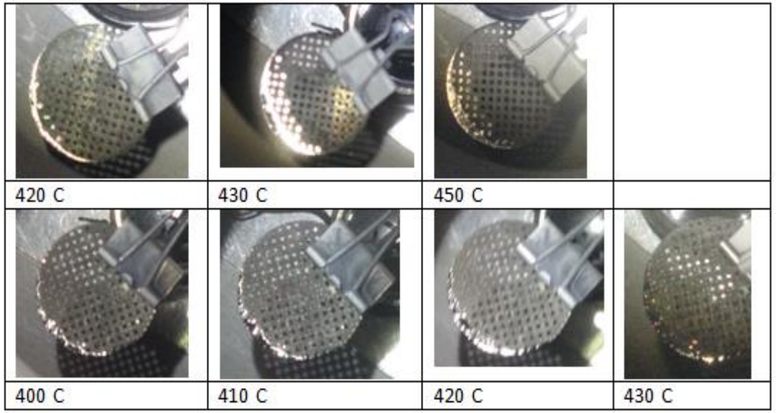


- Lateral movement of Li is favored for smaller channel width (40μm) and inter-channel width (400 μm).

Holes: 1000 μm
Inter-channel width:400 μm
Channel width: 200μm



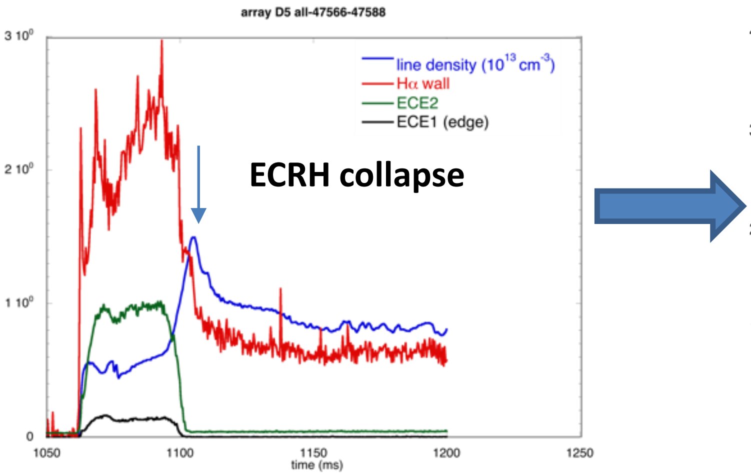
Holes: 800 μm
Inter-channel width:800 μm
Channel width: 400μm

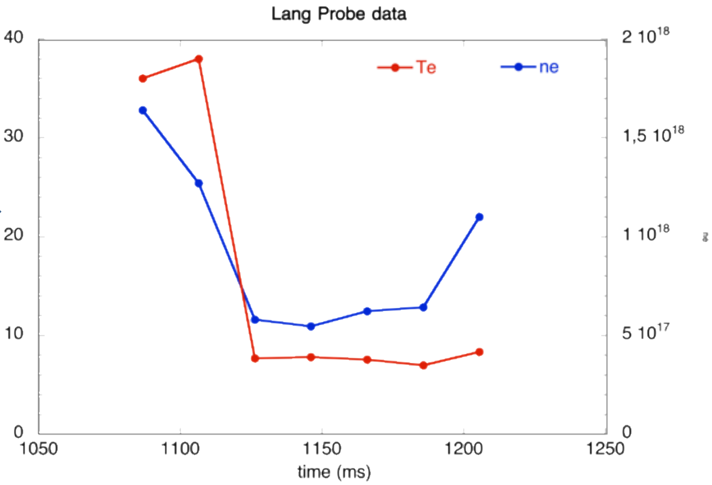


- Lateral movement of Li is hindered with respect to non treated material for wider channels and hole diameters.
- About 20 C higher Twi for wider channels as well.

FUTURE EXPERIMENTS: TJ-II 2021 and beyond

- Understand discrepancy of Sn ionization results
- Extend range of measurements to collapsing, low Te plasmas
- Verify adatom model for thermal sputtering
- Refine thermal simulations of LM target during exposure to TJ-II





OLMAT CW laser

- **Very flexible power and frequency:** heating by different types of ELMs.

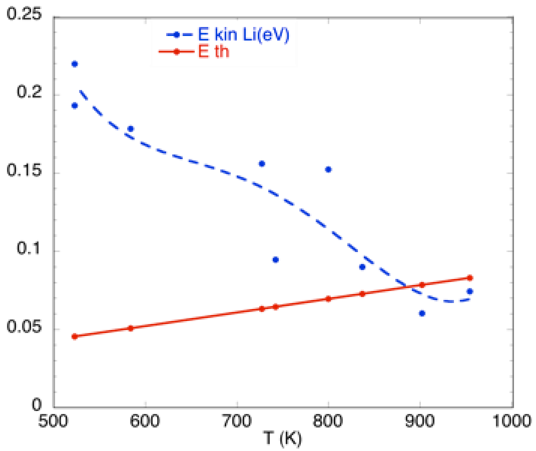
IPG LASER	SPECIFICATION YTTERBIUM LASER SYSTEM Model YLS-1500/15000-QCW-WC-Y14

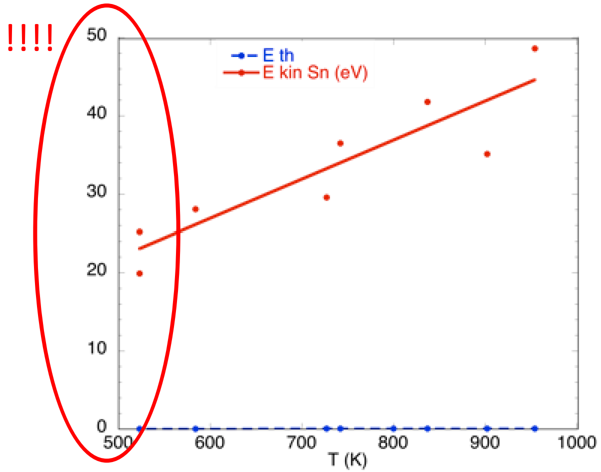
1. Optical characteristics

N	Characteristics	Test conditions	Symbol	Min.	Typ.	Max.	Unit
1	Operation Mode			CW / pulsed			
2	Polarization			Random			
3	CW and Pulsed Maximal Average Output Power		P_{nom}	1500			W
4	Maximum Peak Power			15000			W
5	Pulse Duration			0.2		10	msec
6	Maximum Pulse Energy	Duty cycle 10 %, PRR = 10 Hz, Maximum power	E_{max}	150			J
7	Duty Cycle*	Pulsed mode				50*	%
8	Tuning Range of Output Power			10		100	%
9	Emission Wavelength	Maximum output power	λ	1068	1070	1072	nm
10	Emission Linewidth	Maximum output power	$\Delta\lambda$		5	7	nm
11	Switching ON/OFF Time	Maximum output power			100	150	µs
12	Maximum Modulation Frequency	CW & Pulsed modes		2000			Hz
13	Output Power Instability	Maximum output power Time interval: 8 hrs (T=Constant)			±1	±2	%
14	Red Guide Laser Power				0.4	0.5	mW

**Maximum duty cycle limit is inversely proportional to peak power: 10% for 15000W, 15% for 10000 W,………, 50% for 3000W and lower*

P2: IMPURITY CONTROL: E_{kin} vs T





E_0 Sn: 3.2 eV, E_0 Li: 1.68 eV

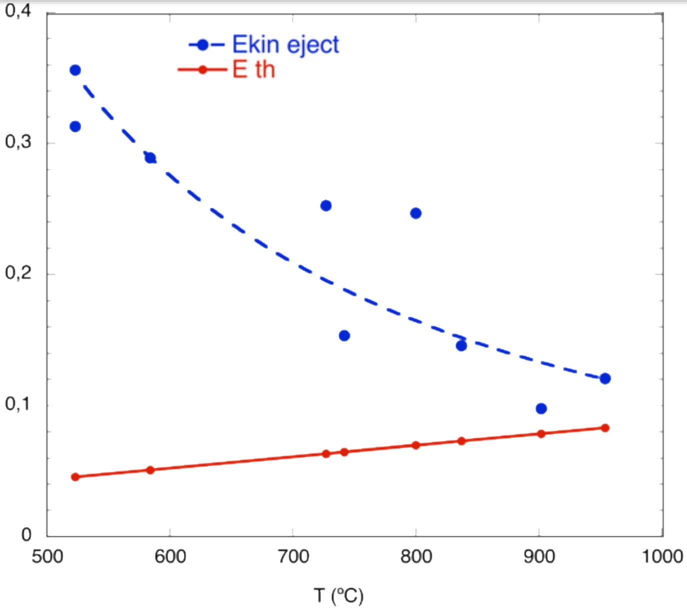
Li as previouly reported: At 900 K, basically all from evaporation

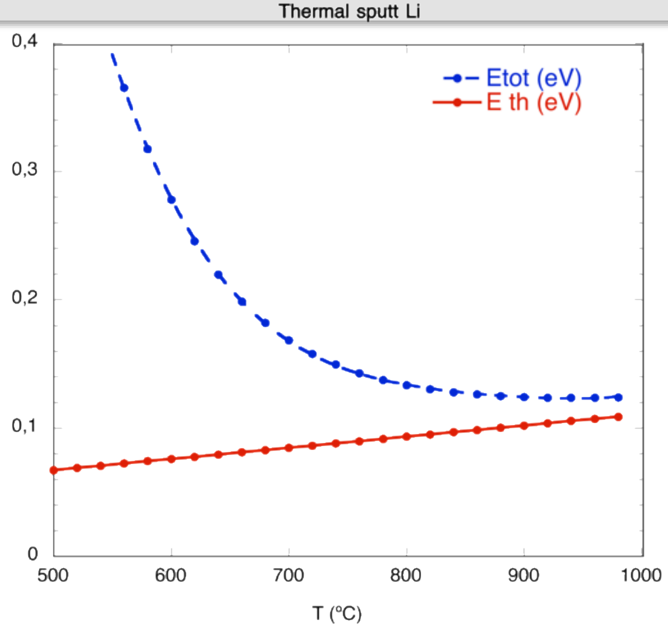
BUT: Sn???:

- Overestimate of ioniz rates?
- Local plasma cooling? *(will also affect Intensity of Sn emission)*

Tabares el al. ISLA-6 Urbana Illi. Oct-2019

P2: IMPURITY CONTROL: thermal sputtering model





Thermal Sputtering model (Abrams et al JNM 2001)

Total yield: 1/3 sputt+ evap+ termal sputtering (ts)

y_{ts} (T+C)=A exp(-Eb/(T+C)), for Li: C=623ºC, E_b= 18500, A=3.5 10^9

TABARES. 2nd Vapour Shielding CRP. Oct. 2020