Studies of Cs Dynamics in Large Ion Sources using the CsFlow3D Code

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RF negative ion sources

Accelerated current  |  40 A in D^-
\[ j_e/j_{ex} \]  |  < 1
Time  |  1 hour

Prototype source (59x30 cm²)
BATMAN test facility
IPP

Source for ITER NBI (190x90 cm²)

Size scaling: half ITER source size test facility ELISE (100x90 cm²)
IPP

SPIDER (Consorzio RFX)
ELISE test facility

Cs evaporation in ELISE:

- Two Cs ovens on the side of the expansion chamber
- Cs continuously evaporated during both vacuum and plasma phases

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Cs dynamics

- Only neutral Cs
- Ballistic transport \((p \approx 10^{-4} \text{ Pa})\)
- Dynamics determined by:
  - Oven outflow profile
  - Source geometry
  - Wall sticking probability (temperature and impurities)
Cs dynamics

VACUUM PHASE

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PLASMA PHASE

- Both Cs neutrals and ions
- Collisions \( (p \approx 0.3 \text{ Pa}) \):
  - Background gas
  - Plasma
- Cs redistribution by plasma
Cs dynamics

- **VACUUM PHASE**
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- **PLASMA PHASE**
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    - Plasma
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  - Cs Sputtering by back-streaming ions
Cs dynamics

- Only neutral Cs
- Ballistic transport ($p \approx 10^{-4}$ Pa)
- Dynamics determined by:
  - Oven outflow profile
  - Source geometry
  - Wall sticking probability (temperature and impurities)
- Stability of the work function
- Sufficient Cs flux onto the grid is needed during the pulse to counteract degradation of the work function
- Both Cs neutrals and ions
- Collisions ($p \approx 0.3$ Pa):
  - Background gas
  - Plasma
- Cs redistribution by plasma
- Cs Sputtering by back-streaming ions
CsFlow3D code

**INPUT**
- Oven nozzle outflow profile, position, direction
- Surface sticking probability
- Plasma parameters

**OUTPUT**
- Cs flux onto surfaces (both neutrals and ions)
- Energy of Cs particles
- Cs coverage
- Neutral Cs density

Monte Carlo Test Particle Transport code
CsFlow3D code

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- Oven nozzle outflow profile, position, direction
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- Neutral Cs density

Exp. measurements of line-averaged neutral Cs density (Laser Absorption Spectroscopy)

Monte Carlo Test Particle Transport code
Investigation of Caesium dynamics

• Results of the code already benchmarked at BATMAN\cite{1}

1. **Plasma drift** effect on neutral Cs distribution **in the larger source at ELISE**

2. **Effect of the PG bias potential on the Cs transport**, i.e. energy of Cs\(^+\)/Cs impinging the PG

3. **Extension to the full source**, simulation of conditioning and long pulses

\cite{1} A. Mimo, AIP Conf. Proc. 1869, 030019 (2017)
Effect of the plasma drift at ELISE

Plasma drift at ELISE:

- At $I_{PG} = 2$ kA, $\frac{n_{plasma, TOP}}{n_{plasma, BOTTOM}} \approx 2$

C. Wimmer (Mon04)
Effect of the plasma drift at ELISE

Plasma drift at ELISE:

- At $I_{PG} = 2$ kA, $\frac{n_{plasma, TOP}}{n_{plasma, BOTTOM}} \approx 2$

**SIMULATION**

- 20 consecutive pulses (conditioning):
  - 20 s plasma phase
  - 200 s vacuum phase
  - Cs evap. rate 10 mg/h (5 mg/h/oven)
Effect of the plasma drift at ELISE

Simulated neutral Cs density with and w/o the vertical plasma drift
Effect of the plasma drift at ELISE

Simulated neutral Cs density with and w/o the vertical plasma drift

Neutral Cs is symmetric both in simulation and experiment

SIMULATIONS

TDLAS top LOS

TDLAS bottom LOS

Neutral Cs density \([10^{14} \text{ m}^{-3}]\)

Pulse number

Simulations

with drift

w/o drift

Experiment
Effect of the plasma drift at ELISE

Simulated neutral Cs density with and w/o the vertical plasma drift

Neutral Cs is symmetric both in simulation and experiment
But this is not necessarily true for the Cs ions...

![Graph showing simulated and experimental neutral Cs density with and without drift.](image)
Effect of the PG bias voltage on Cs flux

- Simulation of a long pulse at ELISE with pulsed extraction: Cs flux consists mostly of ions (up to 70%)
Effect of the PG bias voltage on Cs flux

- Simulation of a long pulse at ELISE with pulsed extraction: Cs flux consists mostly of ions (up to 70%)

Calculation performed for: \[ \Delta \varphi = \varphi_{\text{plasma}} - \varphi_{\text{PG}} = 0 \, \text{V} \]
Effect of the PG bias voltage on Cs flux

- Simulation of a long pulse at ELISE with pulsed extraction: Cs flux consists mostly of ions (up to 70%)

Calculation performed for: \[ \Delta \varphi = \varphi_{\text{plasma}} - \varphi_{\text{PG}} > 0 \text{ V} \]
Effect of the PG bias voltage on Cs flux

- Simulation of a long pulse at ELISE with pulsed extraction: Cs flux consists mostly of ions (up to 70%)

Calculation performed for: \[ \Delta \phi = \phi_{\text{plasma}} - \phi_{\text{PG}} < 0 \text{ V} \]
Effect of the PG bias voltage on Cs flux

- **Energy distribution of Cs\(^+\) ions** onto a sample surface element of the PG during plasma phase

\[
\Delta \varphi = \varphi_{\text{plasma}} - \varphi_{\text{PG}} = 0 \text{ V}
\]

- Peak at 0.57 eV
- Peak at 0.06 eV
Effect of the PG bias voltage on Cs flux

- Energy distribution of Cs$^+$ ions onto a sample surface element of the PG during plasma phase

\[ \Delta \varphi = \varphi_{\text{plasma}} - \varphi_{\text{PG}} = 0 \text{ V} \]

- \( E = -\nabla \varphi \)
- \( T_{H^+} = 0.8 \text{ eV} \)
Effect of the PG bias voltage on Cs flux

- Energy distribution of Cs\(^+\) ions onto a sample surface element of the PG during beam extraction

\[
\Delta \varphi = \varphi_{\text{plasma}} - \varphi_{\text{PG}} = 0 \text{ V}
\]

- Peak at 0.06 eV
- Peak at 0.57 eV
- Peak at 4.4 eV during extr.
Influence of PG bias potential on Cs flux

- Cs ion flux onto the PG for different $\Delta \varphi = \varphi_{\text{plasma}} - \varphi_{\text{PG}}$

![Graph showing Cs flux over time for different potential differences](image)
Influence of PG bias potential on Cs flux

- Cs ion flux onto the PG for different $\Delta \varphi = \varphi_{\text{plasma}} - \varphi_{\text{PG}}$

![Graph showing Cs+ flux as a function of time with different potentials](image)

$\Delta \varphi$ values are shown along the x-axis, and the Cs+ flux is plotted on the y-axis. The graph illustrates the variation of Cs+ flux with time for different potentials.
Influence of PG bias potential on Cs flux

- Cs ion flux onto the PG for different \( \Delta \varphi = \varphi_{\text{plasma}} - \varphi_{\text{PG}} \)
Influence of PG bias potential on Cs flux

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Evaporation close to the PG

- **Evaporation** close to the plasma grid:
  - Limit Cs ionization due to low $T_e$ close to the PG (almost 70% of the flux is neutral)
  - **Direct control of PG caesiation**, not relying on plasma assisted redistribution
Towards the full size source: conditioning at SPIDER

- Simulation of SPIDER:
  - 20 pulses (20 s plasma + 200 s vacuum phase)
  - Different Cs oven configuration

- Total Cs evap. rate to reach ELISE flux: 20 mg/h
Towards the full size source: long pulses at SPIDER

- Long pulses at SPIDER compared with ELISE: 20th pulse after conditioning → Long pulse of 400 s
- Depletion of Cs flux during the long pulse also observed, but much stronger than in ELISE
- Effect of back-streaming ion sputtering not increase the flux, but not enough to compensate the depletion.
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Summary and conclusions

- Plasma drift does not induce asymmetry for the neutrals, but this is not necessarily true also for the ions

- Cs\(^+\) ions mostly affected by the PG bias voltage:
  - Cs\(^+\) ion flux onto PG can be locally different due to locally different values of $\Delta \varphi$
  - Cs\(^+\) released by back-streaming ions reach higher energy ($\approx 4.7$ eV)
  - Evaporation close to the grid beneficial for having mostly neutral Cs flux (control of the caesiumation independently from plasma parameters)

- Simulation of the full source at SPIDER:
  - Depletion of Cs flux during long pulses stronger than in ELISE, (not compensated by the Cs released by back-streaming ion sputtering)
  - Cs density measurements during continuous extraction will be very helpful
Flux of Cs$^+$ / total Cs flux

Distance $d$ from PG [mm]

standard configuration (relying on plasma redistribution)