Max-Planck-Institut für Plasmaphysik

# On the effect of biased surfaces in the vicinity of the large extraction area of the ELISE test facility

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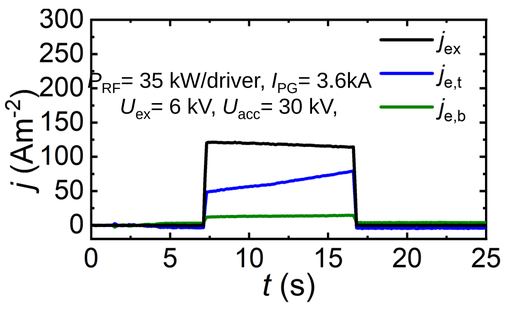
## Motivation of the study

- ITER NBI requirements in deuterium operation:
  - **286 Am$^{-2}$** extracted negative ion current density
  - Extracted **electron to negative ion ratio <1**
  - Pulse length: 400 s → Q = 10 baseline scenario
    3600 s → Q = 5 advanced scenario
  - **Beam uniformity better than 90%**
  - Filling pressure **0.3 Pa** or less

## Deuterium operation

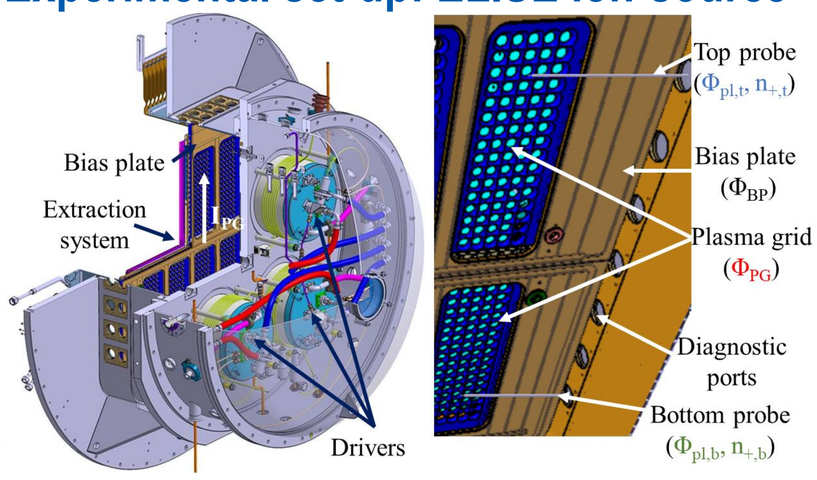
- **High co-extracted electron currents** → isotope effect
- **higher heat load** on the extraction grid → Asymmetry of $j_e$ due to **E x B** drifts
- Co-extracted **electrons increase during the pulse** and **negative ions decrease**
- **Low** extracted **negative ion current** → reduced $P_{RF}$, $U_{ex}$, $U_{acc}$ and increased $I_{PG}$




## Aim of the study

- **Investigation on the effect of the bias of the bias plate on the extracted currents in deuterium operation.**

## Experimental set-up: ELISE ion-source




- **4 RF drivers:** $P_{RF}$ up to 75 kW/driver
- **Expansion chamber:** 2 ovens for ceasium evaporation
- **Extraction system** – **640 apertures in 8 beamlet groups**:
  - **Plasma Grid (PG)** – in a contact with the plasma – **positively biased** ($I_{bias}$) respect to the source walls
  - **Extraction Grid (EG)** – collects the co-extracted electrons – ***U*$_{ex}$ up to 10 kV**
  - **Grounded Grid (GG)** – for acceleration of the beam – **up to 60 kV**
- **Bias Plate (BP) – window-frame surface**, 7 mm away from PG
- $I_{PG}$ – for generation of magnetic filter field ~ $B_{MF}$
- **Diagnostics:** BP and EG vertically divided into two parts allowing to measure the currents on the top and bottom segments, together with top and bottom Langmuir probes
  - Electrical measurements → H$^-$ current density (***j*$_{ex}$**), co-extracted e$^-$ current density on top (***j*$_{e,t}$**) and bottom (***j*$_{e,b}$**), BP current on top (***I*$_{BP,t}$**) and bottom (***I*$_{BP,b}$**)
  - RF compensated **probes**, at **20 mm away from the PG → $\Phi_{pl,t}$, $\Phi_{pl,b}$, $n_{+,t}$,** and **$n_{+,b}$**

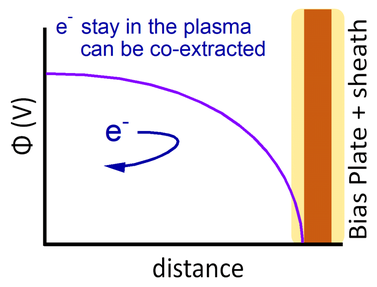
## Results and discussions:

**Deuterium** $P_{RF}$= 35 kW/driver, $I_{PG}$= 3.6kA, $B_{MF}$ = 3.8 mT, $U_{ex}$= 6 kV, $U_{acc}$= 30 kV, **short pulses** (20 s plasma time, including 9.5 s beam extraction phase)

### (1) Bias plate on source wall potential

**$I_{bias}$ = 20 A:**

➢ $\Phi_{BP} < \Phi_{pl,t}$ and $\Phi_{pl,b}$
✓ Electron repelling sheath on the BP



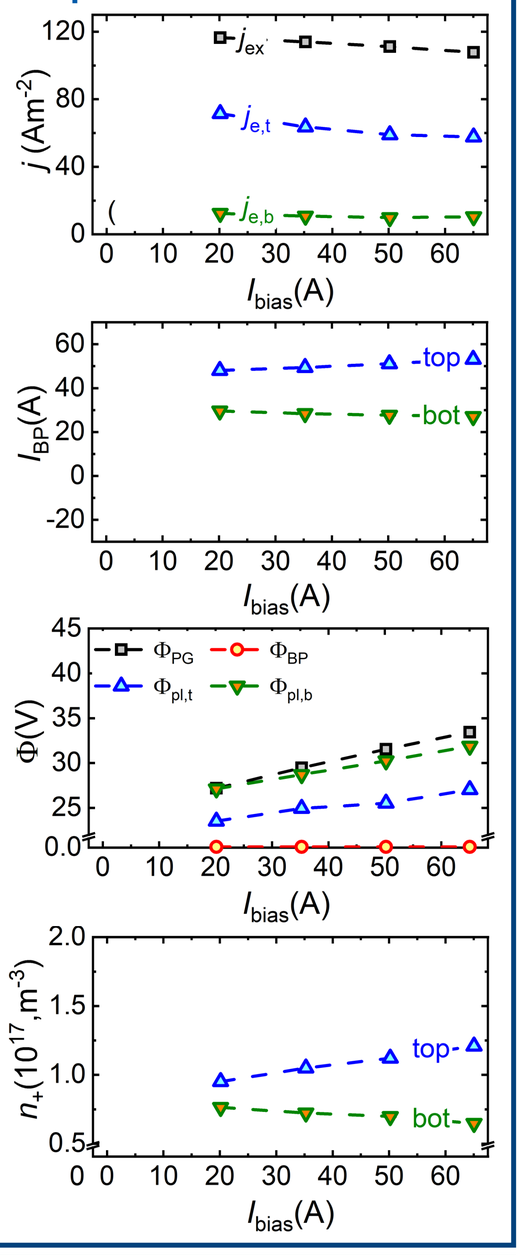

✓ electrons are reflected by the BP
✓ sheath in the plasma and can be extracted
✓ $n_+$ → main contribution in $I_{BP}$

➢ $j_e / j_{ex} \approx 0.75$

➢ Plasma asymmetry: $j_{e,t} \approx 6 \times j_{e,b}$
- $\Phi_{PG} \approx \Phi_{pl,b}$
- $\Phi_{PG} > \Phi_{pl,t}$ → electron attracting sheath
- higher positive ion density on top

**Increase of $I_{bias}$:**

➢ ***j*$_{ex}$ and *j*$_e$ decrease**
➢ **$\Phi_{pl}$ increases**
➢ plasma density **asymmetry increases** $n_{+,t}$ increase and $n_{+,b}$ decrease
✓ **E** x **B**-drift increase due to **$\Phi_{PG}$**

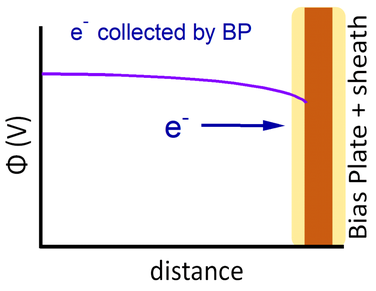



### (2) Floating bias plate

**$I_{bias}$ = 20 A:**

➢ shift of **$\Phi_{PG}$** and **$\Phi_{pl}$**, to **higher values**
✓ $I_{BP} = I_{BP,t} + I_{BP,b} \approx 0$ A; BP top and bottom parts are electrically connected
✓ plasma asymmetry:

- **$\Phi_{BP} \approx \Phi_{pl,t}$**
  - $I_{BP,t}$ – negative → more e$^-$ are collected than $n_+$ by BP

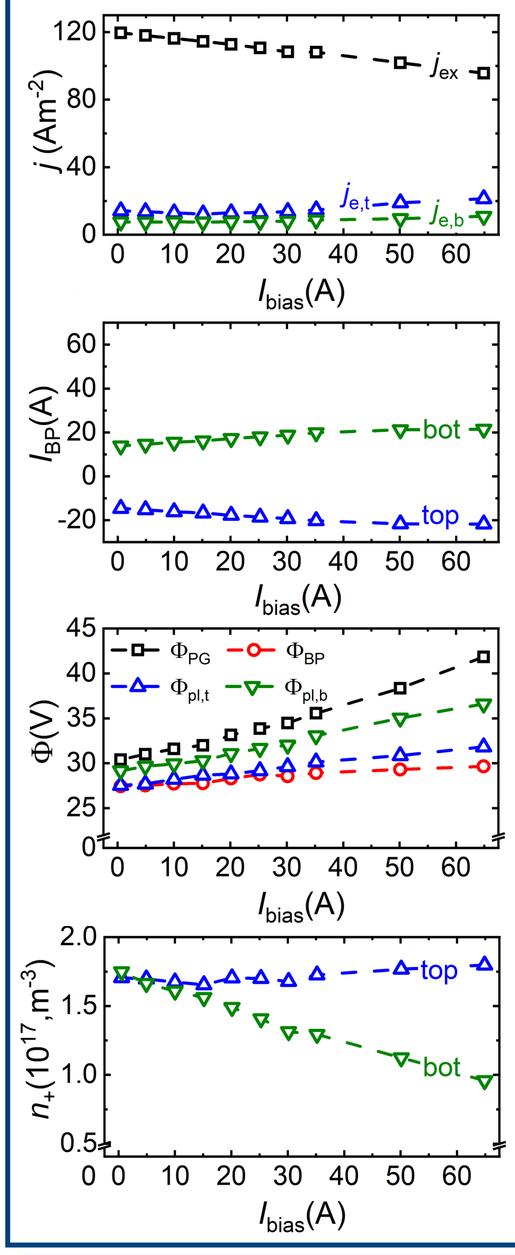



- **$\Phi_{BP} < \Phi_{pl,b}$**
  - $I_{BP,b}$ – positive → less e$^-$ are collected than $n_+$

➢ 4 times **lower *j*$_e$** compared to case (1)
➢ ***j*$_{e,t}$ ≈ *j*$_{e,b}$** → are symmetric
➢ few A/m$^2$ less $j_{ex}$
➢ $j_e / j_{ex} \approx 0.18$
➢ **higher *n*$_+$** compared to case (1) :
- decrease of e$^-$ leads to a lower recombination rate

**Increase of $I_{bias}$:**

➢ ***j*$_{e,t}$ slightly increases, *j*$_{e,b}$ stays the same**
➢ ***j*$_{ex}$ decrease**
➢ **$\Phi_{pl}$ increases**
➢ plasma density **asymmetry increases:** $n_{+,t}$ increases and $n_{+,b}$ decreases



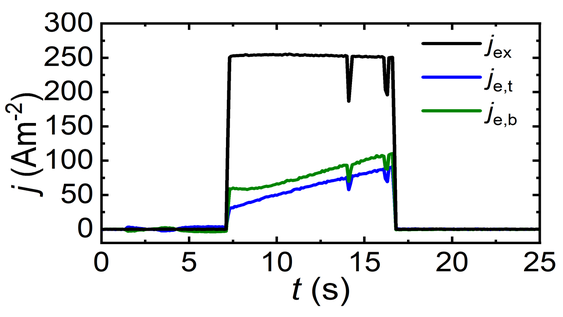

### (3) Time traces: floating BP

$P_{RF}$= 75 kV/driver, $I_{PG}$= 2.2kA, $B_{MF}$ = 2.5 mT,
$I_{bias}$ = 1 A, $\Phi_{BP}$ = floating $U_{ex}$= 10.5 kV, $U_{acc}$= 40 kV

➢ $j_e / j_{ex} \approx 0.674$
- $j_{ex}$ = 256 Am$^{-2}$
- $j_{e,b}$ = 97 Am$^{-2}$ and $j_{e,t}$ = 76 Am$^{-2}$ almost symmetric

➢ $j_{ex}$ constant during the pulse
➢ $j_e$ increases during the pulse

➢ ~ 90% of ITER requirements for extracted negative ion current density in deuterium is reached for short-pulses




### (4) Conclusion

The **floating potential** of the BP **requires zero total net currents**. **Asymmetry of the plasma parameters** in the vicinity of the extraction area provide **different behavior of the BP sheath** on top and bottom. **An electron repelling sheath** remains **on the bottom** part of the BP, resulting in **no changes of *j*$_{e,b}$**. **On the top** segment of BP is observed **higher electron flux**, resulting in **negative *I*$_{BP,t}$**, **5 times lower *j*$_{e,t}$ and *j*$_{e,t}$ ≈ *j*$_{e,b}$**, while $j_{ex}$ slightly decreases. Therefore, this method gives an outlook for a **simple technique for reducing and symmetrizing the co-extracted electrons** during the deuterium operation of the ITER NBI systems.

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19th International Conference on Ion Sources (ICIS 2021)

*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 number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.*

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