Cavity Ring-Down Spectroscopy system for the evaluation of negative hydrogen ion density at the ELISE test facility

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Outline

• Cavity Ring-Down Spectroscopy (CRDS) set up at ELISE for negative ion density

• Reliability of the system

• Results of the experimental campaign:
  • Dependance on the discharge parameters
  • Isotope effect
  • Long pulse behaviour

• Summary and outlook
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CRDS set up at ELISE

- CRDS commissioned at ELISE (end of 2018) with two horizontal lines of sight
- \textbf{H}^-/\textbf{D}^- ion density measured \textbf{by} decay time of the LASER light intensity inside a mirror cavity due to negative ion photo-detachment

![Graph showing reflectivity > 99.995%]

Reflectivity > 99.995 %

Nd:YAG LASER @1064 nm, 100mJ
10 Hz, pulse width < 10 ns.
CRDS set up at ELISE

- CRDS line of sight 20 mm far from PG

- Negative ions detected are:
  - Volume produced (dissociative attachment of H\(_2\))
  - Surface produced (conversion of H, H\(_x^+\))
CRDS set up at ELISE

- CRDS line of sight 20 mm far from PG

- Negative ions detected are:
  - Volume produced (dissociative attachment of H$_2$)
  - Surface produced (conversion of H, H$_x^+$) (major contribution)

- When extraction is turned on:
  - Part of surface produced H$^-$ directly extracted (never reaching the LOS)
  - Some volume produced H$^-$ are also extracted
CRDS set up at ELISE

• Line averaged negative ion density retrieved by measuring the characteristic cavity decay time \( \tau_0 \) and the decay time during plasma \( \tau(t) \):

\[
n_{i^-}(t) = \frac{1}{\sigma_{i^-}} \cdot \frac{d}{cL} \left( \frac{1}{\tau(t)} - \frac{1}{\tau_0} \right)
\]

\[
\tau_0 = \frac{d}{c(1 - R + X)}
\]

• Challenges:
  • Large source, \( \approx 1 \) m plasma length
  • Mirrors need to maintain high performance at high RF power, long pulses (several hundreds seconds)
Reliability of the system

- Temperature of the source walls and of the laser do not affect the cavity alignment (stable $\tau_0$)
- After a plasma pulse, characteristic decay time $\tau_0$ reduced but < 3% for wide range of discharge parameters (pressure, RF power, pulse length)
- Fast recovering of $\tau_0$ after the plasma pulse
Results

• Typical $\tau_0 = 30 \mu s$ top, $50 \mu s$ bottom:
  • Detection limit $> 3 \cdot 10^{15} \text{ m}^{-3}$
  • Error on density $< 10\%$

• Time traces of $n_i$ recorded at 10 Hz frequency

• $n_i$ sensitive to change of discharge parameters (beginning of the pulse)

• During HV extraction: $n_i$ reduced w.r.t. RF

• Similar values for top and bottom
Results – effect of discharge parameters

- Increase of a factor 3 of negative ion density beginning Cs evaporation
- Linear increase with RF power
Results – effect of discharge parameters

• Increase of a factor 3 of negative ion density after beginning Cs evaporation

• Linear increase with RF power

• No significant differences between top and bottom $n_i$ for wide range of parameters.
Results – effect of discharge parameters

- **Extraction voltage** $U_{\text{ex}}$ influence the “jump” $n_i$ (RF) – $n_i$ (HV):
  - Different transport of the ions from the PG towards the source volume?
  - Different charge balance to keep quasi-neutrality?

![Graph showing the effect of extraction voltage on $n_i$ (RF) - $n_i$ (HV)]

- $P_{RF} = 50$ kW/driver
- $U_{acc}/U_{ex} = 5$
- $I_{PG} = 1.6$ kA

- Extraction voltage $U_{ex}$ [kV]

- $n_i$ (RF) - $n_i$ (HV) [$10^{16}$ m$^{-3}$]

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- $n_i$ (RF) - $n_i$ (HV) [$10^{16}$ m$^{-3}$]
Results – correlation with accelerated current

- Same increase of accelerated current measured by IR calorimetry and negative ion density, but different asymmetry:
  - CRDS measures along a line of sight at the center of beamlet group, while IR is a global measurement.
Results – isotope effect

• Switching from hydrogen to deuterium:
  • $n_{i-}$ much more unstable (decreasing) during HV (faster Cs deconditioning of the source?)
  • Slightly higher $n_{i-}$ at the beginning for deuterium
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$$p_{\text{fill}} = 0.3 \text{ Pa}, P_{\text{RF}} = 50 \text{ kW/driver}, B_{\text{filter}} = 3.2 \text{ mT}$$

![Graph showing negative ion density over time for hydrogen and deuterium](image-url)
Results – isotope effect

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Results – isotope effect

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- Jump during the extraction phases: evolution inside a beam blip and immediately after
Results – isotope effect

- Same range of negative ion density achieved for both isotopes (from $4 \cdot 10^{16}$ to $10^{17}$ m$^{-3}$) at 0.3 Pa
- Correlation between extracted current and negative ion density:
  - To achieve high current, $n_{i-} \approx 10^{17}$ m$^{-3}$ needed to achieve high current
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• Moving CRDS LOS from 20 mm down to 3.5 mm distance from the PG:
  • Stronger correlation between negative ion density behaviour and the extracted ion current
  • LOS much closer to the extended boundary layer
  • LOS fully inside the simulation domain of the 3D PIC code ONIX (cooperation with the Paris Sud University, Orsay, France)
Summary

• CRDS system reliably and routinely in operation at ELISE since end 2018:
  • Successful measurement of negative ion density along 1 m plasma
  • Long pulse operation (thousands seconds), reliable and good performance of the cavity mirrors

• Negative ion density between $4 \cdot 10^{16}$ and $10^{17}$ m$^{-3}$ measured 20 mm far from PG
  ($\approx$ vertically symmetric) and stable during long pulses

• Negative ion density strongly affected by beam extraction

• Isotope effect: higher density needed in D$_2$ to reach same extracted current as in H$_2$ ?

• Next campaign: LOS closer to the grid (at 3.5 mm from PG)