ID: IAEA-FET-1245

NOVEL SURFACE ASSISTED VOLUME NEGATIVE ION SOURCE – CONCEPT TO REALITY

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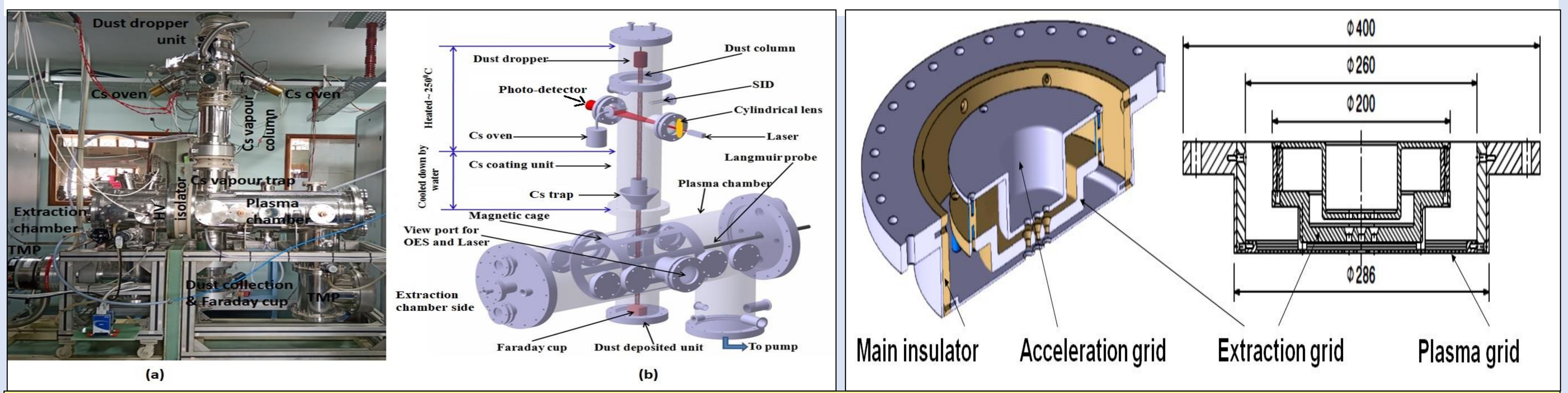
ABSTRACT

- A caesium (Cs) vapour seeded negative hydrogen ion source-based neutral beam injector (NNBI) is an indispensable auxiliary heating & current drive system for ITER-like fusion reactor machines.
- The injection of Cs vapour into the plasma of an ion source is associated with multiple technical issues, related to ion source maintenance and HV breakdown in the ion accelerator system due to high Cs inventory – known as "*Cs pollution*".
- In this poster, a novel ***surface-assisted volume negative ion source*** is described which has address many Cs related technical issues. ***Cs coated dust*** is used in a proof-of-principle experiment as the low work function surface to create negative ions.
- The setup establishes a possibility to overcome *Cs pollution* in the ion source chamber. The negative ion production yield is scalable in terms of surface-to-volume ratio without modifying the source geometry by altering the sprinkled dust density.

EXPERIMENTAL SETUP

- The experimental plan has **two phases**. In the ***first phase***, system performance is evaluated and plasma characterization is carried out in presence of Cs coated dust. In the ***second phase***, a negative hydrogen ion beam will be extracted from the Cs coated.
- Plasma is created by **filament discharge** using two thoriated W filaments having a diameter 0.25 mm, and a total length of 150 mm are used. Each filament is carrying ~6A as the maximum filament heating current with 80V discharge voltage.
- **Plasma chamber** length is ~100cm and the diameter is 30cm having Magnetic cage for plasma confinement.
- **Cs coating unit (CCU)** comprises of a W dust-dropper, with W dust of averaged size ~ 3μ, Cs oven for Cs vapour injection, an SID unit and a Cs vapour trap. Heating and cooling arrangements are on the CCU wall from outside. Cs vapour density and dust density in CCU are monitored by a simple surface ionization detector (SID) and laser scattering unit.
- **Extractor system** consists of ***three grids*** in a nested bucket configuration having three aperture provisions for three beamlets in a vertical orientation plane. Extraction grid is having embedded magnets to filter out co-extracted electrons. The design ensures maximum insulation level between the chamber and the extraction grid and it is ~ 25 kV DC and between the extraction grid and the acceleration grid, it is ~ 50 kV DC.
- **Diagnostic system** consists of a Hiden Analytical Limited make ESPION advanced cylindrical *Langmuir probe*, a Ion Acoustic Wave (IAW) launcher, a *faraday cup fitted with an electrometer* to measure the dust current, a 0.5 m spectrometer fitted with a photomultiplier tube. During beam extraction (2nd phase) another Faraday cup – calorimeter arrangement is placed on the beam axis.
- **Two high voltage power supplies** (15 kV, 2A DC each) for beam extraction.
- PXI based data acquisition & control system with fibre optic (FO) link modules is having ~150 channels for remote operation using Graphical User Interface (GUI) in LabVIEW 2016 platform.



Experimental setup: Photograph, Schematic & design of extractor system

CHALLENGES / METHODS / IMPLEMENTATION

Nascent Cs layer on the Dust surface without being contaminated

- CCU design has ensured that all the dusts are properly coated with Cs while falling through the Cs vapour column inside the CCU.
- Considering Cs atomic size, **~10^{15} /cm^2 atoms are needed to form a monolayer of Cs** and the time to form a Cs monolayer on a micron-sized dust surface in the CCU environment having **Cs vapour density ~10^{16}m^{-3}** is **~ 100μs**.
- The time of flight of the dust particle within CCU is **~ 375ms** while falling freely and enters the plasma chamber. In the plasma the dust grain stays for another **240ms for surface H- ion production.**

No Cs pollution inside Plasma Chamber

- A specially designed **Cs trap**, in the form of an inverted funnel is used inside the CCU at the bottom of the tower, just at the entrance towards the plasma chamber so **that Cs vapour are condensed on its surface & cannot diffuse into the plasma chamber**.
- Lower part of CCU tower is water cooled 12^{o}C whereas upper part is hot at 200^{o}C.

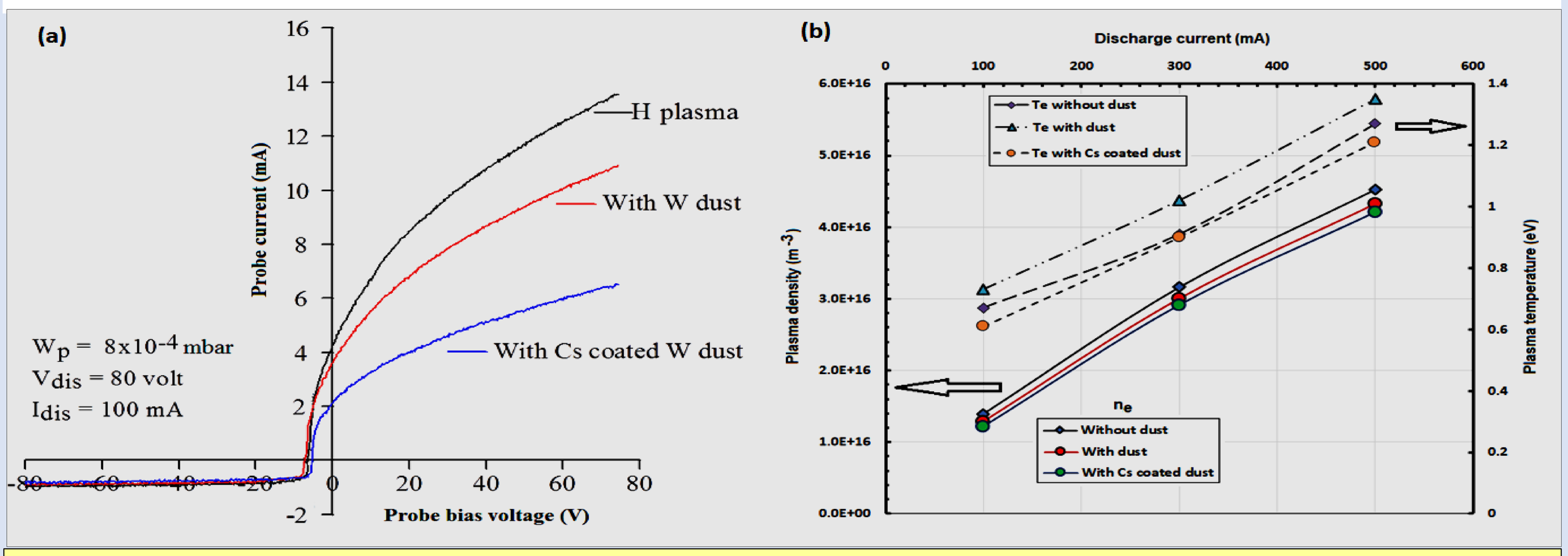
Efficient negative ion extraction

- **The plasma grid** is kept **~ 2 cm** (***survival length of the H- ions)*** **from the Dust column.**

RESULTS AND DISCUSSION

Langmuir probe based study

- The negative ion fraction (α) is estimated from the reduction of the electron saturation current using the relationship, $\alpha = (n_-/n_+) = \left[1 - \left(i_{e\_Cs\_W}/i_{e\_W}\right)\right]$. Where $i_{e\_Cs\_W}$ and i_{e_W} are the electron saturation current values for plasmas with Cs coated W dust and uncoated W dust respectively. [1]



a) Langmuir probe I-V traces for three different plasma conditions, (b)plasma parameters in those three different plasma conditions

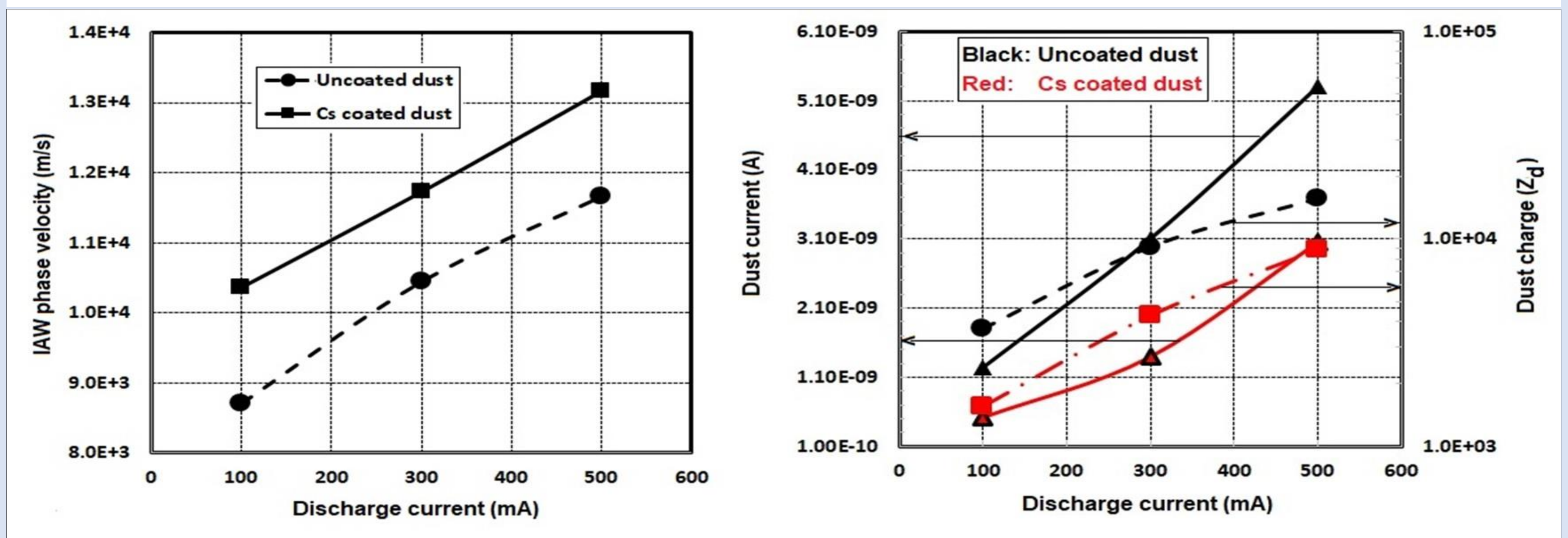
Ion acoustic wave (IAW) phase velocity based study

- A modified dispersion relation of IAW is used, which is valid for plasma having ***only one positive ion species, one negative ion (H- ion in this case), and the dust grain***.

$\left(\frac{\omega}{k}\right)^2 = C_s^2\left\{\frac{1}{(1-\alpha-\delta Z_d)}\right\}\left[1+\frac{\alpha}{M}\right]$. Here, ion-acoustic speed $C_s = (k_B T_e/m_+)^{0.5}$, normalized dust density $\delta = (n_d/n_+) \approx 10^{-5}$, normalized negative ion mass $M = m_-/m_+ = 1$ considering hydrogen case, Z_d is the number of charges (number of electrons) accumulated on a dust grain surface which is ~ 10^4. [2]

Dust current based study

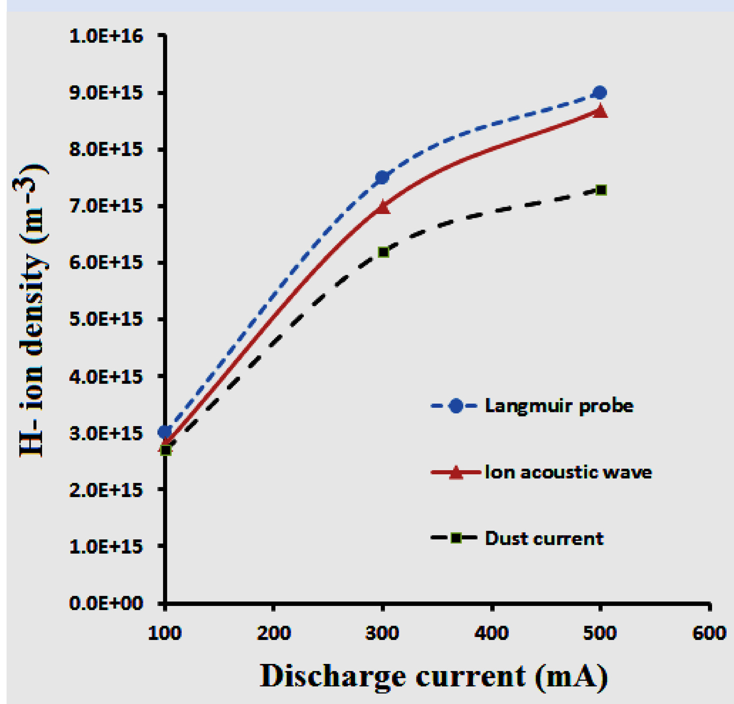
- As soon as a dust grain enters into the plasma, it is immediately charged by the plasma electrons. Dust charge Z_d and correspondingly dust current, measured by a specially designed Faraday cup (FC) directly proportional to the electron density.
- The reduction in Z_d in presence of Cs coated W dust implies reduction of electron density and the presence of H- ions in the plasma. H- ions replace some of the electrons in the plasma and consequently reduce dust charging.
- Capacitive model is used to estimate H- ion fraction.[3]



.(a) IAW phase velocities, and (b) Dust current and dust grain charge values for uncoated and Cs coated W dust

SUMMARY & CONCLUSION

- The novel surface assisted volume negative ion source has addressed many issues of a Cs seeded ion source.
- No Cs pollution in the plasma and it is confirmed by spectroscopy.
- Scalable surface production yield of H- ions by altering the surface to volume ratio by changing the dust density.
- H– ions are emitted from the dust grain surface isotopically & it is not necessary to reverse its trajectory direction for the extraction purpose, like a conventional negative ion source. So, the extraction efficiency would be better & will be tested during the extraction phase (2nd phase) of the experiment.



Measured H- ion density by three different methods

ACKNOWLEDGEMENTS & REFERENCES

- All the authors remember and acknowledge the encouragement and contribution of **Late Prof. P. K. Kaw** throughout the journey from concept to reality of this project.

[1] *Shindo, M., et.al, Measurements of the negative ion density in SF6 /Ar plasma using a plane electrostatic Probe. Rev. Sci. Instrum. 72(5), 2288 (2001); Amemiy, H., Plasmas with negative ions-probe measurements and charge equilibrium. J. Phys. D: Appl. Phys. 23, 999 (1990).*

[2] *Nakamura, Y., et.al., Observation of Ion-Acoustic Shocks in a Dusty Plasma. Phys. Rev. Lett. 83(8), 1602 (1999); Hershkowitz, N.,et.al., Probing plasmas with ion acoustic waves. Plasma Sources Sci. Technol. 18, 014018 (2009)*

[3] *Goree J, Charging of particles in a plasma., Plasma Sources Sci. Technol. 3 400, (1994).*