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Development of megawatt RF ion source for the neutral beam injector on HL-2A tokamak

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ABSTRACT

- A RF positive ion source with extraction parameters of 32kV/20A/0.1s was developed for HL-2A tokamak. A full solid-state RF generator with P_{RF}=80kW, f=2MHz was built by using 8 modules of RF generator with power of P_{RF} = 10 kW
- The line electric efficiency of whole RF generator is 92% and its voltage standing wave ratio is 1.01, thus no water-cooling system is supplied
- Plasma extractive parameters are j=2.4 kA·m^{-2}, n_e=1×10^{18} m^{-3}, H^+/H=79%
- An innovative radiofrequency (RF) plasma source with high-pressure density gradient produced by two sets of RF systems solves initial ignition problem of powerful RF ion source
- The RF negative ion source of 200kV/20A/3600s is developed at SWIP for CFETR

BACKGROUND

- Designed on ITER RF source: 57A(0.2m^2, D$^-$)/1MV/3600s/0.3Pa, I^e/I^{D-}<1
- Developed at QST: 0.23A(12 cm^2, H$^-$)/0.97MV/60s/Arc source
- Developed at ELISE: 18 A(D$^-$)/9kV/10s/1MHz/0.3Pa, duty 6.25% in 2700s
- Achieved on JT-60U: 31.5A(D$^-$)/0.4MV/0.9s/5.8MW/Arc source
- Achieved on LHD: 55.4A(D$^-$)/0.18MV/1.6 s/7MW/Arc source
- Achieved on ASDEX-U: 80A (D$^+$)/60kV/10s/10MW/1MHz
- Designed on HL-2A: 20A(D$^+$)/50kV/3s/1MW/2MHz
- Great challenge for RF negative ion source for ITER

RF POSITIVE ION SOURCE DEVELOPED FOR HL-2A TOKAMAK

Schematic of full solid-state RF ion source and an extraction aperture

Fig.1. The ion source consists of a driver where RF power is coupled to plasma, and an accelerator where the ions are accelerated to required energy Fig.2. There are 313 apertures with a diameter of 6.9 mm on the plasma grid with a diameter of 174 mm, accelerator voltage is V_{PG}=50 kV, V_{SG}= -5 kV

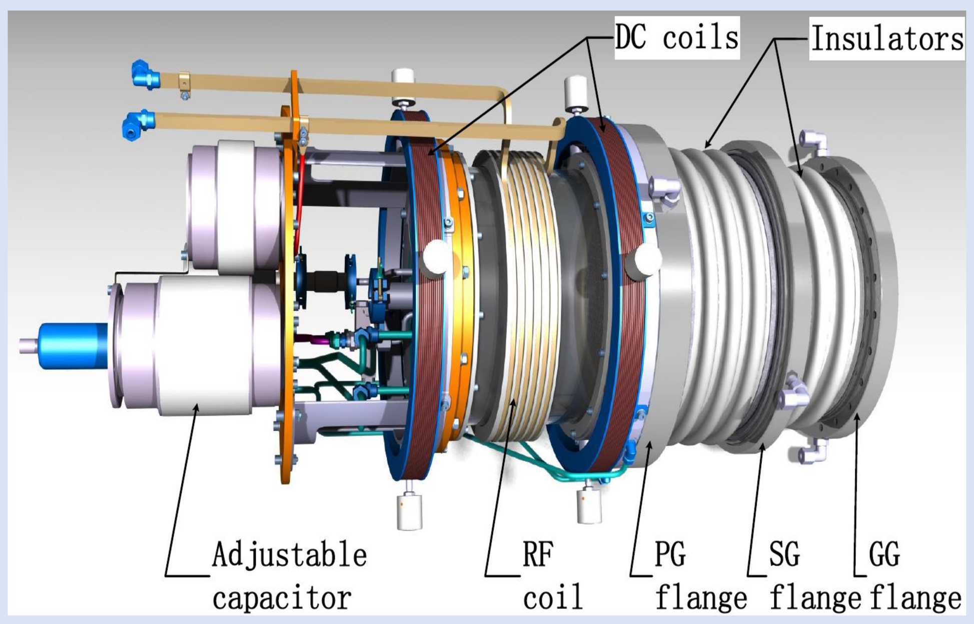

Fig. 1. The schematic diagram of the full solid-state RF ion source

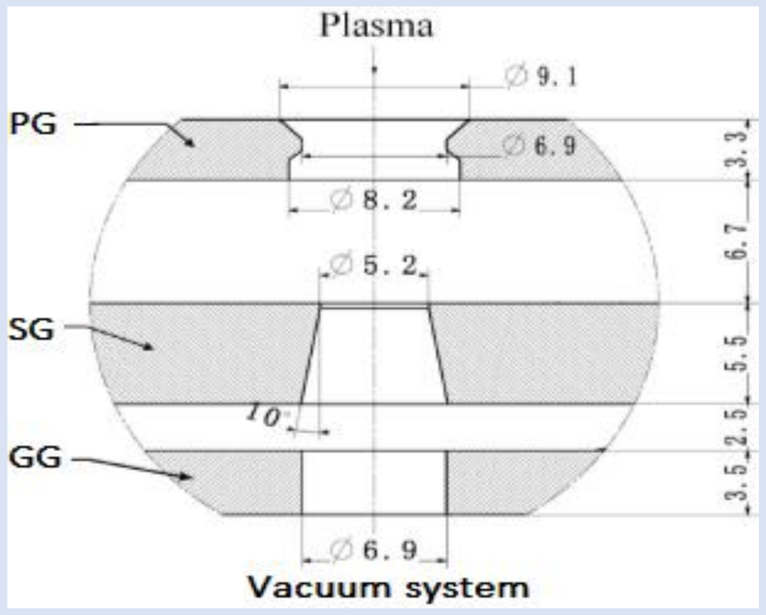

Fig. 2. The sizes of an extraction aperture

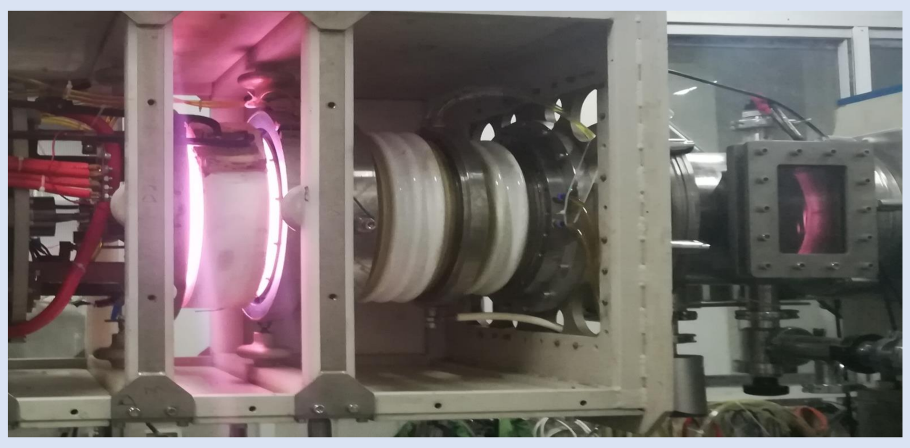

Fig. 3. An RF discharge photo

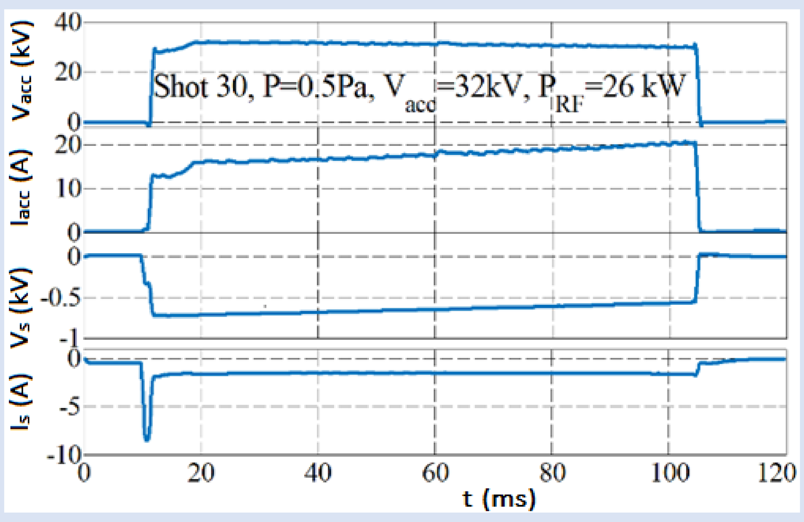

Fig. 4. V_{acc}, I_{acc}, V_s, I_s, via time

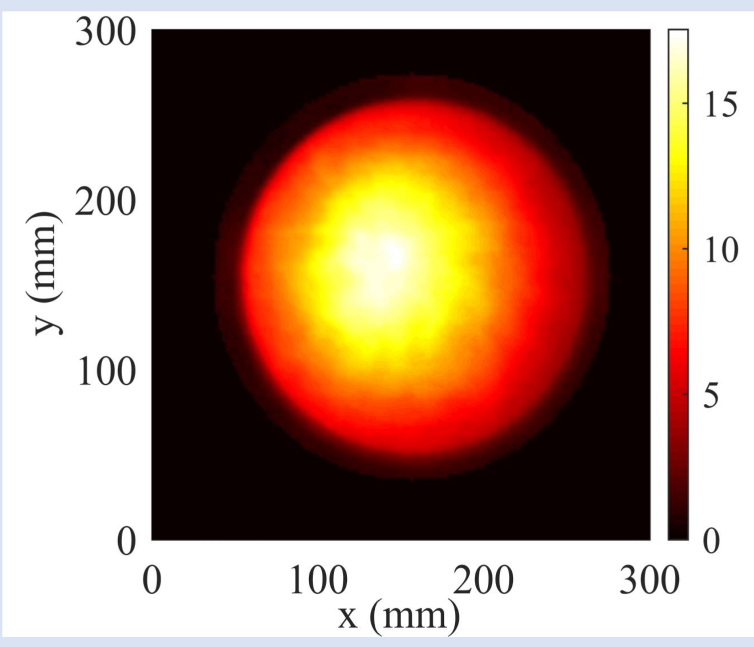

Fig. 5. 2D temperature profile of extracted beam observed by IR camera at target of 1.3 m to PG

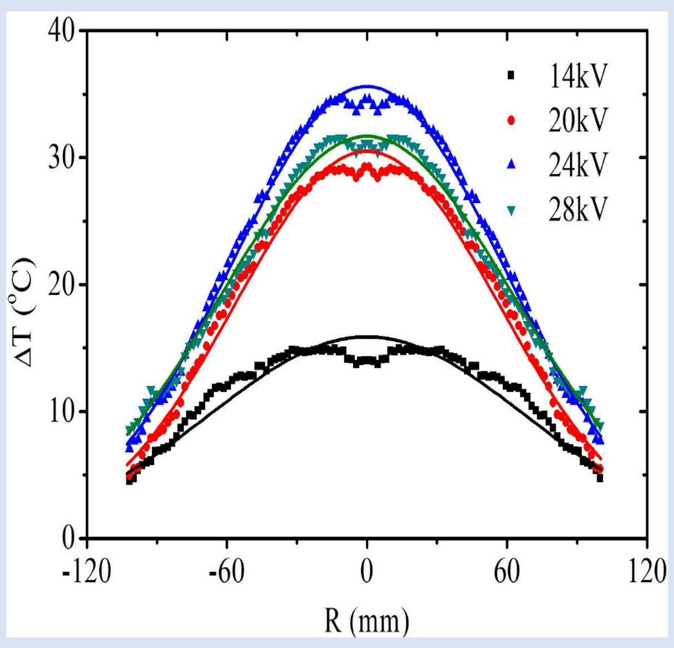

Fig. 6. Radial profile via voltage The minimum width of 1/e decay is 80 mm

OUTCOME

RF positive ion source discharges and main extractive parameters

Fig. 3: Antenna of 6 turns, wounded on outer wall of quartz vessel, is connected to a matching network isolated by 80 kV, RF discharge of no cooling: 20kW/1800s/0.5Pa

Fig. 4: Extraction parameters: 20 A/32 kV/26 kW/100 ms/0.5 Pa, j=2.4 kA·m^{-2}

Fig. 5: 10kW/18kV/0.1s, beam divergence angle of 1.4^0, n_e=1×10^{18} m^{-3}, H^+/H=79%

Fig. 6: Beam widths are 97, 80, 82 and 88 mm at voltages of 14, 20, 24 and 28 kV, corresponding ion currents of 5.6, 6.0, 6.1 and 6.3 A, perveance of 1.7×10^{-6} A·V$^{-3/2}$

Dual-driven RF plasma source and negative ion extraction

- Two sets of RF system (3.5kW/13.56MHz/ϕ45, 40kW/2MHz/ϕ250) solves the initial RF ignition problem below 0.1 Pa, as shown in Fig.7
- RF operation with cooling: 40kW/2MHz/3600s/ ϕ250; 10kW/2MHz/28 hours/ ϕ100
- RF negative hydrogen ion source of 200kV/20A/3600s is developed at SWIP for the CFETR, 4 drivers/ ϕ280mm/2MHz/80kW
- Negative ions are extracted 1.2A with arc power of 45 kW after seeding cesium for 5 hours, and plasma potential is decreased to 2 V from 4 V in Fig.8, The density ratio of co-extracted electrons with ions is n_{e2}/n_{i2-} = 0.22, as shown in Fig. 9

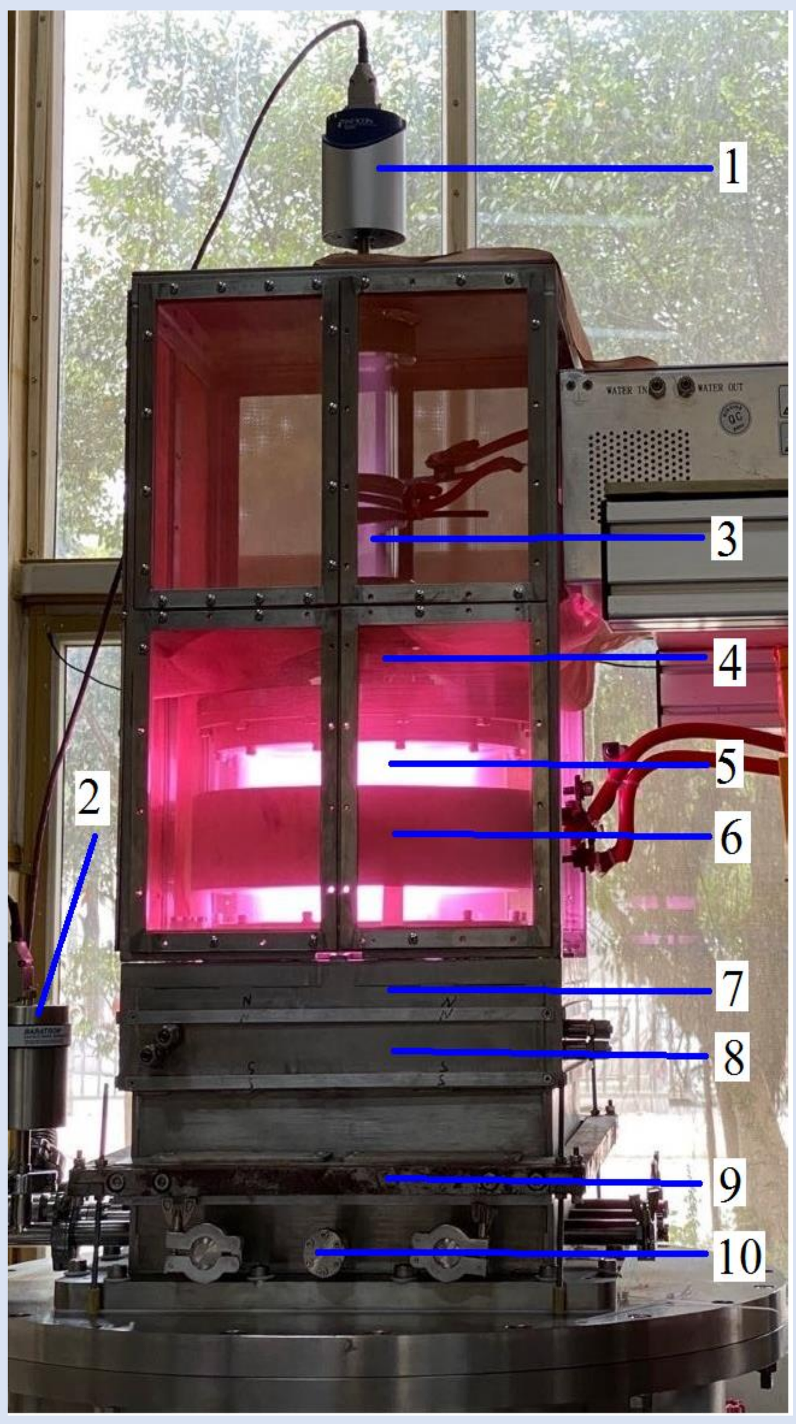

Fig.7 Dual-driven RF plasma source 1, 2-Capacitance gauge; 3-auxiliary discharge chamber; 4-guidance; 5-main discharge chamber; 6-RF coils; 7-plasma expansion chamber; 8-cusp field; 9-magnetic filter, 10-port

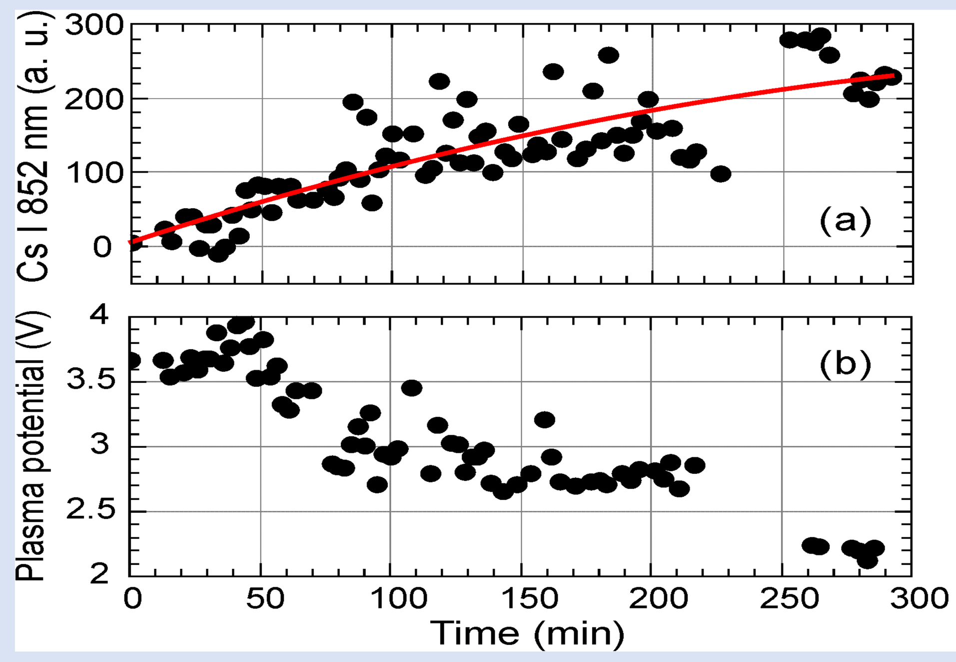

Fig.8. Temporal evolution of relative cesium concentration for Cs I 852 nm (a) and plasma potential (b)

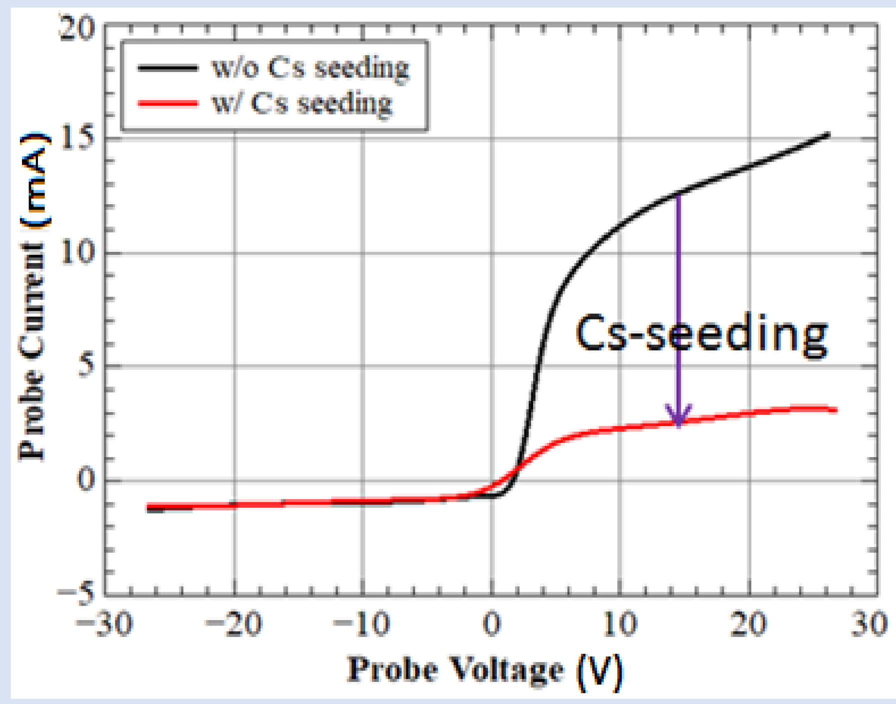

Fig.9. Comparison of probe current with or without cesium seeding injection

CONCLUSION

- 1 MW positive ion source with parameters of 80kW/2MHz/3600s has been developed for HL-2A tokamak, beam parameters are 32kV/20A/0.1s at a test bed.
- RF operation: 40kW/2MHz/3600s/ ϕ250; 10kW/2MHz/28 hours/ ϕ100
- Beam divergence angle is 1.4^0, minimum beam width is 80 mm, and optimized perveance is 1.7×10^{-6} A·V$^{-3/2}$
- The density ratio of co-extracted electrons with ions is n_e/n_{i-} = 0.22
- Single RF driver with 80kW/2MHz/ϕ280 is being tested at SWIP using for CFETR ion source required parameters of 20A/200kV/3600s

ACKNOWLEDGEMENTS / REFERENCES

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