MASS-SEPARATION OF IMPURITIES IN THE ION BEAM SYSTEMS WITH REVERSED MAGNETIC BEAM FOCUSING

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This paper describes the intrinsic capability of ion systems with reversed magnetic beam focusing for impurities mass-separation. Numerical calculation of the ion trajectory deviation with taking into account the experimental ion energy distribution function for hydrogen-oxygen gas mixture was carried out. It is demonstrated that O\(^+\) impurities which are present in the beam are separated and form the circle with a diameter of \(\approx 6\) mm. Therefore, the central part of the spot is free of impurities due to magnetic separation. As a result, the source generates steady-state hydrogen ion beam, which irradiates the surface with high heat and particle fluxes, which approach the upper limit for the flux range expected in a fusion reactor.

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INTRODUCTION

At present, there are two ways for experimental simulation of plasma-surface interaction in a laboratory. Ion beam devices \([1]\) with a magnetic mass-separation provide high-energy ion beam, however, their particle flux is limited by value of \(10^{19}\ldots10^{20} \text{ m}^{-2}\cdot\text{s}^{-1}\). HiFIT ion beam device is capable to provide higher particle flux up to \(3.6\times10^{21} \text{ m}^{-2}\cdot\text{s}^{-1}\) and heat flux up to 0.65 MW\(\text{m}^{-2}\), while mass-separation is excluded. In contrast, plasma devices can generate low energy particle fluxes \(\approx 10^{22} \text{ m}^{-2}\cdot\text{s}^{-1}\) and heat fluxes in the range of 0.1...1 MW\(\text{m}^{-2}\). Therefore, the parameter range of particle fluxes \(>10^{22} \text{ m}^{-2}\cdot\text{s}^{-1}\) and heat fluxes \(>1\) MW\(\text{m}^{-2}\) is currently not achievable for most existing plasma and ion sources used in material research. In the high heat and particle flux range new phenomena related to ion-surface interactions can be found. These phenomena can be extremely important for justifying the material selection.

To fill up the gap between the parameters provided by laboratory tools and ITER relevant conditions, our team from KKhNU has recently developed the FALCON ion source \([2-4]\). It is based on the design of closed drift thrusters (also known as Hall thrusters), which are typically used as space propulsions. Intrinsic characteristics of this type of ion sources are their simplicity (that makes them affordable) and extremely high ion currents, both are tempting for use in material research.

Small percentage of impurities in the beam can distort the results of the plasma-surface interactions experiments. That is why the beam purity is of a great importance for fusion-relevant material research experiments.

The aim of this paper is the numerical study of the capability for impurities mass-separation \([5]\) of systems with reversed magnetic beam focusing.

EXPERIMENTAL TECHNIQUE AND CALCULATED IMPURITIES MASS-SEPARATION POSSIBILITY

The principal design of the FALCON ion source is presented in Fig. 1. It is based on design of Hall thrusters.

**Fig. 1.** The high-flux FALCON ion source principal design: 1 – anode; 2 – ballistic focusing cathodes; 3 – magnetic focusing lens; 4 – magnetic field coils; 5 – magnetic circuit; 6 – the target placed in the H\(^+\) crossover plane; 7 – Hydrogen ions beam trajectory; 8 – impurities trajectory
separation of the impurities (like oxygen). Ions of hydrogen and impurities obtain different momentum in the same magnetic field. As the result, the trajectories of hydrogen ions (7) cross the target (6) plane primarily in the central part of the target, while trajectories of the impurity ions (8) are located farther from the central part (see Fig. 1).

**Fig. 2.** The distribution of the magnetic intensity (bold solid line) that is perpendicular to the ion flux direction obtained via numerical calculations. Dashed line shows the ion flux. Thin lines show the lines of equal magnetic intensity.

The energies of the beam ions are spread over the range from ≈650 eV and up to accelerating voltage of few kilo electron-volts; typical distribution of the ion energies is shown on Fig. 3. The peak of the distribution function is located at ≈40% of the accelerating voltage.

**Fig. 3.** The beam ion energy distribution function measured by energy analyzer. The resolution of energy analyzer is 30 eV.

The impurity is modelled by adding 5% of oxygen to working gas. It is shown that 5% O⁺ impurities being present in the beam are separated and form the circle with the diameter of ≈6 mm. For material oriented experiments one can use pre-filtering of the working hydrogen gas with palladium filter to obtain best possible purity of the ion beam. Therefore, there are all the bases to conclude that magnetic separation provides the purity of the central part of the beam spot in the respect of impurities.
CONCLUSIONS

The numerical study of the intrinsic capability for impurities mass-separation of systems with reversed magnetic beam focusing was carried out. The ion trajectory deviation was studied numerically with taking into account the experimental ion energy distribution function for hydrogen-oxygen gas mixture. It was shown that O\textsuperscript{+} impurities in the beam are separated and form the circle with the diameter of $\approx 6$ mm. Therefore, the central part of the spot is free of impurities due to magnetic separation. As the result, the source generates steady-state pure hydrogen ion beam, which irradiates the surface with high heat and particle fluxes, which approaches the upper limit for the flux range expected in a fusion reactor.

Obtained results could be taken into account for the high-current ion sources development and high-current beams transport experiments.

REFERENCES


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