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A high-flux-density hollow cathode plasma source for the studies on plasma surface interactions

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HIGHLIGHTS

- The plasma source provides high ion flux density for H2/He/N2/Ar, with simple structure, high gas and energy efficiency.
- The systematic scanning for the performaces of hollow cathode have been studied based on argon discharges.

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ABSTRACT

A new type plasma generator based on hollow cathode discharge has been designed and installed on the linear magnetic device, for the researches on helium and hydrogen plasma interaction with plasma facing components. The hollow cathode plasmas for argon/helium/hydrogen discharges were realized. The performances of the hollow cathode source were analyzed based on argon discharges, such as the electron temperature and electron density with respect to radial position, gas flow rate and magnetic field. The plasma parameters have been measured with Langmuir probe on the linear magnetic device. It shown that this hollow cathode source could provide ion flux density up to 10^{22} m^{-2} s^{-1} with high gas efficiency and energy efficiency. Typically, for argon plasmas, it could reach an electron density of 2×10^{19} m^{-3} and an electron temperature of 3.5 eV in core region, with a power dissipation of 1 kW and gas flow rate of 0.25 standard liters per minute. The plasma beam with a radius of 2.5 cm was confined very well with a magnetic field around 0.05 T. By the virtue of these properties, this plasma generator is a good candidate for the fusion related plasma-surface-interaction researches.

1. Introduction

The researches on plasma facing components (PFCs) are still an open issue for fusion device, especially for International Thermonuclear Experimental Reactor (ITER) and also for the future commercial fusion reactors [1,2]. The PFCs play essential roles not only on the impurity accumulation in core plasma due to surface sputtering and anomalous transportation, but also on the fuel recycling due to retention and permeation inside blanket [3]. Thus it needs low sputtering rate under high temperature plasma, low retention and permeation for high and controllable recycling efficiency. For the latter case, large attention has been paid in order to understand the transport properties of deuterium/tritium in fusion blanket. However, it is still an open issue. The conditions in present tokamak devices are so complex that the delicate investigations have to be carried out off-line. To overcome these problems, many kinds of linear magnetic devices have been developed for these kinds of issues to simulate the plasma-surface-interaction processes of fusion device [4–9]. The plasma source is one of the key components in linear magnetic device, which should provide high-flux hydrogen/helium plasmas with high purity. For ITER device, the first wall and divertor are exposed to a high flux of hydrogen isotopes $10^{20} \sim 10^{24}$ m^{-2} s^{-1} with energy ranging from several eV to keV. The flux density is much higher (10^{26} m^{-2} s^{-1}) during transient processes, such as edge localized modes (ELM) and disruptions.

For most of the commercial plasma sources, the flux density cannot fulfill the edge condition in ITER, limiting the extrapolation of present conclusions to ITER. Besides the achievable plasma parameters, the energy and gas efficiencies, and the complexity of structure of a plasma generator are also should be considered. For this pur-

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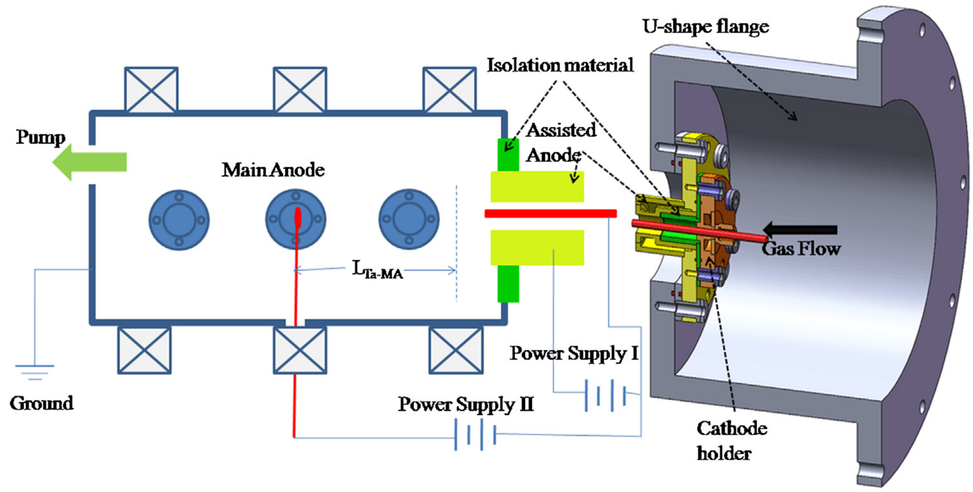

Fig. 1. The experimental setup for the hollow cathode source.

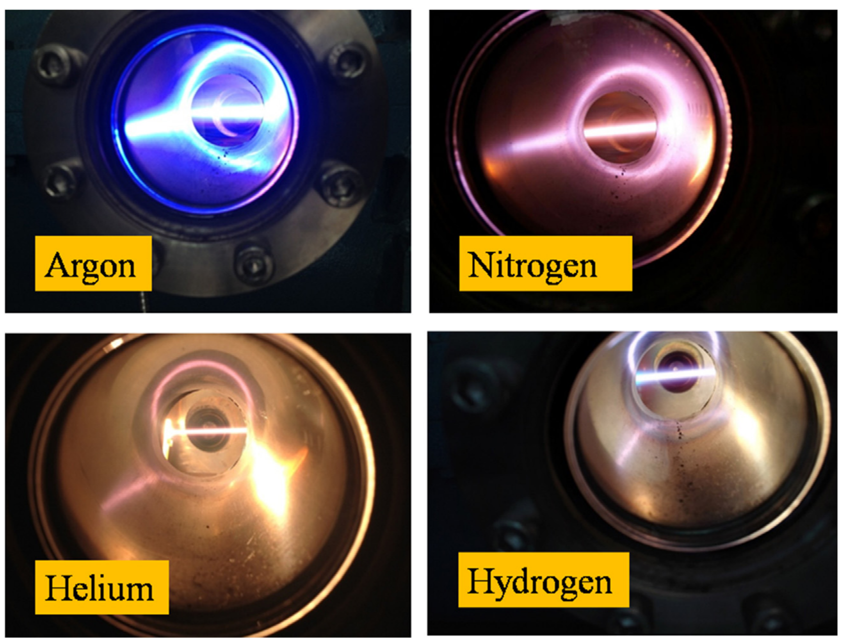

Fig. 2. The hollow cathode discharge pictures for argon, nitrogen, helium and hydrogen.

pose, a high intensity plasma generator based on hollow cathode arc discharge has been developed in a linear magnetic chamber, which is usually applied in the field of film growth and light source. It can provide plasma with electron temperature about 3 eV and electron density in the order of $10^{19}\,m^{-3}$ with an ion flux density of $10^{22} \sim 10^{23}\,m^{-2}\,s^{-1}$. In addition, the hollow cathode plasma source has high energy and high gas efficiencies, which are valuable properties and hard to get in high-density low temperature plasma generator. Thus it is a good candidate for plasma surface interaction studies. The paper is arranged as follows: A brief introduction to experimental setup and the principle of hollow cathode will be presented in Section 2. The performance of the hollow cathode source based on argon plasmas and helium plasma is illustrated in Section 3. Finally, a discussion and summary will be given in Section 4.

2. Experimental setup

The hollow cathode plasma source was developed on a linear magnetic device, located at Sichuan University [10]. The magnetic field with a maximum value of 0.4 T is produced by electrical coils around the vacuum chamber. The vacuum chamber is with an inner diameter of 0.35 m. As shown in Fig. 1, the vacuum was maintained by a set of roots pumps, resulting in a large range of gas inlet flow rate and a base pressure of 1×10^{-2} Pa. The magnetic field was along horizontal direction. The ports between electrical coils were used for plasma diagnostics and electrical feedthroughs. A specially designed ‘U’ shape flange (shown in Fig. 1) put the plasma generator in the place where the magnetic field has low divergence. A set of double-pin electrostatic probe system and visible spectroscopic systems were applied to diagnose the plasma parameters.

The principle of hollow cathode discharge originates from glow discharge [11–14]. When the cathode is changed from planar plate to hollow shape, the negative glow region can overlap in certain condition (depending on the gas pressure and applied voltage), resulting in a ‘pendulum’ motion of thermal electrons and subsequently an enhancement of electron impact ionization efficiency. Then the electron density will be largely enhanced inside the hollow cathode. If the cathode is not cooled, the thermal electron