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Generation of a gas discharge plasma for ion beam plasma interaction experiments

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Abstract

A new concept for the generation of gas discharge plasmas has been proposed recently by J. Christiansen. The proposed new gas discharge is based on a high frequency plasma which is a electrode less configuration. To achieve a high density, the plasma is focused by a magnetic quadrupole field. A cylindrical time independent plasma target experiment is proposed to be used as an ion beam interaction experiment with a high plasma temperature and a high ionisation stage. In order to characterise the plasma target spectroscopic measurements were performed.

1. Introduction

Heavy ion beams are a new tool to introduce dense plasmas and to investigate their properties. Since 2001 at the UNILAC accelerator at GSI an experimental set-up exists to measure the interaction of heavy ions with non-ideal plasmas [1]. The propagation of a high-current ion beam in a background plasma is of considerable interest for many experiments. It has been shown, that the stopping power for heavy ions of a fully ionised plasma is up to forty times higher than of cold gases. However, the determination of the stopping power maximum has not been achieved here. The charge state distribution of heavy-ions crossing a fully ionised plasma is expected to be completely different in comparison with cold gases [2]. The main effects which contribute to the ion beam loses in hot plasmas are the ion charge state, bound electrons and strong inter-particle interactions [3]. One can therefore expect a non uniform behaviour of the stopping power with respect to the target density and temperature. At Frankfurt a new kind of gas discharge plasma target is now under investigation.

2. Principle Plasma Target

In many cases the gas discharge takes place in long tubes with electrodes at each end. This longitudinal direct current (DC) or alternating current (AC) discharge is self-maintained due to ionisation processes caused by collisions between electrons heated by an electric field and gas atoms as well as by recombination of electrons and ions at the tube walls. In other words, in a longitudinal gas discharge the maximum value of electron density and, consequently, maximum electron production rate is achieved in the centre of the tube.

The proposed high frequency gas discharge plasma is based on an electrodeless configuration. The energy deposition into the plasma was done by cw-inductive coupling per antenna [4]. The fact that the plasma is a mixture of charged particles means it can be controlled and influenced by magnetic fields. Generally, charged particles gyrate around the magnetic field lines and thereby move along these field lines. Therefore a radial time independent quadrupole magnetic field confines the plasma [5]. In order to inhibit the movement of the charged particles along the axis two ring magnets are placed at the ends of the discharge functioning as a magnetic mirror.

In this magnetic configuration the radial time independent magnetic field is superimposed on the alternating plasma current. Due to the linear magnetic field gradient the confinement of the radio-frequency plasma is achieved by the stronger focusing than defocusing forces on the alternating electrons during the discharge [5].

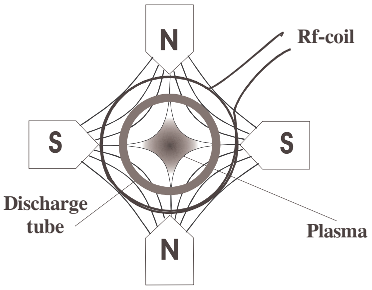

Fig.1: Schematic drawing of the used configuration.

Due to the interaction of the high frequency inductive coupling and the radial magnetic field the electron temperature increases steadily towards the centre of the discharge. During this focusing effect of the magnetic field influenced by the electric fields of the rf-coil the ionisation and excitation of the atoms and ions are very effective and the current density is concentrated within a small area of the centre axis. Because of the magnetic minimum close to the centre axis the electrons will follow only the inductive coupled electrical field. A schematic drawing of the plasma target design for this experiment is shown in Figure 1. This plasma embedded in a magnetic cavity has almost cylindrical shape. For first experiments of the plasma target prototype the chosen gas was argon.

3. Experimental Set-up

The plasma is generated in a RF plasma apparatus called Radio Frequency Quadrupole. The applied rf-frequency in the range of 12 - 50 MHz was generated by a tuneable high frequency amplifier with a maximum power of 300W. The main section of this experimental set-up is a 900 mm long glass discharge tube of 21 mm inner diameter. This discharge tube is partially wrapped with a loop antenna with a length of about 200 mm. Since the electrical impedance of a rf discharge depends on the gas pressure and composition, on the geometry and material of the electrodes, on the frequency, the power deposition and the temperature. It is obviously difficult to estimate the impedance theoretically. For this reason an experimental matching of the impedances of the rf-generator and the discharge had to be provided for efficient energy coupling. Via a capacitive matching network, up to 300 W rf-power can be coupled into the plasma. This inductive coupled plasma is working in a CW mode with nearly steady state conditions. In addition the induced glass discharge tube is embedded inside a permanent quadrupol magnet, with a field strength tuneable from 0 to 2 T. The length of the quadrupole singulette is approximately 250 mm. The based pressure of the discharge tube was in the range of 10^{-7} Pa and was filled with argon at a pressure varying from 0.1 to 5 Pa.

4. Experimental results

Within our experimental work we are beginning to study the plasma parameters of argon depending on the radial magnetic quadrupole field, the gas pressure and the plasma power input. The first measurements were performed with high magnetic fields between 1-1.5 T and at a rf-power input of 300 W. The ignition conditions of the discharge are fulfilled at a pressure of approximately 1.0 to 1.5 Pa. By reducing the pressure further below 1 Pa the discharge becomes more focused. The optimised pressure with the highest brightness of the investigated emission lines at the wavelength 488 nm (ArII) and 514 nm (ArII) are in the pressure range of 0.4-0.5 Pa. Figure 3 shows an end on photography of the discharge. Clearly to be seen in this picture are the pronounced edges at the poles of the magnetic field, which act like magnetic mirrors. After impedance matching of the antenna spectroscopic measurements were performed. The magnetic field strength was adjusted to 1 Tesla. The plasma was examined in the pronounced centre of the discharge. Within this area the condition of this plasma are assumed to be in local thermal equilibrium. To estimate the electron temperature and ionisation degree the Saha-Equation is applied for two successive ionisation states. One emission wavelength intensity depending on the gas pressure of neutral (Ar(I)) – was compared with ionised argon (Ar(II)). According to tables the two selected wavelength have almost the same quantum mechanic oscillator strength. Figure 3 shows the relative intensities of the two Ar-lines as a function of the filling pressure. At a pressure of 1 Pa the emission intensity for neutral argon was dominant. This spectroscopic measurement was also visible as a bright red glow within the gas chamber. With decreasing pressure the neutral emission

Fig. 3: End-On photography of the discharge

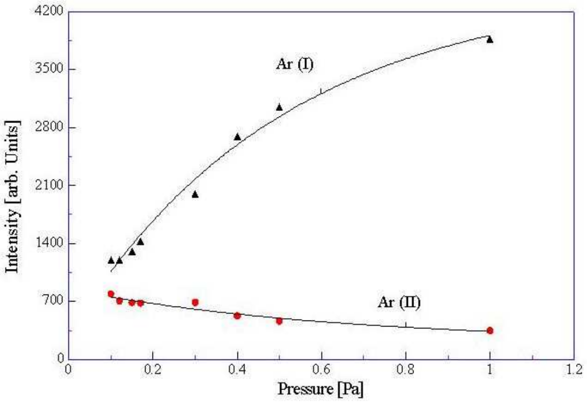

Fig.2: Emission intensity of Ar(I) and Ar(II) arbitrary unit depending on the pressure.

rate decreases whereas the emission intensity of the ionised Argon increases. At a pressure of 0.1 Pa the emission intensity of Ar(II) was higher than half of the intensity of Ar(I). This plasma behaviour suggests a high plasma ionisation degree in the order of more than 50 %. The reason for this behaviour is very likely higher electron temperature at lower pressures. Using [6] the electron temperature can be evaluated from the relative line intensities by applying the Saha equation. First measurements were performed using a UV-VIS spectrometer with a range between 240nm-800nm and a resolution of 0.5nm. The relative intensities of the spectra of two succeeding ion stages were used to determine the temperature of the plasma.

The calculated electron temperature was in the range between 1.1eV-1.2eV. These results are still preliminary. Further measurements have to be performed using a 1m monochromator to scan the line profile and determine the line width.

5. Summary and Outlook

A new plasma target based on a rf electrodeless energy coupling and magnetic focusing has been developed. The most important part of this plasma for this application of a plasma target is the dense plasma core. In further steps higher rf-power of a tuneable amplifier will be used. The plasma is protected from the tube wall and is relatively independent of the tube size. Inspite of our limited power condition of our rf-generator it was shown that with this configuration of the discharge a high ionisation degree can be achieved within in the centre of the discharge tube. Further measurements are planned by variation of the gas and electrical parameter by using a shorter antenna to increase the energy density. By spectroscopic measurements we gain knowledge of the major plasma parameter like electron density, ionisation degree and the plasma shape. Further exerimental investigations will be performed to obtain an optimised set of parameters for this application of ion beam plasma target interaction. This work was partially founded by the BMBF.

6. References

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