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論文内容の要旨

Experimental study of enhancement techniques used in the volume-production-type negative hydrogen ion source

Neutral beam injection (NBI) using negative deuterium (D^-) ion sources is essential as a useful heating method for realizing a thermonuclear fusion reactor. Large current negative hydrogen /deuterium ion (H^- / D^-) sources of the volume production method have been successfully developed for NBI in the thermonuclear fusion research. The enhancement of H^- beam current is achieved by using several empirical techniques; equipment of magnetic filter field in front of the plasma grid, injection of cesium vapor into the arc chamber, addition of bias voltage to the plasma grid against the arc chamber, and so on. However, the physical process in the ion source has not been examined in detail, so that we don't have a clear image on the H^- production in a plasma, and the extraction of negative ions from it.

In order to develop a more efficient ion source, and to extract beams with higher current density, it is important to know what changes the plasma is undergoing in the ion source by applying these empirical techniques, especially in the present "large current" negative ion source.

In this work, the characteristics of H^- and electrons in the extraction region of the plasma source is studied and compared with extracted H^- and electron beam comprehensively. For this purpose, the NIFS-1/6-scale negative ion source, which had been used for R&D work, was modified to use an external magnetic filter and to have a pair of windows for the observation of the extraction region 15 mm apart from the plasma grid. From these windows, a high power laser beam is introduced, and H^- density is measured by the laser photodetachment method. Electron density and temperature are also measured by the same Langmuir probe. The extracted H^- beam is measured by a Faraday cup array installed 20 cm downstream from the extraction system. The extracted electron current is obtained from the drain current of the extraction power supply.

The effects of three empirical techniques are examined; (1) magnetic filter strength on the extraction region, (2) cesium vapor injection into the arc chamber, (3) addition of bias voltage to the plasma grid against the arc chamber.

(1) It is generally reported that the magnetic filter strength is enough if the

electron temperature is suppressed less than 1 eV in the extraction region to avoid the destruction of H- by the collision with the high energy electrons. But it is not the case of our study. Even if the electron temperature is below 1 eV, there still remains a high energy component in the energy distribution of electrons. In this case, the extracted H^- current as well as H- density in the extraction region is small at the high arc power discharge. With the stronger filter field, a high energy component of electrons is decreased, and then destruction of H^- ions at a high arc power is sufficiently suppressed. Hence, in the design of a high arc power H^- ion source, it is important to decide the magnetic filter field so as to suppress the high energy electrons sufficiently.

(2) Under the pure volume discharge, it is observed that both extracted H^- and electron currents are proportional to the H^- and electron densities in the extraction region. After the cesium injection, extracted H^- current increases about twice while the electron current reduces an order of magnitude, which are the common effects observed in other ion sources as well. In the extraction region plasma, however, H^- density increases by 5 ~10 times while the electron density reduces only by half, which are very different from the behavior of the extracted current. The linearity between the extracted current and the density in the plasma still holds in the cesiated discharge, but the coefficient is different from that of the pure volume discharge. While the plasma density (H^- density plus electron density) increases after cesium injection, the electron temperature becomes slightly lower. The difference of coefficient of H^- current to its density is considered to be due to the difference of H^- temperature. Assuming that the thermal ion flux determines the extraction current density, the temperature of H^- is estimated about 0.3 eV in the pure volume discharge, and 0.07 eV in the cesiated discharge. This value is consistent with the results at other volume-production-type H^- sources. We observed a low temperature by measuring a beam emittance in other experiment. It is suggested that cesium ions make H^- temperature lower due to their larger mass.

(3) The bias voltage dependence shows that the extracted electron current sharply decreases when the applied voltage becomes more positive but that the electron density in the extraction region does not vary. On the other hand, H^- current shows the same behavior as H- density in plasma. Therefore the extracted electron current reflects the electron density in the vicinity of plasma grid, where the electron density becomes very small after cesium injection and is sensitive to

the potential difference between the plasma grid and the plasma.

Conclusively it can be said that the addition of cesium in the volume-production-type ion source enhances the H^- production much remarkably than expected from extracted beam current. Actually the H^- density is larger than electron density in the extraction region. On the other hand, the electron density and the temperature does not change much. These results can not be explained by the volume process alone. The fact that the extracted electron current decreases much in the cesiated discharge shows that the electron density in the vicinity of plasma grid is very low (our bias voltage experiments show that the electrons are extracted only from the vicinity of plasma grid), which suggests the surface production of H^- ion on plasma grid. These H^- ions are not extracted directly from the originated region. We observed a good correlation between the extracted H^- beam current and the H^- density in the extracted region. They are accelerated by a potential between the grid and plasma and go through the extraction region affecting by magnetic filter field and collision before extracted from the grid aperture.

However, the other fact that the H^- is still observed at the highly positive bias voltage means that the volume production also remains because H^- ions produced on the plasma grid cannot leave due to the decelerated potential. In order to develop higher current negative ion sources, plasma density should be increased because the present plasma is already "H^- rich". In this case, it is important to use stronger magnetic filter to suppress the high energy tail component of electrons in the extraction region.

論文の審査結果の要旨

Experimental study of enhancement techniques used in the volume-production-type negaitve hydrogen ion source

核融合炉心プラズマの加熱には，大電力の中性粒子ビームがもちいられているが，プラズマのサイズや温度．密度が大きくなるに従いビームエネルギーが高くなり，従来の正イオンビームでは中性化効率の低く使用できなくなってきている．そこで近年の核融合炉の実機規模の実験においては、中性粒子加熱装置のビーム源として負イオン（H-/D-/T-)が用いられてきている．本研究は，実際にこの目的に使用する規模の負イオン源に関する実験的研究である．すなわち，負イオンビーム量増加のため，1)磁気フィルター効果，2)セシウム添加効果，3)プラズマ電極バイアス効果の３点について，その増加効果の機構解明のための詳細な実験を行なったものである．この3点の効果に関しては，加速器規模のイオン源や低密度プラズマ領域では研究されてきたが，小規模の実験でしらべられている現象や物理過程が，実機規模のイオン源に適用できるかどうかという疑問点を抱えていた。

本研究は，実機規模のイオン源で，実用出力に相当する運転領域のプラズマを生成し，実際にビームを引き出した上で，内部プラズマと生成ビームとを総合的に研究したものでる．そのような条件で，プラズマ内の負イオンを光脱離法をもちいて測定し，プラズマパラメーター，引き出しビーム量の測定ともあわせて，上記の効果を詳細に調べた．

まず，負イオン引き出し領域の磁気フィルターの効果に関しては，生成領域の電子温度を下げるだけでは不十分で，電子の高エネルギー成分の抑制が重要であるとの結論を導き出した．

さらに，引き出しH^-ビーム量とプラズマ内のH^-密度との相関に，セシウムを添加した時の顕著な特徴を見い出した．特に，このような放電電力の大きい領域では，セシウム添加効果によりH^-ビーム量が２倍程度増加する一方，イオン源プラズマ内のH^-密度は１０倍にも増加していることを確認したのは新しい発見である．また，プラズマ電極バイアス効果に関しては，プラズマポテンシャルの変化と，電子成分と負イオン成分双方について緻密な測定を行い，セシウム添加効果をも含めた負イオン生成機構解明のための詳細な実験を行った．

これにより，プラズマ内の負イオン生成に表面が関連していることを示す重要なデーターが得られた．本論文内では，負イオン生成機構とともに，生成された負イオンビームの引き出しメカニズムについても，クーロン衝突とラーマー運動の相乗効果として詳細に議論されている．

以上のように，本論文は大電流H^-イオン源での負イオン生成メカニズムと引き出しメカニズム解明の重要な研究であるばかりでなく，今後の負イオン源の性能向上のための多大な貢献をもたらすことが期待できる内容である．よって，本委員会は、本論文は学位授与の対象として十分な内容を持っているものと認めた。