

DIAGNOSTICS IN THE RF-ION SOURCE RIG 10  
PROPOSED FOR NEUTRAL INJECTION

J. Freisinger, S. Reineck, and H.W. Loeb  
1st Institute of Physics, University of Giessen,  
Heinrich-Buff-Ring 16, D-6300 Giessen, FRG

Keywords: Neutral injection, rf-discharge ion source

Compounds: In a hydrogen plasma three ion species are produced:  $H^+$ ,  $H_2^+$ ,  $H_3^+$

ABSTRACT

For additional heating of a Tokamak plasma by neutral injection a plasma source yielding a hydrogen ion beam with a high proton fraction is necessary. The Radiofrequency Ion Generator RIG 10 with 10 cm in diameter has been investigated. First diagnostic results are given. Its feasibility has been demonstrated.

1. INTRODUCTION

Successful heating of a Tokamak plasma by injection of a powerful beam of fast neutral particles depends - amongst other factors - on the purity of the beam and its atomic hydrogen (deuterium) fraction.

In comparison to arc discharge plasma injectors, the rf-plasma source RIG demonstrates some advantages:

- The plasma purity:  
For the plasma production it uses a high frequency, electrodeless, annular discharge. In the plasma there are no discharge electrodes, which could cause additional impurities.
- No lifetime problems:  
Because of working without filaments contacting the plasma there should be no serious lifetime problems.
- High atomic fraction:  
The discharge chamber is made of quartz. At quartz walls the surface recombination coefficient of atomic hydrogen ( $2H \rightarrow H_2$ ) is low (about  $10^{-3}$ ) (1). The special rf-discharge mechanism with mean electron energies of about

8 - 10 eV delivers before ionization high dissociation rates for neutral particles, resulting in a high proton fraction in the extracted ion beam.

## 2. EXPERIMENTAL

### 2.1 Definition of the Components of RIG 10

Concerning the mechanical set-up, the rf-plasma source RIG 10 is very simple. As shown in the half-schematical Fig. 1, it consists of the following components:

1. H<sub>2</sub>-inlet and regulator valve
2. Discharge vessel made of quartz (inner diameter: 10 cm)
3. Distributor: The hydrogen gas enters the discharge chamber radially. Therefore, the stay of the atoms inside the discharge region is enlarged and the probability to be ionized will be increased.
4. Rf-induction coil (air cooled)
5. Extraction system with the subcomponents
  - extraction anode
  - extraction cathode
  - decel electrode

### 2.2 Mode of Working

The hydrogen gas enters the discharge chamber in radial direction. It is surrounded by the induction coil of an rf-generator. Due to the Maxwellian laws, a high frequency magnetic field  $B_{RF}$  and in consequence an electrical rf-field  $E_{RF}$  (Fig. 2) is induced. Free electrons inside the discharge region are accelerated by the rf-field  $E_{RF}$ . When they have gained sufficient energy, they are able to ionize neutral atoms by inelastic collisions. Thereafter, the secondary electrons - created in this ionization process - are accelerated, too, by the same mechanism. We obtain an intense electrodeless, non-thermal rf-plasma. The beam extraction is accomplished by the conventional accel-decel-technique.

### 2.3 Block Diagram and Experimental Plasma Source

Fig. 3 shows the block diagram of the power supply of RIG 10. The rf-generator consists of an rf-driver stage and an air cooled rf-amplifier. It can be tuned from 1.5 MHz to 30 MHz. The maximum rf-power is 1.2 kW. The currents to the extraction electrodes and the return current are registered.

In Fig. 4 we see the experimental plasma source RIG 10 mounted at the automatized vacuum test facility P 100,000, which provides a pumping speed of 100,000 l/s.

Double probes are introduced from the downstream side of the beam into the plasma in the level of the first extraction grid

for measuring the plasma parameters in dependence of the radial position. The discharge pressure, the rf-power, the rf-frequency are varied and the influence of a superposed magnetic field is determined.

### 3. ION CURRENT DENSITY PROFILES (Experimental Results)

#### 3.1 Pressure Dependency

In Fig. 5 you see typical ion beam density profiles. The profiles are rotationary symmetrical to the axis of the plasma source.

The ion beam density increases with increasing discharge pressure (broken curves). It reaches a maximum of  $55 \text{ ma/cm}^2$  at a discharge pressure of 13 mbar. Then the curves for the current densities (solid lines) decrease.

The shapes of the radial profiles are very similar. They show a plateau, and shift only in the intensity (Fig. 5). For injection purposes a decrease in the beam plateau of 5% is allowed. Lower intensities must be cut-off.

For the highest, the 13 mbar-curve of Fig. 5 the area usable for extraction extends up to a distance of 1.5 cm to the wall. This is a very good result - also compared with other injector sources. The ion beam of RIG 10 has, therefore, a diameter of 7 cm.

#### 3.2 Radial Distribution of the Plasma Density and the Electron Temperature

The radial distribution of the plasma density (Fig. 6: broken curve) shows a similar shape as the ion current density profile. The plateau-value amounts to  $2 \cdot 10^{11} \text{ cm}^{-3}$ .

The electron temperature (Fig. 6: solid curve) is highest near the chamber walls, about 80,000 K. It drops to 60,000 K at the axis. This can be easily interpreted by the mode of working of the rf-plasma source (skin-effect).

#### 3.3 Power Dependency

At a fixed discharge pressure of 13 mbar the ion current profiles for different rf-generator power values are plotted in Fig. 7. The current intensity increases almost linear with the rf-power and reaches an ion current density of  $55 \text{ ma/cm}^2$  at 1000 W.

The 5% cut-off-shoulder does not depend on the rf-power. It is positioned at a radius of 3.5 cm.

#### 3.4 Superposition of an Auxiliary Magnetic Field

The superposition of an auxiliary static weak external magnetic field on the discharge plasma increases the ion current density

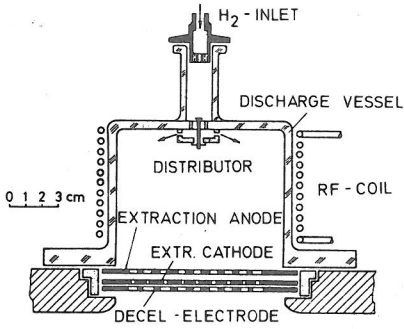


Fig. 1: Definition of the components of RIG 10

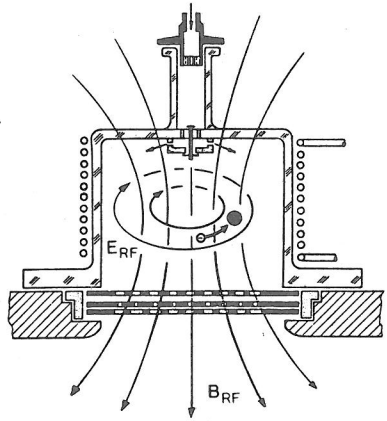


Fig. 2: Principle of rf-discharge ( $\ominus$  electron,  $\oplus$  proton)

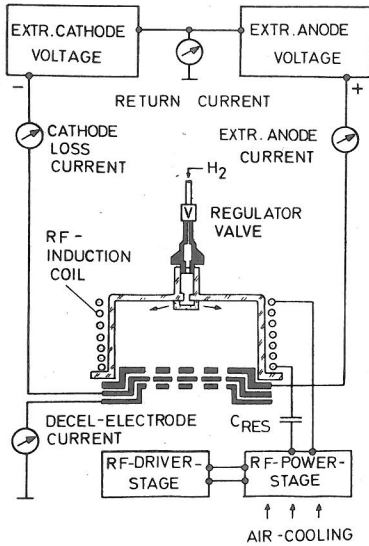


Fig. 3: Blockdiagram of the power supply of RIG 10

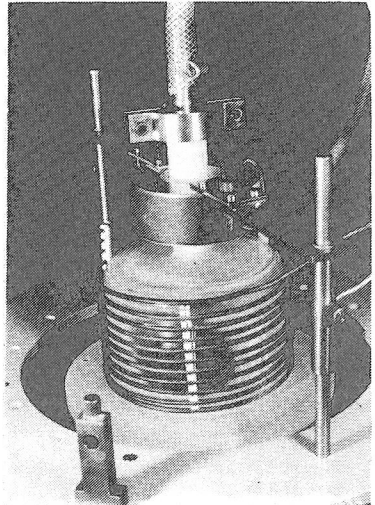


Fig. 4: RIG 10 mounted at the test facility P 100.000

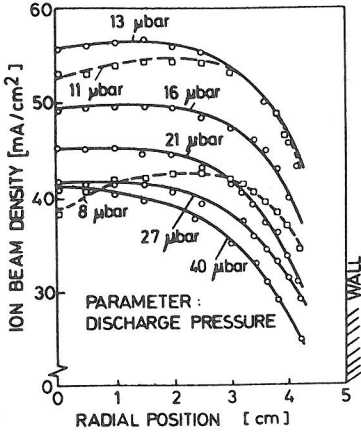


Fig. 5: Ion beam density profile as function of the radial position in the ion source. Discharge power: 1000 W

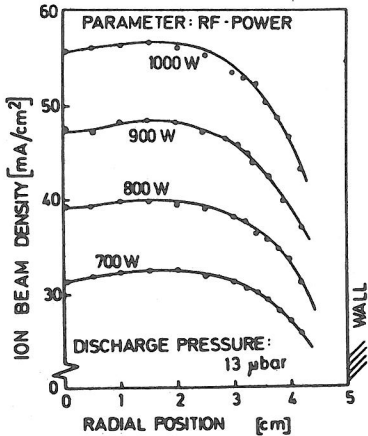


Fig. 7: Ion beam density profile in dependance on the rf-discharge power

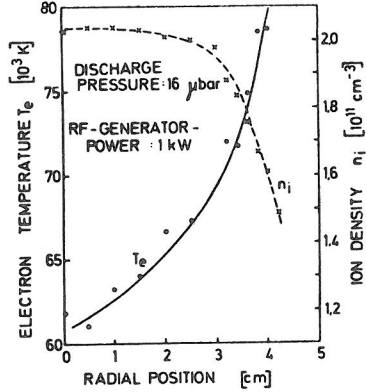


Fig. 6: Radial profile of the electron temperature  $T_e$  and the ion density  $n_i$  inside the discharge

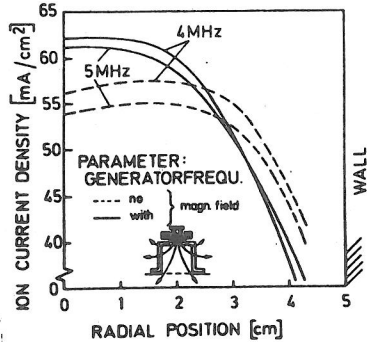


Fig. 8: Influence of the superposed static magnetic field on the ion beam density profile for two generator frequencies  
 rf-discharge power: 1000 W  
 discharge pressure: 13 mbar  
 auxiliary magnetic field:  $\approx 10$  T

by suppressing the skin-effect (Fig. 8). It intensifies the transport of rf-energy into the discharge plasma. The auxiliary field - the configuration is sketched in Fig. 8 - increases the ion current density in the source center, as we can see, when comparing the broken (no external field) and the solid (with auxiliary field) curves. By unskillful choice of the magnetic field configuration the radial profile can be made worse. Works are not just finished and will be supported by theoretical efforts (2).

#### 4. SIMULATION OF THE EXTRACTION SYSTEM

A computer program has been developed to simulate the ion extraction out of the plasma and to describe the acceleration in the extraction system. Basing on experimental and geometrical data the plasma boundary, the equipotential areas in the extraction system, and the ion trajectories are computed and plotted in (3).

#### 5. CONCLUSION

In conclusion we will summarize the main results:

1. The plasma purity can be improved, because the rf-plasma source uses no filament.
2. The proton fraction in the beam is high as the discharge chamber is made of quartz.
3. The ion density plateau extends up to a distance of 1.5 cm to the plasma chamber walls.
4. As computed from the ion saturation current to Langmuir double probes in the holes of the first extraction grid, the rf-plasma source delivers a total ion beam current of 1 to 1.5 amps at an rf-discharge power of 1 kW. The current density amounts to 55 ma/cm<sup>2</sup>.

Investigations at higher discharge power current densities of 200 to 250 ma/cm<sup>2</sup> are being planned. Furthermore, we will measure ion beam's particle species using a magnetic mass analyzer.

#### ACKNOWLEDGEMENT

This paper is a part of the Doctorate Thesis of the 2nd author. The work is supported by the Deutsche Forschungsgemeinschaft.

#### REFERENCES

- (1) Valyi, "Atom and Ion Sources", John Wiley & Son, London 1977
- (2) R.J. Walther, "Investigations of the Rf-Generated Low Pressure Plasmas as Particle Source for Fusion Plasma Heating", IEEE International Conference on Plasma Science, Monterey, Ca., USA, May 1978
- (3) J. Häuser, F. Tanzer, "Algorithms for the Different Steps in the Numerical Solution of Partial Differential Equations and Application to the Design of an Ion Extraction System", see above