*35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-1.103 (2008)*

Development of RF driven H^-/D^- sources for ITER

W. Kraus, M. Berger, H.-D. Falter, U. Fantz, P. Franzen, B. Heinemann, P. McNeely, R. Riedl, E. Speth, A. Stäbler, D. Wünderlich

Max-Planck-Institut für Plasmaphysik, Garching, Germany

IPP Garching is developing negative hydrogen ion sources based on RF for the ITER neutral beam heating system. On a long pulse test facility stable H^- production using surface conversion on Caesium layers has been demonstrated in CW operation. The source performance could be considerably improved by Mo coating of the inner surfaces, which reduced the amount of sputter products. Biasing of the plasma grid with a positive potential with respect to the source is an effective method to reduce the co-extracted electron current.

Introduction

Compared to operational NBI heating systems based on negative ions, the requirements for the ITER source are challenging: one hour beam pulse duration, with an accelerated current density of 30 mA/cm^2 for H^- and 20 mA/cm^2 for D^- at 0.3 Pa, a fraction of co-extracted electrons to ions of less than 1 and an extraction area of 2000 cm^2. In 2007 the decision to choose RF sources for the reference design for the plasma generation in the ITER neutral beam system has been made due to the maintenance free operation with RF sources (no filaments) and the lower Cs consumption compared to arc sources due to the tungsten free plasma. A smaller RF source prototype at IPP has already exceeded the ITER requirements with respect to current density and electron content, but with the pulse length limited to less than four seconds and only an extraction area of ~70 cm^2 [1]. To demonstrate the H^- density and plasma homogeneity over an ITER like extraction area, a half size ITER RF source is being tested without beam extraction [2].

It still had to be proven, whether the results of the small source are also achievable in CW operation and with an enlarged extraction area. Therefore the MANITU test facility (multi ampere negative ion test unit) has been built which enables long pulse D^- beam extraction for up to 3600 s, also using the small source. The source was modified for long pulses and equipped with an extraction area of 204 cm^2. This paper concentrates on the latest results achieved in the long pulse experiments and the stabilisation of the co-extracted electron current.

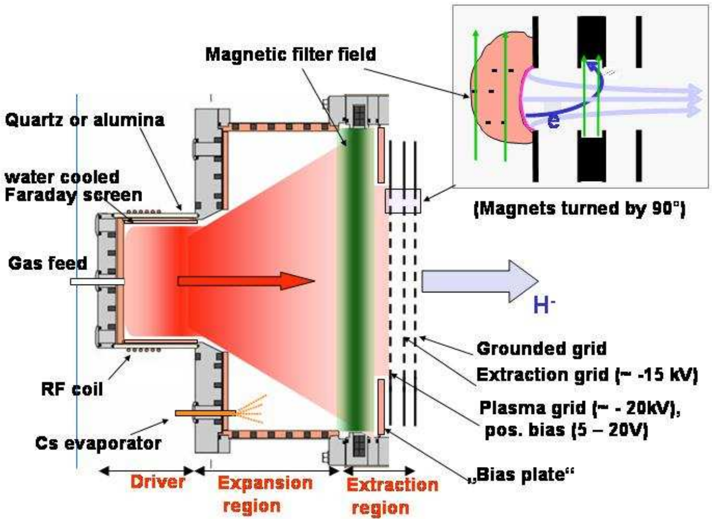

Fig. 1: *Principle of the negative ion RF source*

Set-Up

In the source the RF power is inductively coupled into a circular volume of 25 cm diameter, out of which the plasma is flowing into the main chamber (b x l x d = 30 x 60 x 25 cm^3) (Fig. 1). The ITER source will have eighth of these “drivers”. The negative ions are produced on the plasma grid by surface conversion of hydrogen ions and atoms. The grid is covered with a layer of Caesium in order to reduce the work function. The Cs is evaporated into the source by a Cs oven mounted onto the back plate. The level of the Cs content is detected by a Cs852 line intensity measurement with the line of sight in 2.5 cm distance from the plasma grid. A magnetic filter field of approx. 1000 Gauß cm produced by rows of 4 x 2 Co-Sm magnets on each side close to the plasma was identified in the short pulse experiments as being most suitable to reduce electron temperature and electron current in hydrogen [1]. The negative ions are extracted through 404 chamfered holes of 8 mm diameter in the plasma grid of a 3 grid extraction system. The co-extracted electrons are deflected out of the beam by permanent magnets mounted in the second grid (extraction grid).

The modifications to the source design for long pulses are aimed for temperature control of all surfaces that are exposed to the plasma. This includes active cooling of the Faraday shield that protects the insulator that forms the driver wall from the plasma load and active control of the cooling water used in the side wall and back plate in order to prevent Caesium trapping. The temperature of the plasma grid, which is cooled by compressed air, can be kept constant near 150° during the pulse. The outer parts of the plasma grid not used for extraction are covered by the electrically insulated “bias plate”.

The RF generator is rated for 180 kW CW operation at 1 MHz. For the long pulses new CW HV power supplies for extraction and acceleration voltage (max. 9 kV and 23 kV respectively) as well as a new cryogenic pump have been commissioned [3].

A long pulse calorimeter can be used for beam profile measurements. Depending on the beam perveance the calorimetric currents are in the range of 0.6 to 0.8 of the electrically measured values. In this paper we quote only electrically measured currents.

Results

After the ion source design and power supplies have been modified for CW operation, long pulses with H^- beam extraction have been performed up to 3600 s [3], showing stable ion and electron currents. But in long pulse operation high electron currents were an issue: starting from low values the co-extracted electron current increased within the first 100 s to 150 s, exceeded the ion current and reach a constant but too high level (see Fig. 2). Another observation in long pulse operation was that after some operational time all inner surfaces were covered by a thin layer of copper; apparently sputtered from the copper Faraday shield. It was suspected that this would affect the work function and hence the e/H^- ratio close to the plasma grid. After the Faraday shield and all inner surfaces were coated with a 3 μm Molybdenum layer no more sputter products were found in the source and the performance, in particular for long pulses improved significantly: Higher H^- current at the same power (max. 27 mA/cm^2 at 80 kW) and reduction of electron current by a factor of 2 -3 that remains on this low level also during long pulses was observed (Fig. 3). Due to RF breakdowns at the coil the RF power was limited in most of the experiments to 50 - 60 kW. A homogenous Caesium layer on the plasma grid surface, which is necessary for the optimal performance, can be achieved by controlled evaporation and distribution of Cs by many plasma pulses (“conditioning”). Under these conditions the H^- current increases at high RF power more than the electron

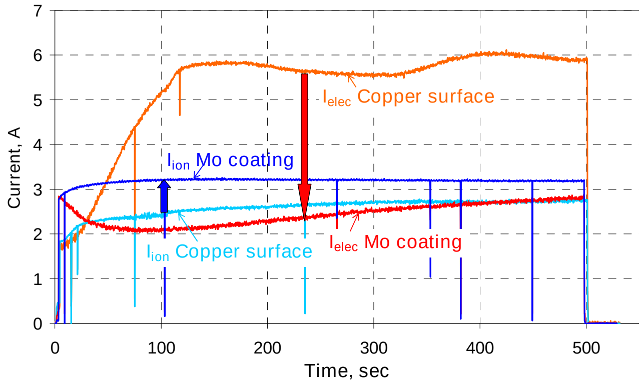

Fig. 2: *Comparison of two 500s-pulses with and without Mo coating at 55 kW and 0.45 Pa*

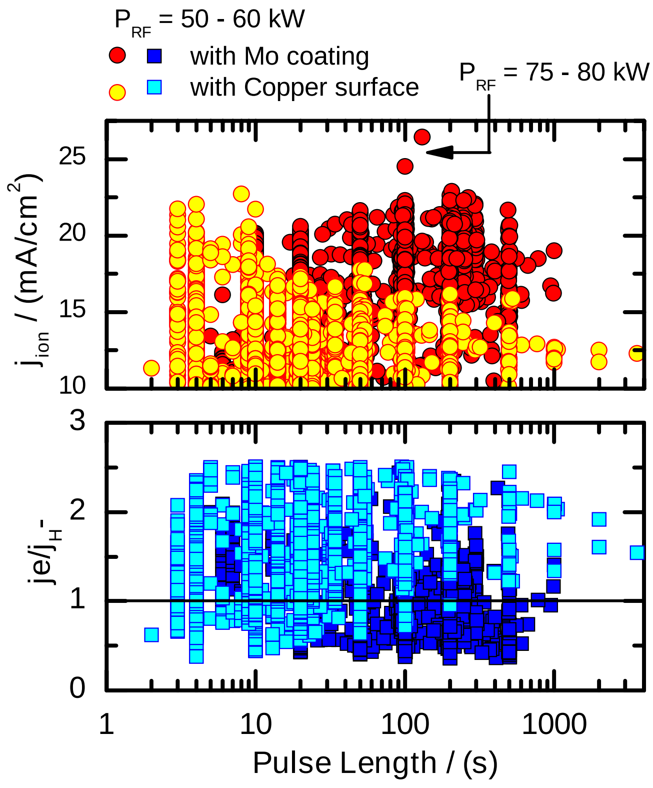

Fig. 3: *H^- current density and fraction of the co-extracted electrons with and without Mo coating of the Copper surfaces inside the source as a function of the pulse duration at 0.45 Pa*

current (Fig. 4). However, the wide spread in the results in Fig. 3 shows that optimal Cs conditions can not always be achieved. But the subsequent loss of H^- current can be compensated by raising the RF power during the pulse and the simultaneous increase in electron current can be drastically reduced by a positive bias voltage of the plasma grid or of the bias plate with respect to the source without significantly affecting the ion current (Fig. 5).

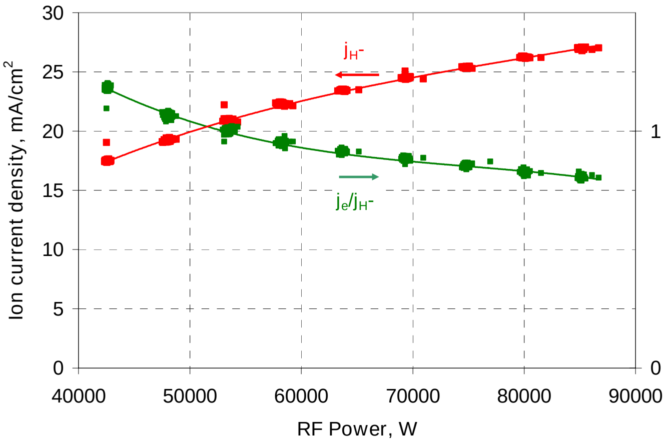

Fig. 4: *H^- current density and fraction of co-extracted electrons as a function of the RF power measured during a 500s Pulse*

The next step will be to solve the breakdown problems in order to enable operation at a higher power level and to reach the required current density on the calorimeter. Another issue is the reduction of the source pressure. Finally the results have to be demonstrated also in Deuterium, which requires according to short pulse experiments additional electron suppression.

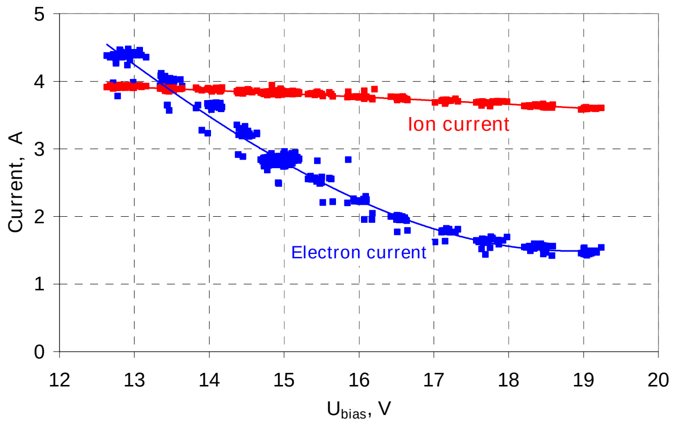

Fig. 5: *Reduction of the electron current by a positive bias voltage of the plasma grid measured during a 500s Pulse*

Conclusion

The Mo coating, which provides Copper free plasma, turned out to be a major step towards the ITER requirements for the negative ion source. First time effective electron suppression has been demonstrated in long pulses.

References

[1] P. Franzen et al., Nucl. Fusion 47, (2007), 264

[2] P. Franzen et al., Fusion Eng. Des. 82, (2007), 407

[3] W. Kraus et al., Rev. Sci. Instrum. 79, 02C108 (2008)