Ion energy measurements using a Retarding Field Energy Analyser on MAST

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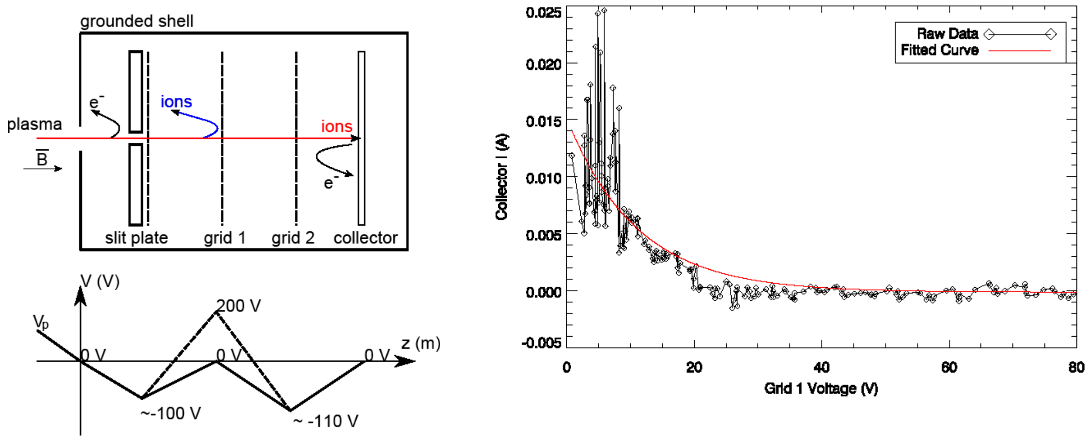
1. Introduction

The energy distribution of ions in the scrape off layer (SOL) of tokamak plasmas is an important parameter in determining sputtering yields of first wall materials. Understanding the amount of sputtering during both steady state plasmas and during transient events such as edge localised modes (ELMs) is important for future fusion devices such as ITER and DEMO where plasma impurities will impact on output power. Accurate measurement of ion energies is also important for the development of computer models of the SOL. Retarding field energy analysers (RFEAs) allow the measurement of the ion energy distribution using a series of electrically biased metal grids. RFEAs have been used in a number of tokamaks for ion energy measurements [1,2,3]. In this paper, preliminary results from a new RFEA installed on MAST will be presented. The new MAST RFEA is designed to measure ion energies on a timescale of tens of μs at energies up to 800 eV.

2. Method

2.1 Retarding Field Energy Analysers

A schematic of a retarding field energy analyser and grid voltage profile is shown in figure 1a. Plasma enters through a slit in a grounded shell which is aligned along the magnetic field to allow the discrimination of ions based on their velocity parallel to the magnetic field line. A negatively biased slit plate repels electrons and reduces the amount of plasma flux passing through to subsequent grids. Grid 1 is swept upwards in voltage to discriminate which energy ions are measured at the collector. Grid 2 is biased with a negative voltage to repel any secondary electrons released by ion impacts inside the analyser.



(a) (b)

Figure 1. (a) Schematic of a RFEA and RFEA grid voltages. (b) Typical sweep of grid one voltage and ion current measured at the collector. T_i=11.0±0.1 eV and I_0=0.015±0.001 A.

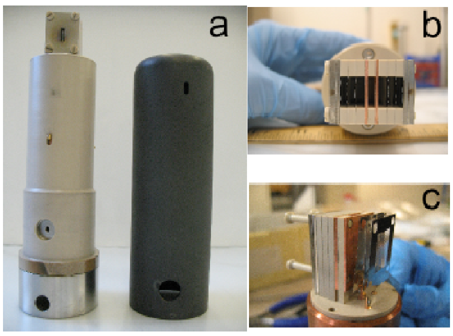


Figure 2. The MAST RFEA. (a) with graphite shell removed to show the two sided grid stack. (b) the grid stack with spacers removed. (c) top view showing bidirectional head.

A typical collector current versus grid 1 voltage graph is shown in figure 1b. The ion energy distribution can be obtained by differentiation of the collector current versus discriminator voltage data [4]. For fusion plasmas, with a Maxwellian ion distribution, the ion temperature (T_i) can be determined by fitting the following equation to the collector current (I_c) versus grid 1 voltage (V_{g1}) graph [5]:

$$I_c = I_0 \exp\left(-\frac{z_i V_{g1}}{T_i}\right)$$

where I_0 is the ion saturation current at V_{g1}= 0 V and z_i is the ion charge. If the electrons have a Maxwellian distribution, T_e can determined by measuring the slit plate current while the slit plate voltage is swept.

2.2 MAST RFEA

MAST is a spherical tokamak with a plasma major radius of 0.85 m and a minor radius of 0.65 m and plasma currents up to 1.5 MA [6]. Core densities range up to $1\text{x}10^{20}$ m^{-3} and core temperatures up to 3 keV. The MAST RFEA, shown in figure 3, has a bidirectional head to

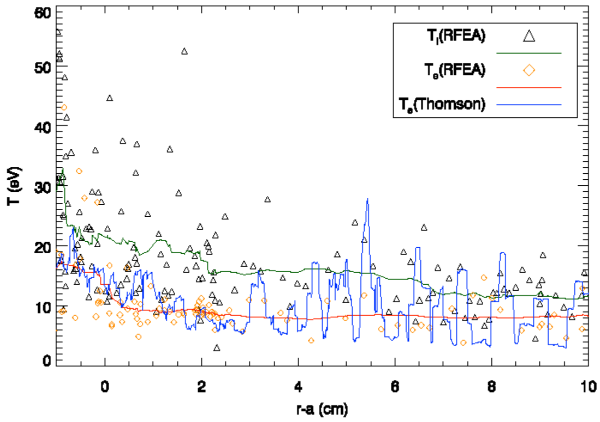


Figure 3. T_i and T_e measured by the RFEA in a L-mode 600 kA plasma as a function of distance from the last closed flux surface. T_e measured by Thomson laser scattering is shown for comparison.

sample ions travelling to both the upper and lower divertors of the vessel. The RFEA is mounted on a midplane reciprocating probe drive which allows measurements to be made over a 10 cm radial range during a shot.

3. Results

Preliminary measurements with the RFEA were made in a deuterium L-mode discharge with a plasma current of 600 kA and a toroidal field of 0.4 T. The RFEA was reciprocated up to the last closed flux surface (LCFS) and both the slit plate and grid 1 were swept (at different times) to allow both electron and ion temperatures to be measured.

Figure 3 shows the ion and electron temperatures measured by the RFEA on the side facing towards the upper divertor as a function of distance from the LCFS. Similar results were recorded on the side facing towards the lower divertor. A comparison to T_e measured by Thomson laser scattering is also shown. As shown in figure 4, T_i was found to be approximately twice T_e in the SOL. This is similar to results found in RFEA measurements in other tokamaks [7]. The spread in T_i values especially near the LCFS is attributed in part, to plasma filaments measured by the RFEA which cause current spikes and affect the curve fitting. Figure 5 shows the ratio of T_i to T_e for a number of MAST L-mode shots obtained using the fluid transport code B2SOLPS [8]. The results show a similar ratio to that obtained using the RFEA in the SOL.

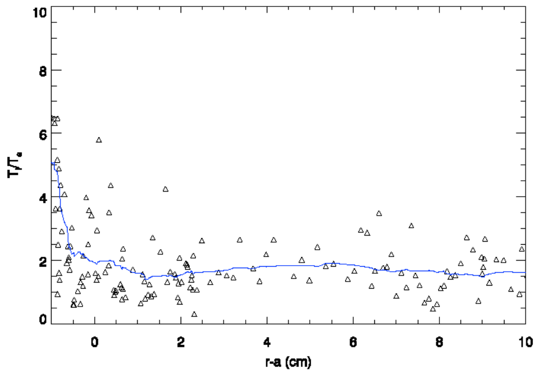


Figure 4. Ratio of T_i to T_e measured by the RFEA.

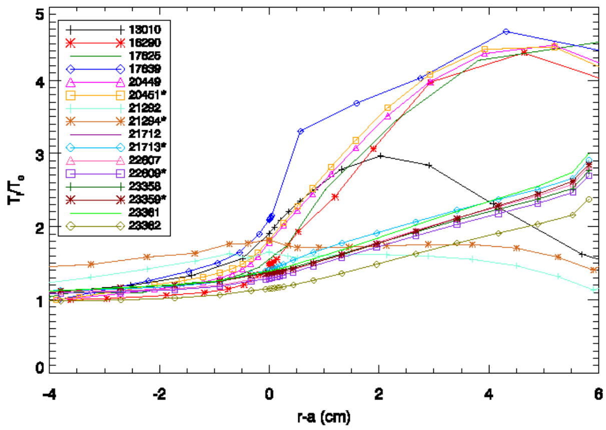


Figure 5. Ratio of T_i to T_e obtained using the fluid transport code B2SOLPS for a number of different MAST shots. The * symbol denotes shots which had stochastic fields.

4. Conclusions

Preliminary measurements of ion energy and density in the MAST SOL have been made using a RFEA in L-mode plasmas. T_i was found to be approximately twice T_e in the SOL which is in agreement with modelling data and earlier measurements. In the upcoming campaign, the RFEA will be used to measure T_i during steady state L and H mode plasmas and during transient events such as edge localised modes (ELMs). These measurements will be combined with those obtained from a new divertor RFEA currently being installed.

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