Impurity transport studies using fast imaging of injected carbon on the MAST tokamak

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The operation of next-generation fusion reactors will be significantly affected by impurity transport in the scrape-off layer (SOL). Current modelling efforts are restricted by a lack of detailed data on impurity transport in the SOL. A short burst carbon injector has been designed and installed on the MAST tokamak. The injector creates short lived carbon plumes originating at the MAST divertor lasting less than 50 micro-seconds. The injector uses high voltage capacitor banks that are discharged across concentric carbon electrodes located in the lower divertor. This results in a very short plume duration allowing resolution of the plume evolution and precise localisation of the plume relative to the X-point on MAST. Carbon was injected into Ohmic L-mode plasmas on MAST and emission from the plumes was imaged using 2 fast filtered cameras positioned at different viewing locations. The majority of images were filtered at the Carbon II(515nm) and Carbon III(465nm) emission lines while a D-alpha and a Carbon I filter were also used to give a measure of the plasma perturbation and initial source. A Langmuir probe was also incorporated into the injector to give a measure of the strike point location. Injection was performed at various distances from the separatrix by varying the timing of the ablation on a microsecond timescale. The plumes can be seen to expand towards the X-point parallel to the magnetic field over 3 frames with a frame rate of 75kHz or $13\mu s$. Significant perpendicular expansion is also visible on some pulses, which could be due to cross-field transport or neutrals being ionised far from the point of injection. This data will be used to constrain simulations using the onion skin model (OSM) code. Presented here are filtered images from the experiments run on MAST.

Introduction

The transport of impurities in the plasma Scrape-Off Layer (SOL) is of vital importance to the performance of existing and future magnetic confinement fusion devices. The impurities play a major role in both the heat loads to the plasma facing components and the performance of the core plasma. An understanding of the impurity transport is required in order to calculate the influx of impurities to the confined plasma which arise due to chemical and physical sputtering of plasma facing components.

The injection of impurities into fusion plasmas is a well known diagnostic technique that has been used to study core impurity transport on several tokamaks [1, 2]. The technique has also been used to study edge impurity transport near the point of injection[3, 4], providing the advantage of a known impurity source for plasma modelling. Detailed studies using edge impurity injection have not been carried out on a spherical tokamak and the advanced diagnostic capabilities available on the MAST tokamak mean that the technique is ideally suited to this machine.

Injector design

The Spark Gap Impurity Injector installed on MAST during campaign 8 ablates small quantities of carbon into the MAST divertor on a timescale of approximately $10\mu s$. A high voltage arc between a pair of concentric electrodes is used to ablate carbon directly from the electrodes. A schematic cross-section of the head design can be seen in figure 1. The head consists of a graphite shell mounted on a steel body. The electrodes are also graphite and are held in place mechanically by a pair of springs that rest on a PEEK support. Boron nitride insulators isolate the electrodes from the shell and also provide the insulation that creates the gap across which the discharge occurs. A Langmuir probe is also incorporated into the injector head. Power is supplied to the head by three kapton coated coaxial cables. The arc is formed by discharging a $1.5\mu F$ capacitor bank charged to 2.5kV across the electrodes. The capacitor bank power supplies and switching circuit are located in a container beneath the MAST vessel. Both the injector head and the power supplies can be installed and or removed from the MAST machine within a few hours. The switching is performed by an Insulated Gate Bipolar Transistor (IGBT) and controlled via an optical signal originating from the MAST data acquisition system.

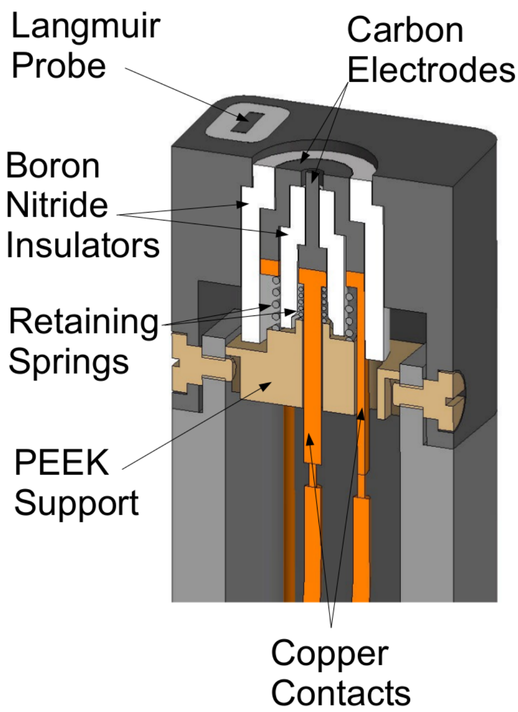

Figure 1: Schematic of the injector head

Experimental results

These initial experiments were seen as part of the commissioning process of the injector. Hence, L-mode shots without external heating were used. 13 injections were performed in the MAST standard shot before the introduction of NBI and 15 into plasmas using shot 26776, which was developed for experiments using the Retarding Field Energy Analyser on the Divertor Science Facility[5].

The carbon plume created by the carbon injector was imaged by a pair of fast filtered cameras located on sectors 1 and 11 of the MAST vessel. A 25mm lens was used on the fast cameras in place of the usual 50mm lens. This reduced the visible area and spatial resolution by a factor 2 but allowed the cameras to be run at 75kHz, close to the camera's maximum speed of 100kHz. This equates to a time between frames of $13\mu s$ and was fast enough to catch the creation and evolution of the plume. The majority of data was taken using filters at the frequency of the CII (515nm) and CIII (465nm) emission lines. Data was also taken using a D_α filter at 656.1nm and CI at 910nm to give a measure of the plasma perturbation and initial source.

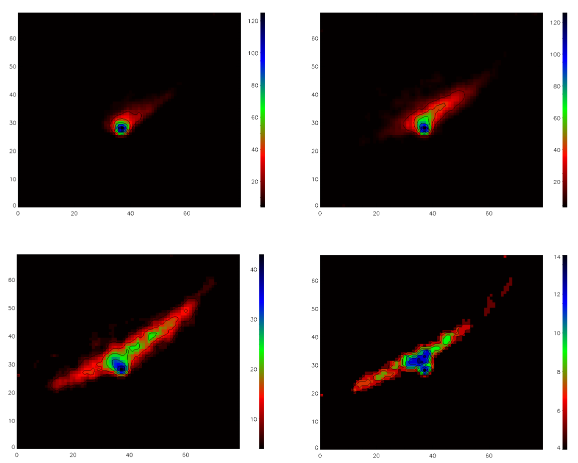

Figure 2: Images from shot 27103 separated by $13\mu s$ showing the evolution of the carbon plume filtered to Carbon II.

Data was taken in two sessions on MAST with the goal of performing a scan of injection locations relative to the outer strike point. The location of the plume was varied by changing the injection timing as the MAST strike points sweep outwards during a shot. The scan range achieved relative to the lower outer target was from 4.5cm inside the private flux region to 2.5cm into the outer SOL. An initial estimate of the timing was made using the EFIT equilibrium reconstruction from the reference shots. This method suffers from large errors due to uncertainties in the equilibrium reconstruction. The Langmuir probe installed on the injector was used to give a considerably more accurate reading of the strike point passing time, which was then used to calculate the actual injection location. The filters fitted to the fast cameras were mounted on remotely changeable carousels that allow the filters to be changed between shots. This allowed images to be taken using a CII filter on one camera and a CIII filter on the second, providing information on the evolution of the different charge states. Stereo images were also taken using

CII filters on both cameras, providing information on the 3D extent of the plumes.

Figure 2 shows carbon injection into MAST pulse 27098 at 180ms with line integrated density $n_e = 1.5 \times 10^{20} m^{-2}$ and plasma current $I_p = 770kA$. The images come from succesive frames of the fast camera located in sector 1 running at 75kHz with a CII filter. The resolution of the images at the injection location is $\sim 5mm/pixel$. The plume can be seen to extend towards the X-point over 3 frames before beginning to disperse in the final frame. This expansion occurs over $40\mu s$ and is somewhat quicker than that expected from a simple calculation of the plasma sound speed. Other images taken using the CIII filter only show emission at the injection location. This may be due to the rapid expansion of the plume along the field line not allowing sufficient time for the C^{2+} state to be reached, although modelling of the injection is required to confirm this. The emission from the plumes in this and other shots can also be seen to extend perpendicular to the field lines. This could be due to injected neutrals becoming ionised away from the injection location or cross-field transport of ionised carbon.

Future work

The data gathered in the injection experiments will be used for modelling of the parallel and cross-field impurity transport using the OSM[6] fluid code and the DIVIMP[7] and EIRENE[8] Monte-Carlo codes. OSM will provide 1 dimensional solutions for the background hydrogenic plasma along individual flux tubes which will then be used as input for DIVIMP and EIRENE. The Divimp code will simulate the impurity ions in the SOL in 2 dimensions. EIRENE will be used to simulate neutrals coming from the injector in 3D. Ideally both ions and neutrals would be simulated in 3D, however further work is required to achieve this.

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