Fast carbon ablation as a diagnostic on the MAST tokamak

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Abstract

The operation of next-generation fusion reactors will be heavily 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 for use on the divertor science facility on the MAST tokamak to create short lived carbon plumes of duration $\sim 10\mu s$. This timescale is considerably shorter than the typical SOL dwell time in the MAST tokamak of $\sim 1ms$. The injector uses sparks generated by high voltage capacitor banks across carbon electrodes to ablate carbon into the plasma. Emission from these plumes can then be imaged using the fast visible and UV spectroscopic cameras available in the MAST divertor, providing data on SOL impurity transport. The short duration of the carbon plumes allows spatial and temporal resolution of the carbon emission, potentially leading to an improved understanding of local parallel and perpendicular impurity transport. Presented are injector design, operational characteristics and high speed imaging of spark plumes.

Introdution

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 the fusion plasmas is a well known diagnostic technique that has been used to study core impurity transport on several tokamaks [1, 2, 3]. The technique has also been used to study edge impurity transport near the point of injection[4, 5], providing the advantage of a known impurity source for plasma modelling. Detailed studies using edge impurity injection have not been carried out on a sperical tokamak and the advanced diagnostic capabilities available on the MAST tokamak mean that the technique is ideally suited to this machine.

Laser ablation and gas injection have previously been used in impurity injection experiments. The goal of this project is to use an injector design consisting of a high voltage discharge across concentric carbon electrodes, allowing small, short duration plumes that should not significantly perturb the plasma. The cost of such a system is also relatively low. The injector will be situated in the Divertor Science Facility (DSF) on the MAST tokamak. This system allows easy placement and adjustment of probes and samples close to the lower divertor targets for the investigation of plasma-material interactions and SOL characteristics. The head of the facility fits into a space in the divertor tiles and can be remotely lowered into an isolated crucible, allowing the head to be replaced without the need to vent the main vacuum vessel.

Design and installation

Figure 1: Electrode geometry

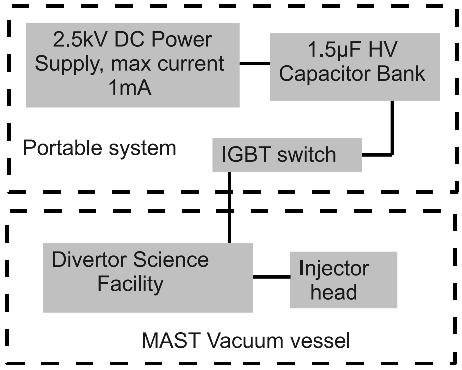

Figure 2: Schematic of the proposed system

Cylindrical concentric electrodes were chosen for the injector head (see figure 1). This takes advantage of the Marshall-gun effect, accelerating ions away from the head into the divertor plasma. The discharge is intended to be $\leq 10\mu$s in duration, significantly shorter than the estimated $\sim$ 1ms SOL dwell time. The fast discharge is accomplished by discharging a $1.5\mu F$ bank of capacitors across the electrodes. The capacitors are charged by a 2.5kV DC/DC converter, equating to a stored energy of 4.7J. The fast switching is accomplished with an Insulated Gate Bi-polar Transistor (IGBT).

The installation of the injector system will be simplified by incorporating the power supplies and switching into a removable container that can be placed close to the MAST vessel when the injector is to be used. This will be connected to the injector head by standard coaxial cabling. The system will be connected to the MAST control systems by a small wall mounted interface supplying 12V power and data transfer. Figure 2 shows a schematic of the proposed system.

Injector testing

The injector is being tested in a chamber operating at pressures down to $\sim 5\times10^{-7}$mbar at Dublin City University. Quartz crystal monitors have been used to measure the mass of carbon ablated from the injector head and this is estimated to be up to $\sim 10^{15}$ particles per discharge. Figure 3 shows the results of energy dispersize X-ray spectroscopy that shows the ablated material to be carbon apart from a small fluorine signal which is likely to have originated from the external environment, the signal due to gold is caused by the gold coating of the quartz crystal monitor.

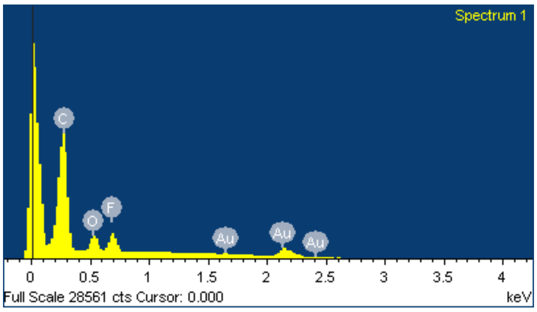

Figure 3: EDX spectrum of ablated carbon

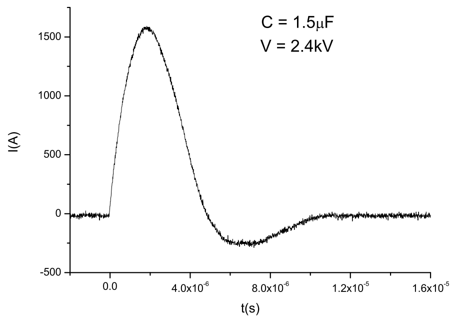

Figure 4: Carbon injector discharge current

The discharge duration is governed primarily by the size of the capacitor bank used. The duration of the current pulse from a 1.5μF capacitor bank can be seen in figure 4. Figure 5 shows fast visible imaging of the plume at 50, 500 and 3000ns for a discharge with a 200nF capacitor bank, showing the creation of the plume less than 50ns after the beginning of the current pulse and the end of the plume after 3μs.

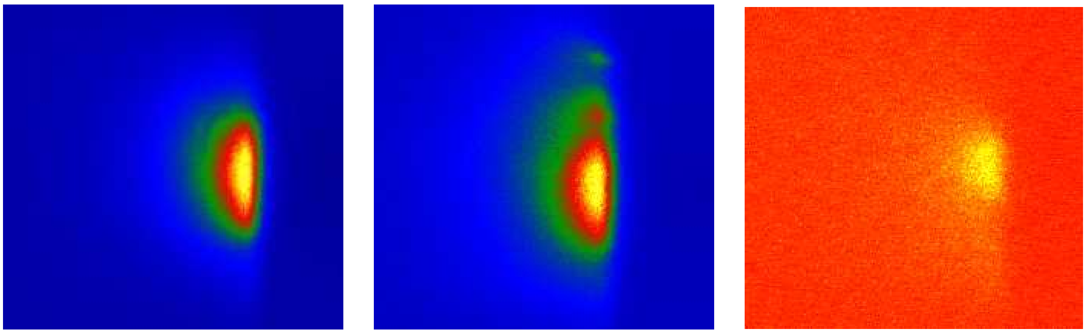

Figure 5: Visible images of the plume at 50ns, 500ns and 3000ns. Actual size 1cm

Impurity transport modelling

The parallel forces on impurity ions in the tokamak SOL are presently represented by the following five terms

$$F_Z = ZeE - \frac{1}{n_Z}\frac{dp_Z}{ds} + m_Z\frac{(v_i - v_Z)}{\tau_s} + \alpha_e\frac{d(kT_e)}{ds} + \beta_i\frac{d(kT_i)}{ds} + \ldots \quad (1)$$

these terms are due to the parallel electric field, the impurity pressure gradient, the frictional drag due to bulk plasma flow and the electron and ion temperature gradient terms.

Spectroscopic images of the evolution of the carbon plumes as well as Langmuir probe and Thomson scattering data obtained in the ablation experiments will be used to verify these terms using the Onion-Skin Model(OSM) code written by S. Lisgo [6]. This code is based on the Onion-Skin Method composed by P. Stangeby whereby the plasma is represented by a collection of flux tubes. This allows the plasma to be treated as a collection of 1-D fluid equations, simplifying the background plasma solution. A time-dependent extension will be added to the OSM code and the OSM fluid model will be coupled with a basic kinetic impurity model allowing the transport of the impurity ions to be studied.

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