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NSTX Tangential Divertor Camera

by

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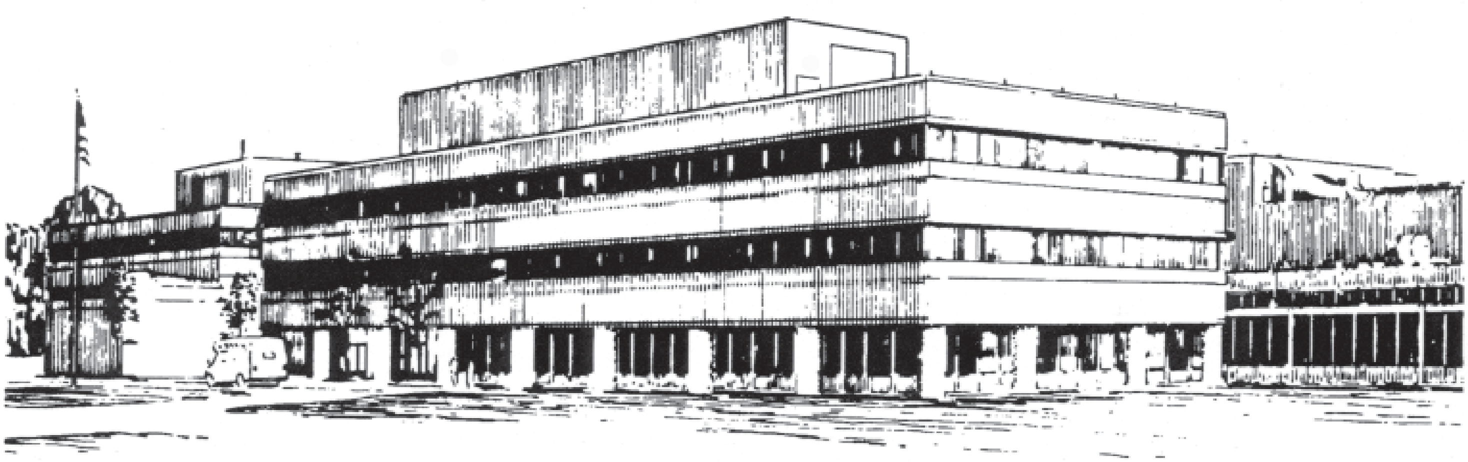

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NSTX Tangential Divertor Camera *

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Abstract

Strong magnetic field shear around the divertor x-point is numerically predicted to lead to strong spatial asymmetries in turbulence driven particle fluxes. To visualize the turbulence and associated impurity line emission near the lower x-point region, a new tangential observation port has been recently installed on NSTX. A reentrant sapphire window with a moveable in-vessel mirror images the divertor region from the center stack out to R~ 80 cm and views the x-point for most plasma configurations. A coherent fiber optic bundle transmits the image through a remotely selected filter to a fast camera, for example a 40500 frames/sec Photron CCD camera. A gas puffer located in the lower inboard divertor will localize the turbulence in the region near the x-point. Edge fluid and turbulent codes UEDGE and BOUT will be used to interpret impurity and deuterium emission fluctuation measurements in the divertor.

I Introduction:

Tangential camera views of the lower divertor have been implemented on D-III D[1], C-Mod[2] and JET[3]. These systems have been used to characterize divertor phenomena such as particle and heat flux propagation, especially in regards to recycling and detached plasmas at the inner and outer divertor regions, impurity line emission, Edge Localized Modes (ELMS), impurity transport and more. Recent results from the 3-D edge turbulence code, BOUT, have predicted that the strong magnetic field shear in the region of the x-point will effectively isolate local turbulence in the divertor region from turbulence upstream. [4] Recently, a tangential view of the lower divertor was developed on NSTX with the primary purpose of studying turbulence and associated transport in the lower divertor region.

As the result of a collaboration between Hiroshima University in Japan and PPPL, an Ultima SE high speed camera manufactured by Photron has been fielded on NSTX specifically to study divertor phenomena. This camera has previously been applied to divertor studies on NSTX but from a downward viewing midplane port.[5] A test of the prediction by BOUT may be obtained by imaging the divertor region with a fast camera and by utilizing the lower dome gas injectors located in the inner divertor which were installed for the coaxial helicity injection experiments. This would supplement the existing gas puff imaging diagnostic already viewing the outer midplane.[6]

II Experimental Configuration

A horizontal port at Bay F on the lower dome of NSTX is located at approximately the height of a standard x-point. The passive plates are located about 60 cm from the port flange. One of the passive plate tiles, 12.8 cm high by 6.4 cm wide, and its copper backing plate were cut away to initially give radial viewing access to the divertor region. Removal of a small section of passive plate had little effect on the wall stabilization properties of the passive plates as the plasma is never in close proximity to the passive plates at this location.

In order to increase the field of view, a re-entrant sapphire window on the end of a 50 cm long by 5cm diameter tube was installed to reach near the cutout in the passive plate. To view the divertor region tangentially through a radially-viewing aperture required angling the reentrant tube slightly off-radial by ~10° and employing a stainless steel polished mirror on the end to aim the view tangentially through the cutout. The primary passive plates are angled inboard at their bottom to conform to the plasma shape. When viewing through this aperture tangentially, the effective aperture becomes an inverted and truncated right triangle. Fig. 1 shows the approximate area of the lower divertor that is being imaged. By adjusting the mirror angle and the location of the fiber, it is possible to see the center stack, the inner strike points and the x–point, but not the outer strike point in one view. The outer strike can be viewed by adjusting the mirror angle to look more outboard.

The mirror doubles as a shutter to protect the sapphire window during glow discharge cleaning, boronization and bakeout. An inspection of the window during a recent vent showed the back of the mirror to be heavily coated but the window and inner mirror surface were still in pristine condition. Stainless steel shim stock is wrapped around the last six inches of the tube and stood off from the tube by 4 mm. This acts as a heat shield and is required because the end of the tube is approximately one centimeter away from one of the bakeout lines that reaches ~375° C.

The image is transferred away from the window by a 2.7 meter long 400X400 fiber optic bundle manufactured by Schott. A 50 mm output lens is close coupled to the camera lens and both lenses are set to infinity. Intermediate to the two lenses is a remotely operated rotating filter wheel that holds up to four interference filters (generally H□, HII, CI, and CIII) with one blank aperture. The camera lens is a 90 mm remotely controlled lens with variable iris, focus and zoom controls. When the camera is operated at its fastest frame rate using only the central 64X64 pixels, the lens can be zoomed out so that the image fills the full active array.

The camera is a charge-coupled device (CCD) camera and is capable of operating from 30 to 4500 frames per second (fps) in the full frame(slow) mode using its full complement of pixels(256X256 pixels). At faster frame rates, the number of active pixels are progressively reduced until the maximum frame rate of 40500 fps is achieved with a corresponding active array of 64X64 pixels. The active subset of pixels are centrally located within the array which simplifies the optics. Once triggered, the camera takes frames until its memory is full. This results in 8012 data frames in the full frame mode and 131072 data frames at 40500 fps. More than 3 seconds of data can be taken at the 40500 fps so that a full discharge ($\leq$ 1 sec) on NSTX can be recorded. The camera memory is more than five hundred megabytes which is an excessively large amount of data to store for every discharge so that each shot is recorded in local memory and only a subset of data, usually amounting to about 50 megabytes per discharge, is selected around the time of interest and permanently archived. The optical components are shown in Fig. 2.

The spatial resolution at the highest speed at the tangency plane of the x-point is estimated to be of order 1cm in the horizontal plane and approximately 0.7 cm in the vertical direction.

III. Operation

Initial operation has concentrated on optimizing the optics to obtain the best view. A 6 mm input lens with a 40° fov and 12 mm input lenses with a 20° fov have been tried. The six mm lens gives the best coverage of the divertor but uses only about 50% of the pixels. The 12 mm lens gives better resolution at the expense of a reduced viewing area so that the optimum lens has not yet been obtained. A larger diameter fiber will also improve the light throughput which is especially useful when the interference filters are used.

The lower dome gas injectors are presently configured so that all injectors open at the same time. Work is underway to allow each injector to be operated individually. Also, in the present configuration, only deuterium gas can be used in the dome injectors because they share a gas bottle with the injectors on the center stack injector which are used almost every discharge. Preliminary gas puffs using all four of the lower dome injectors, each injecting one Torr-liter of deuterium gas, successfully injected into a plasma near the end of the pulse and a noticeable enhancement over the ambient plasma light was observed. The 40500 fps rate was sufficient to reveal a non-coherent churning motion of the plasma, resembling boiling water, and can only be appreciated in movie form. Meaningful localized measurements will have to wait for operation with a single injector.

IV. Initial results

Even without the gas puff, many interesting phenomena have been observed. The formation and evolution of the x-point (Fig. 3) is clearly observed along with its inner strike point with the proper orientation of the fiber optic lens. Also, H-mode transitions and associated ELMS are easily distinguishable and what are believed to be MARFS are routinely formed on the center stack.

An example of the camera performance is given in Fig. 4. The evolution of a small ELM is recorded using an H_{α} filter. The x-point on this discharge was below the fov of the camera. A localized region of emission builds up near the center stack and rapidly collapses downward but stays contained within the envelope of the leg of the x-point. A small reduction in the stored energy is observed. Each frame in Fig. 4 is 25 μsec duration so that the formation and decay of the ELM is over in ~250 μsec.

V. Future Plans

The main improvement to the camera system is to obtain a view of the entire divertor region. This may be obtained by enlarging the limiting aperture in the passive plates or by relocating the window just behind the plane of the plates. The second method would probably result in rapidly coating the window by plasma operation.

The gas puff may localize the turbulence so that spatial inversion of the image is not required. However, other measurements requiring profile information will need to have an inversion performed. This is clearly the case, since the outer strike point is often visible on the far side of the divertor especially in the toroidally symmetric gap between the inner and outer divertor region. Also, a second view is being considered to image the divertor from the top of the machine. More than three fourths of the machine would be visible from an upper view if a re-entrant port is implemented. The view from above would shed light on many issues regarding toroidal symmetry, as well as yield information on the various divertor operating regimes.

Acknowlegments

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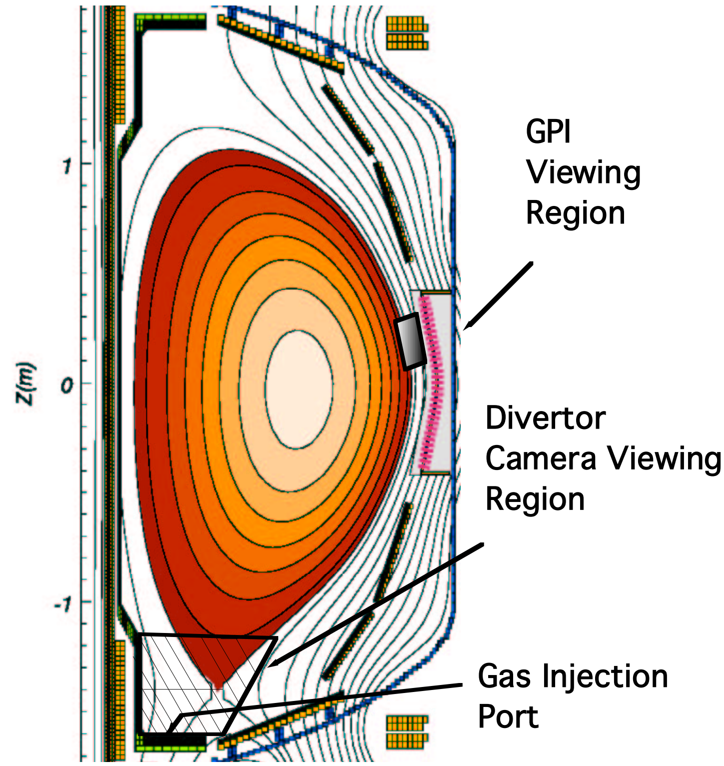
Figure Captions

FIG.1 Elevation of NSTX showing the approximate area imaged by the divertor fast camera. At the x-point the imaged area extends from the center stack out ~ 50cm. The imaged area can be adjusted outboard by changing the mirror angle.

FIG. 2 Optical and mechanical components of the divertor fast camera.

FIG. 3 Photos of the x-point during L-mode operation.

FIG. 4 Evolution of a Type III ELM using H-alpha filter. Each frames is 25μec duration. The emission rapidly increases near the center stack and collapses in 250 μ sec.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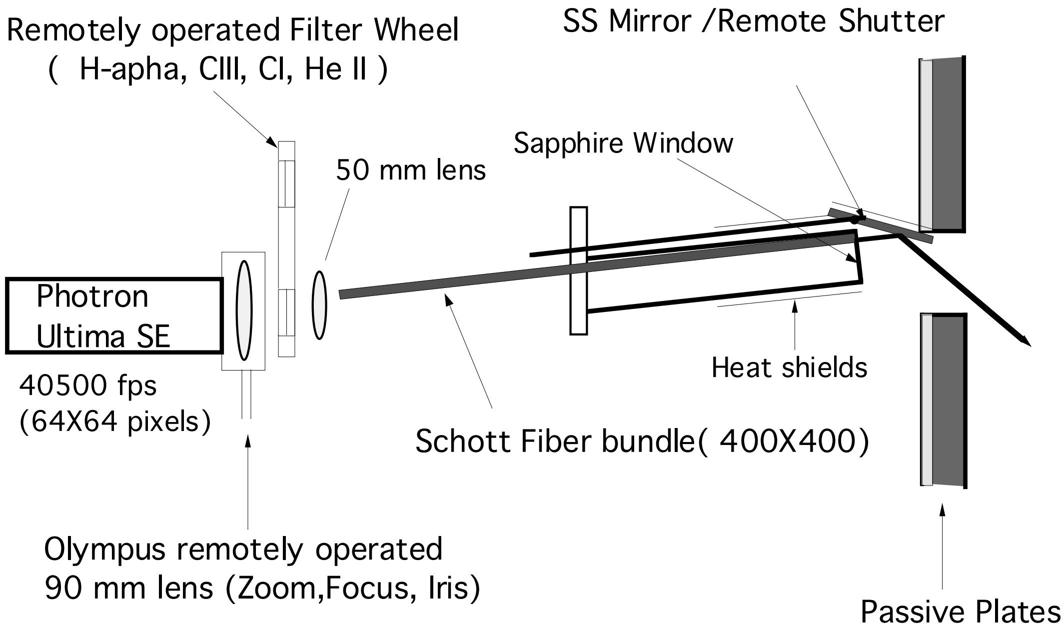
Remotely operated Filter Wheel
(H-apha, CIII, CI, He II)
SS Mirror /Remote Shutter
Sapphire Window
50 mm lens
Photron
Ultima SE
40500 fps
(64X64 pixels)
Heat shields
Schott Fiber bundle(400X400)
Olympus remotely operated
90 mm lens (Zoom,Focus, Iris)
Passive Plates

Fig. 2

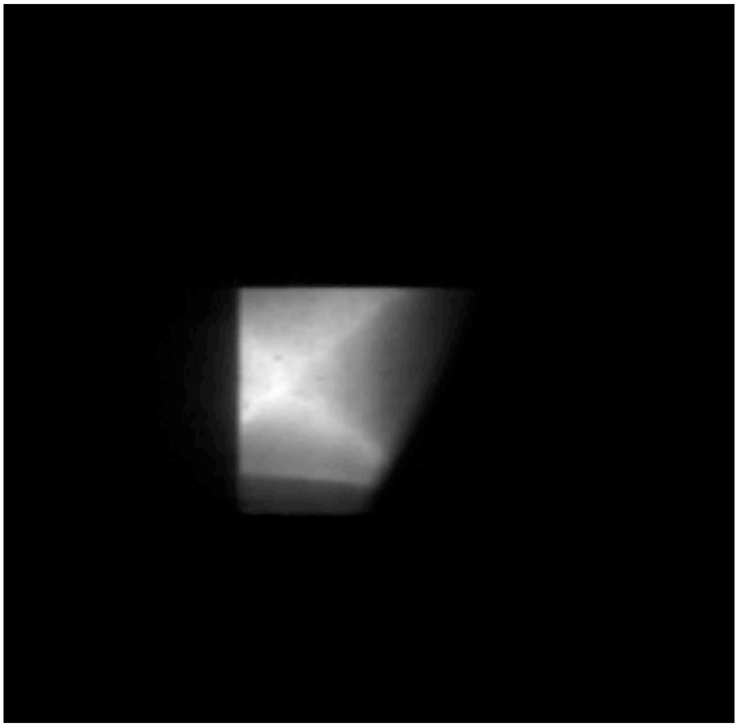

Fig 3

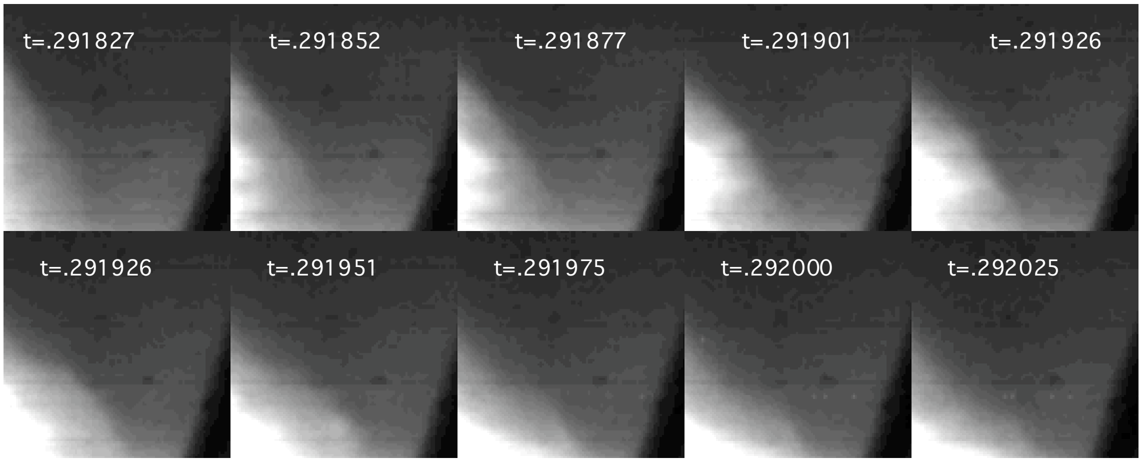
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Fig. 4

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