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Observation of heat flux to outer divertor plate on the HL-2A Tokamak

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Introduction

Since the erosion problem of divertor plates will become severe in reactor-relevant tokamaks with high plasma power densities and discharge durations, the strategy to reduce the peak divertor heat flux and the control of power deposition to the divertor plate are becoming important issues in tokamaks operation and experiments as well as for ITER[1-2]. Typically the heat fluxes can be derived using data from infrared cameras, Langmuir probe array or thermocouples[3-5]. As the first operational divertor tokamak device in China, an infrared camera have been developed on HL-2A to quantify the heat flux to the outer divertor plate and study the characterization of the power deposition under different discharge scenarios.

The new infrared camera system has been used to measure the evolution of surface temperature on the outer divertor plate on HL-2A, from that the net power deposition can be derived by one dimension heat diffusion model. The arrangement of IR camera system is shown schematically in Figure 1. The infrared camera contains uncooled Focal Plane Array detector sensitive from 7.5μm to 13μm radiation, allowing surface temperature from -20°C to 900°C to be measured. A Zinc Selenide window that transmits in the infrared is used as the vacuum window. Camera control can be performed remotely and 60 Hz, 14-bit, 320×240 pixels images can be captured through the Firewire Repeaters and 50m long fibers in real time mode. The field of view is 9°×7°, which can provides good coverage of the strike point on the outer divertor plate and the spatial resolution can be less than 1mm in the vertical direction. The surface temperature has been corrected by object parameters and calibrated in situ in the temperature range up to 120°C during the baking period of HL-2A.

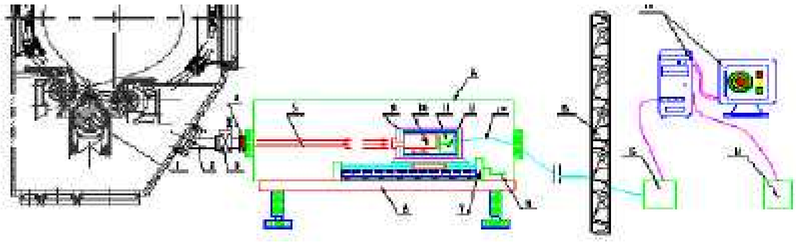

Fig1. The schematic arrangement of IR camera system on HL-2A

1. Observation of the strike point by IR camera

HL-2A is a closed divertor tokamak device and the structure of divertor plate is 8mm thickness copper with water-cooled. The LSN (Lower Single-Null) divertor configuration has been achieved and stably sustained by using parallel connection method with good feedback

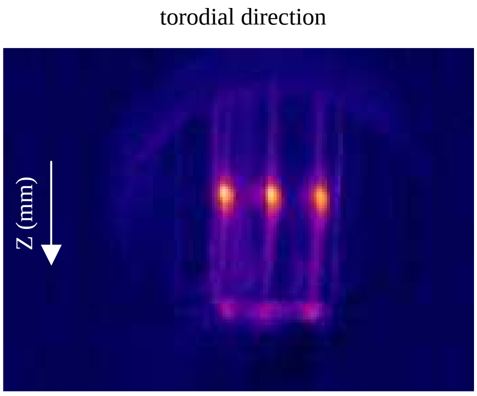

Fig 2. Image captured by IR camera

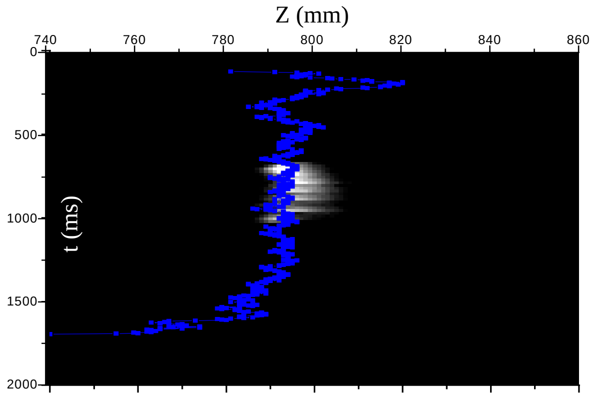

Fig 3. Agreement of CF simulation (blue) with experiment

control of plasma current and position[6]. In 2006 campaign, the torodial magnetic field is reversed to make the drift of ion B×∇B toward X-point. The strike point on the outer divertor plate has been clearly observed by the IR camera system, typically like the image shown in the figure 2. It shows non-toroidally-symmetric heating at the outer divertor strike points. Hot spots are normally found on leading edges of the copper divertor tiles.

The position of separatrix on the outer divertor plate can be simulated by current filament(CF) code[7], which can reconstruct the last closed flux surface(LCFS) of plasma by 18 pick-up coils located around the plasma column. The position of separatrix can also be determined in typical ohmic and L mode discharge by the peak of deposited power density, which is computed from the space and time-dependent surface temperature values. The comparison of the simulation result, which marked by the blue line, with the evolution of deposited power density in shot 6170 is illustrated in figure3. From that, it could be seen that a good agreement exists, especially during the ECRH heating period.

2. Behavior of deposited power density

The deposited power density remains small in ohmic discharge. Typical values are from $20W/cm^2$ to $40W/cm^2$ what amounts up to about 8%-15% of the ohmic heating power for the lower outer divertor plate. The deposited power density increases with the power of auxiliary heating. It can reach 120 W/cm^2 sometimes under ECRH heating. The mean width of the power density profile (FWHM) is obtained to be about 1.5cm in typical ohmic discharge and less narrower in L mode ones. The value and profile of deposited power density are trying to match the data from B2.5. Unfortunately the simulation results from the code show the power density is lower but the mean width of the power density is wider than those obtained by the experiment. Further work is being done.

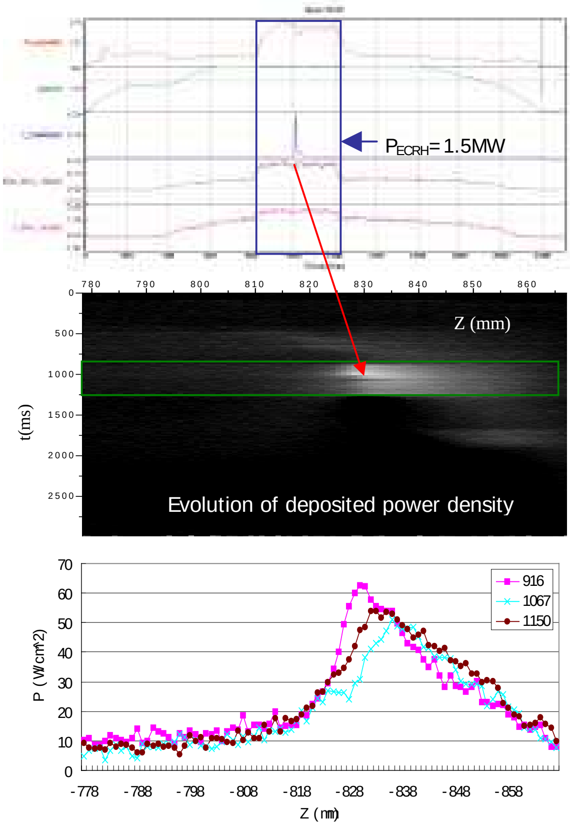

Fig4. Evolution of plasma parameters and profile of deposited power density in shot 5945.

The accurate control of MBI has been developed. From the analysis of deposited power density, it seems the injected MBI pulses in ohmic phase have less effective to the power deposition. But during ECRH heating, the MBI injection could be more effectively to reduce the heat flux to the divertor plate. The evolution of plasma parameters and the profile of deposited power density under ECRH heating in shot 5945 have been illustrated in Figure 4. From that, it is easily to see the deposited power density at the separatrix drops quickly during the MBI injection and then recovers later, though the deposited power density far from the separatrix almost keeps constant.

3. Dissipiating of the divertor heat load

The strategy to reduce the divertor heat load is also an important issue in tokamak operation. Two techniques are normally used to dissipating the divertor heat load. One is the strike point sweeping and another is impurity gas puffing. In 2006 campaign, the strike point sweeping has been achieved by changing the ratio of the plasma current to the current of the second multipole coil. From that experiment, it has been found that the strike point on the outer divertor plate moves about 3cm upward when the ratio of I_p/I_{mp2} increases about 10% in 300ms. The heat load has been effectively dissipated in this enlarged area by sweeping.

The impurity gases have also been injected into the outer divertor chamber for alleviating the heat load. Argon and helium have been used but the result shows the helium is better than argon in last year' s plasma parameters on HL-2A. The results of helium injection in shot 5347 are presented in the figure 5. Six helium gas pulses have been injected into the outer divertor chamber at the plateau of the plasma current. The integrated power radiated from outer divertor chamber increased by a factor of two and the integrated deposited power on the outer divertor plate decreased to its half value before and after the helium injection, and the total

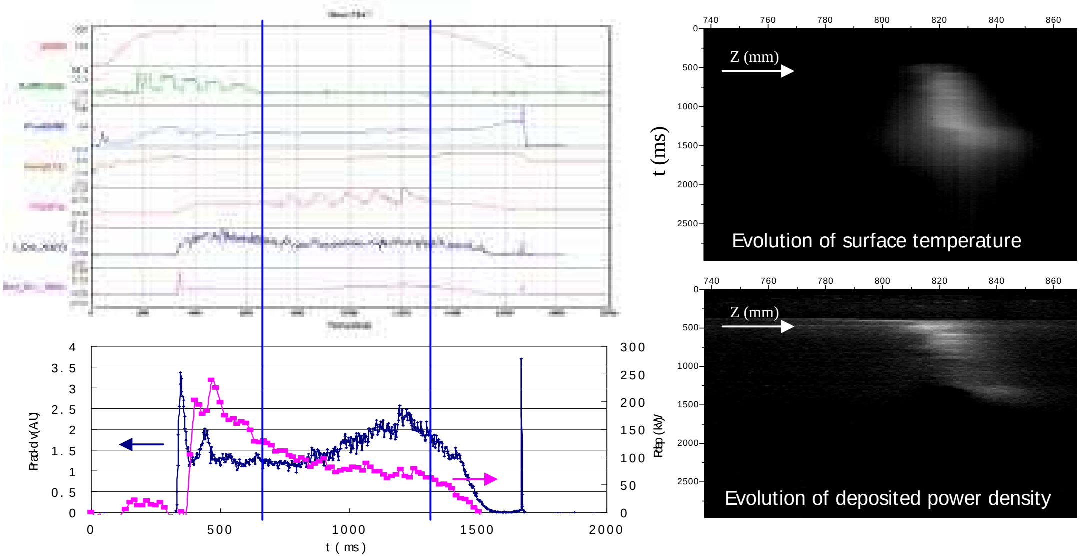

Fig5. The evolution of plasma parameters during helium injection in shot 5347

power radiated from the core plasma almost kept constant. The heat load is effectively dissipated by enhanced radiation in the divertor charmber. It can also be proved by the data from Langmuir probes fixed on the outer divertor plate.

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