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The observation of dust behavior in TRIAM-1M

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Abstract

The observation of dusts in plasmas was carried out by high speed camera in full non-inductive lower hybrid current drive (LHCD) plasma on TRIAM-1M. The velocities of dusts were 10–50 m/s. The number of dust generated per second increased with the discharge duration in the range of 20–57 s. This suggests that a part of dusts were generated from a movable limiter whose the surface temperature increases with the discharge duration. Dusts were coming from various directions even close to the movable limiter. Dusts were collected in the vacuum vessel by use of a kind of cleaner and the composition and the size of dust were examined by Scanning Electron Microscope (SEM). Dust size was several μm and composition was Molybdenum mixed with small amount of elements of stainless metal. The poloidal distribution of the collected mass of dusts was almost uniform.

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Keywords: Limiter materials; Molybdenum

1. Introduction

On the fusion reactor research, considerable uncertainty still exists in the prediction of several key aspects; for example, tritium retention, disruption, impurity control, ELMs, SOL transport and dusts [1]. The main impact of the dusts was related to tritium inventory. Recently it is also considered that dust behavior can be an important mechanism of core plasma contamination by impurities [2].

Collection of dusts in the vacuum vessel had been executed on several devices; NSTX, ASDEX-Upgrade, LHD and JT-60 [3–5]. The average size of the collected dust particles was about ∼3 μm in NSTX, ASDEX-Upgrade and JT-60, and about ∼9 μm in LHD. Dusts contained some amount of carbon. The reason seems to be that some of the plasma facing components (PFC) was made of carbon. Dusts may play an important role in the tritium inventory even in the metal wall devices.

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The characteristics of dusts in the metal wall devices should be investigated.

The generation and movement of dusts are not investigated so much. For example, the relationship between the amount of collected dusts and images of dusts moved in plasma or generated from limiters is not clear. To investigate the mechanism of generation of dusts in plasma, the dusts behavior in plasma should be studied.

In this paper, the characteristics of dust during the plasma discharge in the TRIAM-1M superconducting tokamak with PFCs made of metal such as molybdenum and stainless steel was observed with the high speed camera, and the dust collection was executed after the experimental campaign.

2. Experimental apparatus

2.1. Experimental conditions

TRIAM-1M ($R_0 = 0.84$ m, $a \sim 0.12$, $B = 6$–7 T) is a high field tokamak with superconducting toroidal field coil, and it has a capability to produce a long duration discharge by use of full non-inductive lower hybrid current drive (LHCD) way up to more than 5 h [6] in the significant low power region (<20 kW). In high power region (>50 kW), it is difficult to maintain the plasma more than 2 min because of the significant effect of hot spots on PFCs. The two kinds of power source to heat the plasma are installed on TRIAM-1M, one is a 2.45 GHz LHCD system with microwave power up to 50 kW and the other is two 8.2 GHz LHCD systems up to 400 kW. Dust behavior in the plasma was mainly observed in high power discharges with limiter configuration, in which the parameters are plasma current ~30 kA, electron density $1.2 \times 1019\ \mathrm{m}^{-3}$, RF power ~60 kW, duration discharge 20–60 s.

2.2. High speed camera

The high speed digital camera was installed in TRIAM-1M to observe dusts behavior in plasma. The observations in two views of the fast camera as shown in Fig. 1 were executed. In the view of (A) in Fig. 1, the camera was set up at a position about 2.4 m away from the plasma center because of the complicated port configuration. The focus of a lens was 100 mm. The camera can operate from 30 to 4500 frames per second (fps) in the full frame mode using its full complement of pixels (256×256 pixels). In this experiment, high speed camera operated at 4500 fps. The camera data was stored around the plasma termination. The stored duration of images was about 1.8 s.

In the case of view of (B) in Fig. 1, the optical fiber was used. The surfaces of the fixed limiter and the movable one were able to be observed directly. The shutter was installed on the vacuum window to prevent from being coated by sputtering materials.

3. Observation of dusts in plasma

Dusts in the plasma are able to be observed by high speed camera in the view of (A) in Fig. 1. In the appearance of dusts, the electron density, the

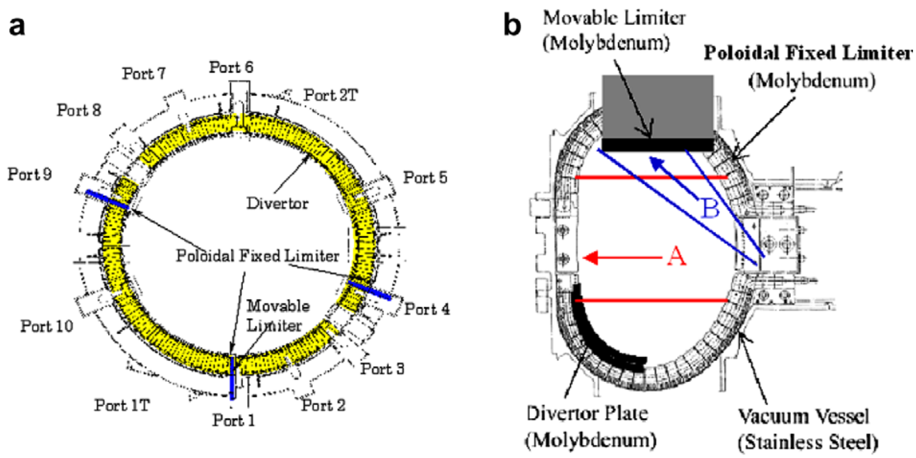

Fig. 1. Schematic diagram of TRIAM-1M. (a) toroidal view; (b) poloidal view at port 1. The high speed camera was installed at port 1.

plasma current, and radiation from impurities did not vary significantly. The plasma was attached to the movable limiter as shown in Fig. 1. The time-traced images around the appearance of dusts are shown in Fig. 2. It is clearly seen that a dust moved in the plasma from the left under to the upper right. The velocity of the dust can be estimated from time interval between two images and the moving distance referred to the size of a fixed limiter. The estimated velocity of dusts was in the range of 10–50 m/s. The number of dusts per second duration in the view of (A) shown in Fig. 1 clearly increases with the duration of the discharge (Fig. 3). It should be noted that all plasma parameters become to be in

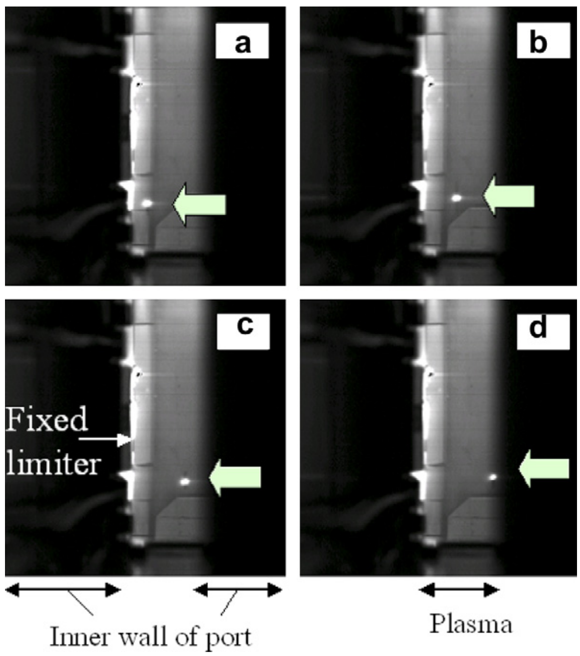

Fig. 2. A series of pictures of moving dust in the view of (A) in Fig. 1. The time interval of the pictures is about 3 ms.

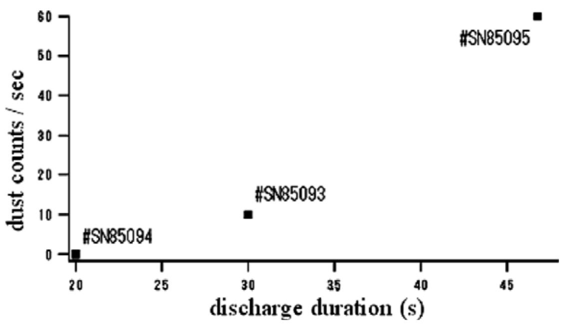

Fig. 3. The relation between discharge duration and the number of dusts counted in the view of (A) in Fig. 2.

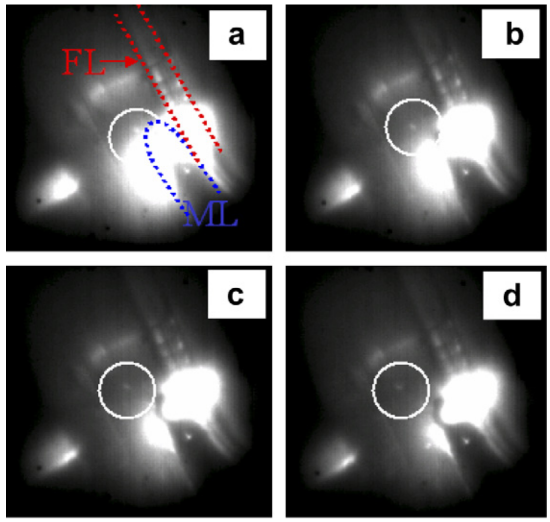

Fig. 4. Picture of a dust emitted from movable limiter in the view of (B) in Fig. 1. FL: fixed limiter, ML: movable limiter.

steady state even in a 20 s discharge and the temperature of the first wall made of stainless steal does not change yet, while the surface temperature of the limiter monitored by the infrared spectroscopy increases with the duration of the discharges [7] and a hot spot appears on the limiter surface during the discharge. This strongly suggests that a part of dusts were generated from limiters.

To make sure that dust generation is emitted from the surface of the limiter, the observation in the view of (B) shown in Fig. 1 was carried out. The bright region corresponds to the hot spot on the surface of the limiter. A dust was emitted from the hot spot and it moves as shown in Fig. 4. This indicates that the hot spot is a source of dusts.

The move direction of dusts was also investigated. Dusts come from various directions even in the view of port 1, where was close to the movable limiter position. Dusts generated on the limiter sur-

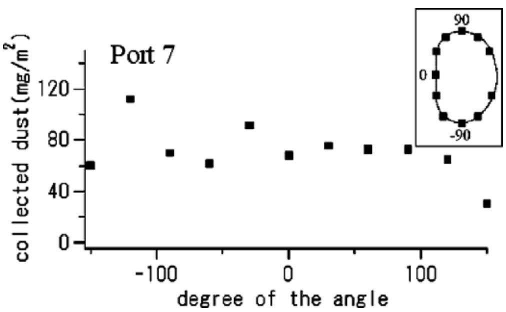

Fig. 5. The poloidal distribution of collected dust at port 7.

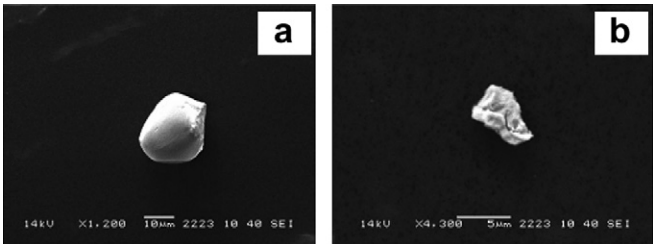

Fig. 6. SEM images of dust obtained from lower divetor plate on port 7. (a) Spherical type, (b) flake type.

face may be reflected by the wall. In fact, the reflection of a dust was observed with the high speed camera in discharges. It is not clear that the reflection of dusts play a dominant role in the presence of dusts in various directions. It should be considered the other the dust generation approaches, such as arcing.

4. Dusts collection in the vacuum vessel after the experiments

No effects on the main plasma parameters were observed in the experiment, when many dusts were moved in plasma. This indicates that the volume of dust was very small. The collection of dusts in the vacuum vessel was executed to investigate the size of dusts. Dusts were collected through the 100 nm filtered vacuum technique [8].

Twelve locations in the poloidal direction were sampled at port 7 and the increment of weight before and after the sampling is plotted in Fig. 5. Port 7 is far from movable and fixed limiters as shown in Fig. 1, so it is expected that the averaged amount of dusts is estimated. The distribution of amount of dusts is uniform and this suggests that the gravity does not play an essential role in the attachment of dusts to the wall. The distribution has no contradiction with the observation by the high speed camera, which implies dusts moved in various directions.

SEM is used to investigate the component and the shape of dusts. Typical SEM images of the collected dusts are shown in Fig. 6. There are two shapes of dusts. One is the spherical shape as shown in Fig. 6(a) and the other is the flake shape in Fig. 6(b). The size of about 90% dusts was 1–5 μm. Most of the dusts with more than 10 μm are the spherical shape, while the size of the flake type is less than 10 μm. The elemental composition of the collected dusts was detected by energy dispersive X-ray (EDX) analysis. Most dusts consisted molybdenum and a few elements of stainless steel from the limiter and the vacuum vessel.

5. Summary

The observation of dusts was carried out on TRIAM-1M in two ways. The behavior of dusts in plasma was observed by high speed camera. The velocities of dusts were 10–50 m/s in various directions. The number of dusts per second increased with the discharge duration. Dusts were collected in the vacuum vessel after the experiments and the poloidal distribution of the total mass of dusts was almost uniform. The size of most dusts was 1–5 μm and composition was Molybdenum mixed with a few stainless steel. Two shapes of dusts, such as spherical and flake, were observed. Most of the dusts more than 10 μm are spherical shape.

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