Dust Particles: Morphology and Observations in the Plasma

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1. Introduction

Formation of dust particles in magnetic controlled fusion devices with carbon or beryllium/carbon plasma facing components (PFC) is a known fact being one of the consequences of plasma - material interactions [1-4]. The term "dust" refers to small loose particle agglomerates, ranging in size from several tens of nanometers to millimeters, found after longer operation periods on bottom parts of PFC and in pumping ducts. The issue has recently gathered much interest and the observations of dust in the plasma have become more systematic because of the dust influence on the plasma behaviour (e.g. density fluctuations) [5], spectroscopy measurements (decreased signal transmission via co-deposits and dust covered windows) [6] and hazards connected with the fuel accumulation (tritium inventory) [7] and – if grains are formed in substantial quantities, i.e. in kg range – steam reactions involving carbon in case of a leak of cooling water into the vessel. Several possible pathways leading to the formation and release of dust have also been discussed: disintegration of thick flaking co-deposited layers [1-4, 8], emission of particles under local high heat flux loads [9] and, as tentatively suggested, plasmo-chemical processes occurring in a cool region of the far edge plasma [1]. Reasons and consequences of dust charging effects in the plasma have also recently been addressed [10].

This contribution is focused on the examination and comparison of dust particles in the EXTRAP T2 reversed field pinch (RFP) and the TEXTOR tokamak. The common feature of both machines was the operation with graphite PFC (at EXTRAP until the end of 1998 [11], i.e. in the period when the device was operated with the former OHTE [Ohmically Heated Toroidal Experiment] vessel with a complete graphite liner consisting of some thousands of small (3 cm x 3 cm) tiles [12]). Dust formation, its behaviour in the plasma and morphology of grains were of the main interest.

2. Experimental

CCD cameras were used for the observation of dusty objects in the plasma. At EXTRAP a Pulnix camera with an infrared (IR) filter (1040 ± 20 nm) was installed either on the bottom or a tangential port, then viewing 3 % or 11 %, respectively, of the vessel volume. The temperature of recorded objects could be estimated in the range between 850 ^{o}C (noise level) and 1200 ^{o}C (signal saturation). A camera at TEXTOR was recording in visible range producing images in H_{α} light. In both cases, the image integration time was 20 ms, which - in the case of EXTRAP - was longer than the pulse duration, typically 7-12 ms. Magnetic diagnostic at EXTRAP consisted of an array, 6 poloidal x 32 toroidal, of pick-up coils, as described in detail elsewhere [13]. The diagnostic aimed at the measurements of magneto-hydrodynamic instabilities, including studies of wall locked modes creating problems for RFP operation and causing localized heat flux deposition [13,14].

Following operation periods comprising several thousands of plasma discharges (corresponding to about 50 s at EXTRAP and 14 000 s at TEXTOR), the machines were open and dust particles were collected, from the floor and diagnostic windows, using a vacuum cleaner with a specially designed filtration system. The dust was investigated by means of electron microscopy (SEM), nuclear reaction analysis (NRA), thermal desorption spectroscopy and energy dispersive X-ray spectroscopy (EDS) using a windowless detector.

3. Results and discussion

3. 1 Observations in the plasma

In the IR image shown in Fig. 1 one perceives tracks of glowing dusty objects passing through the plasma during a discharge. Track orientation with respect to the toroidal direction, path lengths and radial position with respect to the reversal surface (RS) can be inferred for the three cases (a-c); the results are collected in Table 1. The analysis of the thermal image itself does not allow the size determination.

Table 1. Characteristic of dust tracks in the plasma

Track	Path length (mm)	Angle (°)	Radial position (cm)
a	23	120	17.4 (outside RS)
b	11	30	6.2 (inside RS)
c	13	60	8.8 (inside RS)

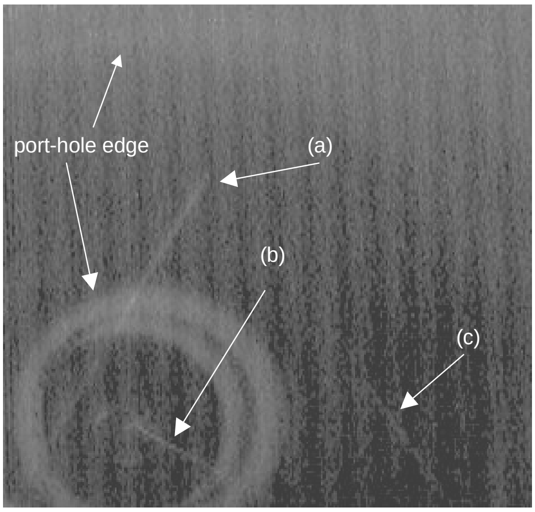

Fig. 1. IR image recorded during a discharge EXTRAP. Tracks of dust are indicated.

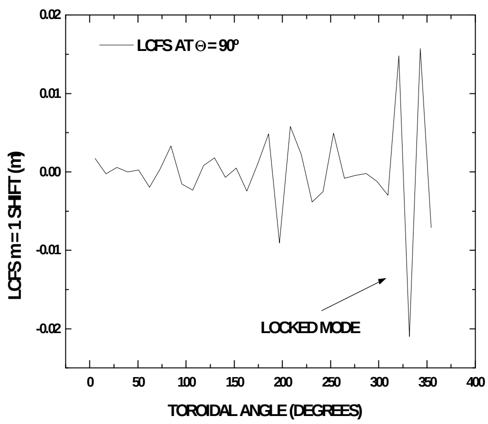

Fig. 2.Magnetic signals recorded at during the same discharge.

Fig. 2 shows the reconstruction of the last closed flux surface based on the m = 1 magnetic signals [15] recorded during the discharge when the presence of debris in the plasma was observed. Wall locking is observed at the toroidal position of 330°, i.e. in the position where the camera was located. A correlation between the locked mode and the presence of dust makes it plausible that small graphite debris got ejected due to a local energy deposition by wall locking of the plasma and causing so-called brittle destruction of PFC. It may also be suggested that the release of larger debris (in sub-millimeter size) occurs predominantly on the edges of non-perfectly aligned graphite tiles. The mechanism of ejection is, to some extent, analogous to the one observed under an electron beam irradiation of graphite [9,16]. Brittle destruction is a threshold type phenomenon observed for graphite at power loads exceeding 360 MW m^{-2} [16]. The area loaded at EXTRAP during a wall locked mode varies from discharge to discharge, but it can be estimated between 20 and 500 cm^2. Taking into account the energy stored in the plasma (2000 J) and the time scale of wall locking (1 ms) the power locally deposited during the process would be in the range 40 – 1000 MW m^{-2}. Therefore, in some shots the threshold for brittle destruction and ejection of particles is overcome. This is in agreement with the observation of dust only in some discharges.

The observation of dust release and its correlation with magnetic measurements may also contribute to a better understanding of the evolution of fundamental signals: n_e, T_e, I_p, Z_{eff}, V_{loop}, CV. Though all discharges at EXTRAP are wall locked, two clear types of temporal evolution of those signals have been observed: i) fairly smooth profiles over the whole discharge; ii) profiles indicating a sudden impurity (carbon) influx at a certain moment during the pulse [17]. To our opinion, this sudden increase in the C content followed by a drastic density fluctuation is most probably attributed to the appearance of graphite debris penetrating the plasma. The observation proves also indirectly a threshold process for dust release. For instance, a single debris 80 μm in diameter contains approximately 2.6 x 10^{16} C atoms and some of them get released when entering the plasma. Production of even larger debris, as shown below, could also occur. Flying dusty objects at TEXTOR are also frequently observed. On some occasions, particles are confined by the magnetic field and follow the lines. They appeared in the plasma because of detachment and peeling-off of thick flaking co-deposits on major PFC.

3. 2 Morphology

Three categories of objects were identified during the *ex-situ* studies of material found at EXTRAP: i) very thin fiber-built flakes about 1 μm in thickness, ii) small graphite debris with sharp edges or disintegrated co-deposits peeled-off from the wall, iii) fairly regular spherical/oval grains 20 –200 μm in diameter. In the latter case, quasi-spherical shape might be attributed to the surface "smoothening" occurring due to the material ablation when a debris was passing through the plasma during a few ms discharge. It can not be excluded that some grains were recycled, i.e. were removed from the floor and transported in the plasma several times during consecutive shots. A SEM image in Fig. 3a exemplifies a grain collected. The main constituents were carbon and hydrogen with some traces of boron resulting from the former solid target boronisation of EXTRAP.

Various structures, though not so regular in shape, were also found when studying the material collected at TEXTOR. These were mostly debris of brittle co-deposits peeled-off from the limiters. An example of such a thick flaking deposit is shown in Fig. 3b. As proven with several analytical methods, the dust is composed of carbon, deuterium and other elements originating from the wall conditioning (B, Si) and the erosion of an inconel liner (Ni, Cr, Fe, Mo) and high-Z limiters (W) tested as candidate PFC.

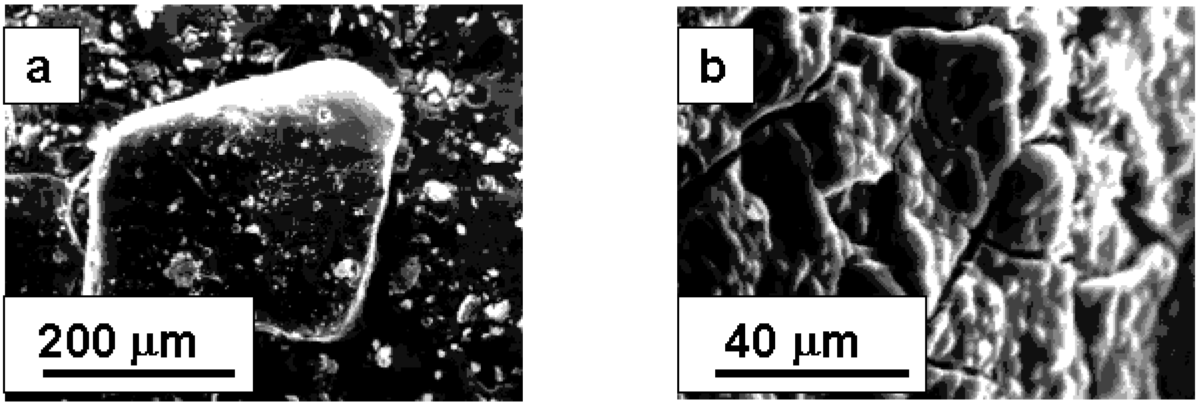

Fig. 3 Structure of dust particles found at (a) EXTRAP and (b) TEXTOR.

Summary and Conclusions

The comparison of dust particles formation in the devices indicate that the particles are born in two different processes with respect to energy and time scale. At RFP the main dust releasing mechanism is related to high power deposition by wall locked modes resulting in brittle destruction of graphite PFC. In a tokamak plasma, dust appears mostly as a consequence of detachment of thick flaking co-deposits.

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