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Observation of Dust Production During Carbon Pellet Ablation in W7-AS Stellarator

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Introduction. A number of theoretical and experimental investigations [1-3] shows that a thermal blow on a solid carbon surface can cause its brittle destruction with emission of microparticles of 0.01-10 μm in diameter. It was supposed earlier [1], that such effect in plasma physics can be observed during ramp-down in tokamaks. However, integrated photos of light emission, which are obtained during ablation of carbon pellets injected into the high-density, strongly NBI-heated discharges of Wendelstein 7-AS (W7-AS), show that small particles (*micropellets*) tear away from the pellet. It is differ from three types of carbon pellet ablation observed earlier in W7-AS [5,6]. An analysis of the characteristic sizes and velocities of these micropellets is presented.

Experimental setup. In the experiments, spherical carbon pellets with 0.35-0.41 mm diameter were injected by means of DIM-6 injector [4] into the W7-AS plasma towards the magnetic axis at velocities of 250-300 m/s. The pellet ablation process was observed by a CCD camera and a wide-view photodetector. The CII (723 nm) line emission was registered through interference filters. The details of the experimental setup are described in Refs. [5,6]. The ablation rate profile $\dot{N}(r)$ was determined from the CII line emission I_{cl} assuming that $\dot{N}$ is proportional to I_{cl} [6]. Injection into NBI heated plasmas with the following parameters was performed: n_{e0} = (1.1-1.5)·10^{14} cm^{-3}, T_{e0} = (300-450) eV, P_{NBI} = 1.75 MW.

Experimental Results and Discussion. A typical image that illustrates emission of micropellets during pellet ablation is shown in Fig. 1. The curves, diverging from the main pellet track (the pellet moves from the left to the right), are the tracks of the micropellets flying away.

1. <u>Micropellet velocities.</u> Micropellet velocities were evaluated under assumption that the pieces fly away from the pellet in the direction normal to the pellet trajectory in the plane of the image (see Fig. 1). Such assumption may yield underestimated velocity values. Detailed

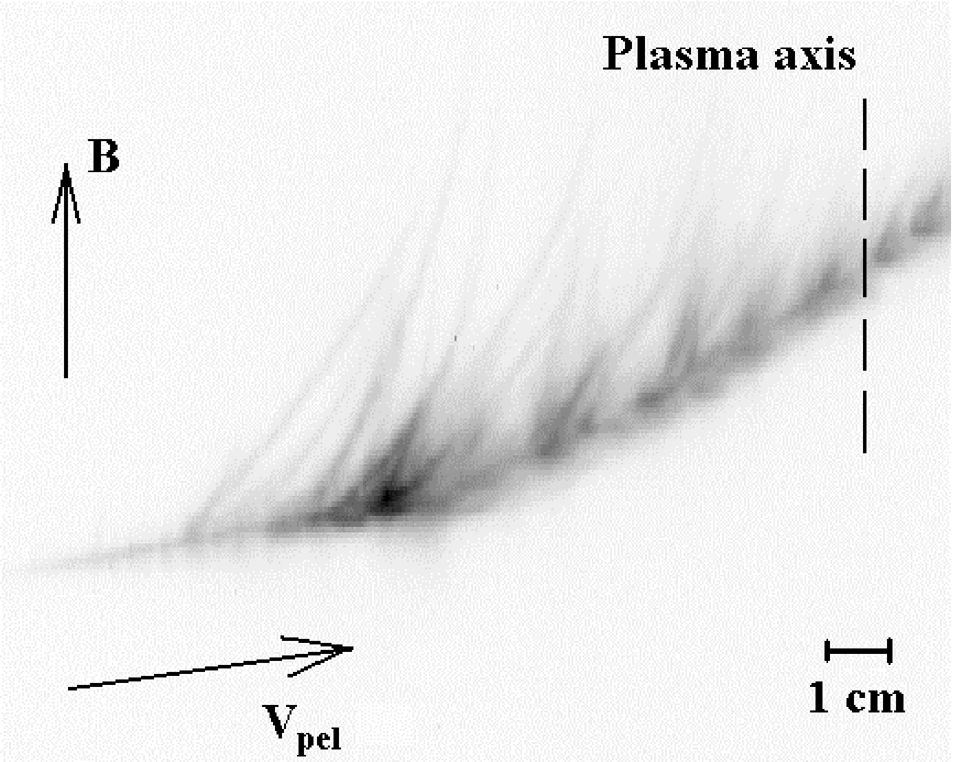

Fig. 1. Integrated photo of the pellet track in shot #41025.

statistical studies of micropellet velocities were carried out for shot #41025, where photo with the highest contrast and the maximal number of pieces was obtained. Twelve distinct micropellet tracks in Fig. 1 flying "upwards" with a certain angular distribution were chosen to obtain the histogram where the velocity was assumed perpendicular (normal) to the trajectory for simplicity. As can be seen in Fig. the micropellets emerge the pellet in the

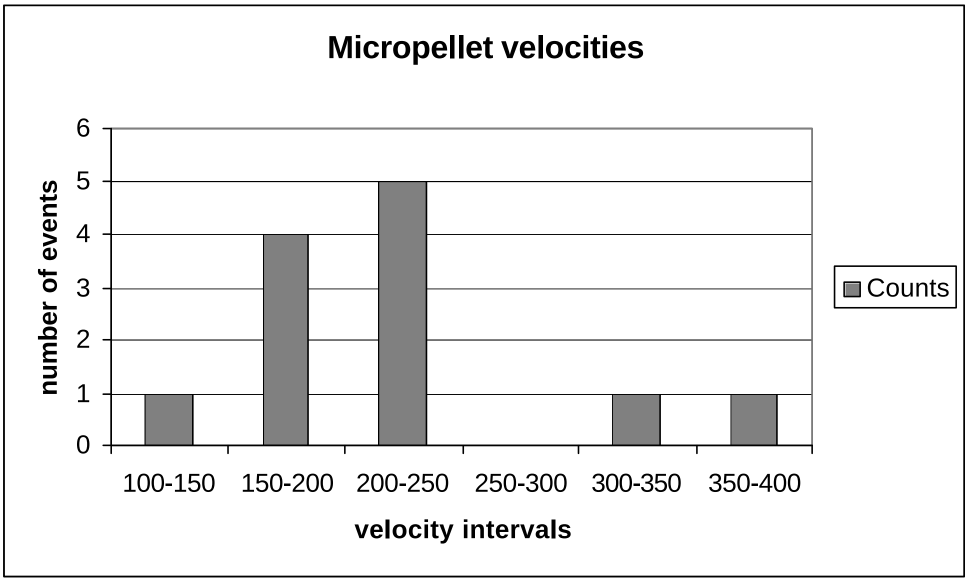

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Fig. 2. Histogram with the perpendicular velocity distribution of micropellets in shot #41025.

direction of 30-40 degrees relative to the local pellet velocity. The histogram of micropellet velocities in Fig. 2 shows that most probable normal velocity lies in the 150-250 m/s range. It is notable that the pieces fly away from the pellet not only in the direction “upwards” in Fig. 1. Careful examination of the image reveals tracks of micropellets scattering “downwards”. It implies that in this direction there is a force which curves correspondingly trajectories of both a main fragment of pellet and pieces emerged “upwards”. Unfortunately, the image quality is poor for the detailed investigation of the micropellets emerged “downwards”. Results of the statistical investigation of the micropellet parameters in shots #41018, 41019, 41025 are presented in Table 1.

Table 1. Micropellets velocity evaluations.

Shot number	V_{pel}, m/s	total number of micropellets	number of the micropellets studied	Emerging “upwards”	Mean angle of scatter, deg.	Mean scatter velocity V_0, normal to pellet track m/s
41018	300	3	3	3	41.3	270
41019	260	11	5	11	55.1	385
41025	280	≥ 23	13	≥ 16	37.1	220

The velocities of carbon dust particles observed correlate with the model [1] predicting 240 m/s velocity V_0 for dust particles generated by carbon surface $V_0 = \alpha \cdot T \cdot \xi \cdot c$, where $\alpha = 2x10^{-5}$ K^{-1} is the heat expansion factor, $T = 4000$ K is the surface temperature [8], $\xi \cong 1$ is the fraction of stressed grain and $c = 3x10^5$ cm/c is the sound velocity in carbon.

<u>2. Methods of the micropellet size determination.</u> *2.1. The ratio of the integrated emission intensities.* Shot #41018 ($n\varnothing_{pel}$ = 0.41 mm, V_{pel} = 300 m/s) was chosen for investigations because micropellets in the photo are mostly remote from each other and their tracks don’t overlap. It allows us to determine the emission intensity of the micropellet ablation cloud. Since micropellet tracks start in the region where the main pellet radiates intensively, this background emission was excluded from the total pellet+micropellet emission. For this purpose, the pellet toroidal light distribution was approximated exponentially according to experimental observations in Ref. [7]. Then, the difference between the total intensity and the approximated background intensity of the main pellet cloud was determined in the micropellet vicinity for each vertical column in Fig. 1. Thus, the micropellet cloud intensity was obtained. The ratio of the integrated emissions from micropellet and pellet is proportional to their atomic contents. The number of particles in the micropellet was deduced from the given pellet radius. Thus, 22.0 μm micropellet radius was found, which

corresponds to 0.2% of the pellet atomic content. Accuracy of these estimations are (100-200)% due to problems with exclusion of a low light signal of microparticle from intense pellet light.

2.2. Penetration depth and simulations by the Neutral Gas Shielding Model (NGSM). The micropellet's radius can be more precisely estimatedby comparison of its measured penetration length with prediction of NGSM [8] (see Table. 2). Due to small tracks of micropellets, it was assumed in simulations that the r_{micpel} micropellet position in plasma and corresponding $n_e(r_{micpel})$ $T_e(r_{micpel})$ values are constant. From Table2 one can see that the averaged track length increases with plasma electron density and smaller micropellet sizes of microns range can be evaluated.

Table 2. Micropellets size evaluations.

Shot number	41018	41019	41025
$n_e(r_{micpel})$, x10^{13} cm^{-3}	1.7	3.1	9.1
$T_e(r_{micpel})$, eV	160	160	200
Measured averaged track length, cm	1	2	4
Micropellet radius derived from modeling its track length with V_{micpel}= 400m/s	4	7	25

Summary. Evaluation of the micropellet radius from the ratio of the integrated intensities gives values of about 20 µm. The measured micropellet penetration depths correspond to their size of microns range. Micropellets leave the pellet surface with mean angle of about 45 degrees relative to the pellet trajectory. The micropellet velocity component perpendicular to the pellet trajectory lies in the 220 – 385 m/s range that correlate with the theoretically predicted values of velocity of graphite pieces emerging the solid graphite surface due to thermal blow.

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