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Dust particle formation due to interaction between graphite and helicon deuterium plasmas

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ABSTRACT

The collection of dust particles using divertor simulation helicon plasmas has been carried out to examine dust formation due to the interaction between a graphite target and deuterium plasmas, which are planned to operate in the large helical device (LHD) at the Japanese National Institute for Fusion Science (NIFS). The collected dust particles are classified into three types: (i) small spherical particles below 400 nm in size, (ii) agglomerates whose primary particles have a size of about 10 nm, and (iii) large flakes above 1 μm in size. These features are quite similar to those obtained through hydrogen plasma operation, indicating that the dust formation mechanisms due to the interaction between a carbon wall and a plasma of deuterium, which is the isotope of hydrogen, is probably similar to those of hydrogen.
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1. Introduction

The study of dust particles formed in fusion devices due to the interaction between carbon walls and plasmas has been receiving increasing attention, because appreciable amounts of dust particles have been found in many fusion devices [1–9]. These carbon dust particles pose potential problems in future long-term operations of fusion devices. For instance, the dust particles can contain a large amount of tritium, and their existence in the device could also lead to deterioration of the plasma confinement [2,10]. Moreover, the dust-air cloud formed due to air ingress can even be an explosion hazard during normal plasma operation in fusion devices [11]. Therefore, it is important to understand their formation mechanism, their transport as well as their accumulation areas, and to suppress their formation in fusion devices having carbon divertors. Many papers concerning dust particles formed in fusion devices have mainly focused on μm-sized dust particles. We have studied the formation of nm-sized dust particles due to the interaction between a graphite and a hydrogen plasma in the large helical device (LHD) and in a helicon plasma reactor which we have developed to simulate divertor plasmas in the LHD [12–14]. A large number of spherical particles of nm in size and a relatively small number of their agglomerates whose primary particles are about 10 nm in size have been collected in both the helicon plasma reactor and the LHD. The composition of these dust particles is carbon which is the component of the graphite target of the helicon plasma reactor as well as the divertor material of the LHD. The agreement of the features of such dust particles formed due to the interaction between a hydrogen plasma and a carbon wall is an evidence to support the fact that the helicon plasma reactor simulates the LHD well. Deuterium plasma operation is being planned in the LHD in the immediate future, and hence preliminary experiments concerning dust formation using the helicon deuterium plasma reactor provide important information on the dust formation due to the deuterium plasma – carbon wall interaction in the LHD. In this paper, we report the results of the collection of dust particles having a size of μm–nm, which are formed due to the interaction between a graphite and a helicon plasma of deuterium in the helicon plasma reactor. Finally the formation mechanisms based on these results are discussed.

2. Experimental

Experiments were carried out with the helicon plasma reactor, shown in Fig. 1. The reactor is composed of a stainless vessel with 267 mm maximum inner diameter and 294 mm length, a quartz tube of 50 mm diameter and 200 mm length, as well as an antenna for the $m = 1$ helicon mode excitation of 170 mm length placed around the tube. A uniform magnetic field of 150 G was applied along the tube axis with four magnetic coils placed as shown in

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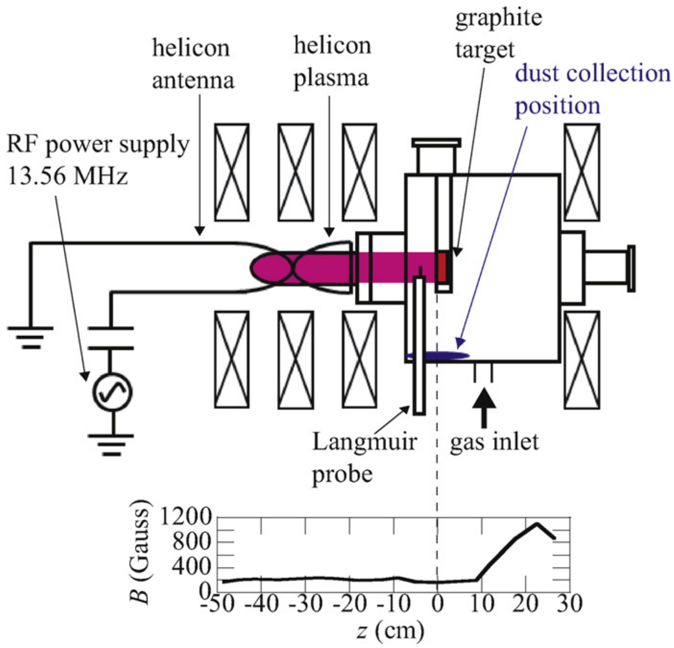

Fig. 1. Experimental setup and magnetic field profile of the helicon plasma reactor.

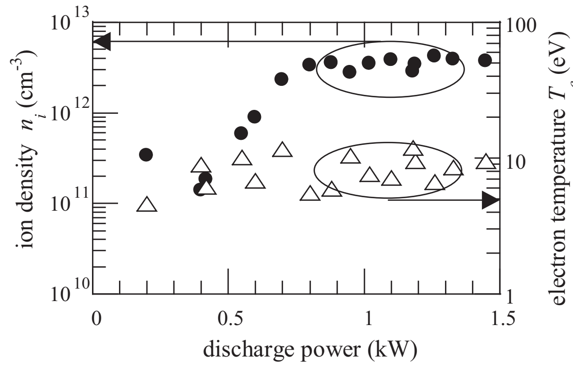

Fig. 2. Discharge power dependence of ion density and electron temperature. D_2 0.5 sccm, 5 mTorr, discharging period 250 ms, 150 G.

Fig. 1. Pure deuterium (D_2) gas was supplied to the reactor at a flow rate of 0.5 sccm with a pressure of 5 mTorr. Deuterium plasmas were generated by applying pulsed rf voltage of 13.56 MHz to the antenna. The discharge power was in the range of 0.1–1.5 kW. The discharging period and interval were 0.25 s and 1.0 s, respectively. The total discharging period for dust sampling was 100 s. The ion density and electron temperature were measured with a Langmuir probe. The Langmuir probe was located 20 mm away from the graphite target. A graphite target 35 mm in diameter and 8 mm thick was placed at $z = 0$ mm as shown in Fig. 1. Dust particles were collected using a vacuum collection method described elsewhere [3,4,13] just after the deuterium plasma operation. For the vacuum collection method, a plastic holder equipped with a transmission electron microscope (TEM) grid as well as a polycarbonate membrane filter having pores of 100 nm diameter was used as a particle collector. Dust particles were collected on the TEM grid and polycarbonate membrane filter at the collection position (111 mm below the center of the plasma column, see Fig. 1) whose surface area was 40 cm^2 for 7.5 min. The dust particles on the TEM grid and polycarbonate membrane filter were observed with a TEM (JEOL JEM-2010) and a scanning electron microscope (SEM, JEOL JSM-6320FZ), respectively. The composition of the dust particles was analyzed by energy-dispersive X-ray spectroscopy (EDX).

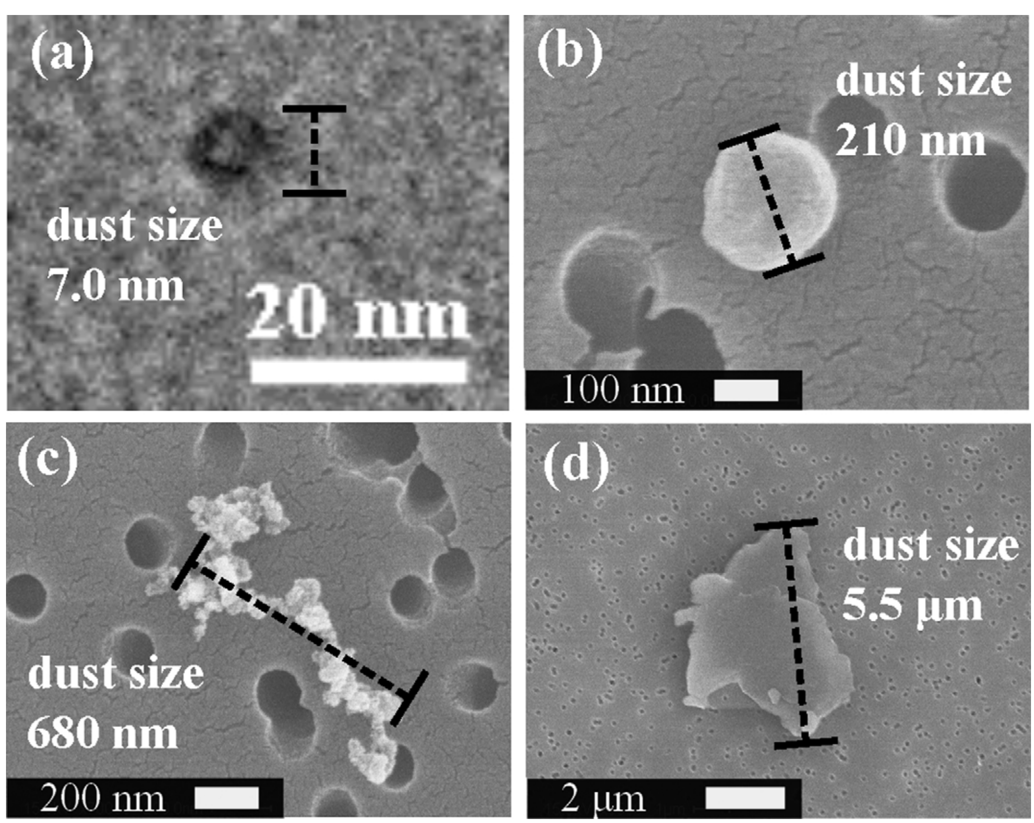

Fig. 3. Images of typical dust particles collected using the vacuum collection: (a) and (b) small dust particles, (c) an agglomerate, and (d) a large dust particle. The image (a) was obtained by TEM and the images (b)–(d) were obtained by SEM. D_2 0.5 sccm, 5 mTorr, discharging period 250 ms, 150 G.

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