GA–A26126

CORRELATION OF SUBMICRON DUST PRODUCTION IN DIII-D TO IMPULSIVE WALL HEATING FROM ELMS

by
B.D. BRAY, W.P. WEST, D. RUDAKOV

JUNE 2008

GENERAL ATOMICS

DISCLAIMER

GA–A26126

CORRELATION OF SUBMICRON DUST PRODUCTION IN DIII-D TO IMPULSIVE WALL HEATING FROM ELMS

by
B.D. BRAY, W.P. WEST, D. RUDAKOV*

This is a preprint of a paper to be presented at the Eighteenth International Conference on Plasma Surface Interactions, May 26-30, 2008, in Toledo, Spain, and to be published in J. Nucl. Mater.

*University of California-San Diego, La Jolla, California

Work supported by
the U.S. Department of Energy
under DE-FC02-04ER54698
and DE-FG02-07ER54917

GENERAL ATOMICS ATOMICS PROJECT 30200
JUNE 2008

GENERAL ATOMICS

ABSTRACT

Submicron dust particles are observed by Rayleigh/Mie scattering from ND:YAG laser light during plasma discharges at DIII-D. The observed dust density decreases gradually over the tokamak major radius in the scrape off layer (SOL) ($1.0<\Psi<1.2$ for typical discharges) to the plasma edge. There is a significant increase in dust density with ELMing H-mode discharges relative to L-mode and ELM-free H-mode discharges. The dust density in ELMy H-mode discharges is sensitive to many parameters including the pedestal temperature and ELM frequency and can increase as much as a factor of two with pedestal temperature for similar pedestal pressure and injected power. Dust density decreases with increasing ELM frequency compared to shots with similar stored energy and less frequent ELMs. These measurements suggest the particles are created by impulsive heating from ELMs and the dust density is less sensitive to steady heat flux to the wall.

1. INTRODUCTION

Dust consisting of small loose particles ranging in size from tens of nanometers to millimeters has been observed in many plasma fusion devices. A review of dust in tokamaks outlines the operational and safety issues of dust and previous experimental results measuring dust density and particle size [1]. The large heat fluxes, long discharges and high divertor particle fluxes in next step machines will make plasma wall interaction (PWI) control critical for success. A better understanding of PWIs is necessary to minimize the erosion of plasma facing components (PFC), control contamination in the plasma core, and manage the accumulation of tritium within the vacuum vessel and loose dust. Mie scattering measurements made concurrently with electron density and temperature measurements of the DIII-D Thomson scattering system can detect dust particles with radii as small as 50 nm. Many processes including sputtering and sublimation can produce erosion from the PFCs [2] and inject dust into the tokamak. Studies at DIII-D indicate that the majority of neutral carbon originates from the divertor region [3]. Dust particles are observed moving quickly in plasma discharges [4] and can travel long distances in the SOL. Dust particles collected during entry vents in DIII-D are mostly comprised of carbon from the PFCs and are typically 1 μm in diameter [5]. Loosely redeposited layers which are subject to release are also observed on the PFCs.

The DIII-D Thomson system provides quantitative, time resolved measurements of the dust density. While the detection rates are low, accumulation of data over years of operation allows statistical analysis and the determination of correlation with plasma parameters. Analysis of the scattered light signals from dust particles indicates an average radius of 120 nm for the dust particles in the DIII-D SOL [6,7]. Time-averaged dust concentrations as high as 30000 m^{-3} are observed far into the SOL and drop to near zero at the last closed flux surface. A typical ELMy H-mode dust density of 20000 m^{-3} represents a carbon atom density of $\sim 10^{15}$ m^{-3} in the SOL. The dust density is significantly higher during H-mode shots than it is during L-mode shots and correlations with plasma parameters suggest that edge localized modes (ELMs) are a significant source of the observed dust.

2. MEASURING DUST WITH LASER SCATTERING

The DIII-D Thomson system is designed to measure electron density and temperature in the plasma [8,9]. Polychromators measure the scattered light spectrum over a series of adjacent wavelength bins at 44 locations in the vessel, each having a viewing volume 0.2 cm^{-3}. Narrow bandpass filters at the laser wavelength are very sensitive to Mie scattering from dust particles in the vessel. The scattering observation volumes for the system are small, the laser repetition rate is low, and the dust density low so particles are observed infrequently. A sample set total of 5192 SOL dust particles in 6152 discharges were observed during the 2004 to 2007 run campaigns which corresponds to a mean number density of 4000 m^{-3} in the SOL during the shot after the current ramp. Statistical analysis of this group of particles provides evidence of parameters which affect the dust density. In the far SOL [normalized radius (Ψ) of ~ 1.2] the dust density can be 10 times larger than the mean density. The data from the DIII-D run campaigns include a significant number of different running conditions. In this set, upper single-null (USN) H-mode and lower single-null (LSN) L-mode plasmas are the most common. Dust densities rise from the last closed flux surface into the SOL for both discharge types (Fig. 1). The small event rate observed inside the last closed flux surface (100 ± 10 m^{-3} particle density) is at the noise level.

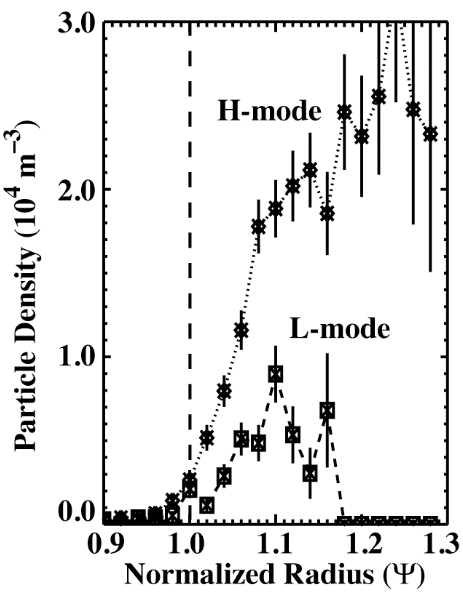

Fig. 1. Radial profile of dust density in the SOL for L- and H-mode.

Very little dust (~100 m^{-3}) is observed from the start of gas injection at $t = -300$ ms through breakdown, and the dust density increases during the first two seconds (ramp up) of the discharge (Fig. 2). Quiescent H (QH) mode [10] discharges have high injected power and high confinement but no ELMs. The QH-mode discharges have much lower dust levels than the H-mode discharges until late in the discharge when ELMing phases increase the dust by a factor of three. During discharge periods where resonant magnetic perturbations (RMP) [11] are applied to suppress ELMs, a similar reduction in the dust density is observed. The injected power and stored pedestal energies in these RMP discharges are similar to the H and QH discharges suggesting that ELMs play a very significant role in the dust density and quiescent power flux to the wall is secondary.

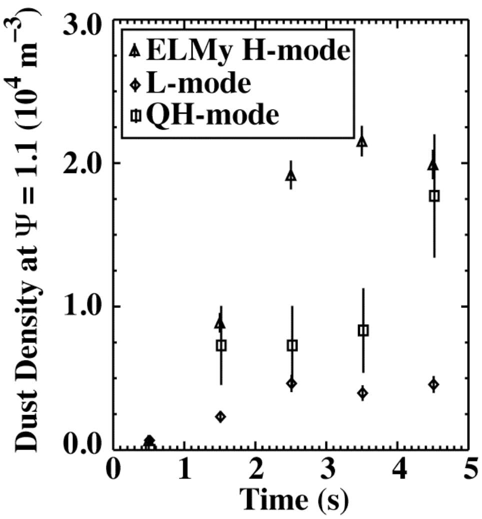

Fig. 2. Time dependence of dust density in the SOL (Ψ = 1.1) for L, QH and ELMy H-mode.

3. ELM DYNAMICS HAVE A LARGE INFLUENCE ON DUST DENSITY

ELMs cause localized heating on a short time scale on the divertor and wall PFCs [12], on DIII-D roughly 100 kJ of energy is released in ~ 10^4 during an ELM. It is reasonable to associate dust production rates with the energy released per ELM which has been shown to increase strongly with pedestal temperature.

Comparisons of the dust density with the average electron temperature and density pedestal heights show strong dependence of the dust density in the SOL with the electron pedestal temperature (Fig. 3) in ELMing discharges. High pedestal temperatures are also correlated with higher injected powers, higher stored energy in the pedestal and higher energy outflux to the wall during an ELM. QH-mode plasmas also have a characteristic high temperature at low density pedestal, which suggests pedestal temperature alone does not play a dominant role in dust production. High pedestal densities which are associated with greater stored energy but inversely with energy release per ELM in the pedestal are not correlated with increased dust densities (Fig. 4).

Dust density also shows a significant dependence on the ELM rate for H-mode plasmas. ELM occurrences are identified by peaks observed in the D_α light emission by the plasma. Discharges with more frequent ELMs have been shown to have lower energy per ELM [13] and have lower dust densities than discharges with less frequent ELMs (Fig. 5). This dependence combined with the pedestal temperature results are strongly suggestive of a significant role of the impulsive ELM power in the dust levels at DIII-D.

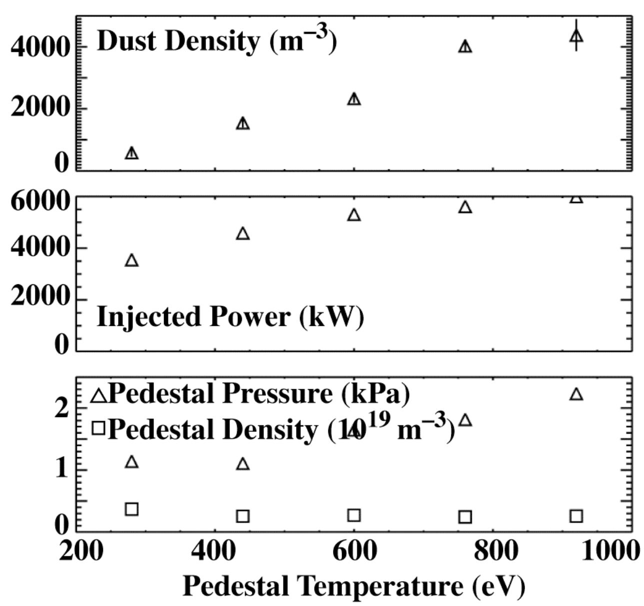

Fig. 3. Observed (a) dust density (b) injected power and (c) pedestal pressure and density as a function of pedestal temperature.

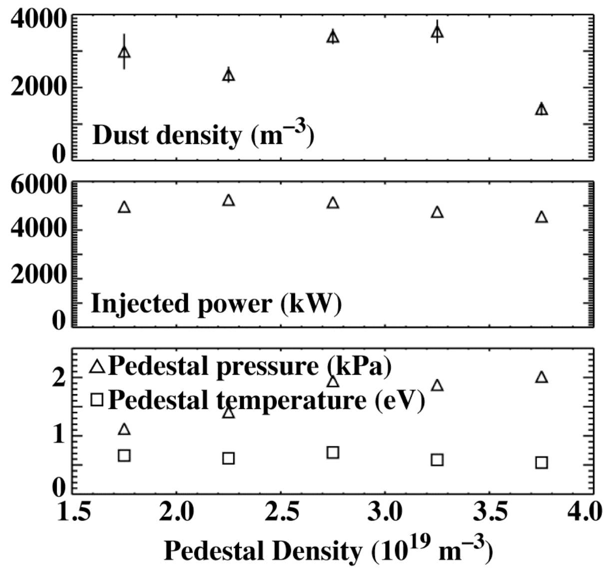

Fig. 4. Observed (a) dust density (b) injected power and (c) pedestal pressure and temperature as a function of pedestal density.

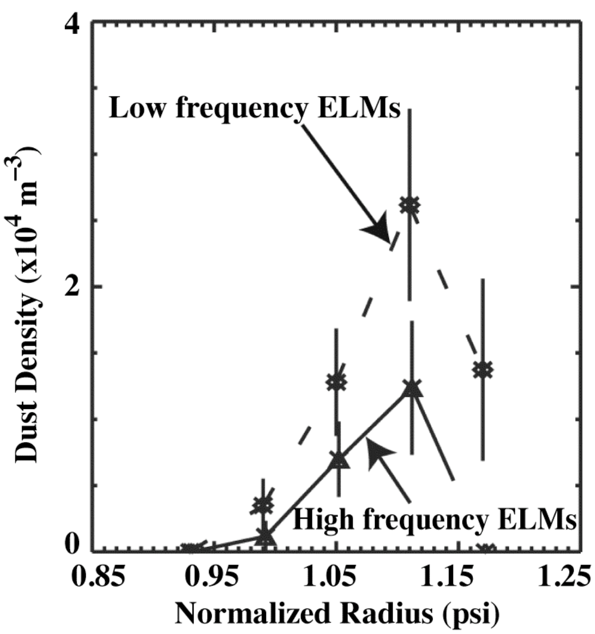

Fig. 5. Radial profile of dust density for discharges with frequent or infrequent ELMs.

The dust density in the SOL rises quickly after an ELM (Fig. 6) to a peak within 10 ms of the end of an ELM and decays with a half-life of approximately 60 ms. The DUSTT code [14] has been used to model the transport of dust particles of the mean size observed by the Thomson system at DIII-D. The observed density decay is longer than the predicted half life of 10–20 ms for particles produced at the outer wall of the vessel.

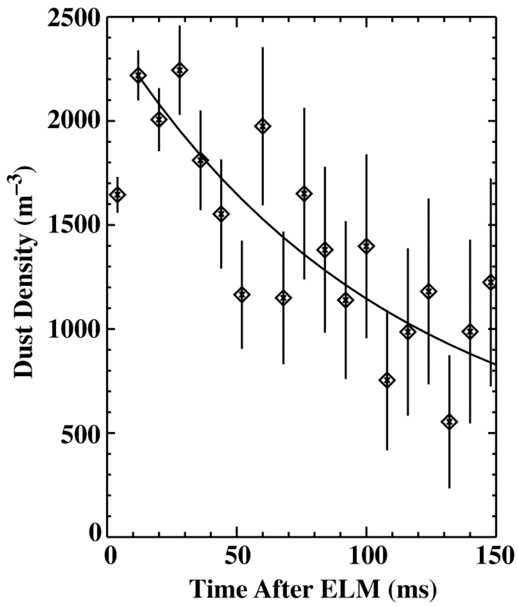

Fig. 6. Time dependence of dust rate after an ELM. Line is an exponential fit.

Decreasing the gap between the equatorial outer wall and the last closed flux surface only slightly increases the dust density (Fig. 7), suggesting that contact between ELMs and the outer midplane walls in not a significant source of the dust.

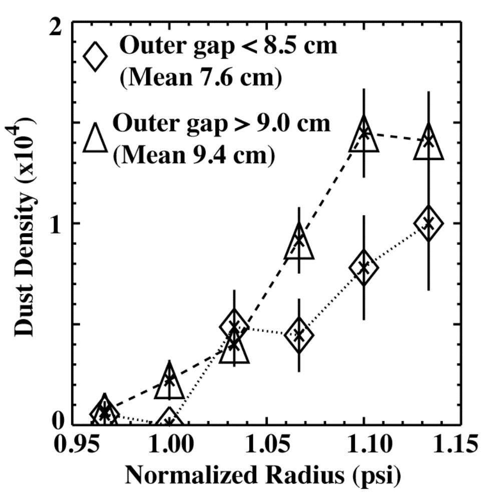

Fig. 7. Radial profile of dust density in the SOL for small and large outer wall gaps.

4. CONCLUSIONS

The DIII-D Thomson system directly measures the dust concentration in the SOL during plasma discharges. There is little dust before plasma breakdown, during the gas fill phase, and the dust density increases during the initial phase of plasma discharges. ELMy H-mode discharges display the largest concentration of dust in the SOL. The data is consistent with ELMs playing the dominant role in dust generation. High power discharges such as QH-mode plasmas and H-mode plasmas with RMP ELM suppression have similar levels to L-mode discharges. The dust density increases for high temperature, low collisionality pedestals which eject a larger fraction of stored pedestal energy per ELM in larger, less frequent ELMs. The dust density is not sensitive to the outer wall gap in ELMy plasmas which suggests that ELM-divertor interactions are the significant factor in dust generation. The dust density is largest about 10 ms after an ELM and decays with a half-life of 60 ms. The decay of dust density is presently inconsistent with DUSTT simulations of 100 nm graphite particles originating at the vessel outer wall with a lifetime of 10 to 20 ms; suggesting the observed particles may originate from the divertor region. Continued comparisons of observed parameters to dust transport models should help understand dust production and transport at DIII-D and benchmark the models for simulations of future machines. Of particular interest is the production of dust by plasma disruptions.

REFERENCES

[1] G. Federici, et al., Nucl. Fusion 41 (2001) 1967.

[2] R. Behrisch, et al., J. Nucl. Mater. 313-316 (2003) 388.

[3] R.C. Isler, et al., J. Nucl. Mater. 313-316 (2003) 873.

[4] M. Rubel, et al., Nucl. Fusion 41 (2001) 1087.

[5] D.H.J. Goodall, J. Nucl. Mater. 111-112 (1982) 11.

[6] W.P. West, B.D. Bray, J. Burkhart, Plasma Phys. Control. Fusion 48 (2006) 1661.

[7] R.D. Smirnov, et al., Phys. Plasmas 14 (2007) 1.

[8] T.N. Carlstrom, G.L. Campbell, J.C. DeBoo, et al., Rev. Sci. Instrum. 63 (1992) 4901.

[9] S.L. Allen, D.N. Hill, T.N. Carlstrom, et al., J. Nucl. Mater. 241-243 (1997) 595.

[10] K.H. Burrell, et al., Phys. Plasmas 8 (2001) 2153.

[11] T.E. Evans, et al., Phys. Rev. Lett. 92 (2004) 235003.

[12] T. Eich, et al., J. Nucl. Mater. 337-339 (2005) 669.

[13] A.W. Leonard, et al., Plasma Phys. Control. Fusion 44 (2002) 945.

[14] A. Yu, et al., Phys. Plasmas 12 (2005) 122508.

ACKNOWLEDGMENT

This work supported by the U.S. Department of Energy under DE-FC02-04ER54698 and DE-FG02-07ER54917.