Available online at www.sciencedirect.com
ScienceDirect
Journal of Nuclear Materials 376 (2008) 29–32
journal of nuclear materials
www.elsevier.com/locate/jnucmat

Large aperture electrostatic dust detector

C.H. Skinner [a,*], R. Hensley [b], A.L. Roquemore [a]

[a] Princeton Plasma Physics Laboratory, Princeton, NJ 08543, USA
[b] Embry-Riddle Aeronautical University, Prescott, AZ 86301, USA

Received 3 January 2008; accepted 5 February 2008

Abstract

Diagnosis and management of dust inventories generated in next-step magnetic fusion devices is necessary for their safe operation. A novel electrostatic dust detector, based on a fine grid of interlocking circuit traces biased to 30 or 50 V has been developed for the detection of dust particles on remote surfaces in air and vacuum environments. Impinging dust particles create a temporary short circuit and the resulting current pulse is recorded by counting electronics. Up to 90% of the particles are ejected from the grid or vaporized suggesting the device may be useful for controlling dust inventories. We report measurements of the sensitivity of a large area (5 × 5 cm) detector to microgram quantities of dust particles.

PACS: 52.40.Hf; 52.90.+z

1. Introduction

Dust particles are ubiquitous on the interior surfaces of contemporary tokamaks [1–4]. The particles can be produced by the disassembly of plasma facing tile surfaces or of co-deposited layers under intense transient heating by ELMs or disruptions, or by the chemical agglomeration of sputtered C_n clusters [5–7]. In next-step devices such as ITER, the scale-up in plasma stored energy and pulse duration will cause high levels of dust to be generated and this has important safety consequences as the dust can be radioactive from tritium or activated metals, toxic and/or chemically reactive with steam or air [8]. Tritiated dust has been observed to levitate because of self charging by the tritium beta decay [9]. The in-vessel dust inventory will need to be controlled, however measuring the dust particle inventory is a challenge in existing tokamaks let alone one with the radiological environment and scale of ITER. Diagnostics that could provide assurance that ITER is in compliance with its dust inventory limits are in their infancy [10,11]. A separate challenge is demonstrating techniques that could remove dust from the tokamak, once the limits are approached [12].

A novel device to detect the settling of conductive dust particles on remote surfaces has recently been developed [13]. A 12 mm × 12 mm grid of two closely interlocking traces on a circuit board was biased to 30–50 V (Fig. 1). Test particles scraped from a carbon fiber composite tile, were delivered to the grid. Miniature sparks appeared when the particles landed on the energized grid and created a transient short circuit. The current pulse flowing through the short circuit created a voltage pulse that was input to an Ortec 551 single channel analyser and the total number of counts generated was related to the mass of dust impinging on the grid. The device worked well in both atmosphere and vacuum environments. The sensitivity was enhanced by more than an order of magnitude by the use of ultrafine grids with 25 μm spacing between the traces and the response was found to be maximal for the finest particles [14]. This is a favorable property for tokamak dust which is predominantly of micron scale [1]. Larger particles produce a longer current pulse, providing qualitative information on the particle size. Typically open circuit conditions are rapidly restored in both air and vacuum environments, indicating that the dust particles have been removed from

* Corresponding author.
E-mail address: cskinner@pppl.gov (C.H. Skinner).

0022-3115/$ - see front matter
doi:10.1016/j.jnucmat.2008.02.001

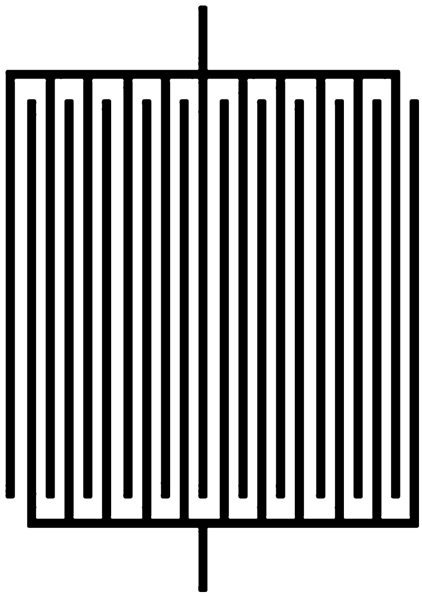

Fig. 1. Schematic of electrostatic dust detector (not to scale).

the circuit board. The fate of the dust particles has been tracked by measurements of mass gain/loss of the circuit board. Heating by the current pulse caused up to 90% of the particles to be ejected from the grid or vaporized, an encouraging result for its potential application to the management of dust inventories [15].

Real time measurements of dust on surfaces in contemporary tokamaks are challenging because of the low dust levels. For example, the average flux of dust in the National Spherical Torus Experiment (NSTX) that accumulated on a glass slide was 5.6 ng/cm^2/discharge, a level below the estimated sensitivity of the 12 mm × 12 mm grid detector of 36 ng/cm^2/count that was extrapolated from previous measurements at ~mg/cm^2 dust levels [15]. The present work is aimed at increasing the sensitivity of the detector to enable measurements on contemporary tokamaks. We note that 100 kg of dust evenly distributed on the lower part of ITER amounts to ~60 mg/cm^2 so sensitivity will not be an issue for ITER.

2. Experimental setup

The experimental strategy to increase the sensitivity of the detector was to increase its area and to test its performance with microgram quantities of dust particles. A large area, 50 × 50 mm, grid was fabricated with a laser direct write process on a PEEK (polyetheretherketones) substrate. The traces and intertrace space were 25 μm wide as before but the area was 17× larger than grids used previously. Particles were scraped from a CFC tile [13,14] and filtered through a vibrating mesh with square apertures 104 μm a side. The particle count median diameter is 2.9 μm [15]. The particles were spread evenly over a dust tray with a 22 mm square double 104 μm mesh bottom. For weighing purposes this was placed on a second catch tray of Al foil to catch any released dust. This tray combination was weighed with a Satorius ME5-F microbalance with 1 μg resolution, 5 g capacity and 50 mm diameter pan. Extreme care was needed to get high resolution readings. Neoprene gloves and tweezers were used to handle the trays as a fingerprint weighs about 40 μg. While the mass readout for small mm-scale objects stabilized in about 8 s, small temperature differences between the larger objects and the balance could cause air currents and lengthy stabilization times (up to 20 min). A reading was considered final after it was stable for 1–2 min. Measurements took place over a fresh sheet of Al foil that was cleared of ambient dust with compressed gas to facilitate spotting any spills. Covers were used to prevent ambient dust landing on the samples.

The mesh tray was carefully positioned in a holder attached to the top flange of the test chamber (Fig. 2). The grid was mounted on the bottom flange. For experiments in vacuum the chamber was evacuated to 150 mtorr. A baffle was installed over the evacuation port in the chamber to deflect air currents from the grid during evacuation or venting. To avoid disturbing the dust, pumping was done slowly over ~4 min and then the pumping valve closed for dust measurements. For experiments in nitrogen, the chamber was first evacuated to ~1 torr, then filled with atmospheric pressure nitrogen.

Application of a 60 Hz vibrator tool to the top flange for differing periods of time released 1–120 μg of dust particles that fell onto the grid below. It was verified that the dust fell in a 25 mm square area in the center of the grid in both air and vacuum conditions. To check the experimental uncertainty in mass accounting a stainless foil tray was

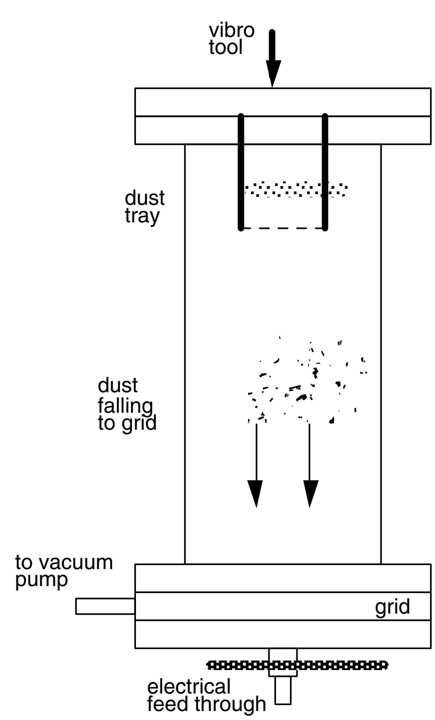

Fig. 2. Experimental setup.

placed at the grid position. Dust was released on to the foil in air and the measured mass gain of the foil compared with the measured mass loss of the dust tray. Averaged over 5 measurements, the missing mass was 0.6 μg with a standard deviation of 2.6 μg indicating good reproducibility in the mass measurements. This small adjustment of 0.6 μg was applied to all the measurements.

3. Detector response

The response of the energized grid to dust was recorded using the electronics as described in Refs. [13,14]. The number of counts often continued incrementing slowly after the vibration ceased, especially for the larger quantities of dust. The final count was taken when the count number was constant for at least 60 s. Both the new 50 × 50 mm grids and the 12 × 12 mm grids used previously were measured. A 30 V bias was used for air, N_2 and vacuum (previously 50 V bias was used in vacuum with grids written by photolithography on an Ultralam substrate that had a higher voltage standoff). The power supply current limit was typically set to 25 mA. To measure the flux of dust incident on the small grids a 12 × 12 mm plate was placed at the position of the grid and the mass of particles incident on the plate and that lost by the tray was measured separately. Fig. 3 shows the response in counts of a 12 × 12 mm grid in air and vacuum vs. the incident flux of particles. An increased current limit (100 mA and 200 mA) was set for two measurements and these follow the general trend showing that the 25 mA current limit was not a significant factor in the number of counts. A least squares fit of the data to a linear equation is shown in the figure. The small intercept on the x-axis is within the experimental uncertainty. The response appears quite linear down to the lowest mass indicating that single dust particles are sufficient to

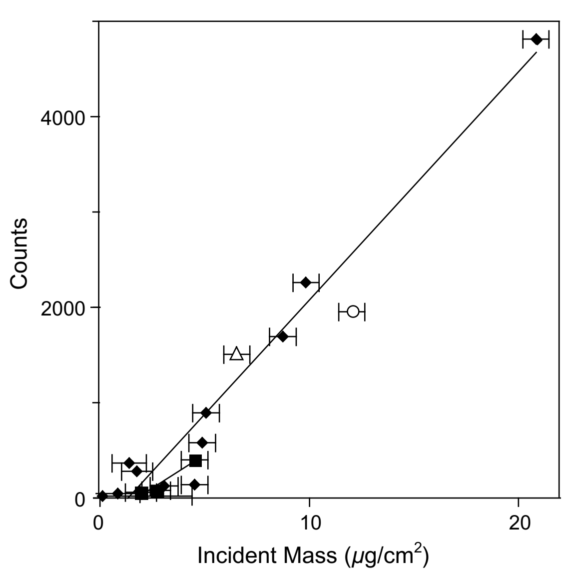

Fig. 3. Response of 12 × 12 mm grid in air (diamond) and vacuum (square points). The current limit was 25 mA except for the open triangle (100 mA) and circle (200 mA). The lines are least squares fits to the data.

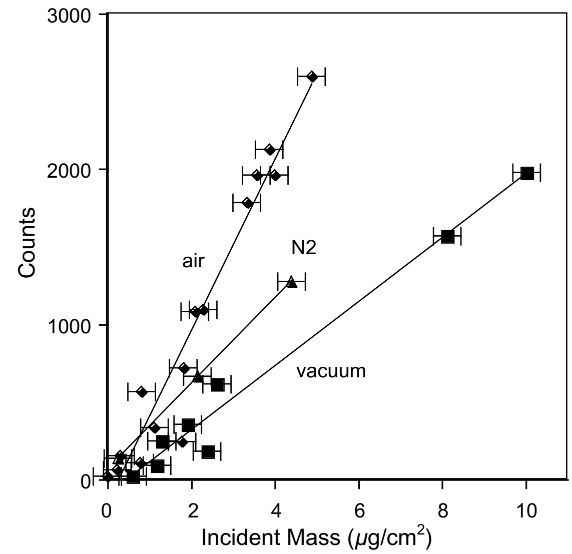

Fig. 4. Response of 50 × 50 mm grid in air (diamond), nitrogen (triangle) and vacuum (square points). Current limited to 25 mA. The lines are least squares fits to the data.

cause breakdown. The sensitivity is indicated by the slope of the response and is 239 counts/μg/cm^2 in air and 142 counts/μg/cm^2 in vacuum. The same procedure was followed for the 50 × 50 mm grid and the results are shown in Fig. 4. The sensitivity of the larger grid is 552 counts/μg/cm^2 in air, 275 counts/μg/cm^2 in nitrogen and 206 counts/μg/cm^2 in vacuum.

4. Conclusions

The disparity in scale between the most numerous dust particles (2.9 μm count median diameter) and the 25 μm gap between the traces on the grid raised the question as to whether multiple particles are necessary to bridge the gap between the traces to cause breakdown. The present results show a linear response down to the lowest masses measurable indicating that multiple particles are not necessary to generate a count for the mass range measured. The breakdown and general ruggedness of the laser written grids on the PEEK material proved to be not as good as the photolithographic grids on Ultralam used previously. We note that the sensitivity of the 50 × 50 mm PEEK grid was higher than the 12 × 12 mm Ultralam grid, but the increase was lower than the ratio of areas. We are planning to test 50 × 50 mm Ultralam grids that should maintain the high sensitivity seen at smaller area.

A mosaic of these devices based on nanoengineered traces on a low activation substrate such as SiO_2 could be envisaged for remote inaccessible areas in a next-step tokamak. This mosaic would both detect conductive dust settling on surfaces in these areas and could ensure that these surfaces remained substantially dust free. Work is in progress to explore these possibilities. We note a large-scale electrostatic dust transport system has been previously demonstrated [16].

Acknowledgements

The authors would like to thank T. Holoman and T. Provost for technical assistance. R. Hensley acknowledges support from the 2006 National Undergraduate Fellowship in Plasma Physics and Fusion Energy Sciences. The 50 mm grids were supplied by MicroConnex of Snoqualmie, WA. We thank IPP Garching for funding these grids. Work supported in part by US DOE Grant No. DE-AC02-76CH03073.

References

[1] G. Federici, C.H. Skinner, J.N. Brooks, J.P. Coad, C. Grisolia, A.A. Haasz, A. Hassanein, V. Philipps, C.S. Pitcher, J. Roth, W.R. Wampler, D.G. Whyte, Nucl. Fusion 41 (2001) 1967.
[2] G. Federici, Phys. Scripta T 124 (2006) 1.
[3] C.H. Skinner, J.P. Coad, G. Federici, Phys. Scripta T 111 (2004) 92.
[4] C.H. Skinner, G. Federici, Phys. Scripta T 124 (2006) 18.
[5] J. Winter, Plasma Phys. Control. Fusion 40 (1998) 1201.
[6] M. Rubel, M. Cecconello, J.A. Malmberg, G. Sergienko, W. Biel, J.R. Drake, A. Hedqvist, A. Huber, V. Philipps, Nucl. Fusion 41 (2001) 1087.
[7] Ph. Chappuis, E. Tsitrone, M. Mayne, X. Armand, H. Linke, H. Bolt, D. Petti, J.P. Sharpe, J. Nucl. Mater. 290&291 (2001) 245.
[8] J.P. Sharpe, D.A. Petti, H.-W. Bartels, Fusion Eng. Des. 63&64 (2002) 153.
[9] C.H. Skinner, C.A. Gentile, L. Ciebiera, S. Langish, Fusion Sci. Technol. 45 (2004) 11.
[10] C.H. Skinner, A.L. Roquemore, A. Bader, W.R. Wampler, Rev. Sci. Instrum. 75 (2004) 4213.
[11] G.F. Counsell, A.P.C. de Vere, N.St.J. Braithwaite, S. Hillier, P. Bjorkman, Rev. Sci. Instrum. 77 (2006) 093501.
[12] G.F. Counsell, C.H. Wu, Phys. Scripta T 91 (2001) 70.
[13] A. Bader, C.H. Skinner, A.L. Roquemore, S. Langish, Rev. Sci. Instrum. 75 (2004) 370.
[14] C. Voinier, C.H. Skinner, A.L. Roquemore, J. Nucl. Mater. 346 (2005) 266.
[15] C.V. Parker, C.H. Skinner, A.L. Roquemore, J. Nucl. Mater. 363–365 (2007) 1461.
[16] Y. Oda, T. Nakata, Y. Seki, I. Aoki, S. Ueda, R. Kurihara, J. Fusion Energ. 16 (1997) 231.