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Feasibility study for a blow-off technique to real-time monitor dust particles in fusion plasmas

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Introduction. One of the most challenging diagnostic problems remaining to be solved in fusion plasma control is the real-time detection of dust particles. Its importance for ITER have been widely recognized [1] while its impact on current fusion device performance is still not understood, this being largely due to the lack of a method for detecting their presence and quantifying their properties. Although considerable information has been compiled on residual dust collected after many months of device operation [2], such particles cannot be tracked, except at the plasma periphery [3], during plasma operation.

The method proposed here consists of burning dust particles that lie along the path of a pulsed laser beam and detecting, in real-time, the resultant emissions produced by the hot dust particles. Since the laser power repetition rates (10 - 100 Hz) needed can be achieved using commercially available systems, the method seems to have the appropriate temporal and spatial resolution required to make it attractive for pursuing this goal.

The method described here arose from experiments conducted to obtain a better understanding of the laser ablation technique used for injecting impurities into the TJ-II stellarator. It is intended to use the same experimental set-up to evaluate the feasibility of this technique. The main problem envisaged is a low concentration of dust [4]. Finally, a log of dust particles entering TJ-II plasmas, as detected by VUV spectroscopy, has been kept during recent experimental campaigns. This log has allowed these materials to be identified.

Dust detection in fusion devices. It is generally believed that most of the impurities introduced into plasmas are in the form of atoms or molecules although some are in the form of small solid particles such as flakes or micro-particles. Goodall observed the behaviour of such micro-particles, termed UFOs, during plasma discharges by capturing their emitted visible light on high-speed film [5]. Their size range spans from several tens of micrometers for micro-particles to a few millimetres for flakes. The absence of micro-particles smaller than a few tens of micrometers may reflect measurement limitations and the particle formation processes.

Narihara [6] reported of dust particle signatures in the Thomson scattering monitor of the JIPPT-IIU. These were observed in several channel positions at times ranging from 0 to 220 ms after current disruptions. They were assigned to scattering as they only appeared at the moment of the laser shot and no signatures were observed in posterior gates taken at 20 and 40 μs for monitoring plasma background. However, evaporation of such small particles would be very fast and leave a track in the first integration window only, the one centred on the laser pulse. A technique for in-situ real-time monitoring of dust and flakes based on infrared thermography was proposed for Tore Supra [7], and a list of works to detect dust can be found in astrophysics [8], using either ERE –extended red emission- or infrared observation.

Experimental. Time-resolved vacuum ultraviolet (VUV) spectra are systematically collected during TJ-II discharges. Occasionally, material falls into a plasma producing abrupt signals in bolometers and phosphor screens as well as characteristic line emission spectra in the VUV spectrometer. Subsequent analysis of VUV spectra permits their atomic composition to be determined and the material to be identified, see Fig. 1. However, their origin cannot always be specifically pinpointed as in many cases the material in question is widely distributed about the vacuum chamber. For instance, carbon and fluorine (Teflon® used on in-vessel diagnostics), aluminium and oxygen (alumina ceramic on a fast reciprocating probe), as well as iron and/or chromium (from the vacuum chamber walls) are the most common materials.

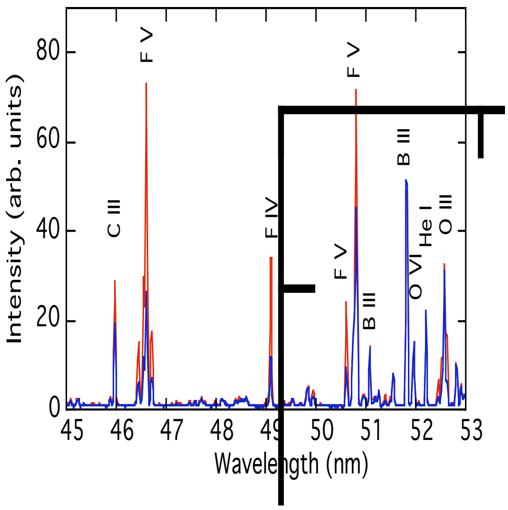

Fig. 1. The atomic composition of the material was identified by comparing time-resolved VUV spectra taken before and during its entry into the plasma.

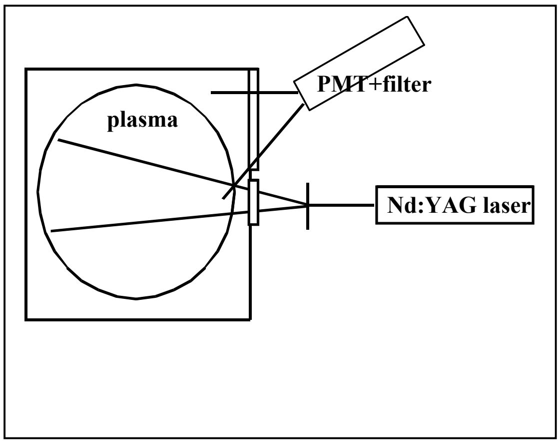

Fig. 2. Sketch of the experimental set-up devised to explore the proposed dust detection scheme.

The detection technique. The general theory of laser-induced incandescence (LII) is well described [9]. The absorption of laser energy is the key point in this laser-particle interaction; if δ is the absorption length parameter, the break in the absorption curve occurs at a ~δ, where *a* is dust size. In the visible δ ~0.1 mm for soot particles, while in the ultraviolet (200-300 nm) δ may be as small as 10-20 nm. When a dust particle is exposed to a laser pulse, most of the energy is transmitted, but a small portion is scattered at the particle surface (Mie/Rayleigh scattering) or absorbed by the particle. In the LII technique, the intensity of the continuum emission depends roughly on particle radius as r^4, this being different from Rayleight scattering, *i.e.* r^6. Radiative losses becomes the dominant process at low pressure and high temperature, and this results in a temperature dependence of the LII signal which is proportional to the cube of the particle temperature. The slope of the logarithmic LII signal is inversely proportional to the size and material properties of the particles. The LII signal is not affected by the laser pulse shape or by its intensity. Several authors have investigated the features of LII signals by developing numerical codes and comparing their results with experimental data [9]. Several conclusions has been reached that can serve as reasonable guides for its application to fusion plasmas: the LII signal persists for hundreds of nanoseconds, is not superimposed on the laser pulse and has a weak dependence on laser energy once a threshold level has been reached. Finally, LII thermal emission has been estimated by Eckbreth [10] as a function of particle size.

In a feasibility study for a fusion plasma, it is planned to use the experimental set-up depicted in Fig. 2. The geometry, except for the focusing optics, is the same as that used for impurity laser ablation in TJ-II. The Nd:YAG laser beam is focused along a sheet volume using a cylindrical/spherical lens combination. This beam can induce incandescence in dust particles, of an appropriate size to absorb the laser power, that traverse the laser beam during its 10 ns pulse time. Possible dust particle emissions, across a broadband range in the near infrared, will be detected using a filtered photomultiplier and a fast amplifier. This radiation detector by itself constitutes a fast surveillance system for exploring the interaction of dust with the plasma in a fast time scale, which could reveal its presence in a broad region not influenced by the laser.

We have performed, what posteriori can be seen as a dust-simulation experiment that on the one hand, suggests, and on the other, supports the proposal presented in this paper. We have studied the temporal evolution, at different discrete wavelengths, of the plasma emission produced after the pulsed ablation of a Fe sample. The emission collected at 90º to, and 20 mm from, the Fe sample using a fibre and a monochromator, $\Delta\lambda$ = 3 nm, exhibits two peaks separated in time. These are shown in Fig. 3 (lhs). The first peak does not coincide with the laser shoot and therefore is not a direct influence of laser itself. It corresponds to a prompt response of the interaction between the unabsorbed laser power and the first debris emerging from the sample. The second peak, in our opinion, corresponds to the result of the ablation of the film bulk. When the spectra of the two temporal peaks, depicted in Fig. 3 (rhs), are compared they exhibit different dependencies with wavelength. We hypothesize that the first peak is produced by the incandescence emission caused by the laser on the small dust particles generated in the first moments of the ablation process.

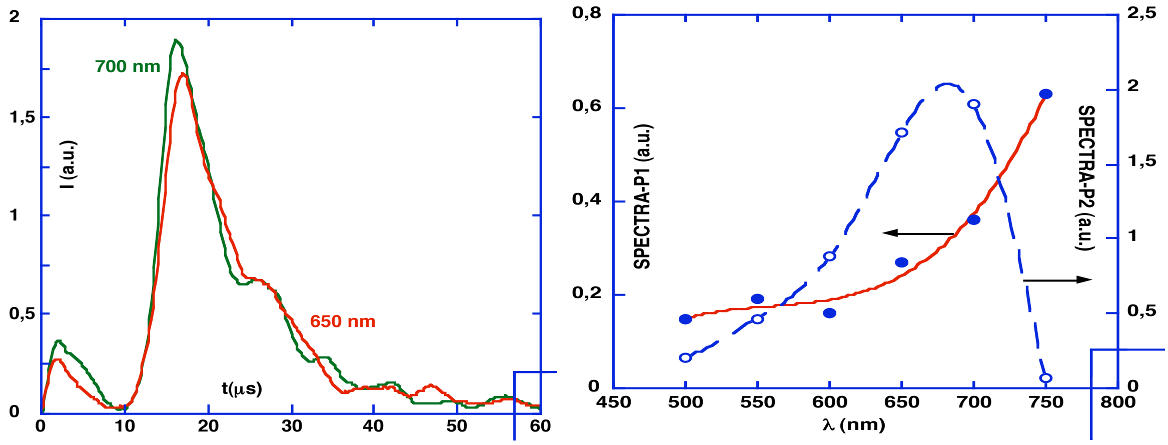

Fig. 3. Results of a dust-simulation-experiment using the TJ-II laser blow-off injection system. Here: left) is the time evolution of the signal at two wavelengths; right) is the spectral shape of the two separate temporal peaks: the first peak is identified as a dust by-product effect.

In conclusion, this work suggests a method to detect small dust particles in fusion plasmas and describes a simulation set-up for studying it under well-controlled conditions.

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References

[1] J.P. Sharpe, Fus. Eng. and Des. **63-4**, 153 (2002).

[2] W.J. Carmack, Fus. Eng. and Des. **51-52**, 477 (2000).

[3] A. Bader et al., Rev. Sci. Instrum. **75**, 370 (2004).

[4] S.I. Krasheninnikov et al., Phys. Plas. **11**, 3141 (2004).

[5] D.H.J. Gooddall et al., J. Nucl. Mater. **111&112**, 493 (1982).

[6] K. Narihara et al., Nucl. Fusion **37**, 1177 (1997).

[7] R. Reichle et al., J. Nucl. Mater. **290-293**, 701 (2001).

[8] B.T. Draine *The cold universe: Saas-Fee Advanced Courses 32*. Spring Verlag (2003).

[9] G.S. Eom et al., Appl. Phys. Lett. **83**, 1261 (2003); J. J. Appl. Phys. **43**, 6494 (2004).

[10] A.C.J. Eckbreth, Appl. Phys. **48**, 4473 (1977).