Development of TESPEL Configurations for Plasma Diagnostics

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A Tracer-encapsulated Solid Pellet (TESPEL) injection method has been shown to be useful for many fields of plasma diagnostics. In order to provide more flexibility for such plasma diagnostics, we are developing various types of TESPELs. Here we report a new type TESPEL with a thin shell made of poly-dichlorostyrene useful for the impurity transport study. The new multilayer TESPEL configuration is also discussed. This type of TESPEL is not only useful for impurity transport study but also for the neutron observation due to the transient increase of the deuterium in the local position in the plasma for the upcoming LHD D-D experiment.

Keywords: TESPEL, pellet, tracer, impurity diagnostics, neutron diagnostics

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A Tracer-encapsulated Solid Pellet (TESPEL) injection method has contributed so far to the various fields of plasma diagnostics as reported [1]. However, we noticed that more detailed control of the tracer deposition location is necessary in particular for promoting the impurity transport study. Thus, we are developing new TESPEL configurations for aiming at more flexible tracer deposition with a multilayer concept. From the technical viewpoint, regarding the production of the conventional TESPEL, we need to first drill a polystyrene ball, then insert relevant tracers, and, finally, cover the hole with a tiny polystyrene ball as a lid. Making TESPELs thus requires much time. Moreover, the tracer material is often in an irregular form, so it is difficult to estimate the precise amount of the tracer, although it is possible to estimate the amount roughly from the visually observed volume. In order to solve these problems, a new type TESPEL with mixing tracers as a compound or as a colloidal dispersion in the base polystyrene becomes a candidate.

Recently we reported two types of TESPEL configurations [1], namely, (i) thick-shell-type and (ii) thin-shell-type [2] for the accurate impurity transport diagnostics. In particular, it was shown that the impurity transport feature depends on the source location of the impurity and also on the collisionality (between impurities and bulk ions).

Regarding (i), the polystyrene ball (polymer in the form of $(C_8H_8)_n$) with a diameter of up to 0.9 mm is drilled with a typical diameter of 0.2 mm, and the tracers are put inside the polystyrene ball, and then the hole is covered with a tiny polystyrene ball (a typical diameter of 0.2 mm) as a lid. In case (ii), the polystyrene shell with a typical shell thickness of ∼75 μm is produced for the shallower deposition of the tracers in the plasma, and the procedure described above is similar to case (i). Case (i) is called "thick shell," and has a typical shell thickness of 0.24 mm. In Ref. [1], to enhance the difference of the tracer deposition, the outer diameter of the TESPEL is set as approximately 0.73 mm in case (i) and approximately 0.6 mm in case (ii). In this paper, we will report the new configuration of the TESPEL.

Based on the recent result [1], the shallower location of the tracer deposition compared to case (ii) is planned for investigating the impurity transport property more precisely. Therefore, we made (iii) a thin shell-type TESPEL whose shell is made of Poly-2,6-dichlorostyrene: $(C_8H_6Cl_2)_n$. In case (iii), the tracers are put inside the shell, but the Cl also performs the role of tracers. Thus, more outer deposition locations of the tracers become possible. Although we observed only H_α emission light for the shell ablation process in the experiment, there is no reason why the Cl tracer is separately ablated from the compound of Poly-2,6-dichlorostyrene: $(C_8H_6Cl_2)_n$. Therefore, as shown in Fig. 1, the Cl tracer can be considered to be deposited in the plasma periphery, although the deposition profile is rather broad. Thus, the transport property of the Cl tracer from the shell can be compared directly to that of the tracers inside the shell. In fact, as shown in Fig. 2, the Li-like emissions from the Cl tracer stemming from the shell and the V tracer stemming from the central core of the TESPEL in the high density case are measured by a high-resolution, time-resolving soft x-ray multi-channel spectrometer (SOXMOS) [3]. These are compared with the data calculated by the 1-D impurity transport code STRAHL in which the diffusion coefficient D (= 0.1 m^2/s) and the pinch velocity V (the peak value of

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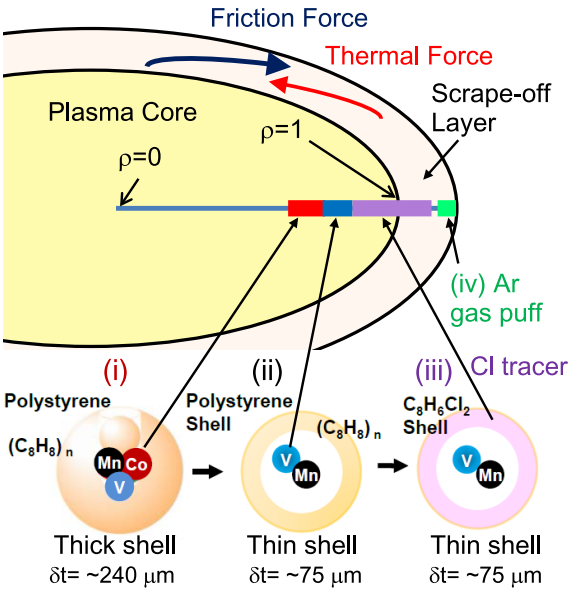

Fig. 1 Schematic view of the different tracer deposition locations using the types (i) - (iii) of TESPEL configurations, and the outermost deposition location with the case (iv) Ar gas puff.

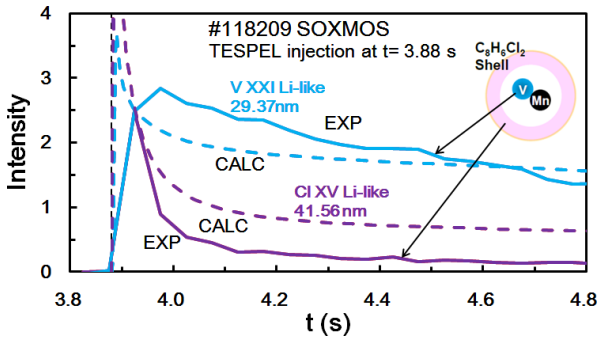

Fig. 2 Temporal development of the Li-like emission of the tracer V, and the Li-like emission of Cl contained in the thin-shell. The intensities calculated by the STRAHL code by assuming the same D and V are also shown by the broken lines.

-2 m/s at $r_{\rm eff}/a_{99} = 0.9$) are taken as the same values, and any shield effect is not included. The Cl Li-like emission observed experimentally decays faster than the calculated emission compared to the case of the V Li-like emission. This indicates the existence of the shield effect of the impurity in the plasma periphery [4].

The schematic image of the deposition locations for the cases (i) - (iii) in the Large Helical Device (LHD) is summarized in Fig. 1 together with the case (iv) gas puff such as Ar, which corresponds to the outermost deposition location of the tracer. Photographs of the samples of the polystyrene shell for case (ii) and the Poly-dichlorostyrene shell for case (iii) are shown in Fig. 3. Photographs were taken by an optical microscope focusing on the equatorial

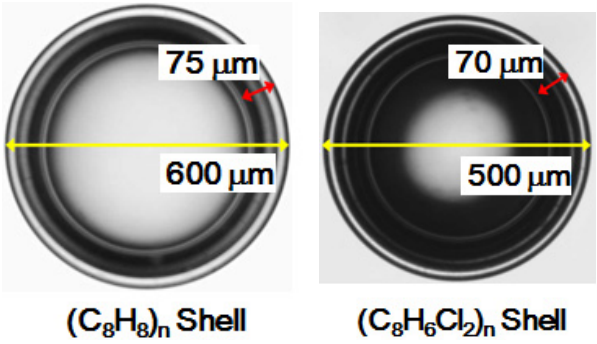

Fig. 3 Photographs of samples of the shells for cases (ii) and (iii).

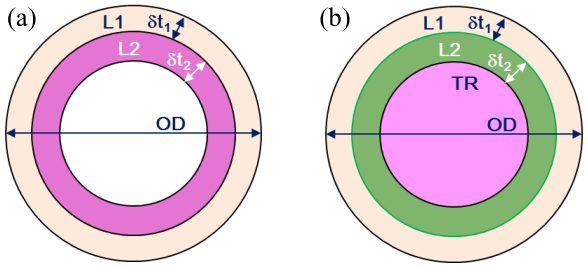

Fig. 4 Schematic of a multilayer TESPEL. (a) L1: $(C_8H_8)_n$ layer, L2: $(C_8H_6Cl_2)_n$ layer. Typical diameter OD: 500 - 900 μm, typical thickness δt1: 40 - 100 μm and δt2: 60 - 80 μm for LHD. (b) L1: $(C_8H_8)_n$ layer, L2: $(C_8D_8)_n$ layer. TR: tracers such as cobalt.

plane of the shell. The illumination light goes through in the center, while it is refracted in the periphery part of the shell.

A multilayer TESPEL is attractive, because the procedure of the drilling, inserting tracers, and covering the hole is not necessary as stated in the introduction. The accuracy of the amount of the tracer also improves. A schematic of one example of a multilayer TESPEL is shown in Fig. 4 (a). The typical diameter OD and the thicknesses δt1, and δt2 for the LHD are given in the figure caption. As an example, the outer layer L1 is made of $(C_8H_8)_n$, while the inner layer L2 is made of $(C_8H_6Cl_2)_n$. Thus, more flexible adjustment of the tracer (Cl in this case) deposition becomes possible compared to the case (iii). Recently the prototype of multilayered TESPEL has been realized by modifying the microencapsulation method [5] originally developed for the inertial-fusion-energy fuel pellet. The TESPEL consists of the outer layer of $(C_8H_8)_n$ with a diameter of 0.64 mm, and the inner layer of $(C_8H_6Cl_2)_n$ with a diameter of 0.39 mm. Based on this method, we are now developing the various configurations with different materials. The method to produce such a multilayer TESPEL will be reported elsewhere. The other tracer material is, of course, also set at L2. A TESPEL having 3 layers or more will be also possible as shown in Fig. 4 (b). This will give more flexibil-

ity to the experiments. For the coming LHD D-D experiment, a multilayer TESPEL having a $(C_8H_8)_n$ layer in the outer layer L1 and a $(C_8D_8)_n$ layer in the inner layer L2 may be useful. The advantage of this method is that the amount and the deposition location of the deuterium can be known precisely. Thus, the source location of the observed 2.45 MeV neutron increase can be identified as the deposition location of the deuterium (and the broadening due to diffusion depending upon the lapse time). As the absolute number of the deposited deuterium is known, the measured neutron flux can be calibrated, if the flux of the fast deuteron beam is estimated quantitatively. In the case of the outer diameter of 0.9 mm of TESPEL with thickness of $\delta t1 = 80\,\mu m$, the average electron density increase due to this shell is only $1.9 \times 10^{18}\,m^{-3}$, which is much lower than the typical bulk plasma density. The amount of the deuterium in the inner shell can be set up to 1×10^{19} depending upon the thickness of $\delta t2$. This number can be easily increased with the larger OD, if necessary. Furthermore, tracers TR such as cobalt and the other tracer materials for observing impurity transport can be set simultaneously inside a multilayer shell. The form of TR can also be shell type.

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