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Analysis of impurities on contaminated surface of the tokamak limiter using laser induced breakdown spectroscopy

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ABSTRACT

Laser induced breakdown spectroscopy (LIBS) analysis of plasma dust/impurities deposited on the surface of graphite limiter of Aditya tokamak is presented in the manuscript. LIBS spectra of contaminated curved surface of the limiter show the presence of Fe, Cr, Ni, Mo, Mn, Cu and C. The depth profile analysis of impurities has been performed by recording LIBS spectra with successive number of laser shots. Variation of spectral line intensity of impurities on its surface with distance from one end of the curved surface to the other end has been studied which shows spatial analysis i.e. deposition pattern of plasma dust/impurities on its surface. The concentration of constituents has been calculated using calibration free LIBS (CF-LIBS) method. The study demonstrates the capability of LIBS for depth profile and spatial analysis of deposited impurities on tokamak limiter.

1. Introduction

In modern tokamak operation, the wall protection is one of the prime concerns. In recent years, graphite/tungsten coated graphite are commonly used as limiter and first wall material for complete coverage of the internal vacuum vessel surfaces of the tokamak [1–4]. The hot plasma interacts with the limiter and vacuum vessel wall introducing impurities in the plasma [5]. These impurities get deposited on limiter, vacuum vessel wall and other internal components like optical windows etc. Limiter made of graphite is used in Aditya tokamak to reduce plasma-wall interaction and protect the vacuum vessel wall as well as inside components [5]. To understand the plasma-wall interaction, it is necessary to identify the deposited impurities and their pattern of deposition, if possible in real time during plasma discharge. The shape of the plasma-facing surface of the limiter of Aditya tokamak, IPR is curved. Hence in present work, contaminated curved surface of the limiter obtained from IPR, Gandhinagar has been analyzed for detection and quantification of impurities deposited on its surface.

LIBS is a very popular technique due to its versatility described in books [6–7] and research articles [8–15]. The major advantages of LIBS are its speed, ability to obtain multi-elemental analysis in a single laser shot, a very small amount of material (~1 μg) or volume is required, and can be used for in-situ analysis. It is readily applied to the real site with the help of suitable instrument and optical fiber [10]. Due to its unique properties, LIBS has become a potential tool for in-situ and real-time analysis of the nuclear material [13,16–21]. Using LIBS technique, Karhunen et al. [22] have performed the depth profiles analysis of different ITER-relevant material mixtures, Gasior et al. [23] have used LIBS for diagnostics of fuel retention and removal and wall composition in ITER, Mercadier et al. [24] have performed time and space-resolved studies of PFCs and Grisolia et al. [7] have studied the capability of the heating diagnostic coupled with LIBS analysis in different PFCs. In the present work, the limiter of the Aditya tokamak, IPR, Gandhinagar, Gujarat, India has been studied.

2. Material and method

The experimental setup for recording LIBS spectra of limiter is shown in Fig. 1. It consists of a frequency-doubled (532 nm) Nd:YAG laser (Continuum Surelite III-10), capable of delivering maximum energy of 425 mJ with pulse width 4 ns (FWHM) and variable repetition rate of 1–10 Hz. The laser is focused on the surface of the limiter using a convex lens of focal length 15 cm, which produces the plasma on its surface. Characteristic photons emitted from the plasma is collected at an angle of 45° to the incident laser beam using collection optics (CC52 collimator, Andor Technology) and fed into the Mechelle spectrograph (ME5000, Andor Technology) equipped with an ICCD camera (iStar 334, Andor Technology) having spectral resolution (λ/Δλ) equal to 6000. The LIBS spectra have been recorded in atmospheric air at atmospheric pressure (1 bar). Slit width of spectrometer is 10 μm and ICCD camera gain is 2000. Gate delay and gate width was optimized to get better signal to noise ratio at 0.7 μs and 10 μs respectively.

To analyze LIBS spectra, Andor SOLIS software along with NIST atomic spectroscopic database [25] is used. The best signal to background ratio and signal to noise ratio have been obtained at laser energy (110

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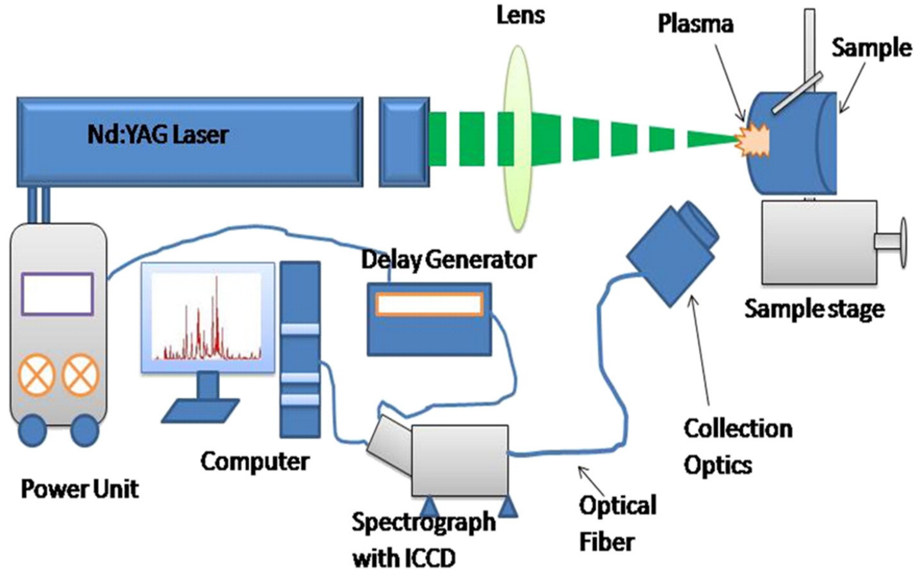

Fig. 1. Experimental setup to record LIBS spectra of Limiter of the tokamak.

mJ/pulse) and pulse repetition rate (2 Hz). Laser pulse energy is measured with an energy meter (Genetec-e model UP19K-30 H-VM-DO).

To study the shot wise variation of impurity element, the laser was focused on the surface of the limiter and LIBS spectra have been recorded for one laser shot, two laser shot and up to 15 laser shot on the same point of the limiter.

3. Results and discussion

3.1. Qualitative analysis

We have recorded LIBS spectra of impurities deposited on the surface of the limiter by keeping the limiter at suitable sample stage so that every time the laser hits at fresh surface of the limiter. LIBS spectra (Fig. 2) clearly show the presence of spectral lines of Fe, Cr, Ni, Mo, Mn, Cu, C, Ca and Mg.

These elements are also present in LIBS spectra of impurities deposited on the other plasma-facing components like optical window and flange obtained from Aditya tokamak as discussed in our earlier work [14–15]. The present experimental results clearly demonstrate that most of impurity material deposited on limiter surface is also due to erosion of tokamak wall during plasma-wall interaction.

3.1.1. Study of impurity layer on the plasma-facing surface of limiter (depth profile analysis)

For depth profile analysis of impurities deposited on the limiter surface, laser beam is focused on its curved surface and the single shot LIBS spectra is recorded for 15 successive laser shots at the same point. Total of 15 such point have been considered in different vertical lines starting from middle of the curved surface to the one end of the curved surface to get final LIBS spectra and named as 1st scan, 2nd scan, 3rd scan up to 9th scan (Fig. 3a). Fig. 3(b) shows the photograph of the limiter and its arrangement in the tokamak.

The variation of intensity of spectral lines of impurity elements (Cr 428.9 nm and Fe 371.9 nm) present in LIBS spectra of successive laser shots for middle portion (1st scan) is shown in Fig. 4(a–b). It is clear from Fig. 4(a–b) that the spectral intensity of impurity elements decreases with successive number of laser shots and becomes almost zero after 7th–8th laser shots. It means the material related to impurity layer is removed after 7th - 8th laser shot and hence the deposited impurity layer is in the form of a thin layer.

Fig. 5(a–b) show the variations of spectral intensity with successive laser shot for other vertical lines (3rd to 9th scan) and found similar type of behavior as that of the 1st scan (Fig. 4a–b). One can also see form Fig. 5(a–b) that the spectral intensity in first laser shot LIBS spectra

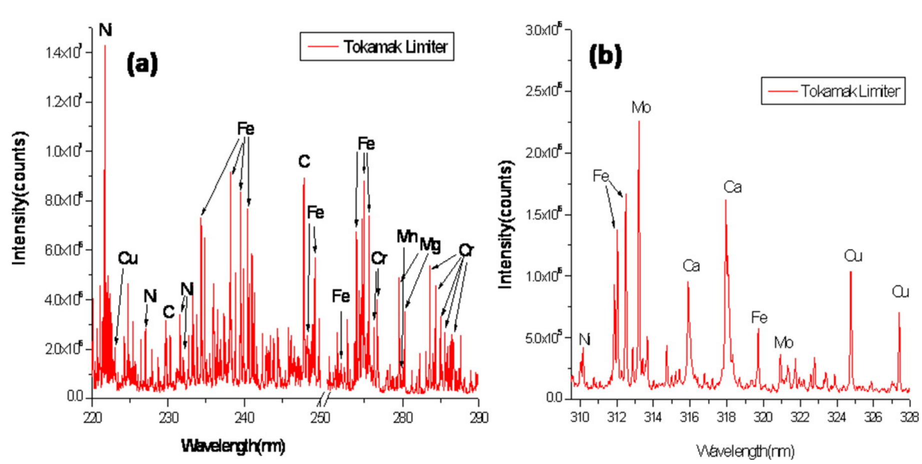

Fig. 2. Typical LIBS spectra of limiter using high resolution spectrograph equipped with ICCD (The maximum deference between observed and reported peak values of spectral lines is ±0.01 nm).