In situ measurements of spectral reflectivity of metallic mirrors in low density plasmas

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Introduction

Metallic mirrors belong to the most essential and most sensitive parts of optical diagnostics monitoring the dynamics and processes in plasmas. Optical emission spectroscopy, laser absorption spectroscopy, laser-induced fluorescence, Thomson scattering or Motional Stark Effect diagnostic are a few prominent examples for the application of mirrors. For many industrial plasmas, including fusion plasmas, some mirrors must be located inside the vacuum chamber often in direct contact with the plasma. Then, due to physical and chemical processes in the plasma, e.g., deposition or sputtering, the optical properties of the mirrors change with time more or less rapidly depending on the plasma conditions [1]. Also the heating of the mirrors due to interaction with laser pulses [2] can lead to a considerable drop of the mirror reflectance. As a result the mirror must be removed out of the plasma to be recalibrated and consequently the technological processes and experiments have to be interrupted for this procedure. Up to now there exists no practical solution addressing the problem of *in-situ* recalibration. In the present work, we demonstrate the new passive DSRM (**D**oppler **S**hifted **R**eflectance **M**easurements) diagnostic that allows to derive the spectral reflectivity (reflectance) of any electric conductive surface in the plasma at the wavelengths of the Balmer-series of H or D atoms [3].

Principles of the DSRM diagnostic

The principles of operation of this diagnostic are sketched in the Figure 1. The emission of atoms moving in front of the mirror with velocity v towards the detector results in the observation of two lines separated by the wavelength interval $\Delta\lambda = 2\frac{v(l.o.s.)}{c}\lambda$ according to the Doppler shift. Here $v(l.o.s.)$ −is the velocity of the atoms along the line of sight, λ_0 −is the corresponding wavelength, and c −is the speed of light.

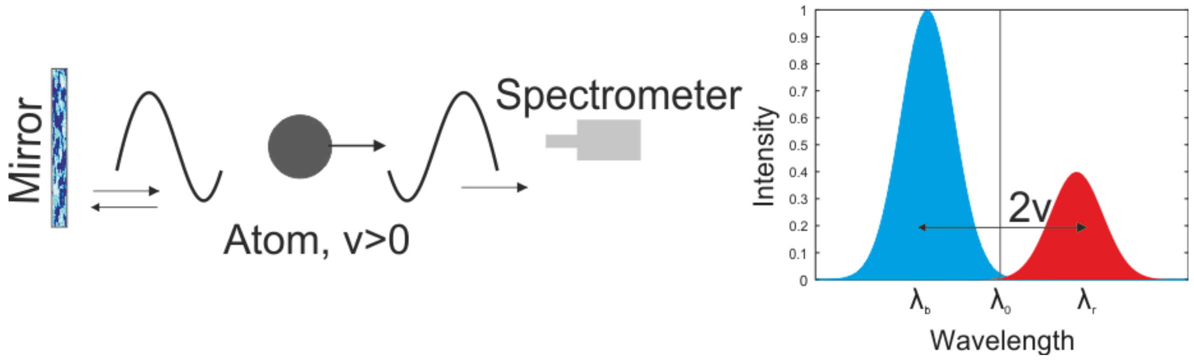

Figure 1. Principles of the DSRM diagnostic: The blue shifted line (λ_b) is the result of emission of the atom moving toward the spectrometer; the red-shifted line (λ_r) is the result of the emission of the photons reflected at the mirror and detected by the spectrometer as well. The ratio between the two lines provides the value of spectral reflectance at the un-shifted wavelength (λ_0).

If the separation of the spectral lines is large enough, so that the resolution of the instrument allows to distinguish both lines, and the separation also exceeds the width of the existing line, then the ratio between the red- and the blue-shifted signals could be used to derive the reflectance of the mirror. In order to realize this simple picture in the plasma a number of requirements have to be met. First, the eventually observed atoms need a well-directed velocity component in the close vicinity to the mirror. Second, one has to find an efficient excitation source of the spectral lines which exists only in the vicinity of the surface. Also, the collisions of atoms, emitting the photons, with plasma particles should not disturb the emission of the spectral line on the time-scales comparable with the lifetime of the excited levels (few ns).

Practically all of these requirements could be realized in low density Ar-H or Kr-H plasmas. By applying a negative potential $U<0$ to the mirror one accelerates the plasma ions towards the target. The energy of the fast neutralized atoms reflected at the target ~$|eU|$ could be made higher than the thermal energy (kT) of the atoms and ions at the plasma edge. Such picture is routinely realized in numerous examples of low-temperature laboratory and technological plasmas. Second, as the atom-atom collisions demonstrate the maximum of the cross sections in the energy range above 50 eV (Figure 2) one could potentially realize the schematic in Figure 1 by applying a negative potential of the order of -50..-300 V to the mirror. Our first experimental data of emission of D atoms in front of the W surface [8-9] have demonstrated stronger emission of fast atoms in Ar-H mixed plasmas than in Kr-H mixed plasmas. In case of other gases including pure H or D plasma the emission signal could be hardly distinguished from the background. The excitation transfer between the metastable levels of Ar and the excited levels of H or D remains therefore the second option of excitation of H and D atoms in front of the surface.

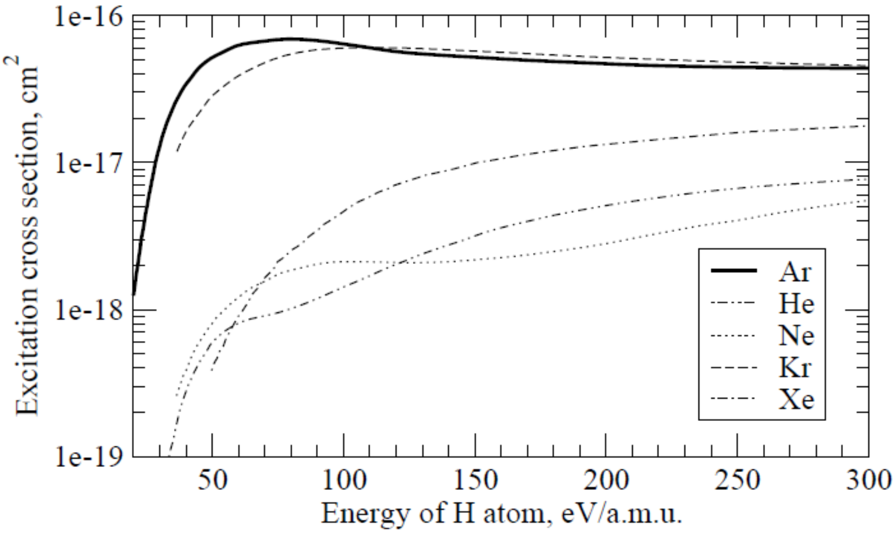

Figure 2. Excitation cross section of H_α line excitation by collision with different noble gases. The cross sections are based on the references [4-7].

Finally, the condition of low density plasma is required to limit the signal caused by the charge-exchange collisions within the sheath, including broadening caused by the Stark effect [10]. The loss of information on the target due to collisional quenching among excited levels becomes also supressed.

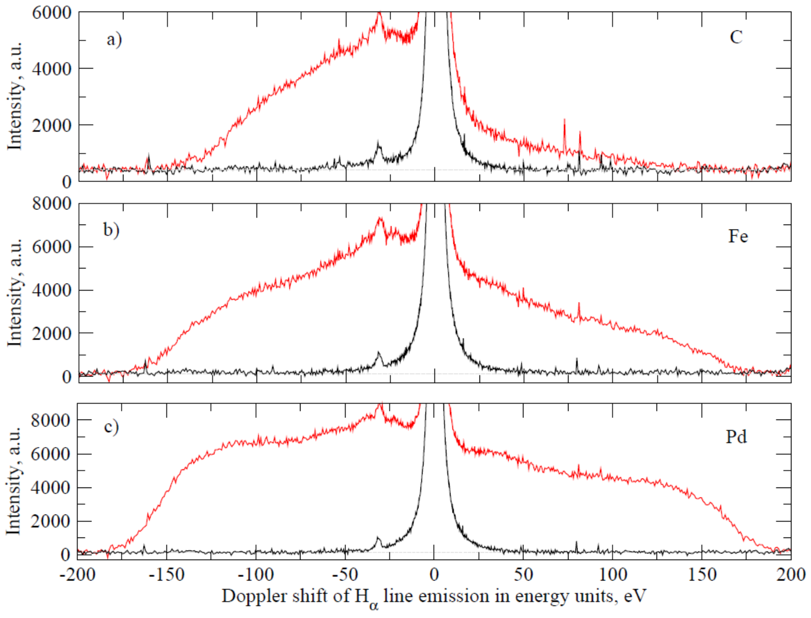

Figure 3. Example of emission of fast H atoms in front of C, Fe and Pd targets. In all cases the same voltage of -200 V is applied; observation angle is 35°. The red curves show the example of emission for the mirrors being at -200 V, the black curves show the measurements for the mirrors being at floating potential [13].

Experimental Results

The proposed picture of reflectance measurements using the DSRM diagnostic was realized in the linear plasma device PSI-2 [11] for different mirror materials. In the measured spectra for the cases of C, Fe and Pd targets shown in Figure 3 [13] the following is observed. First, the modification of the blue-shifted signal correlates with the material of the target. Second, in all cases the red-shifted profile follows the behaviour of the blue-shifted one. It is essential for the measurements of reflectance.

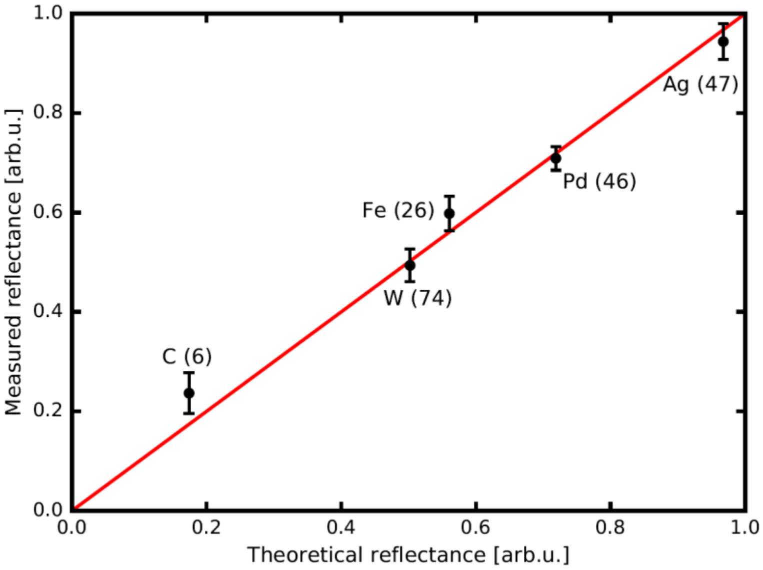

Figure 4. Comparison between the measurement and the available data of reflectance [12].

For C target, for example, the red-shifted signal is the lowest one among all the targets, which corresponds to the reflectance of the C on the order of 20% [12]. The experimental value of reflectance of specific mirror was obtained as the ratio between the red- and the blue shifted signals from Figure 3, where the non-overlapped wavelength regions of the direct and reflected emission at the observation angle of 35° were used. The result of this comparison is shown in Figure 4 [14]. In all cases one observes a rather good agreement between the measured values of reflectance in the plasma and available data [12]. We conclude that using the proposed DSRM approach one obtains a new powerful tool to perform *in-situ* calibrations of mirrors in wide ranges of laboratory applications.

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