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An in-situ realtime ellipsometer for TEXTOR

T. Dittmar[1], A. von Keudell[1], A. Kreter[2], B. Schweer[2] and the TEXTOR team

[1] *Arbeitsgruppe Reaktive Plasmen, Fakultät für Physik und Astronomie, Ruhr-Universität Bochum, Bochum, Germany*

[2] *Institut für Energieforschung - Plasmaphysik, Forschungszentrum Jülich, Association EURATOM-FZJ, Trilateral Euregio Cluster, Germany*

Introduction

Deposition and erosion at plasma facing surfaces within fusion experimental devices are a key issue in present and future fusion experiments. At the present a direct in-situ diagnosis to estimate deposition rates and simultaneously measure changes in composition and texture of the deposited layers is not available. This gap can be closed with ellipsometry. Nevertheless conventional ellipsometric instruments are not suitable in a tokamak environment due to the Faraday effect in the retarding elements and problems with optical access close to the first wall. These problems are solved for TEXTOR with the construction of a size optimized in-situ reverse ellipsometry probe head using a four diode stokesmeter mounted in a vacuum lock system. Using the stokesmeter and a careful overall design of the probe head, it was possible to eliminate the effects of the high magnetic fields within a tokamak.

Experimental setup of the ellipsometric probe head

The probe head consists of two sections separated by a central flange with a fused silica window: the cooled atmospheric housing holds the electronics and the vacuum platform holds a fused silica sample. Fused silica provides transparency and high optical isotropy. The probing beam is generated by a 640 nm, 30 mW laser diode situated in a thermo-stabilized mount. By using peltier-elements and a simple feedback circuit the temperature of the laser diode can be controlled to approximately 0.1 °C. To distinguish between laser signal and stray light from the tokamak discharge the intensity of the laser is modulated in the kHz region. The state of polarization is well defined by the aid of a thin film polarizer and coupled through a small fused silica window in the central flange to the vacuum platform. The laser beam is directed onto the backside of the sample with an incident angle of 35°. The diameter of the illuminated area on the front of the sample is approximately 2 mm. The sample itself is tilted in a way that the toroidal field lines strike the surface of the sample at an angle of about 10° when the probe head is mounted in the bottom vacuum lock system of TEXTOR. The fraction of the laser beam which is reflected from the either pre-coated or directly in the discharge deposited film system on the plasma exposed surface of the sample is routed back into the stokesmeter. In the stokesmeter the incoming light is consecutively reflected of four photodiodes placed non-planar in space. For better linearity the diodes are operated in photovoltaic mode and are fed to transimpedance amplifiers. The feedback resistors of the amplifiers are chosen so that all output-voltages are in a comparable signal range. The four currents measured yield all the information needed to determine the state of polarization of the back-reflected light beam. A fifth diode is directed at the light which is reflected from the linear polarizer in order to measure the total power of the laser beam.

Calibration and testing

Azzam [1] has shown that the current I_i of the ith-diode in the stokesmeter can be expressed by the following equation

$$\mathbf{I} = \underline{\mathbf{A}}\mathbf{S},$$

where **I** is the vector of the four currents, **S** the stokesvector of the incident light and $\underline{\mathbf{A}}$ is the instrument matrix of the stokesmeter. This instrument matrix depends on the actual configuration of the reflection angles at the photodiodes and their surface properties. It also strongly depends on the rotation of the planes of incidence between two consecutive reflections on the diodes. Therefore the instrument matrix has to be measured by calibrating the stokesmeter. One way for this calibration is to measure the response of the stokesmeter to different states of externally primed polarized light. This leads to a direct calculation of the instrument matrix elements. In [2] a calibration procedure including the compensation of imperfect polarizing elements is given. Using this scheme the instrument matrix of the stokesmeter in the ellipsometric probe has been determined. This allows a test of the system on

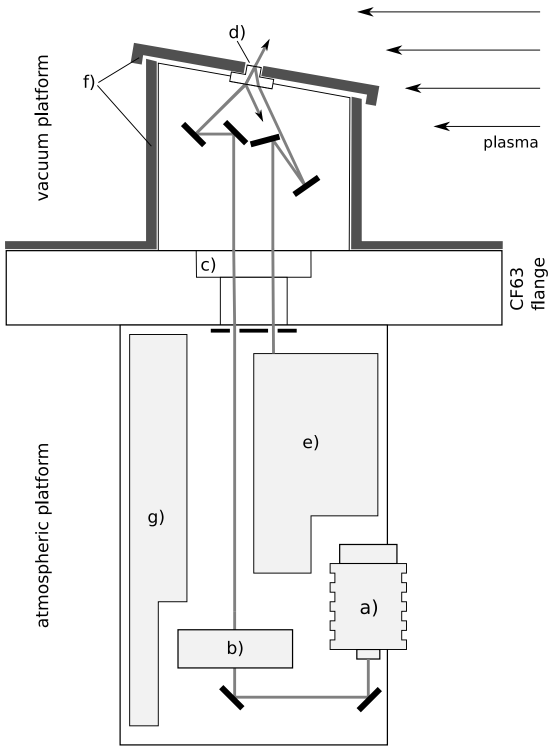

Figure 1: **Schematic of the probe head.** The laser beam is generated (a), polarized (b), and directed through a fused silica window (c) to the vacuum platform. The light is reflected at the plasma facing surface of the sample (d) and finally analyzed in the stokesmeter (e). The mirrors on the vacuum platform are protected by a graphite shielding (f). The probe head also contains the amplifying and thermal control electronics (g).

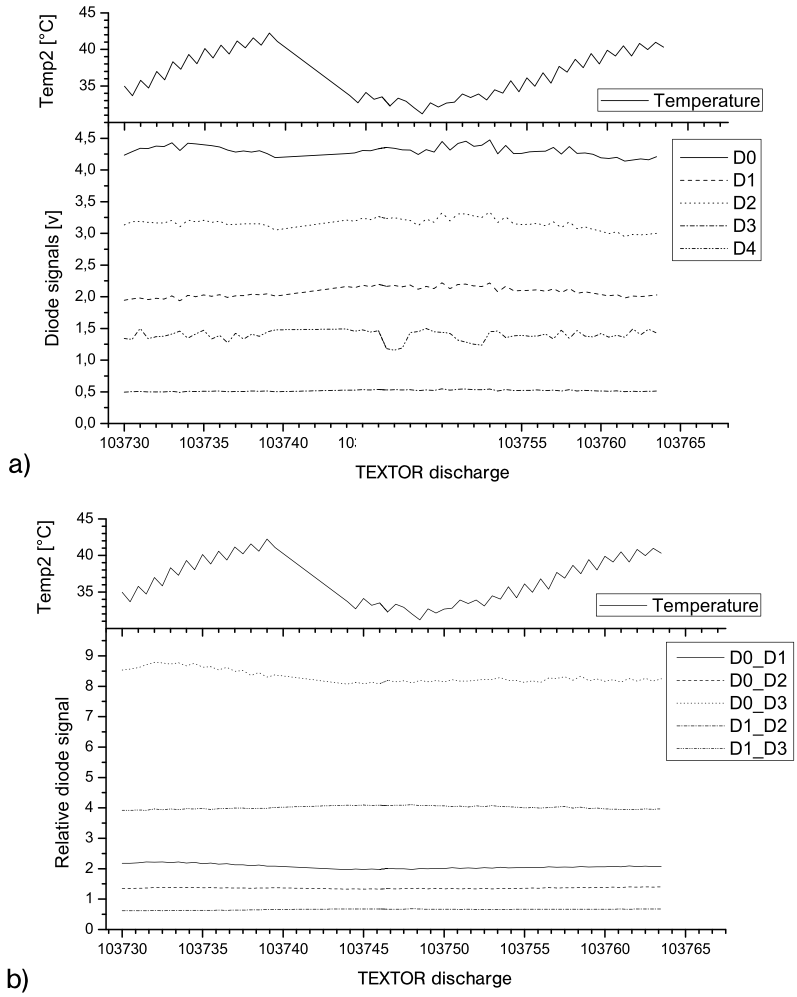

Figure 2: **Study of a-C:H film deposition in TEXTOR**

a) Diode signals during consecutive ohmic discharges at TEXTOR (I_P =350 kA, B_t =2.25 T).

b) Relative diode signals

an inductively coupled plasma (ICP) reactor. Different amorphous carbon layers (a-C:H) film systems with varying thicknesses, ranging from soft ($n \approx 1.6$) to diamond-like ($n \approx 2.1$) carbon films have been studied. For deposition measurements a-C:H films where grown from methane or ethane plasmas. The erosion measurements were done on pre-deposited films using argon-oxygen plasmas. During the tests at the laboratory plasma relative changes of 1 nm could easily be detected. This applied for either deposition and erosion studies.

Measurements at TEXTOR

For the measurements in a tokamak it is essential to protect the electronics and optical elements on the probe head against the influx of particles and heat from the plasma. Therefore the atmospheric platform of the probe head is mounted in a water cooled housing and the vacuum platform is covered by a graphite shielding. For the measurements at TEXTOR the complete probe head is then installed in a vacuum lock system. This way it can be positioned at the radius of interest. The effectiveness of the cooling system for sustaining acceptable temperatures in the inside of the probe head has been verified. For this experiments the probe head was either situated in the heated limiter region or deployed in the scrape-off layer, approximately 30 mm behind the last-closed flux surface. The temperature sensors inside the probe head show a maximum of 20 K rise above room temperature with an average of 4 K rise per discharge. The probe head was further used in several campaigns at TEXTOR for system integration and studies of a-C:H film deposition. Experimental data from such measurements is presented in figure 2. This data was taken during a series of ohmic discharges while the sampling area of probe head was positioned 26 mm behind the last closed flux surface. The experiment started with a clean fused silica sample. External analysis of the sample shows a deposition of a 7 nm thick a-C:H film with $n \approx 1.6$. The change of the relative diode signals is approximately four times bigger than the expected change in relative signal attributed to a deposition of 7 nm carbon film. This makes the analysis of the measured data challenging. The large change of the relative diode signals is caused by thermal stress in the vacuum platform where the rise in temperature during the discharge is considerably larger than in the cooled atmospheric platform.

Conclusions

We have presented a brief overview of the design, calibration, and testing of a novel ellipsometric probe head for measuring erosion and deposition of carbon films within tokamaks. System integration at the TEXTOR tokamak was successful. The effectiveness of the cooling system for a save operation of the probe head under typical heat loads in ohmic discharges has been verified.

Erosion and deposition of a-C:H films have been studied at an ICP reactor and in TEXTOR. The measurable change in film thickness in the laboratory is about 1 nm. At the moment the use of the ellipsometer is limited to studying film thickness changes greater than 30 nm due to thermal drifts in the signals of the photodiodes.

References

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