

# FLUENCE AND ENERGY DEPENDENCE OF CHEMICAL EROSION OF CARBON FIBRE COMPONENTS (CFC)

W. Bohmeyer, P.Kornejew, H.-D. Reiner and C.H. Wu\*,

*Max-Planck -Institut für Plasmaphysik, Bereich Plasmadiagnostik, EURATOM Association  
Mohrenstr. 41 , D-10117 Berlin*

*\*NET /ITER Hometeam, Boltzmannstr.2, D-85748 Garching*

## 1. Introduction

Graphite and different CFC materials are favorite materials for future fusion reactors. It is well known that the erosion by chemical sputtering and its strong dependence on the plasma parameters may limit their application. Therefore a systematic study of the interaction between different graphites and a stationary hydrogen or deuterium plasma has been started. In these investigations the dependences of chemical erosion with respect to temperature / 1 /, ion mass and flux density / 2 / were included. For this study clean plasma conditions were established. Thus only very small contamination (<1 %) of the target surface with other elements (Cu, Mo, B) had to be tolerated. Such clean conditions are not expected in future tokamaks that use different wall materials.

In this paper the dependence of the chemical erosion yield on the bombarding energy will be presented. In the experiments a Si-doped CFC-target is exposed to a deuterium plasma; its biasing voltage is changed between floating voltage and -250 V. Furthermore the influence of plasma impurities on the erosion yield of different CFC materials has been investigated. During long term exposure of these materials at fixed plasma conditions the chemical erosion yields have been measured by means of optical spectroscopy and mass spectrometry. Surface analysis methods have been applied to determine the contamination of the target surface. The composition of the target surface layers has been determined by AES and the lateral distribution of impurities was studied in the imaging mode of SIMS.

## 2. Experiment

The PSI-1 facility and its diagnostics are described in detail in /1/. The erosion experiments described in the following were performed in deuterium. For the erosion experiments discharges in deuterium have been used. The ion flux density was varied by changing the discharge power and simultaneously matching the neutral gas pressure thus establishing a nearly constant electron temperature. The ion flux density has been varied between  $(0.1 \dots 5) \cdot 10^{22} \text{ m}^{-2} \text{ s}^{-1}$ , the electron temperature was always lower than 10 eV and the electron density range was between  $(0.05 \dots 2.5) \cdot 10^{18} \text{ m}^{-3}$ .

The desired temperature of the target could be controlled by using either a water cooled or a gas cooled target holder. The ion flux densities was determined from the measured saturation current using a molybdenum target with the same front area and a ceramic mantle giving values in agreement with the saturation current determined by Langmuir probe measurements at the same radial position.

The process of chemical erosion was analysed by optical spectroscopy (CD-band at 430 nm) and by a differentially pumped mass spectrometer (different m/e values) simultaneously. In all spectroscopic measurements the intensities were normalized to  $D_\gamma$ . A weight loss analysis after exposure was applied additionally for some targets.

### Calibration procedure

The calibration of both diagnostics, mass spectrometry and spectroscopy, was carried out by injecting a well defined flow of  $CD_4$  into the plasma for each set of the plasma parameters. The gas was blown into the target chamber under nearly identical discharge conditions replacing the carbon target by a molybdenum target. This calibration is based on the assumption that  $CD_4$  is the main product of chemical erosion which will be cracked by the plasma to CD. However, when  $CD_4$  is injected into the plasma the mass spectrometer shows remarkable signals not only for  $m/e = 20$  ( $CD_4$ ) but also for  $m/e = 28$  ( $C_2D_2$ ) and  $m/e = 32$  ( $C_2D_4$ ) caused by the production of  $C_2$ -hydrocarbons at the walls or / and by reactions of  $CD_x$ -radicals in the mass spectrometer. It should be noted, that no D/XB-coefficients connecting photon and particle fluxes are needed.

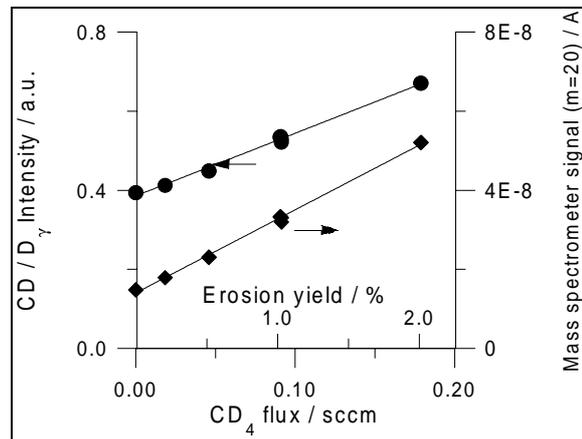
In Fig. 1 typical calibration curves for both diagnostics are shown. For  $CD_4$  concentrations found in the experiment the relations between the gas flow and output signals for both diagnostics are linear. There is a measurable background for both diagnostics caused by graphite components of the discharge setup which has to be subtracted.

Another observation indicating the importance of plasma chemical reactions is the long relaxation time of the mass spectrometer signal ( $m/e = 20$ ) of nearly 15 min. when  $CD_4$  is injected into the plasma, whereas the same time constant is about 3 sec without plasma.

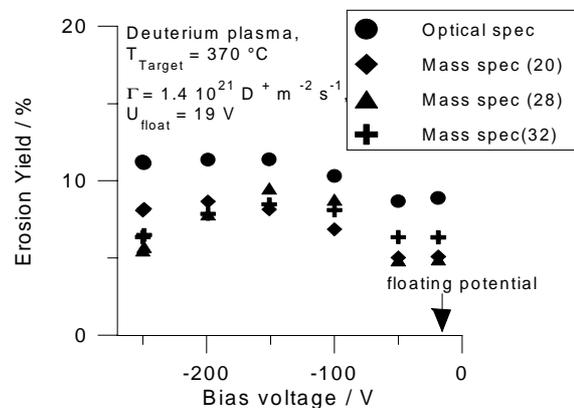
### 3. Results

In Fig. 2 the dependence of the chemical erosion yield on the ion bombarding energy is shown. These measurements are performed at higher target temperatures ( $T = 370^\circ C$ ) and lower ion flux densities ( $1.4 \cdot 10^{21} D^+ m^{-2} s^{-1}$ ) explaining the high yield.

In this diagram the results of optical spectroscopy and mass spectrometry for different masses  $m/e = 20$  ( $CD_4$ ), 28 ( $C_2D_2$ ) and 32 ( $C_2D_4$ ) are shown. It is clearly seen that optical and mass spectrometric data show the

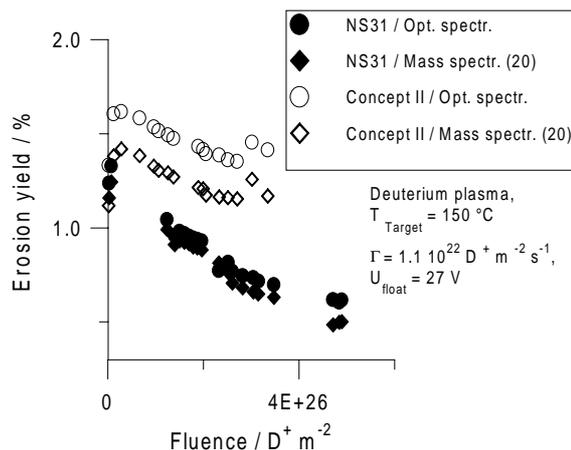


**Fig. 1:** Dependence of the signals of the erosion measurement diagnostics in dependence on the  $CD_4$  flux injected into the plasma through a nozzle



**Fig. 2:** Ion energy dependence of the erosion yield of NS 31

same tendency but, in general, optical spectroscopy yields slightly higher values. This can be explained by comparing the CD-band spectra of the erosion measurements with that of the calibration procedure when a molybdenum target is used. The CD spectra taken in front of the graphite target show an increase in some of the  $D_2$  rotational lines which are in the same wavelength region as the CD band. It can be explained by the occurrence of recombination of deuterium atoms at the graphite surface. The recombined  $D_2$  molecules leave the surface with the target temperature /3/ leading to another rotational temperature.

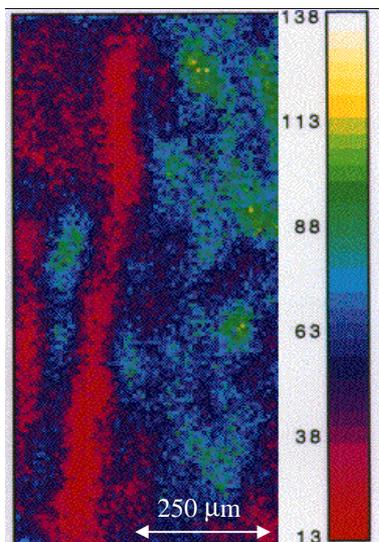


**Fig. 3:** Fluence dependence of CFC targets exposed to a deuterium plasma

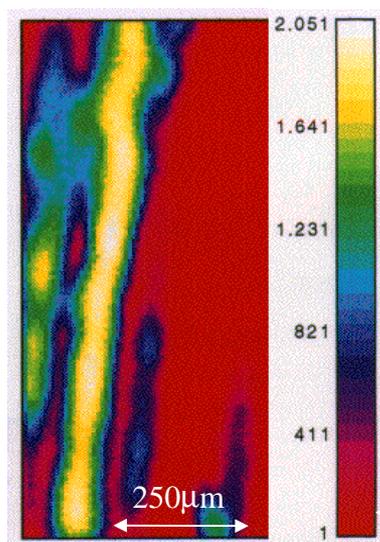
For these conditions the influence of biasing is low, leading to a maximum of the erosion yield for 150...200 eV ion bombarding energy.

For a target temperature of 150 ° C long term exposures for NS 31 and Concept II have been carried out up to a fluence of  $5 * 10^{26} D^+ m^{-2}$  (see Fig. 3). Under such conditions a certain amount of anode and cathode material (Cu, B) is continuously deposited on the target. At the beginning of the experiment the erosion rate showed the expected values between 1,2 and 1,6 % (150 ° C ,  $\Gamma=1.1 * 10^{22} D^+ m^{-2} s^{-1}$ ). During exposure the erosion rate of both samples was found to decrease nearly linearly up to a value of 50 % for NS 31 and 75 % for Concept II respectively. The total weight loss of both samples giving an average erosion yield of 1.2% for NS 31 and 1.6 % for Concept II respectively is slightly higher than the values determined by the other diagnostics.

The reduction of erosion can mainly be explained by the covering of the target surface with copper and boron. There is a clear difference between the two materials concerning the absolute erosion yield at the beginning and during the exposure.



**Fig. 4a:** SIMS C image



**Fig. 4b:** SIMS Si image

SIMS measurements have been applied for determining the spatial distribution and depth profiles of various impurities (Si, Cu, B). The depth profiles showed that the impurities can be found only at the surface. As can be seen from Figure 4 a - d for Cu and B, the impurity concentration distribution on the surface is well correlated with the Si distribution in the bulk.

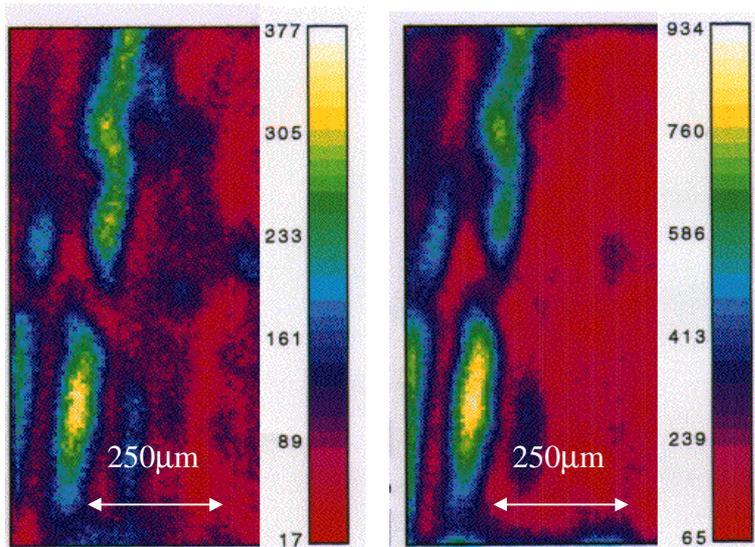


Fig. 4c: SIMS Cu image

Fig. 4d: SIMS B image

This means that Si enriched surface regions are predestinated for impurity deposition. Similarly, a correlation of the Cu and B concentrations at the surface of the Dunlop Concept II probe has been found. The impurities are inhomogeneously distributed, obviously in correlation with the structure of the carbon fibres at the surface.

AES measurements were performed in order to determine the relative density of the impurities. For NS 31 Cu/C values in the range of 0.11 to 1.9 were found whereas the Cu/C density ratio varies from 0.15 to 1.26 for Dunlop CII. Averaging over 30 different positions of the analysed surface area a mean Cu concentration of 45 % was found. This should lead to a decrease of the erosion yield of 45 % at least-in agreement with chemical erosion yield described above.

#### 4. Summary

The chemical erosion yield ( $D_2$  discharges,  $T_{\text{Target}}=370^\circ\text{C}$ ,  $\Gamma=1.4 \cdot 10^{21} \text{m}^{-2}\text{s}^{-1}$ ) shows only a weak dependence on ion bombarding energy having a maximum value between 150 and 200 eV.

In long term exposure experiments fluences up to  $6 \cdot 10^{26} \text{D}^+ \text{m}^{-2}$  could be realized. The decrease of chemical erosion yield observed in the experiments could be explained by a reduction of the effective target surface due to metallic coating.

Spectroscopic and mass spectrometric diagnostics are in good agreement, but the formation of deuterium molecules at the graphite target causes a systematic difference between both diagnostics.

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#### References

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