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# Erosion of W and deposition of C due to bombardment with D and $CH_3$

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**Abstract**

The bombardment of W with 3 keV $CH_3$ and 2.4 keV C at normal incidence is investigated experimentally and by computer simulation with the program TRIDYN. The weight change of the bombarded target and the total implanted amount of C is found to agree well between experiment and simulations at least for C bombardment. Calculations are then used to determine the sputter yield of W at steady state conditions as a function of the plasma edge electron temperature for three C impurity concentrations in the incident D flux, typical for fusion plasmas. 

## 1. Introduction

In the design of future fusion plasma devices like ITER several elements are regarded as possible first wall materials. Both, low-$Z$ elements as Be and C, and heavy elements as Mo and W are currently being considered. If these elements are eroded from walls or divertor plates, they will eventually lead to impurity contamination of the discharge. In this case plasma facing components will be bombarded simultaneously with hydrogen isotopes as well as by these impurity species. Of the high-$Z$ elements W has been used in ASDEX-Upgrade [1] and Mo in Alcator-C [2]. Earlier investigations have shown that experimental data are well reproduced by simulations for the bombardment of W with C only [3]. Therefore, in this paper the effects of a simultaneous bombardment of W with D and C are investigated experimentally and compared to computer simulations to validate the modelling of this more complex situation.

## 2. Experiment

Polished W targets were bombarded with 3 keV $CH_3^+$ ions produced by a high current source [4]. The weight change of the target was measured in situ with a microbalance at different fluences. The accuracy of the weight measurement is about 1 μg. The implanted C was detected with Rutherford backscattering (RBS) and with the nuclear reaction $C(^3He,p)^{14}N$ [5,6]. The first excited state of $^{14}N^*$ with an energy of 2.31 MeV and a Q value of 2.467 MeV is used, because protons emitted from the ground state of $^{14}N$ could not be detected due to the limited thickness of the detector. The peak in the energy spectrum of the protons is above the high energy edge of protons backscattered from W, see Fig. 1. The sensitivity for the C detection in W with this method is about $10^{17}$ at./cm$^2$. The best ratio of peak intensity to background was found at 2.4 MeV $^3He$. In addition, the shift of the W edge of the RBS spectrum due to the energy loss of the backscattered particles in the C layer on top of the W substrate was used to determine the C areal density independently.

## 3. Simulation

The calculations were performed with the Monte Carlo program TRIDYN (version 40.3) [7,8]. This program takes all collisional effects as implantation, reflection, and sputtering into account. Target composition changes due to the bombardment are regarded as well, so that effects like sputter yields, reflection coefficients, and composition profiles can be determined

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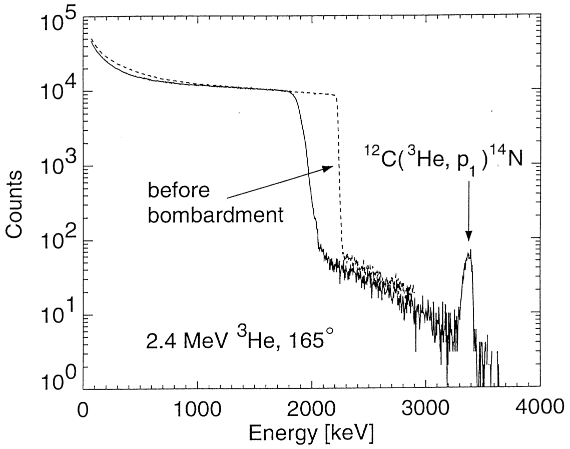


Fig. 1. Energy distributions of backscattered $^3$He from a pure W target (dashed curve) and a C implanted W target (solid line). The C fluence is $8.2 \times 10^{18}$ at./cm$^2$. Analysis is performed with 2.4 MeV $^3$He, the backscattering angle is 165°.

as a function of the bombarding fluence. The program also allows simultaneous bombardment with several species of fixed energy or with a Maxwellian incident distribution. Surface binding energies, important for sputtering, are based on the elemental heats of sublimation, but the surface binding energies are interpolated due to the surface composition of the target [9]. Chemical erosion, diffusion and segregation are neglected.

## 4. Results and discussion

The bombardment of the polished W surfaces was performed with 3 keV $CH_3^+$ and with 2.4 keV $C^+$. In the case of $CH_3^+$ it is assumed that C has an energy of 2.4 keV and each H has an energy of 200 eV. During the implantation the weight change of the W target is measured intermittently at several increasing fluences. The results are shown in Fig. 2. Additionally, Fig. 2 gives the calculated weight loss for the same two cases as in the experiment, but for the $CH_3^+$ bombardment two examples are considered; one where no hydrogen is retained in the target and one where the maximum concentration is 30%. Good agreement is found for C and $CH_3$ bombardment at low fluences, but large deviations are observed for the $CH_3^+$ bombardment at larger fluences. The difference cannot be explained by chemical erosion of C by H because of the low chemical erosion yield. The most probable reason for the observed discrepancy is the inhomogeneous $CH_3$ bombardment and, as a consequence, the strong contribution of W sputtering at the edge of the bombarded spot, where the much lower fluence leave some W at the surface as proven by RBS.

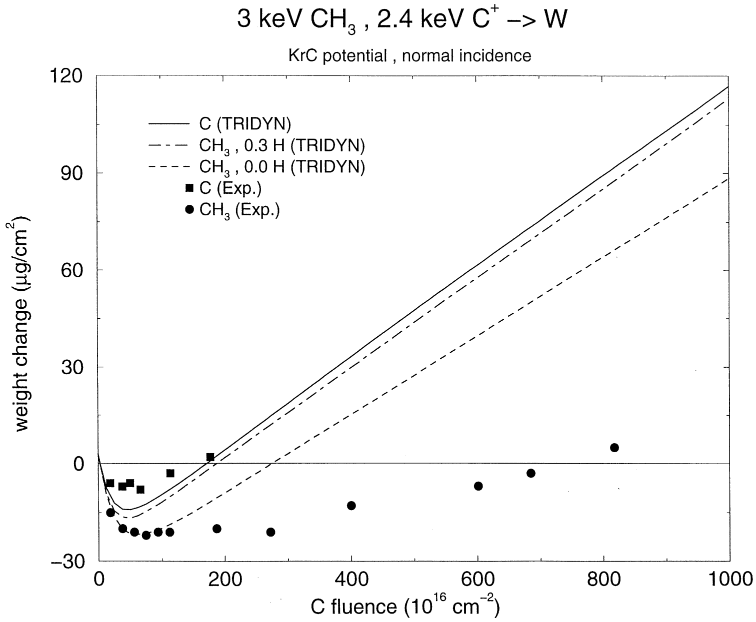


Fig. 2. Weight change (µg/cm$^2$) of a W target versus the C fluence due to the bombardment with 2.4 keV C and 3 keV $CH_3$. In the case of $CH_3$ TRIDYN results are shown for zero H concentration and 30% maximum H concentration in the bombarded W target.

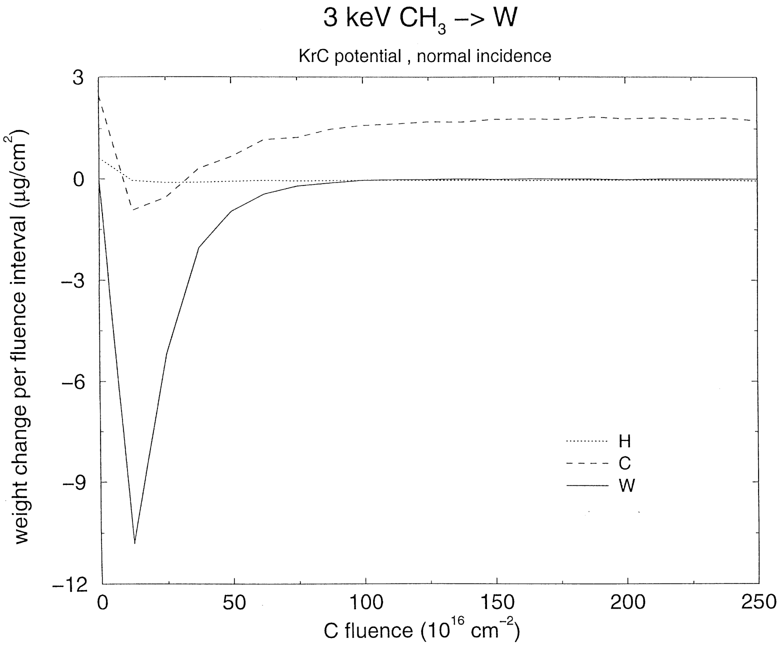


Fig. 3. Weight change per fluence interval versus the incident C fluence for the three species H, C and W. W is bombarded with 3 keV $CH_3$ allowing a 30% H concentration in the target (TRIDYN).

The explanation for the behaviour of the weight loss curves in Fig. 2 is given in Fig. 3, where results from calculations show that the weight loss at low fluences is mainly determined by the erosion of W until at higher fluences the deposition of C dominates leading to a constant weight increase. The influence of H to the weight change is negligible. It should be mentioned that in contrast to this paper the weight

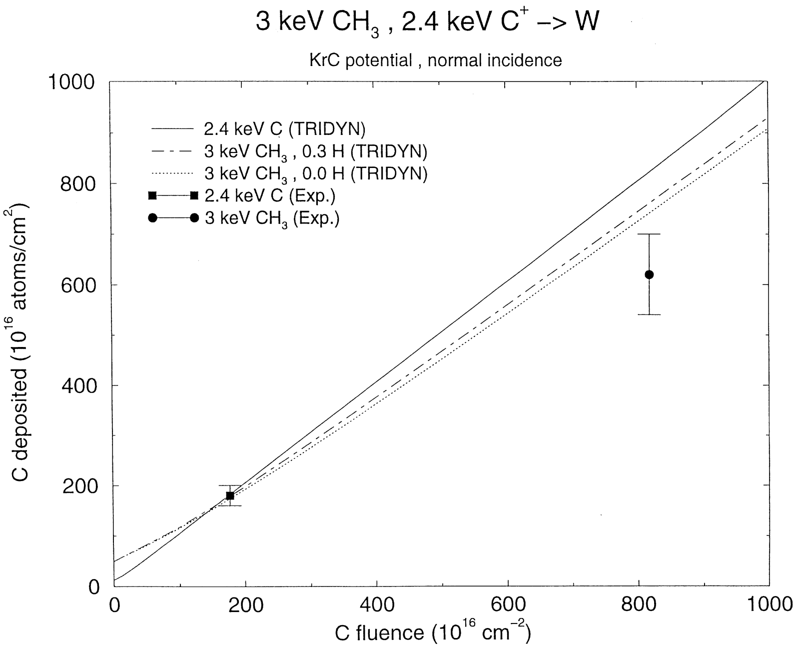


Fig. 4. Total deposited amount of C in a W target due to the bombardment with 2.4 keV C and 3 keV $CH_3$ at normal incidence.

change in [3] was given per bombarded spot size, not per $cm^2$.

The weight measurement cannot distinguish between the loss of W and the gain and loss of C. The total implanted amount of C can, however, be determined by the above mentioned nuclear reaction analysis and by the shift in the W edge of a RBS spectrum. Both methods give the same result. The measured C amount at the highest fluence in Fig. 2 for C bombardment is in good agreement with the calculated value, see Fig. 4, but for the $CH_3^+$ bombardment the measured implanted C amount is slightly lower than the calculated value. Tungsten carbide formation, which could lead to an increased W erosion, and diffusion of C cannot be seen in the RBS spectra and has not been found in earlier experiments [3].

Assuming that the calculations give a reasonable approach to the problem of simultaneous bombardment, calculations for a Maxwellian distribution of simultaneous bombardment of W with $D^+$ and $C^{4+}$ have been performed. The results for the sputter yield of W at steady state are given in Fig. 5 for three fusion plasma relevant C concentrations in the bombarding flux versus the plasma edge electron temperature. Steady state is reached when the surface composition stays constant with further bombardment; the thickness of the deposited C layer may still increase. Whereas at higher temperatures (above 25 eV) the C impurity level is not important in the range considered, the W sputter yield remains higher at lower impurity levels. The reason is a higher remaining W concentration at the surface. Due to the much lower incident energies and the smaller C fraction compared to the keV bombardment discussed above the sputter yield is strongly reduced and leads to a C deposition below about 10 eV depending on the C impurity flux, an effect also discussed earlier [10].

## 5. Conclusions

It is shown that the experimental data are in good agreement with results calculated by TRIDYN at low fluences, but large deviations are observed for $CH_3$ at high fluences. This is explained by an inhomogeneous incident flux in the bombarded spot. For the $CH_3$ bombardment it is demonstrated that the influence of H is negligible. At low fluences the weight change of the target is dominated by the loss of W until C deposition remains as the only process at larger fluences. These results justify the application of calculations for more fusion plasma relevant conditions. At steady state conditions the sputter yield of W decreases strongly below about 20 eV electron temperature leading to C deposition below about 10 eV electron temperature.

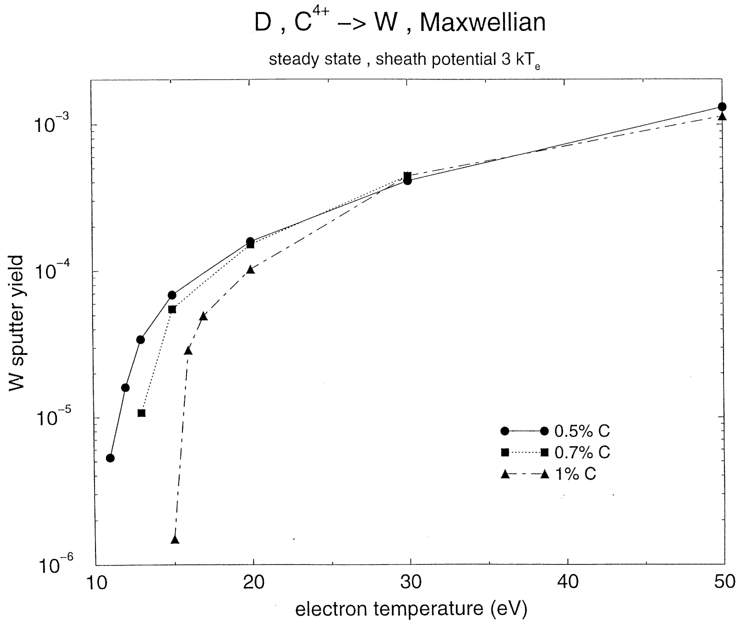


Fig. 5. Sputter yield of W versus the plasma edge electron temperature (eV) at steady state conditions for a Maxwellian incident distribution of D and $C^{4+}$, assuming a sheath potential of 3 $kT_e$. Parameter to the curves is the $C^{4+}$ impurity percentage in the incident flux. Lines drawn to guide the eye.

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