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Operation of Textor-94 with siliconized walls

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1. Introduction

To analyse the behaviour of TEXTOR-94 with silicon as a medium Z plasma facing material, TEXTOR-94 has again been siliconized after this was first performed in 1992 (1,2). The main aim was to study in detail the impurity release characteristics of Si simultaneously with the behaviour of other impurity sources and the influence of released Si on the plasma edge properties, the radiation behaviour and the general plasma performance. This contribution focuses on the Si source at the limiters, the simultaneous behaviour of carbon and oxygen impurities and the corresponding appearance of these impurities in the confined plasma. The influence of the siliconisation on operational limits (3) and the achievement of high confinement regimes (RI mode) is described elsewhere (4).

2. Experimental

TEXTOR-94 has been siliconised using the standard RF assisted DC plasma in a mixture of 80% He and 20% SiH_4.or SiD_4 as precursor gas at a wall temperature of 300° or 350°C, a total current of 8 A and a DC voltage of typically 600V. Si coatings of about 120-150nm are deposited rather uniformly over the entire wall, as measured by post mortem analysis of probes positioned at 3 different locations inside the torus. The impurity release was measured by emission spectroscopy on the toroidal ALT pump limiter and in addition on two graphite test limiters, which were introduced through limiter locks from the bottom and the top of the machine. The absolute C, O impurity fluxes have been determined from CI (909nm) and OI (844nm) lines and Si from a SII line at 597.9 nm. Impurities in the confined plasma have been analyzed by VUV spectrometers, total radiation and Zeff measurements. Plasma edge parameteres have been determined using atomic beam techniques.
TEXTOR-94 was operated for this type of studies under standard conditions of 350 kA, 2.25 T and 1.3 MW NBI-co injection. The density behaviour was investigated by slowly ramping of the electron density.

3. Results

After the siliconisation, silicon is the dominant impurity in the plasma. Fig 1a shows the change of the carbon and oxygen fluxes and the appearance of the silicon measured on the ALT main limiter after a siliconisation in SiD_4 as function of shot number. Data are for 1.3 MW D-co-injection heating at n_e= 3 $10^{19}/m^3$. Carbon and oxygen fluxes are reduced to values below 0.5% and the silicon release dominates with yields of about 10% at this plasma density. A very similar behaviour is observed on VUV impurity emission lines taken for the same shots, shown in fig 1b. Interestingly, the carbon fluxes and the CIII carbon radiation recover continuously within the first 30 shots up to the same level than before the siliconisation, whereas the oxygen and silicon fluxes and impurity radiation does not change much during this series of discharges. The increase of the carbon impurity content is due to a continously progressing mixing of the Si surfaces with C released from remote carbon sources (CO, CxHx ..) and from carbon released from highly loaded edges at the limiters from which the Si is eroded rather quickly. The increasing carbon fluxes in the plasma edge lead also to an increased sputtering of Si from the Si/C mixed surfaces which explains the nearly constant Si impurity content despite the decrease of the Si content at the surfaces due to the mixing process. Fig 2 shows the relative impurity fluxes measured at a test limiter as a function of the density for freshly siliconised conditions in hydrogen and deuterium operation.

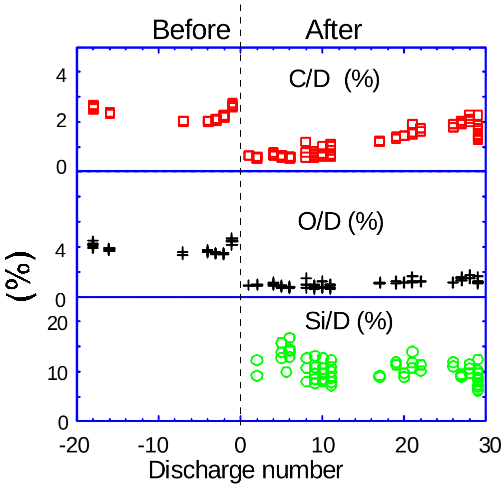

Fig 1a: Evolution of carbon, oxygen and Si fluxes on the main limiter before and after siliconisation

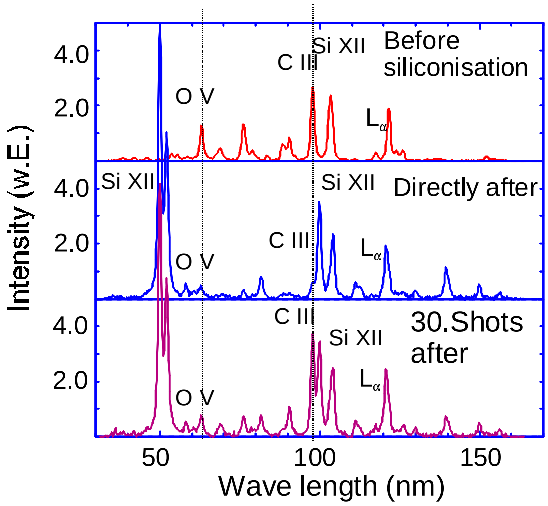

Fig 1b: VUV spectrum before and after siliconisation

The silicon fluxes reach rather high values at lower plasma density with values between 10 % and 20% with a clear isotope dependence but decrease down to about 2% at the highest plasma densities. The high yields result from Si self-sputtering which is about 0.75 at T_e=50eV and approaches unity at T_e= 100eV for Si $^{4+}$ ions impinging on Si. The radiation level is close to unity at the low densities and a non linear coupling between the Si release by selfs-puttering, radiation losses from Si and the plasma edge temperature develops.

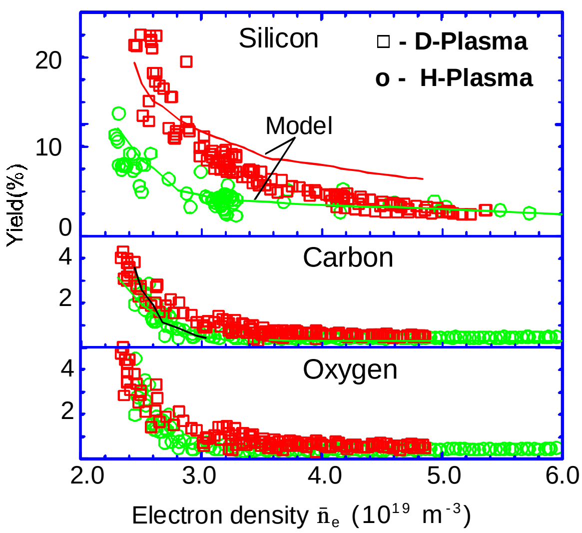

Fig 2: relative fluxes of Si, carbon and oxygen as function of density after fresh siliconsation

Under these conditions the plasma edge is largely diluted from hydrogen which results in an apparent increase of the oxygen and carbon yields when releated to the hydrogen flux as seen in figure 2. In fact carbon and oxygen is released under these conditions mainly by Si ion sputtering (carbon) together with some contribution from photon induced impurity release (oxygen). The solid line in the figure is the result of modelling the Si release using the measured hydrogen, carbon, oxygen and Si fluxes, the plasma edge electron and ion temperature, which is about twice the electron temperature at low plasma densities. The agreement is quite good at lower plasma densities with some deviations at higher densities in D-plasmas, which remains to be clarified yet. A possible chemical release of Si by hydrogen has been analyzed by emission spectroscopy of the SiD molecular band at 414nm, determining the velocity distribution of neutral Si in front of a SiC limiter and by residual gas analysis after the discharges. None of these measurements indicates a significant contribution of chemically released Si.

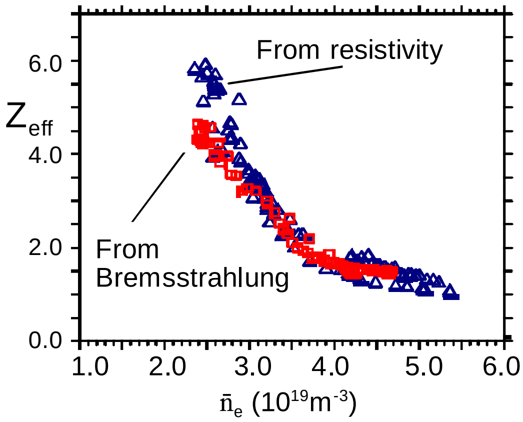

Fig 3a: Z_{eff} as function of av. density

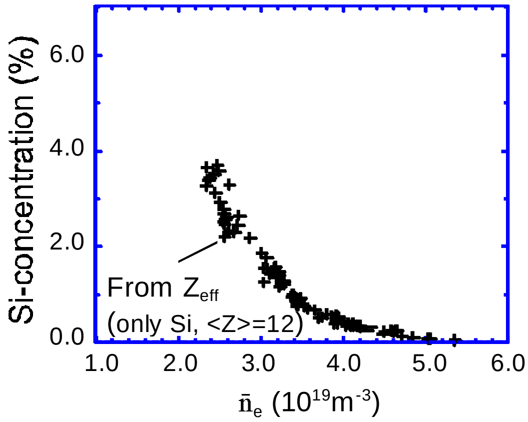

Fig 3b: Si concentration derived from Z_{eff}

Fig 3a shows Z_{eff} evaluated both from bremsstrahlung and conductivity as function of density assuming charge state of 12. Fig 3b displays the corresponding Si-concentration. The Si-concentration falls below 1% already at a density of 3.5 $10^{19}/cm^3$ and reaches values well below 0.5% at the highest densities. This shows again that sufficiently clean plasmas can be achieved with a limiter configuration at densities approaching the Greenwald density. The figure shows also that the Si concentration in the plasma core is much smaller than the relative fluxes at the limiter and decreases faster with density than the Si source (fig 2). This is due to screening effects in the plasma boundary which increases with increasing density, mainly due to a decreasing penetration of the Si neutrals at the limiter at high plasma densities.

The Si released from the limiters by physical sputtering establish plasmas with high internal radiation levels between 60 and 100% depending on density and the hydrogen isotope. This is shown in fig 4.

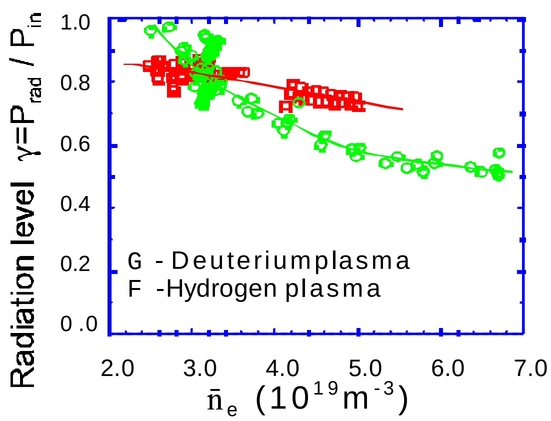

Fig 4: Total radition as function of density after fresh siliconisation (1.3 MW co-injection)

These high radiation levels can be used to establish plasma conditions with improved energy confinement due to Si-impurity radiation (RI mode), as it is routinely done by injection of neon (4). The Si- RI-discharges fits very well in the RI-mode database obtained by Neon or Argon injection.

Fig 5 shows the long term behaviour of a siliconisation showing the evolution of the Si^{11+} radiation and the Si fluxes on the limiter as function of the integrated hydrogen flux to the limiter for identical plasma conditions. As can be seen the effect of siliconisation is rather stable up to an integrated flux of about $2{\cdot}10^{19}/cm^2s$ from which on the Si concentration and the Si fluxes steadily decrease. This flux is about 4 times more than the flux estimated to erode the Si-layer and thus indicates that about 80% of the eroded Si returns back to the limiters prolonging the lifetime of the Si-coating. The remaining part of the Si diffuses in deeper regions of the SOL and is lost by deposition on side walls of limiters or other obstacles in the SOL.

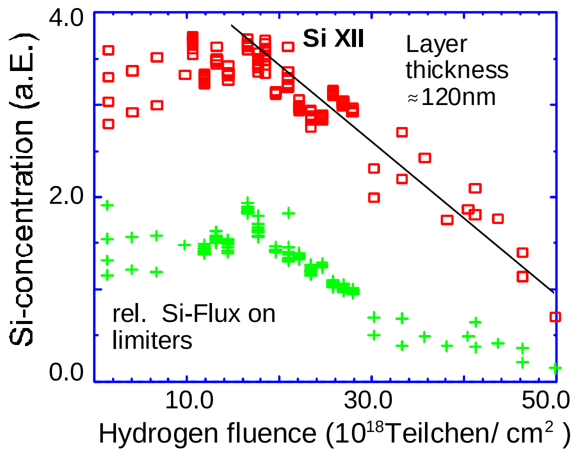

Fig 5: Evolution of Si-radiation and Si flux in H plasmas after siliconisation

Summary

After siliconisation, silicon is the main plasma impurity for about 30 auxiliary heated discharges (1.3 MW). The oxygen impurity content is reduced significantly and remains low for longer periods. The carbon impurity content recovers continously within about 30 shots, resulting from a mixing of C with the Si surfaces. The carbon is released from remote, not Si covered, sources and form highly loaded edges from which the Si is eroded quickly. The Si is released by physical sputtering. Its release and concentration in the plasma is high at lower plasma densities but shows a very strong decrease with increasing density. At high densities the Si concentration in the plasma core is well below 1%. Si sputtering resulted in high radiation levels between 60 and 100%, slightly decreasing with density and depending on the hydrogen isotope. This enables the achievement of improved energy confinement by impurity radiation (RI mode) with Si released from the walls. The lifetime of the coating is about 5 times longer as estimated from gross erosion indicating that about 80% of the eroded Si returns back to the location of production. The remaining part of Si is deposited on areas in the SOL and is responsible for the limited life time.

References:

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