*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-1.024 (2005)*

Removal of carbon layers by oxygen treatment of TEXTOR

V.Philipps[1], G.Sergienko[1], A.Lyssoivan[2], H.G.Esser[1], M. Freisinger[1], H. Reimer[1], U. Samm[1]

[1] *Institut für Plasmaphysik, Forschungszentrum Jülich GmbH, EURATOM Association, D-52425 Jülich, Germany*

[2] *Laboratoire de Physique des Plasmas / Laboratorium voor Plasmafysica, ERM / KMS, EURATOM Association, B-1000 Brussels, Belgium*

Introduction

Long term retention of tritium fuel in the surface or bulk material of plasma facing components is one of the major problems in nuclear fusion, since the amount of in-vessel retained Tritium is limited[[1]]. The dominant retention mechanism under carbon wall conditions is co-deposition of carbon with hydrogen to hydrogen rich carbon layers, which can grow continuously on the plasma facing sides but also on hidden areas like gaps or other remote areas. This circumstance has driven the ITER design to avoid as much as possible graphite and to use Be on the main wall and W in the divertor. Thus, the development of methods to remove fuel from in-vessel components and to demonstrate their tokamak compatibility is a highest priority in fusion research. Among several possible mechanism to remove fuel form the walls, oxidation of carbon layers is one of the most promising, but only applicable to C-layers. [[2]]. Removal of C-layers by molecular oxygen has been done previously in TEXTOR [[3]] but this technique requires wall temperatures in excess of 500-600K, which are hardly to reach in ITER in the present design. This contribution reports on the removal of carbon and stored fuel from the TEXTOR tokamak using conventional glow discharge conditioning (GDC) and ICRF discharge conditioning (ICRF-DC) [[4]] with full toroidal magnetic field in He/O_2 gas mixtures.

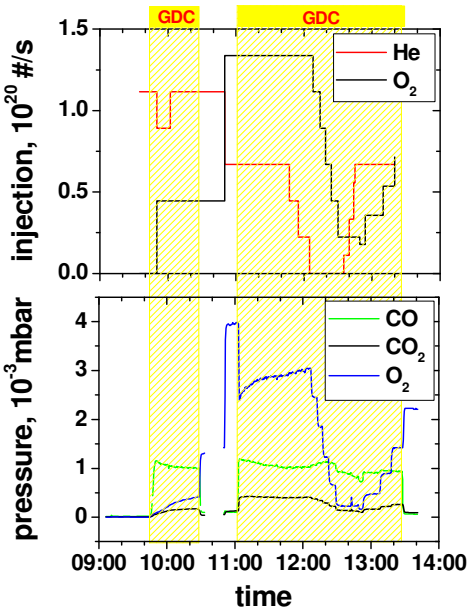

Fig 1: Temporal evolution of the O_2 and He injection rates (upper) and the partial pressures of CO, CO_2 and O_2 . The shadowed areas indicate GDC on/off.

2. Results and discussion

2.2. GDC oxygen treatment

A RF supported (13.2 MHz, ~ 250 W) DC glow discharge was applied in TEXTOR in gas mixtures of O_2/He, with ratios as shown in fig. 1.

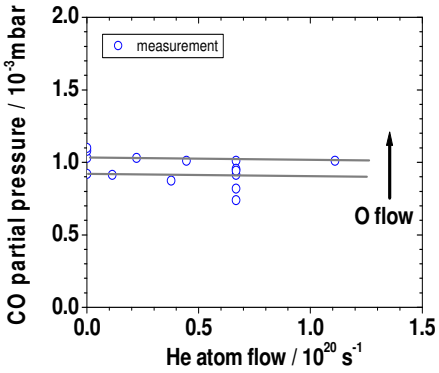

Fig 2: CO partial pressure at different O_2 injection rates depending on the He injection rate.

Fig 3: appearance of Si probes coated with a-C:H film before and after O_2 GDC treatment

The discharge is sustained by 4 antennas with a positive bias (anode) and with the TEXTOR wall and limiters (total area about 35m^2) as cathode. The total DC ion current was feedback controlled to 6A resulting in a bias voltage between 400 and 500V typically. This corresponds to an ion flux density of 10^{14} ions/cm^2 if it is distributed homogenously over the full wall area. Fig. 1 shows the temporal evolution of the injection rates of O_2 and He and the partial pressures of O_2, CO, CO_2 both during GDC on and off, measured by a differentially pumped quadrupol mass spectrometer (QMS). One can see that, when switching on the GDC all the O_2 is consumed and CO appears suddenly, while the CO_2 and O_2 pressures rise then slowly. When the O_2 injection rate is increased, the CO pressure does not changed much while CO_2 and the neutral oxygen pressures grow. This shows that the increase of the molecular oxygen partial pressure does not increase the CO production at a given ion current indicating that the CO production is dominated by O-ion impact, while the CO_2 production rate seems to be also due to atomic and molecular oxygen impact, which increases with increasing O_2 injection at constant ion current. The carbon removal rate is given by the CO&CO_2 partial pressures multiplied with the pumping speed and is about 2.1x10^{19}C/sec. The integral of CO and CO_2 pressure sums up to about 5.22 g of C removed from the vessel during the GDC treatment. With respect to removal of hydrogen, only HD can be measured accurately (D_2 overlaid by He, H_2 has a large background) which is about 4% with respect to that of C. This would yield a fuel removal of 8% of carbon assuming a H:D ratio of 1:1. This is in reasonable agreement with the average hydrogen content of redeposited carbon layers in TEXTOR [5]. Fig. 1 shows directly that addition of He to the GDC does not influence the production of CO and CO_2. This is demonstrated in more detail again in fig. 2 showing the CO partial pressure at different O_2 injection rates depending on the addition of He. As can be

seen, the addition of He and the increase of O_2 injection does not influence on the CO production.

Fig. 3 shows the appearance of Si probes which had been coated in beforehand with an amorphous carbon layer (a-C:H) of about 190 nm. Surface depth profiling and sputter Auger proved the complete removal of the a-C:H layer while a probe coated with a boron layer (upper left probe) was not affected. From this, a lower limit for the C-erosion of $1x10^{14}$C/cm^{2}s can be inferred and extrapolated to $3.8x10^{19}$C/sec for the whole wall area of TEXTOR which is similar to the rate deduced from the mass spectroscopy.

2.1. ICRF discharges in oxygen.

The ICRF plasma discharges have been performed with the toroidal magnetic field B_T=2.3 T switched on and ignited in continuous He flow with partial pressures of about $1\text{-}2x10^{-4}$ mbar, to which oxygen was added 100 ms after ignition through a fast gas injection. Reproducible

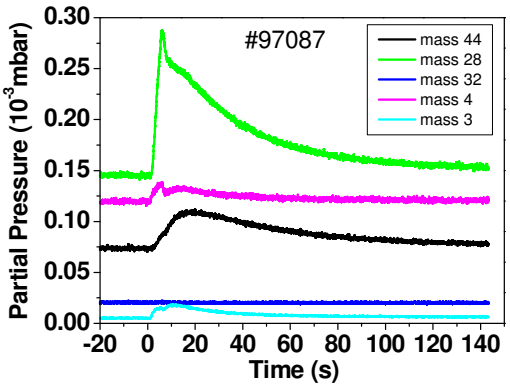

Fig 4: temporal behaviour of CO, CO_2 ,O_2 and HD partial pressure during and after ICRF pulse. The ICRF pulse lasted from 1-3.9 sec and oxygen was injected at 1.1.-4 sec with rate of 2.1 10^{20}/sec.

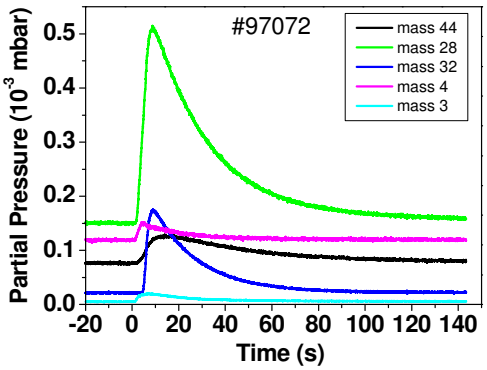

Fig 5: temporal behaviour of CO, CO_2 ,O_2 and HD partial pressure during and after ICRF pulse. The ICRF pulse lasted from 1-2.7 sec and oxygen was injected at 1.1.-4 sec with rate of 3 10^{20}/sec.

ICRF plasma generation could be demonstrated with coupled RF power about 50–60 kW (f=29 MHz). The ICRF pulse length was typically 5 sec and oxygen switched off 1 sec before the end of the ICRF pulse. Optical and differentially pumped mass spectroscopy (QMS) was used to analyse formation of oxygen reaction products and oxygen retention.

When oxygen was inserted during the presence of ICRF plasma, no neutral oxygen pressure rise could be seen while CO and CO_2 were formed together with the release of HD and D_2, but with about one order of magnitude lower intensity (fig. 4). Most of the CO and CO_2 is released after the ICRF pulse, the maximum total pressure was about 10^{-3} mbar. Fig. 5 shows the same conditions but with the ICRF pulse failed at 2.7 sec. At this time, the oxygen neutral pressure rises strongly while the CO pressure starts to drop. This proves that the ICRF pulses „consume" the injected O_2 molecules to 100% within the accuracy of the measuring system.

The maximum oxygen injection was given by the maximum allowable neutral pressure of about 10^{-3} mbar (mainly CO and CO_2) at the antenna box, which determines, thus, the maximum of the C exhaust rate. Higher pumping speeds would increase the removal rate. In a typical ICRF pulse as shown in fig. 4, about 8.5 10^{20} O-atoms have been injected from which about 50-70% is exhausted in form of CO and CO_2 with the major part released after the ICRF pulse. About $1.2x10^{22}$ O-atoms in total have been injected during 15 ICRF pulses with a total ICRF length of 51 s. The majority of this is transformed to CO and CO_2 but exhausted in between shots, while the amount of released CO and CO_2 during the 5 sec ICRF pulse is only about 15%. Assuming a duty cycle of 1:10 (5s ICRF on/50s off, to allow for pump out), the effective C-removal rate would be about 1.8 10^{19} C/s, similar as for the GDC. If one would aim for steady state ICRF pulses, the C- removal during the ICRF pulse itself is limited by the maximum antenna pressure, which is similar to the neutral $CO+CO_2$ pressure during GDC, thus, limiting the C-exhaust to a similar value as for GDC. To improve this, much higher pumping speeds are necessary, which may allow to take advantage of the higher power and higher ionisation/dissociation capability of the ICRF plasma compared with GDC.

3.Conclusion.

GDC in oxygen shows the transformation of oxygen to CO and CO_2, which can be pumped out. CO production is determined by O ion impact, while CO_2 increases with additional O atom impact, addition of He does not influence on CO and CO_2 production. The C-removal rate by GDC is about $2.1x10^{19}$C/sec. This is about 10 times lower then the integral carbon redeposition rate in TEXTOR [5] but about 10 times higher than the integral C-removal rate by venting TEXTOR with oxygen to 0.3 mbar at about 630K wall temperature [3]. ICRF pulses of 5 sec duration ignited in He at $1\text{-}2x10^{-4}$ mbar and with oxygen added during the pulse with a rate of typically $1.5x10^{20}$ O/sec show also a complete consumptions of oxygen and transformation to CO and CO_2. However, the carbon oxides are mainly released after the pulses, while the removal during the pulse is limited by the pressure limit at the ICRH antenna. Assuming a duty cycle of 1:10, the overall removal rate is similar as observed in GDC. Increasing the C-removal rate would require higher pumping speeds.

[1] G. Federici, C.H. Skinner, J.N. Brooks et al., Nucl. Fusion, **41** (2001) 1967
[2] J. Davis, A.A. Haasz, Phys.Scripta T91 (2001) 33-35
[3] V. Philipps, H. G. Esser, J. von Seggern, et al J. Nucl.Mat., 266-269 (1999) 386
[4] A. Lyssoivan et al., in:14th Topical Conf.on Radio Frequency Power in Plasmas, Oxnard 2001, AIP Conf. Proceedings 595, New York, 2001, p.146.
[5] P. Wienhold, et al, J. Nucl. Mat., 313-316 (2003) 311