IMPURITY PRODUCTION AT THE DIVERTOR PLATES AND DEPOSITION IN ASDEX

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Abstract:

In the divertor tokamak ASDEX the metal atoms released from the divertor plates have been investigated after the change of the plate material from Ti to Cu. Erosion rates measured spectroscopically and with collector probes have been found consistent with sputtering rates due to the divertor plasma. The comparison of erosion rates with the Cu content in the plasma yields values for the divertor retention efficiency, which is strongly dependent on plasma density. The final sink for the Cu atoms could be determined by detailed mapping of the vessel walls using long term collector probes and analysing wall structures. Deposition mainly occurs at the walls of the divertor chamber, only to a small fraction at the main plasma vessel wall. Erosion rates at the divertor plates are not balanced by redeposition back to the plates.

Introduction:

In today's fusion experiments the main plasma wall interaction occurs at limiters /1/ or divertor plates /2/. When the boundary plasma interacts with the divertor plates a secondary divertor plasma is formed, which is dominated by the boundary plasma parameters and by recycling processes at the divertor plate. This leads to a considerable reduction of the divertor plasma temperature and an increase of particle fluxes to the plate. Details of the erosion at the plate, ionization and transport in the divertor plasma are still poorly understood /3,4/. However, the knowledge of these processes is important to estimate lifetimes of future divertor plates as well as radiation losses and dilution due to plasma impurities /5/. In ASDEX the erosion processes /6-8/ as well as the divertor retention for impurities /9/ and final redeposition /10/ have been investigated for the first time in a divertor tokamak.

Experimental:

After 7 years of operation the ASDEX divertor plates were changed from Ti to a watercooled Cu structure /11/. This offered the possibility to study the transport of Cu to the surface structures of the vessel walls. The erosion of Cu is determined from absolute measurements of the Cu I (3247 Å) line radiation in front of the plates /9/ as well as by collecting the eroded Cu after ionization on the time resolving rotating collector probe /12/. The erosion rates are compared to sputtering rates calculated using divertor plasma parameters /13/ and sputtering yield data /2,14/. In order to determine the divertor retention capability /9/ the erosion rates are compared to central plasma Cu concentrations measured spectroscopically

/15/. The deposition of Cu atoms is finally determined by analyzing a large number of poloidally and toroidally distributed C and Si long term probes on the vessel walls /10/.

Results and discussions:

Figure 1 shows the Cu erosion profile in front of the divertor plate for an ohmic deuterium discharge at a central plasma density n_e of $4 \cdot 10^{13}$ cm^{-3}. Integrating the profile and multiplying with the divertor circumference a total erosion of $2.5 \cdot 10^{19}$ Cu/s can be evaluated. The deuterium ion flux distribution impinging onto the divertor plate was obtained from the measured divertor plasma temperature and density profiles /13/ and used to calculate the neutral Cu flux profile, as shown in fig. 1 (solid line). This profile was recalculated for the observation geometry into an emission profile of the Cu I line, exited in the divertor plasma (dashed line) and agrees well with the experimental data /16/.

Figure 2 shows the total sputtered Cu atom flux as calculated from sputtering due to divertor plasma ions compared with data from spectroscopy and collector probe as function of average plasma density. Sputtering due to the divertor plasma can explain the observed fluxes within the experimental uncertainties both for ohmic and neutral beam heated (NBI) plasmas. The increase of sputtered Cu atoms for ICRH heating is by far smaller than for NBI, while ICRH leads to a much stronger increase of atoms sputtered from the main plasma vessel wall /2/. For comparison with long term deposition measurements the average source strength of Cu atoms over a discharge period including ICRH, NBI and ohmic discharges at various densities can be estimated to about $3 \cdot 10^{19}$ Cu/s.

The central plasma concentration of impurities originating from the divertor plates varies with average plasma density much stronger than the eroded flux (fig. 2 and 3). The strong decrease of the Cu concentration with increasing plasma density indicates that the retention capability of the divertor increases with density /9/. Taking a central confinement time of about 50 ms a Cu content of 10^{15} at high densities and a production rate of $1 \cdot 10^{19}$/s results in a retention probability of 98%. At low densities, however, the retention probability decreases to 90%. Similar values are obtained for neutral beam heating and ICRH /2,9/.

The estimates of the divertor retention indicate, that the largest part of the impurity flux remains in the divertor chamber. However, only a detailed balance can tell, which fraction returns to the divertor plate and can possibly reduce the net local erosion by redeposition. For 3 operation periods the distribution of Cu atoms deposited on the walls of the main vessel and on the shield opposite to the outer divertor plates have been investigated. Further, a metal oxide layer deposited on the divertor plates was stripped using adhesive tape and analysed. All three distributions show the same pattern and roughly the same deposition rate. As an example the pattern for the last period from October 1987 through June 1988 is shown in fig. 4.

While on most vessel areas the deposited layer is of the order of $2 \cdot 10^{16}/cm^2$, the shields opposite to the outer divertor plates are covered with layers up to $6 \cdot 10^{18}/cm^2$. Integrating over the whole circumference these areas alone yield a coverage with $1.6 \cdot 10^{23}$ atoms while the vessel walls are covered with $6\cdot10^{21}$ atoms only. This deposition equals more than 50% of the total eroded Cu, amounting for about 4000 discharges at an average length of 2.5 s to $3\cdot10^{23}$ atoms. The metal layer covering a 3 cm wide band outside the separatrix intersection with up to $1\cdot10^{19}$ Cu/cm^2 contained a total amount of $5\cdot10^{22}$ atoms, i.e. about 17% of the eroded material.

With the knowledge of the divertor plasma parameters the probability for sputtered neutral Cu atoms to escape ionization before redeposition at surfaces can be evaluated. Figure 5 shows the neutral Cu density in the divertor region for a medium density discharge ($4\cdot10^{13}$ cm^{-3}). It can be seen, that the direction of highest escape probability before ionization is in an upward direction away from the separatrix. The areas where the largest deposition was found on the divertor shields and on the plate are indicated in fig. 5. This may lead to the conclusion, that the Cu atoms reach the shield predominantly as neutral atoms, while the coverage on the plate originate from backstreaming Cu ions. The streaming pattern of hydrogen and impurity ions in the divertor and back to the main plasma, however, awaits its modelling by 2D-comupter simulation /3,4/.

Conclusion:

The detailed investigations on the production and transport of divertor impurities lead to the following conclusions:

- The measured erosion fluxes are in good quantitative agreement with sputtering by ions from the divertor plasma.
- The divertor retention is strongly dependent on average plasma density and reaches in the best (high density) cases values of 98%.
- Redeposition fluxes at the target plate are only a minor fraction of the eroded fluxes and do not significantly reduce the net local erosion.
- The large deposition on the shields opposite to the intersection of the separatrix with the divertor plates may possibly originate from neutral Cu atoms escaping ionization in the divertor plasma.

References

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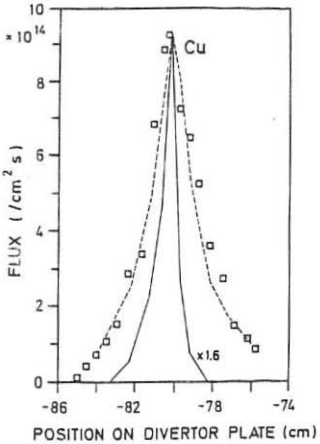

Fig.1: Distribution of sputtered Cu flux in front of divertor plate (curves see text).

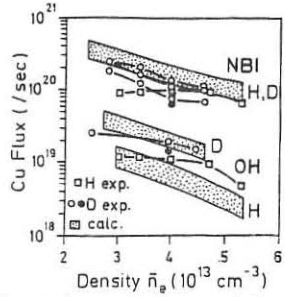

Fig.2: Comparison of measured Cu flux with calculations from sputtering.

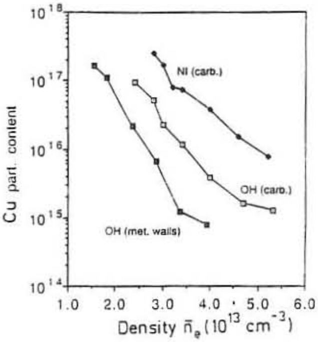

Fig.3: Dependence of the Cu content on the main plasma on plasma density.

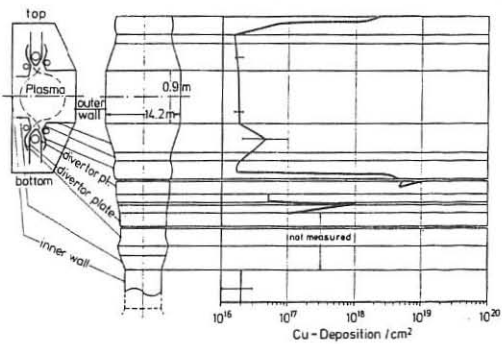

Fig.4: Deposition of Cu on the wall structures of ASDEX.

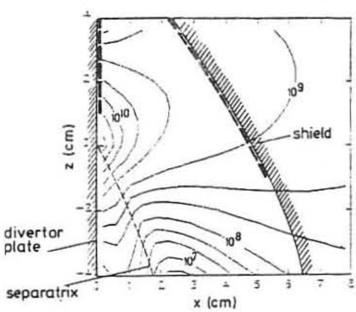

Fig.5: Contour lines of neutral Cu density in the divertor plasma.