CONCENTRATION OF SPURIOUS IMPURITIES IN ASDEX UPGRADE

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1. Introduction

Besides carbon and boron, the main elements of boronized graphite tiles which face the plasma in the ASDEX Upgrade tokamak, there occur many other impurities with often unknown sources. They decrease the fusion rate due to dilution of the fuel and plasma cooling caused by line radiation and Bremsstrahlung. On the other hand gaseous impurities like nitrogen or noble gases are intentionally injected to overcome the problem of excessive power loads on plasma facing components which will be a major problem in future devices [1].

This paper presents results of a systematic investigation on impurity concentrations and behavior in the plasma of ASDEX Upgrade which have been achieved with a Bragg crystal spectrometer. Concentrations will be shown for copper and all elements between nitrogen and argon and possible sources of some impurities will be discussed.

2. Method of Concentration Measurement

The measurements have been performed with a Bragg crystal spectrometer, which has been absolutely calibrated for use with a KAP crystal between 4.5 Å and 26 Å by ab initio calculations and comparison with several other ASDEX Upgrade diagnostics. Both, spectrometer and calibration procedure will be described in Ref. [2]. A spectrum of a relatively "dirty" plasma measured with the KAP crystal is shown in Figure 1. It has been achieved by rotation of the KAP crystal during the plasma shot. Therefore at any time only one wavelength is detected. Two full spectra can be measured during an ASDEX Upgrade shot of 8 seconds duration.

The correlation of impurity concentration C and line intensity I for given electron density and electron temperature profiles $n_e(l)$ and $T_e(l)$ can be written as

$$C = \frac{4\pi \cdot I}{\mathrm{h}\nu \cdot \int_l f_x(T(l)) \cdot n_e^2(l) \cdot \langle\sigma v_e\rangle(T(l)) \cdot \mathrm{d}l}. \quad (1)$$

Here $\mathrm{h}\nu$ denotes the energy of the emitted photons, $f_x(T(l))$ the fractional abundance of the observed ion and $\langle\sigma v_e\rangle(T(l))$ the excitation rate coefficient [3]. Both, f_x and $\langle\sigma v_e\rangle$ are temperature dependent. $\langle\sigma v_e\rangle(T)$ can be determined from the ADAS database [4] whereas $f_x(T(l))$ must be calculated for each shot with a parametrization function using results of the transport code STRAHL [5].

For given profiles $n_e(l)$ and $T_e(l)$ and an arbitrary impurity source strength at the plasma edge STRAHL calculates line emission intensities of any desired ionic line for which $\langle\sigma v_e\rangle(T)$ data exists. With C_{strahl} and I_{strahl} denoting impurity concentration and emission line intensity

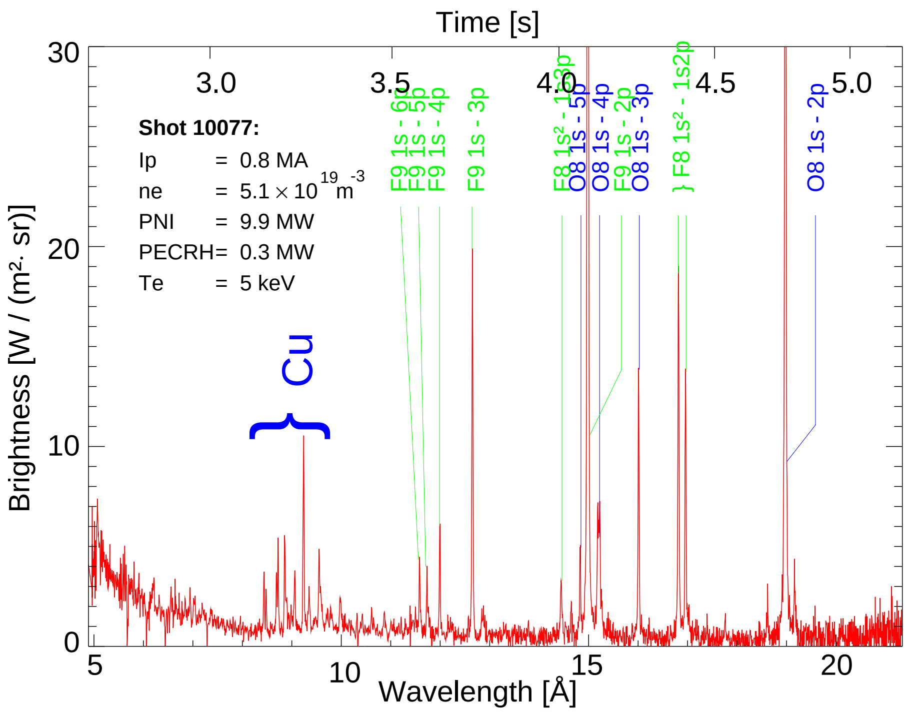

Figure 1. X-ray spectrum of a "dirty" ASDEX Upgrade plasma. Usually lines of H- and He-like oxygen and fluorine dominate the measured spectra. In this particular shot additional lines occur between 3.15 and 3.35 s which have been identified as copper. In contrast to the simple spectrum of oxygen and fluorine heavier elements show many overlapping lines which are difficult to identify.

as calculated by STRAHL the determination of impurity concentrations C_{meas} from measured line intensities I_{meas} reduces to the application of:

$$C_{meas} = C_{strahl} \cdot \frac{I_{meas}}{I_{strahl}}. \qquad (2)$$

3. Results

Nitrogen – argon are the only elements that show emission lines of the H- and He-like ionisation stages within 4.5 Å and 26 Å, the usable wavelength range of the KAP crystal. Advantage of H- and He-like ions over ionisation stages with more electrons are the simple spectra (see Figure 1) and a relatively high accuracy of atomic data available from the ADAS data base. As H- and He-like copper lines are below the low wavelength limit of the KAP crystal, copper concentrations have been deduced from Be-like ions. Identification of copper against other "medium Z" elements was made by a set of Ne-like lines.

The composition of the last ≈ 2000 ASDEX Upgrade shots has been analyzed with the result summarized in Table 1. Usually oxygen and, surprisingly, fluorine are the dominant impurities by far, followed by copper and silicon. All other impurities occur only sporadically or have never been seen.

In Figure 2, the evolution of fluorine concentration with the shot number is shown. Starting directly after boronization the fluorine concentration first increases with shot number and then

Element	Transition	Wavelength [Å]	Detection limit [ppm]	C_{meas} [ppm]		ΔZ_{eff}	
				typ.	max.	typ.	max.
N	1s − 4p	19.8	500	–	–	–	–
O	1s − 2p	19.0	19	1500	5000	0.1	0.3
F	1s − 2p	15.0	13	1500	40000	0.1	2.9
Ne	1s − 2p	12.1	8	–	–	–	–
Na	1s − 2p	10.0	< 8	–	–	–	–
Mg	1s − 2p	8.4	< 8	–	–	–	–
Al	1s − 2p	7.2	2	–	5	–	0.0008
Si	1s − 2p	6.2	2	2	9	0.0004	0.002
P	1s − 2p	5.4	< 2	–	–	–	–
S	$1s^2$ − 1s2p	5.1	4	–	20	–	0.005
Cl	1s2p − 1s4s	19.1	3000	–	–	–	–
Cl	$1s^2$ − 1s2p	4.5	5	–	30	–	0.008
Ar	2p − 5d	13.4	1700	–	–	–	–
Ar	(1s − 2p)	(3.7)	(1)	–	(1)	–	0.0003
Cu	$2p^2$ − 2s3p	9.2	2	10	100	0.008	0.08

Table 1. Composition of the ASDEX Upgrade plasma during shots 8800 – 10800 (i.e. the last 2000 shots). The detection limits are given for a central electron density of $n_e = 7 \times 10^{19}$ m^{-3} and electron temperature of T_e = 4 keV ($\hat{=}$ 5 MW neutral injection).

becomes constant with a typical concentration of ≈ 0.15 %. After boronization the concentration is reduced to less than ≈ 0.05 %. Investigations with a Teflon probe exposed to the plasma indicate that fluorine is emitted from Teflon by disintegration through heat and probably also photo dissociation [2]. About 10 monolayers of fluorine have been found on a divertor tile by PIXE [6] indicating that not all fluorine is pumped off after a plasma shot. The remaining fluorine covers plasma facing components as a thin layer and can be injected into the next plasma shot, therefore explaining the increase of concentration with shot number. With increasing fluorine content inside the vacuum vessel more fluorine is pumped off and an equilibrium originates. Boronization reduces fluorine concentrations by covering the fluorine layer and chemical reaction from fluorine and boron to the gas BF_3, which is pumped off. The high fluorine concentrations which occured around shot number 9900 were strongly reduced, after removal of some Teflon containing pieces and protection of the remaining ones against direct UV- and particle flux by metal sheets.

Oxygen shows the same behavior as fluorine: increasing concentrations with shot number which are decreased by boronization. Sources of oxygen are water and O_2, both being stored in the graphite tiles inside the vacuum vessel. Possible source for silicon are dust and glass fibers contained in the vacuum vessel. Micro probe X-ray fluorescence analysis showed parts of mineral wool and other silicon containing particles in a dust sample. Dust is also a possible source for copper, as small pieces of copper cables have been found in a dust probe from ASDEX Upgrade [2].

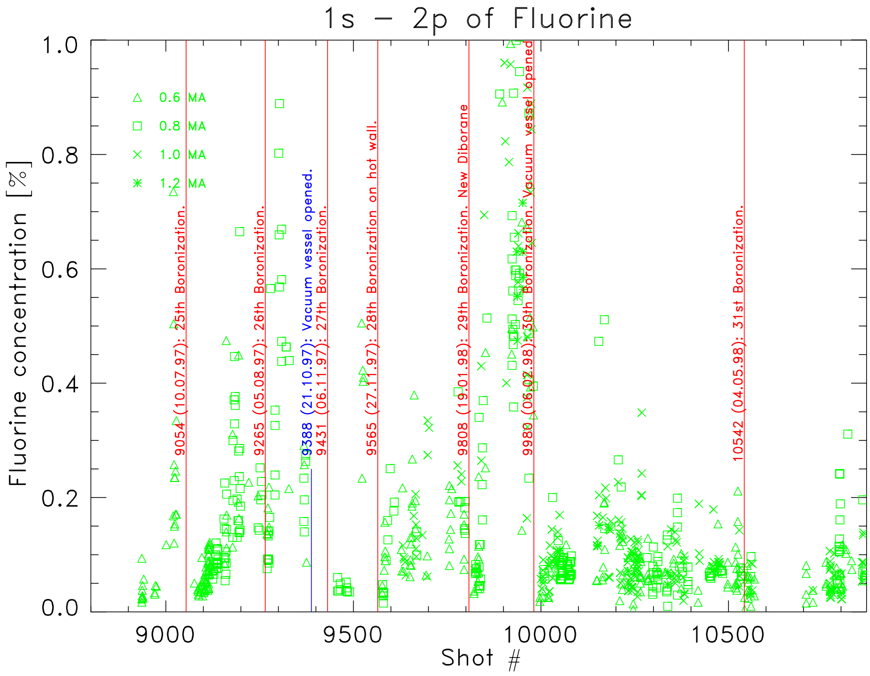

Figure 2. Concentrations of fluorine as function of shot number for the last ≈ 2000 ASDEX Upgrade shots. Vertical lines indicate either boronization or vacuum vessel openings.

4. Conclusion

Observation of impurity concentrations during the last ≈ 2000 ASDEX Upgrade shots shows the results given in Table 1. Except boron and carbon, which are not considered in this investigation, oxygen and fluorine are the dominant impurities with concentrations around 0.15 %. Both are reduced after boronization. Teflon was identified as main source of fluorine due to disintegration by heat and probably also by photo dissociation. Concentrations of other elements than oxygen and fluorine are usually not higher than 10 ppm.

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