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Impurity Transport Studies of Intrinsic Mo and Injected Ge in High Temperature ECRH Heated FTU Tokamak Plasmas

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DISCLAIMER

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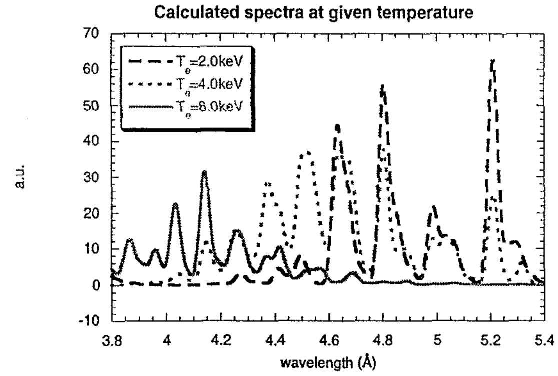
I) INTRODUCTION

FTU plasmas reached a peak electron temperature up to 11 keV with ECRH heating during the current ramp up phase. For these plasmas X-ray emission of highly ionized molybdenum, the dominant intrinsic impurity, are presented in section II, and VUV spectra of injected germanium are presented in section III. In section IV the conclusions are discussed.

II) MOLYBDENUM X-RAY EMISSIONS

Lawrence Livermore National Laboratory (LLNL) and the Johns Hopkins University (JHU) have developed a collisional radiative (CR) model for the L-shell transitions of Mo^{30+} to Mo^{39+} and determined the relative charge state distribution at high temperature (5-15 keV). With peak electron temperatures $T_e(0)$ of about 8 keV, these ions (Mo^{30+} to Mo^{39+}) extend over a large part of the plasma's minor radius, $0 < r/a < 0.7$ where a=30 cm. The ionization equilibrium times of these ions are in the range 1-5 ms, much shorter than the timescale of the evolution of the macroscopic plasma parameters affecting these emissions. The plasma has a current, I_p, of 0.7 MA, a line averaged density, $<N_e>$, of 0.8×10^{20} m^{-3} and a magnetic field, B, of 5.4 T. Spectra, whose time resolution is 5 ms, were analyzed in a discharge with on axis heating (400 kW) during the current ramp up. At this time the magnetic shear is still negative or zero (#12658). Synthetic spectra are produced from the CR model and in fig. 1 are shown for three different temperatures at a fixed density. The best fit (fig.2) of the synthetic brightness (continuous line) to the experimental spectrum (dotted line) was performed assuming all the ions in coronal equilibrium (no anomalous transport) and with a peaked N_{Mo} profile (N_{Mo} (r=0) / N_{Mo} (r=15 cm)=3). A negligible impurity transport and a central impurity peaking, are consistent with a neoclassical transport regime.



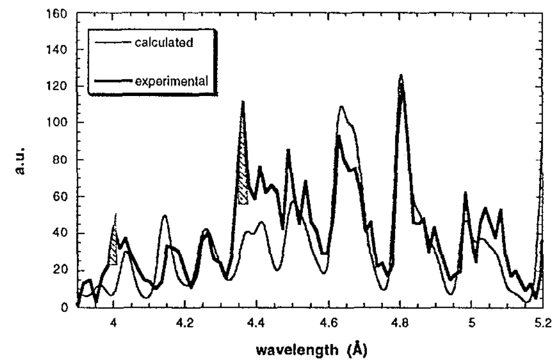


Fig. 1 Calculated Molybdenum spectra, at low resolution, for a homogeneous plasma at electron temperature of 2.0 , 4.0 and 8.0 keV

Fig. 2 Best fit of the soft X ray molybdenum spectrum for the shot #12658.

III) INJECTIONS OF GERMANIUM

Using the laser blow off techinque, germanium was introduced during the current ramp up phase of an ECRH heated plasmas. The goal was the investigation of the very high electron temperatures produced and the core impurity transport processes in these plasmas. While molybdenum is intrinsic, germanium is transient and its time history gives important information. Two plasmas will be discussed in detail. The first one, shot #15505, has off axis heating (800 kW) and an injection at t=0.18 s after the onset of sawtooth activity (t=0.070 s). The plasma current reaches the plateau value at t=0.135s. The second one, shot #15507, has on axis heating (800 kW) and an injection at t=0.08 s while the current is still diffusing. The steady state values for both the discharges are I_p=0.7 MA, $<N_e>$ =0.8×10^{20} m^{-3} and B=5.4 T (on axis heating) or B=5.7 T (off axis heating). The VUV transitions of Ge were recorded with a grazing incident high resolution spectrometer ($\Delta\lambda$ = 0.7Å). The resonant lines of Li-I, Be-I and K-I like germanium were detected. These three charge states which exist in a wide temperature range (3-15 keV), are sensitive to the local electron temperature and transport processes. These resonant lines (λ= 122.8 Å Li-I like, λ= 92.8 Å for Be-I like and λ=113.8 Å for K-I like) are well measured. Time history of three different charge states: two central (Li-I and Be-I like) and one peripheral (K-I like) are plotted for these two plasmas in fig. 3. While the time behaviour is the same for the edge ions in the two shots, the central ones exhibit a significant difference. The time decay in shot #15507 is much longer than in #15505. When magnetic shear is still negative or zero (#15507), the injection during the current ramp up phase reveals a longer impurity confinement time (roughly a factor 3). This is consistent with the analysis of the intrinsic molybdenum. In fig. 4 the ratio of the Li-I to the Be-I resonant lines is plotted at different times and for different shots as function of the peak electron temperature measured with ECE. This ratio depends on the electron temperature and transport. The continuous lines represent the theoretical values and are calculated with an impurity transport code (MIST). The anomalous transport coefficients D and V are constant over the radius in one case and with a strong reduction in the center ($r/a < 0.3$) to simulate a neoclassical core in the second case. These curves fit approximately the experimental points up to 8 keV. Beyond this value the measured ratio is less than expected. Further simulations of the ECE spectra with a Fokker Planck code that describes the coupling of ECRH waves with the plasma revealed in fact the existence of suprathermal distortions and a temperature overestimation at very low density and high temperature.

IV) CONCLUSION

During the ramp up phase when shear is still negative or zero, X ray spectra of molybdenum at high temperature (up to 8 keV) show that impurities have no anomalous transport up to half radius. The impurities peak at the center (Molybdenum), and the core impurity confinement time is much longer (Germanium). Moreover, Li-I and Be-I like Ge ions are sensitive to the temperature in the hot central region. Their line ratio implies that the electron temperature measured by ECE is overestimated at very low density, due to the contribution of fast electrons created by ECRH heating. Germanium and Molybdenum are therefore a excellent diagnostic tools to study these hot plasmas in different transport regimes.

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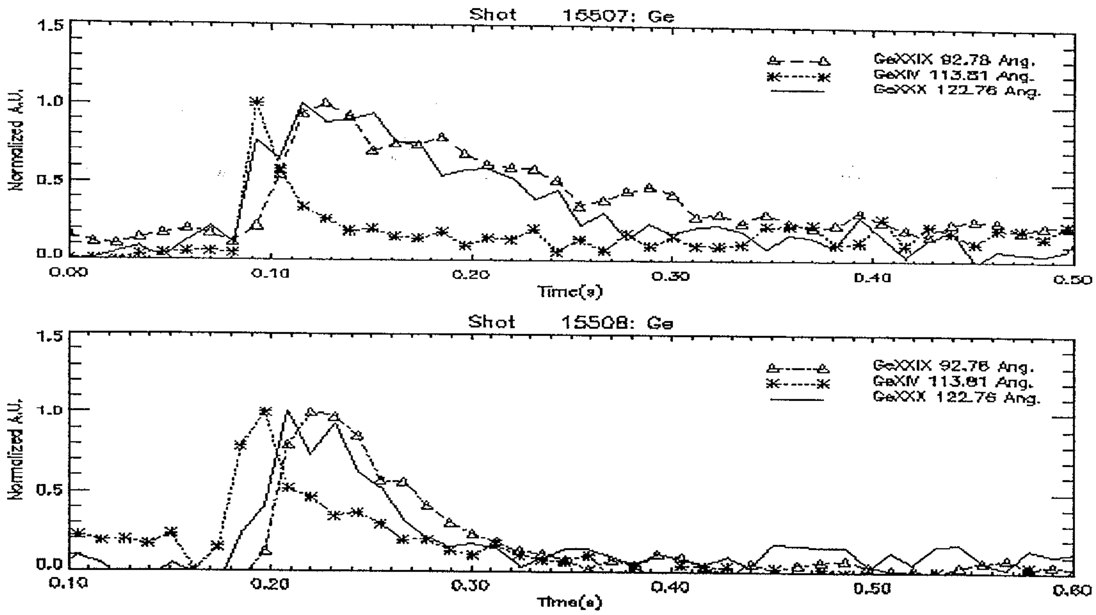

Fig. 3 *Time histories of the VUV emissions of central (GeXXX and GeXIX) and peripheral (GeXIV) charge states in ECRH heated discharges with negative or zero magnetic shear (top #15507) and positive shear (bottom #15505)*

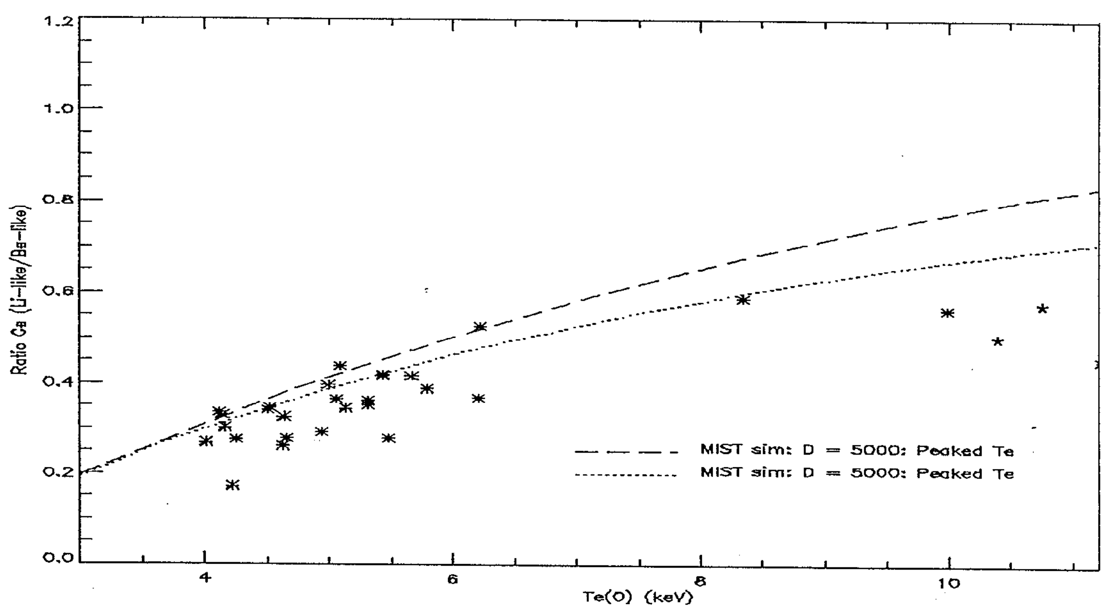

Fig.4 *Measured ratio of Li-I to Be-I like Germanium VUV brightness (stars) vs central electron temperature measured by ECE. Curves show the simulated values using an impurity transport code (MIST) with different transport coefficients*