*32nd EPS Conference on Plasma Phys. Tarragona, 27 June - 1 July 2005 ECA Vol.**29C**, P-1.093 (2005)*

Fast electron studies in T-10 plasmas by means of carbon pellet injection

V.M. Timokhin[1], V.G. Skokov[1], V.Yu. Sergeev[1], S.V. Krylov[2], B.V. Kuteev[2]
and the T-10 team[1]

[1] *State Polytechnical University, St.Petersburg, Russia*

[2] *Nuclear Fusion Institute, RRC "Kurchatov Institute", Moscow, Russia*

Introduction

Studies of nonthermal electrons especially during intensive ECRH are of great interest because those can affect plasma instabilities and transport properties [1]. The impurity pellet-injection method could be a useful application for fast electron studies [2]. The first evidence of fast electrons influence on carbon pellet ablation in low-density T-10 plasmas in electron cyclotron current drive regime had been reported in Ref. [3]. However, the mechanisms of fast electron generation, electron energy, density and localization in T-10 plasmas required additional investigation. After the new pellet injection system installation on T-10 [4] the carbon pellets ablation studies with high spatial resolution were carried out in a wide range of plasma parameters and two T-10 heating modes (OH and OH+ECRH). In this paper main results of these experiments and their analysis are presented.

Experimental setup

In the experiments, spherical carbon pellets of 0.4–0.6 mm in size were accelerated to 250–500 m/s velocities top-down in the direction of the plasma core. The pellet ablation was observed through interference filters in CII (723 nm) line emission by the CCD camera, the wide-view photodetector and the set of the narrow collimated photodetectors. The ablation rate profile $\dot{N}(r)$ was determined from the CII line emission I_{cl} assuming that $\dot{N}$ is proportional to I_{cl}. The accuracy of $\dot{N}(r)$ mapping to minor radii was about 1 cm. The details of the experimental setup are described in Ref. [4]. The following range of plasma parameters has been studied: $n_e(0)=1.4–8.2\times10^{13}$ cm^{-3}, $T_e(0)=800–3000$ keV, $I_{pl}=150–300$ kA, P_{ECRH}– 400-950 kW.

Experimental results and discussion

Typical ablation rate curves for OH regime with different $n_e(0)$ are shown in Fig 1a,c. The enhanced ablation zone of about several centimeters in widths is clearly seen when the central plasma density is about 2×10^{13} cm^{-3}. In Fig. 1a a comparison between the experimental ablation profile (red curve) and calculated one using Neutral Gas Shielding

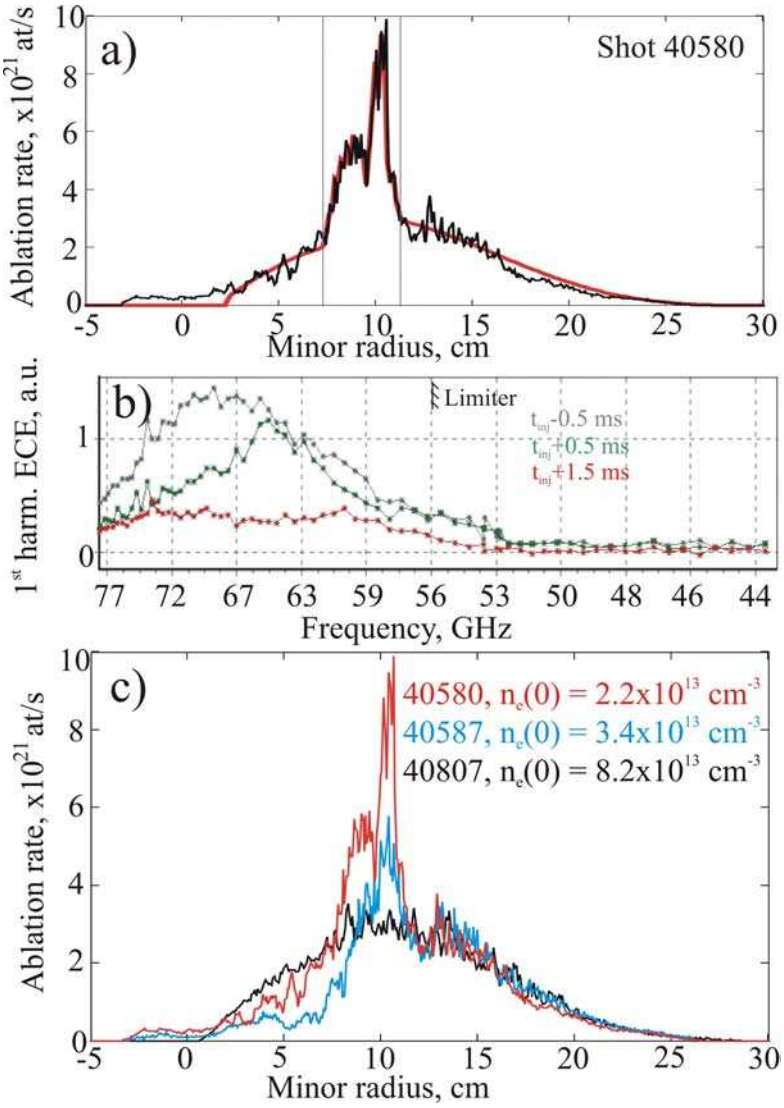

Fig.1 Carbon pellet ablation in T-10 OH mode. a) Experimental and NGS model calculated ablation profiles. b) Evolution of first harmonic ECE spectra during pellet ablation. c) Density scan.

Model (NGSM) [5] (black curve) is presented. The localization area of the enhanced ablation zone is (7–12) cm of minor radius (vertical lines denote margins of this ablation zone) that corresponds fairly well to a vicinity of q=1 surface position (≈ 13 cm) in the discharge presented. The ablation rate amplitude during enhanced ablation is several times higher than the ablation level predicted by NGSM. In the Fig. 1a NGSM simulation presented is replaced by experimental data in the enhanced ablation zone with purpose to emphasize a local nature of the enhanced ablation effect. The experimental ablation rate outside from the zone is in a good agreement with the model prediction. A density scan in OH shots is presented in Fig. 1c. It is seen that the enhanced ablation zone on the pellet ablation rate radial profile becomes less pronounced at higher plasma densities and almost completely disappeared at plasma densities above 8×10^{13} cm^{-3} value. Evolution of 1st harmonic of Electron Cyclotron Emission (ECE) spectra for the typical OH (250 kW) shot #40580 is presented in Fig. 1b. Here grey line is spectra were taken in approximately 0.5 ms before the start of pellet ablation, green is 0.5 ms and red is 1.5 ms after this moment correspondingly. In OH shots there is noticeable ECE signal at low frequencies which corresponds to thermal emission from the area outside limiter. This emission indicates to a population of the nonthermal electron presence in the plasma column [2].

According to experimental data shown above one can suppose that the reason of the enhanced ablation might be the heat flow delivered to pellet surface from runaways beams. In

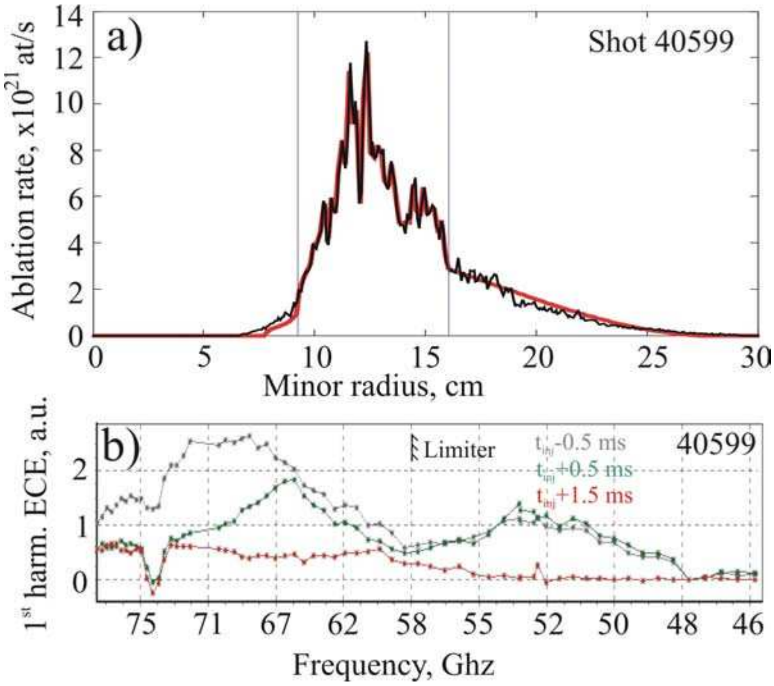

Fig.2 Carbon pellet ablation in T-10 ECRH mode. a) Experimental and NGS model calculated ablation profiles. b) Evolution of first harmonic ECE spectra during pellet ablation.

compliance with Ref. [6] they are generated around the q=1 surface due to magnetic reconnection around the X point of the m=1, n=1 magnetic island. Using the energy value E_{st} the density of the runaway population n_{st} can be estimated from the ratio of thermal and nonthermal energy fluxes onto the pellet surface: $n_{st} \propto n_e (T_e / E_{st})^{3/2}$ where n_e and T_e are the bulk plasma electron density and temperature correspondingly. Thus, the observed effects on the $\dot{N}(r)$ curve might be produced by the runaway electrons with densities ~10^{10} cm^{-3}, which correspond to ~0.1% of the bulk plasma density.

A typical ablation rate profile for discharge with ECRH is shown in Fig 2a. ECRH power in the presented shot is 950 kW, OH power is 150 kW. In the OH+ECRH regime ablation rate the additional enhanced ablation zone can be distinguished in comparison with the OH case. The NGSM simulation with replacing of calculated ablation rate by experimental data in the enhanced ablation zone is presented in the Fig. 2a and shows a local nature of the effect as well. The 1^{st} harmonic of ECE spectra in ECRH shots (see Fig 2b) are differed from the spectra in OH (Fig 1b) shots. In this case a low frequency emission that corresponds to thermal emission from outside limiter area is more pronounced. Furthermore, an additional maximum at low frequency part of the ECE spectra is clearly seen. The appearance of the ECE "hump" can be associated with suprathermals generation like was done in Ref. [2].

One can assume that the enhanced pellet ablation for shot #40599 presented in Fig. 2 is caused by suprathermals population [2]. The magnetic surface where suprathermals are observed on ablation profile should meet the resonance conditions in the ECRH launch cross-section. From the equation for the electron cyclotron frequency $\omega_{ce} = eB / m_0 c\gamma = 140 GHz$, electron energies ~50 keV could be obtained. Here e is the electron charge, B is the magnetic field in the suprathermal generation zone (≈ 10 cm from magnetic axis to high field side in

ECRH launch cross-section), m_0 is the electron rest mass, c is the light velocity and γ is the relativistic factor. On the other hand, accounting for the peak position on the $\dot{N}(r)$ curve and assuming that the low-frequency "hump" of the ECE spectrum corresponds to the suprathermal emission one can estimate the suprathermals energy by relativistic mass shift of the electron as ~100 keV. Then, the density values are close to previous estimation (~10^{10} cm^{-3}, ~0.1% of the bulk plasma density) that could be an evidence of approximately equal influence of runaways and suprathermals on enhanced pellet ablation.

Conclusions

The enhanced ablation of carbon pellets was observed in both OH and OH+ECRH regimes of the T-10 tokamak. A dependence of the enhanced ablation zones behaviour on plasma density and a correlation of the enhanced ablation existence to the behaviour of the low-frequency part of ECE spectra testify that these zones are caused by nonthermal electrons. In the OH shots the enhanced ablation might be produced by the runaways. The measured localization of the enhanced ablation zones (7–12 cm of minor radius) is close to the q=1 surface position [6]. In OH+ECRH shots either runaways or suprathermals might contribute to the pellet enhanced ablation. Evaluations based on the localization of the enhanced pellet ablation and ECE spectra give an order of energy magnitude as 50-100 keV for suprathermals. The density of the nonthermal electron population which is able to produce the observed effects on ablation profiles is estimated as ~ 10^{10} cm^{-3} that corresponds to ~0.1% of the bulk plasma density.

References

[1] Parail V.V., Pogutse O.P., Review of plasma phys., New York, 1986, Vol. 11, p. 1.
[2] Timokhin V.M. et al., Techn. Phys. Letters **30** (2004) 298.
[3] Egorov S.M. et al., Nuclear Fusion, Vol. 32, No. 11 (1992), pp. 2025-2028
[4] Belopolsky V.A. et al., Europhys. Conf. Abs., Vol.27A (2003), P-3.117.
[5] Kuteev B.V., Sergeev V.Yu., Tsendin L.D., Plasma Phys. Rep. **10** (1984) 572.
[6] Savrukhin P.V., Physics of Plasmas, Vol. 9, No.9 (2002), p.1.