Contribution ID: **3** Type: **Oral**

Impurity holes induced by energetic electrons during electron cyclotron resonance heating in tokamaks with helical core

Monday, 6 December 2021 16:00 (20 minutes)

Tungsten accumulation is one of the main challenges for successful operation of ITER and future reactors. For this reason, various techniques have been developed recently in order to mitigate such accumulation. One of such methods is the application of wave heating, in particular electron cyclotron resonance heating (ECRH) deposited close to the plasma center.

Recent 3D equilibrium calculations have revealed that ITER plasmas in the hybrid scenario are prone to spontaneous helical core formation [1]. Such helical cores with dominant mode numbers *m/n=1/1* are routinely observed between sawtooth crashes in ASDEX Upgrade discharges with central ECRH [2]. The long-standing mystery of these shots, which motivated present work, is deeply hollow tungsten density profile between crashes, which manifests itself by inverted sawteeth on the soft X-ray signals.

In the present contribution it is shown that ECRH-generated energetic electrons are responsible for the tungsten hole [3]. Such electrons 'run away' along RF-induced quasi-linear diffusion path in velocity space and form strongly anisotropic population with banana tips accumulated at cyclotron resonance position on the magnetic surface. When cyclotron resonance is located on the high-field side, as in the ASDEX experiments described in [2], magnetic drift of the energetic electrons' banana guiding centers bacomes 'reversed', i.e. it is directed in the co-current direction and can balance the opposite electric drift associated with *positive* radial electric field E_r. As a result, banana guiding centers of energetic electrons become trapped in the *n=1* toroidal 'ripple' of the magnetic field induced by internal kink, which generates strong non-ambipolar flux of the hot electrons, Γ_e^{hot}, due to super-banana motion. For relarive density of hot electrons ~ few %, this resonant flux exceeds by order of magnitude the flux of non-resonant thermal ions, which for kink-distorted equilibrium was estimated in [4]. The ambipolarity condition thus becomes $\Gamma_e^{hot}(E_r) = 0$. The *stable* root of this equation (i.e. a stable fixed point of the radial current balance $(1 + 2q^2)(c^2/V_A^2)\partial E_r/\partial t - e\Gamma_e^{hot}(E_r) = 0$) yields a self-consistent 'electron' root with $E_r \sim +10kV/m$ (in the frame with static internal kink). Trace tungsten should respond adiabatically to this root, i.e. with Boltzmann distribution, $\nabla n_Z/n_Z = ZE_r/T_i > 0$, which corresponds to the deep hole, consistent with experiment [2].

This results imply that high-field side ECRH can be a viable option to prevent tungsten accumulation in the hybrid ITER discharges prone to spontaneous helical core formation [1], since recent modeling suggests that helical core itself *augments* impurity accumulation [5].

1. A. Wingen *et al.*, Nucl. Fusion **58**, 036004 (2018).
2. M. Sertoli *et al.*, Nucl. Fusion **55**, 113029 (2015).
3. V.S. Marchenko, Phys. Plasmas **27**, 022516 (2020).
4. S.V. Putvinskij, Nucl. Fusion **33**, 133 (1993).
5. M. Raghunathan *et al.*, Plasma Phys. Control. Fusion **59**, 124002 (2017).

Speaker's Affiliation

Institute for Nuclear Research, Kyiv

Member State or IGO

Ukraine

Primary author: MARCHENKO, Victor (Institute for Nuclear Research, Kyiv, Ukraine)

Presenter: MARCHENKO, Victor (Institute for Nuclear Research, Kyiv, Ukraine)

Session Classification: Effects of Energetic Particles in Magnetic Confinement Fusion Devices

Track Classification: Effects of Energetic Particles in Magnetic Confinement Fusion Devices