4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Plasma electron acceleration in a non-resonant microwave heating scheme below the electron cyclotron frequency

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Microwave heating is an indispensable tool in high- and low-temperature plasma physics experiments. In magnetized plasmas, the injected microwave frequency must be equal to or higher than the electron cyclotron frequency (ECF) to transfer its energy to the plasma [1]. The latter scenario requires high electron temperatures on the order of keV to be efficient. In low-temperature plasmas, heating at the ECF is restricted to the fundamental resonance. Alternatively, over-dense plasmas, where the plasma density exceeds the cut-off density of the injected microwave, can be heated via power deposition at the upper-hybrid resonance [2] or via coupling to the electrostatic electron Bernstein waves [3].

In contrast to these conventional microwave heating scenarios, we have found an operational regime where the heating occurs well below the ECF but still well above the lower-hybrid frequency. Microwave energy is deposited at the so-called O-resonance. This process has been briefly discussed in an ionospheric context and for laboratory experiments in the 1960s and 1970s [4,5]. To the best of our knowledge, this presentation provides the first detailed study in a toroidal magnetic confinement device. High-energy electrons have been detected in this heating regime, with calculated energies up to the MeV regime.

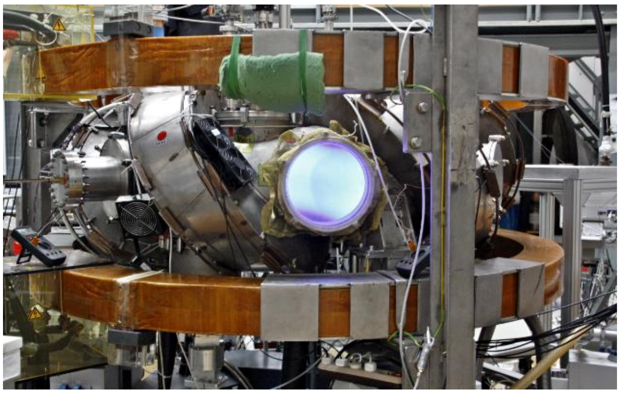

Figure 1: TJ-K stellarator located at the University of Stuttgart.

The experiments were carried out at the TJ-K stellarator [6] shown in Fig. 1. It is an $l = 1$, $m = 6$ stellarator of type torsatron with major and minor radii of 0.6 m and 0.1 m, respectively. Plasmas can be created over a large magnetic field range up to $B_0 \leq 0.5$ T with a variety of microwave heating sources: a magnetron operating at 2.45 GHz with a maximum power output of 3 kW, a klystron operating at 7.9 – 8.4 GHz with a maximum power output of 3 kW, and three klystrons operating at 14 GHz with a maximum power output of 3 x 2.5 kW. The plasmas in TJ-K are typically characterized by electron temperatures of 10 eV, ion temperatures of 1 eV, and plasma densities of 10^{18} m^{-3}.

In the observed heating scenario, microwave power is coupled to Whistler waves via tunneling and mode-conversion in the vicinity of the O-mode cut-off. Power deposition then occurs at the O-resonance in over-dense plasma regions. Strong wave electric fields at the resonance are thought to be responsible for a population of high-energy electrons observed in this heating scenario.

We have described this novel scheme for accelerating plasma-electrons from simple physics considerations taking into account the 3D structure of the confining magnetic field, yielding values for the electron energy in agreement with experimental findings. Induced toroidal net currents an order of magnitude larger than those usually detected are described by the physics model for the electron acceleration and thus are attributed to the energetic electrons.

References

[1] M. Bornatici *et al.*, Nucl. Fusion **23**, 1153 (1983).
[2] A. Köhn *et al.*, Plasma Phys. Control. Fusion **52**, 035003 (2010).
[3] H.P. Laqua, Plasma Phys. Control. Fusion **49**, R1 (2007).
[4] M.A. Heald *et al.*, Plasma Diagnostics with Microwaves (New York: John Wiley & Sons Inc., 1965)
[5] V.E. Golant *et al.*, Sov. Phys. **14**, 413 (1972)
[6] U. Stroth *et al.*, Phys. Plasmas **11**, 2558 (2004)