Highly Localized Electron Cyclotron Heating and Current Drive and Improved Core Transport in DIII–D*

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Electron cyclotron heating (ECH) and current drive (ECCD) are widely recognized as methods of depositing highly localized power and current in a plasma, based on calculations of wave absorption. The experiments on the DIII–D tokamak reported here are the first to demonstrate that ECCD can be as localized as theory predicts. This narrow profile of electron heating and current drive by electron cyclotron waves can have dramatic effects on the plasma, creating high central electron temperatures and generating a strong transport barrier in the electron fluid near the location of the heating, as illustrated in Fig. 1 and discussed below.

Previous work [1] on DIII–D has shown that the driven current is centered at the location predicted by ray tracing, but the width of the current drive profile appeared to be generally wider than that predicted by theory. Recent re-analysis of these experiments has used measurements of the internal poloidal magnetic field derived from the motional Stark effect diagnostic to infer more directly the width of the driven current density profile. This work has shown that the effective deposition profile is in close agreement with that predicted by theory. The earlier result that the profile of ECCD appeared wider than theory may be due to an instrumental effect related to limits on the spatial resolution which can be obtained using the present parameterization of the toroidal plasma current in the EFIT equilibrium fitting code. This result is very supportive of experiments which require highly localized current drive with controlled location, such as the stabilization of neoclassical tearing modes for which the key parameter is the driven current density rather than the total driven current.

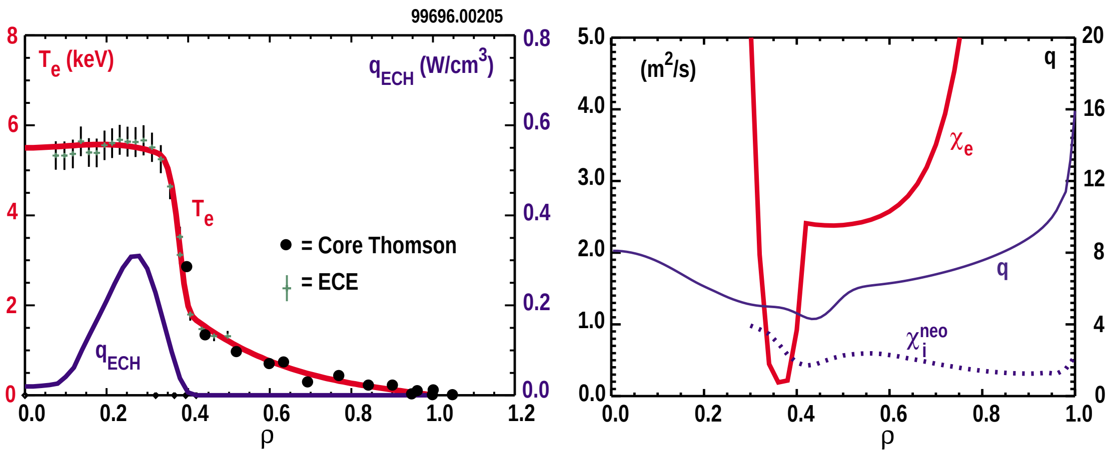

Fig. 1. Profile of electron temperature, the ECH heating power density as calculated by the TORAY code, electron diffusivity, and ion neoclassical diffusivity at 205 ms into discharge 99696. Also shown is the q profile. The plasma current is –0.51 MA.

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In Advanced Tokamak experiments on discharges with modified profiles of magnetic shear, ECH was used as a means of increasing T_e early in the ramp of the plasma current in order to increase the plasma conductivity. Under conditions of reversed plasma current, neutral injection in the low current phase of the discharge was found to be unsuitable due to excessive introduction of impurities by unconfined ions. In one set of experiments, the ECH power from a single 110 GHz gyrotron was launched during the current ramp in the counter-current direction with power incident on the plasma around 0.5 MW. The calculated ECCD was 58 kA. A modulated counter-CD neutral beam with average power 0.5 MW was also applied. With the calculated EC power absorbed at a minor radius peaking at $\rho=0.27$, a narrow but deep decrease in the electron thermal diffusivity appeared in the electron fluid at $\rho=0.36$ just outside the heating location, as shown in Fig. 1. The upper limit to the diffusivity in this barrier is calculated to be around half of ion neoclassical diffusivity, also shown in Fig. 1, and the central electron temperature reached 6 keV at a density of 1×10^{19} m^{-3}. This discharge had a current profile which was strongly hollow, having the profile of safety factor q shown in Fig. 1. This work implies that ECH in combination with a current ramp can be an economical and flexible means of modifying the magnetic shear.

The physics behind the generation of the transport barrier is being determined. Some neutral beam heated discharges with strongly negative magnetic shear have also observed a localized reduction in the electron thermal diffusivity [2]. Linear drift wave stability analysis of these discharges showed that the $E\times B$ velocity shear was sufficient to quench ion gyro-scale turbulence (ion temperature gradient and trapped electron modes). The electron temperature profile was found to track the marginal stability condition for the short wavelength electron temperature gradient (ETG) mode in the steepest gradient region. Raising T_e/T_i is known to be stabilizing to the ETG mode so the ECH heated discharge of Fig. 1 may also benefit from this effect.

The detailed properties of ECCD and the effects of localized ECH/ECCD on transport will be studied during the 2000 experiment campaign, during which the ECH system will be upgraded to 3.5 MW. The recent addition of a flexible ECH launching structure (designed and constructed by PPPL) will allow changes in the toroidal and poloidal angle of launch between shots and facilitate these studies. Current drive by ECCD will be increased through operation at lower density and higher temperature, made possible by application of new pumping systems at the top of the vessel. Two cryopumps with associated baffling are effective at reducing the density in high triangularity H–mode discharges.

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