DOUBLE TRANSPORT BARRIER PLASMAS IN ALCATOR C-MOD

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Plasmas with internal transport barriers (ITBs) provide an attractive advanced tokamak operational scenario through their enhanced energy confinement and driven bootstrap current. Formation of the ITBs is believed to occur when the **E**×**B** shearing rate (proportional to the rotation velocity gradient) exceeds the maximum growth rate for ion temperature gradient driven microturbulence, whence the ion thermal conductivity drops, resulting in improved energy confinement [1]. Most tokamak ITBs are produced with neutral beam injection [2-5], applied during the plasma current rise phase, which leads to $q_0>1$ and a non-monotonic q profile; the foot of the ITB is often located near the minimum q value. The connection between ITB formation and plasma rotation in neutral beam heated plasmas is obscured by the inherent momentum input and particle sources. Observations of ITBs in discharges heated solely by ICRF waves or in purely Ohmic H-mode plasmas remove these ambiguities.

Double transport barrier plasmas comprised of an edge enhanced D_α (EDA) H-mode pedestal and an internal transport barrier (ITB) have been observed in Alcator C-Mod [6]. The ITB can be produced in EDA H-mode discharges that are either ohmically heated or where the minority cyclotron resonance is off-axis near $|r/a| \sim 0.5$ in ICRF heated plasmas. The formation of the barrier appears in conjunction with a decrease or reversal in the central (impurity) toroidal rotation velocity. The ITB foot is located near r/a = 0.5, regardless of how the barrier was produced. The ITBs can persist for ∼15 energy confinement times (τ_E), but exhibit a continuous increase of the central electron density, up to values near $1\times10^{21}/\mathrm{m}^3$ (in the absence of an internal particle source), followed by collapse of the barrier. The presence of a thermal barrier is evident from the fact the central ion temperature remains constant as the central density increases and a significant decrease in the core thermal conductivity is confirmed by modeling. The presence of sawtooth oscillations throughout most of the ITB period allows sawtooth-induced heat pulse analysis to be performed. This analysis indicates that there is an abrupt radial discontinuity in the heat pulse time-to-peak profile when the ITB is present, which appears to move into the core plasma from the edge region in about 0.2 s [7].

Application of additional on-axis ICRF heating arrests the density and impurity peaking, which occurs along with an increase (co-current) in the core rotation velocity. This is demonstrated in Fig.1. The EDA H-mode and ITB were formed by 2 MW of ICRF power at 80 MHz, delivered for the time interval between 0.7 and 1.5 s, as seen by the green curve in the 4^{th} panel of the figure. The EDA H-mode was well established when around 0.85 s the rotation velocity began to drop in conjunction with the formation of the ITB, as seen in the continuous rise of the core electron density. Adding 600 kW of power at 70 MHz (red curve, 4^{th} panel) arrested the density peaking, while the core rotation velocity returned to the co-current direction. Steady state double barrier plasmas have been maintained for 10 τ_E or longer, with $n/n_{GW} \sim 0.75$ and with a bootstrap fraction of 0.13 near the ITB foot. The ITB formation and stabilization may be visualized by examination of the evolution of the electron density profiles at several times during the discharge of Fig.1, as shown in Fig.2. During application of the 80 MHz ICRF, the density profiles (shown in dashed green) continued to peak in the core, while the outer half of the profile remained quite constant, maintaining the edge pedestal intact, together with the strong ITB, and in the absence of an internal particle source. During the application of the additional 70 MHz ICRF, the density profile was held steady for 200 ms (solid red curves). The density peaking is found to be consistent with an inward neoclassical pinch velocity and a reduced particle diffusivity. Linear growth rate calculations indicate the ion temperature gradient (ITG) mode is stablilized in the barrier region. However, the trapped electron mode (TEM) is found to exist with a growth rate that increases with the application of central ICRH power.

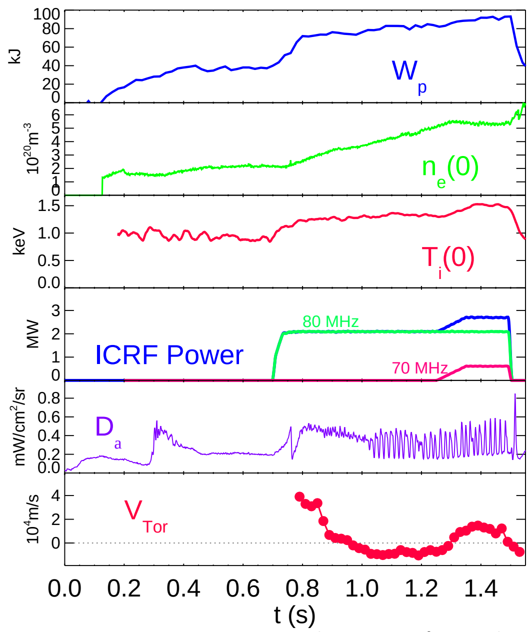

Fig. 1: Parameter time histories for a double barrier plasma. In the top panel is the plasma stored energy, and in the 2nd and 3rd panels are the central electron density and ion temperature, respectively. In the 4th panel is the ICRF power at 80 MHz (green) and 70 MHz (red), with the total shown in blue. D_α emission is shown in the 5th frame and in the bottom panel is the central toroidal impurity rotation velocity.

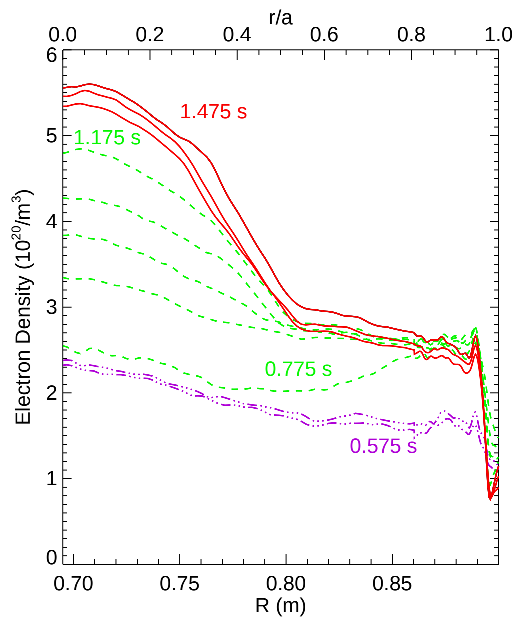

Fig. 2: Electron density profiles shown every 100 ms, beginning at 0.575 s, for the double transport barrier plasma of Fig. 1. The purple chain curves are from the Ohmic L-mode portion of the discharge, while the dashed green and solid red traces are from the evolving and steady state ITB phases, respectively.

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