Confinement and Transport in the National Spherical Torus Experiment (NSTX)

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Systematic and statistical studies have been conducted in order to characterize both the global and thermal energy confinement as well as the local transport at low aspect ratio in high power L- and H-mode NSTX discharges. NSTX operates with plasma currents up to 1.5 MA, toroidal fields up to 6 kG and neutral beam heating power up to 7 MW. Plasmas are run in either the Lower Single Null (LSN) or Double Null (DN) diverted configuration with elongations up to 2.5 and triangularity up to 0.8. NSTX typically operates at high toroidal beta, with β_T values up to 40%. The plasmas are well diagnosed with high spatial and temporal resolution measurements of the electron and ion temperature and density profiles, the toroidal rotation profile and the first ever internal magnetic field pitch (current profile) measurements in a low aspect ratio device using the Motional Stark Effect (MSE). In addition, a high spatial resolution tangential scattering system will diagnose microturbulence from the ITG to the ETG regimes with $k_\theta \rho_i \leq 20$.

The global and thermal confinement times are found to be enhanced relative to scalings developed from higher aspect ratio devices for both L- and H-modes, indicating that the parametric scalings of these fits are not entirely appropriate for the low aspect ratio regime. While systematic scans indicate dependences on plasma current and heating power that are similar to those at higher aspect ratio, statistical analyses indicate a weaker current dependence, due in part to a correlation between plasma current and density, and a significant dependence on B_T. This dependence is related to a reduction in the core electron transport relative to that of the ions as B_T increases (Fig. 1). These parametric dependences translate into favorable dependences with decreasing normalized gyroradius ρ_* (at least as favorable as gyroBohm) and collisionality ν_* ($B\tau \sim \nu_*^{-0.4}$), and a β_T dependence that varies from unfavorable ($B\tau \sim \beta^{-0.65}$) to null ($\sim \beta^0$), depending on the specific statistical analysis used. The dependences on the physics variables in NSTX are consistent with those dependences seen at higher aspect ratio [1,2]. Scatter in the confinement data, at otherwise fixed operating parameters, is found to be due to variations in ELM activity, low frequency density fluctuations and plasma shaping.

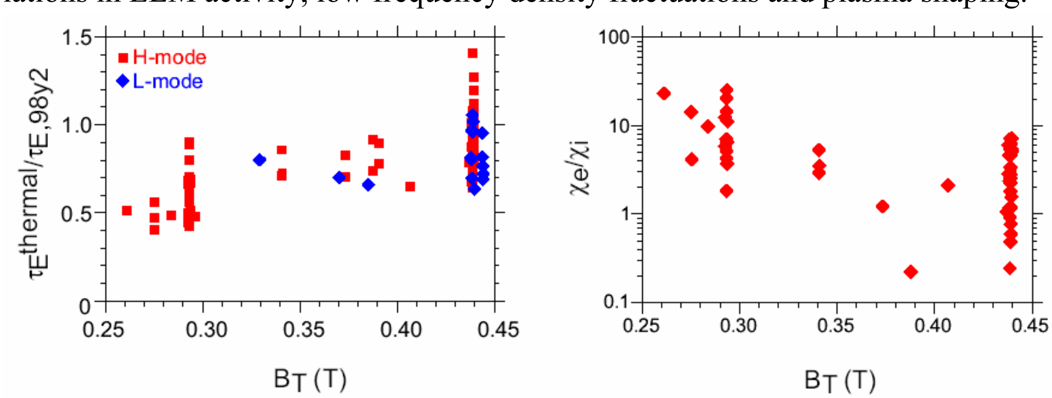

Fig. 1 Thermal energy confinement time normalized to the value given by the ITER98(y,2) scaling (left panel) and ratio of electron to ion thermal diffusivity at r/a=0.4 (right panel) as functions of toroidal field.

The electron channel usually dominates the loss of energy of NSTX plasmas, with $\chi_e > \chi_i$ in the core of the plasma (see Fig. 1, right panel). The ion thermal diffusivity in the core (r/a<0.5) are typically 2 to 10 times greater than the NCLASS [3] neoclassical value, but can drop to near neoclassical values farther out in the plasma. Recent calculations using the GTC-NEO code indicate that non-local effects, especially important in NSTX, can modify the neoclassical transport and thus the value of the neoclassical thermal diffusivity [4]. Improved electron confinement has been observed in plasmas with a fast initial current ramp which develop a region of reversed magnetic shear in the core, as confirmed with MSE measurements. The electron temperature profile in a reversed shear plasma is more highly peaked, and the electron thermal diffusivity is reduced by a factor of 1.5 to 2 over the inner 2/3 of the plasma, relative to a discharge without reversed shear. Tangential scattering measurements will be available to diagnose the change in microturbulence between the two conditions. A period of an "enhanced pedestal H-mode", with double the plasma stored energy relative to that in the pre-enhanced H-phase, was observed. This period is characterized by energy confinement time enhancements of ≥2.7 over L-mode scaling values and significant plasma pedestal values, with $T_i \sim T_e \sim 600$ eV at the top of the pedestal (Fig. 2).

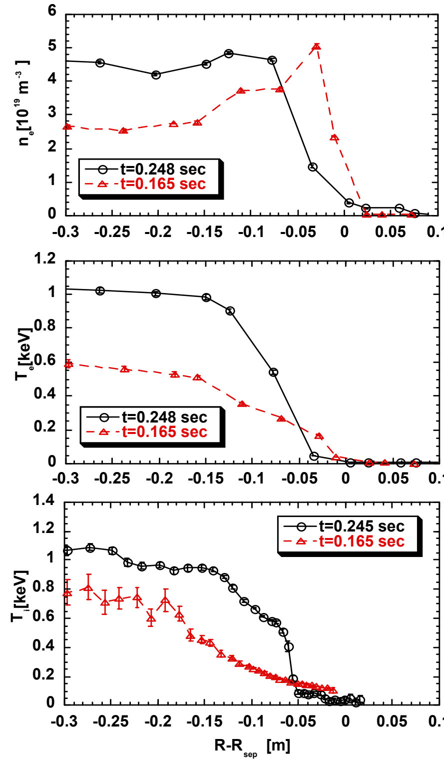

Fig. 2 n_e, T_e and T_i profiles showing the increase in pedestal height during the enhanced H-mode

Nonlinear electrostatic GYRO simulations of ITG/TEM microturbulence in L-mode NSTX plasmas have been carried out and show that the simulations with adiabatic electrons produces much weaker transport than those with a fully kinetic treatment. ExB shear (estimated from the pressure and toroidal velocity profiles) greatly reduces the transport, but the residual level is comparable to or greater than the transport power deduced from the experiment. Transport is also strongly reduced in simulations with radial domains that include a linearly stable region in the deep core (r/a~0.3-0.4); this is a finite ρ_* effect known as 'turbulence draining'. In all these simulations the ion heat transport is three or more times stronger than the electron heat transport, although they are roughly equal in the experimental transport analyses. The ion/electron power split will be examined in electromagnetic simulations in both L- and H-mode plasmas.

This research was supported by U.S. DOE contract DE-AC02-76-CH03073.

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