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Observation of Non-Collisional Bulk Ion Heating by Energetic Ion Driven Geodesic Acoustic Modes in LHD

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In a reversed magnetic shear (RS) plasma produced by tangential counter neutral beam injection (NBI) having high beam energy of ˜160 keV in LHD [1], bulk ion temperature at the plasma center Ti(0) measured by soft X-ray crystal spectrometer (XICS) often increases linearly in time for ˜0.3-0.4 s by a factor of ˜ 1.5-1.7 in the constant electron density and NBI absorbed power phase. The Ti(0)-increase begins when the off-axis minimum of the rotational transform decreases beyond the rational value 1/3. The value reached at the end of the Ti(0)-increase is the same as or slightly above the central electron temperature (Te(0)˜ 1.3 keV). In the latter case, two dimensional XICS shows that the region of Ti > Te extends in the plasma core region of <r>/<a> < 0.5, where <r>/<a> is the normalized minor radius. At the onset of the Ti(0)-increase, plasma potential fluctuation amplitude of energetic-ion-drive geodesic acoustic mode EGAM [2] measured by heavy ion beam probe decreases noticeably (by about ˜30- 40%). The fluctuation amplitude is kept nearly constant having large value of ˜1.3 kV at the plasma center, during the Ti(0)-increase phase. The Ti(0)-increase ceases by a sudden and large jump up of the EGAM amplitude, correlated with sudden drop in the reversed shear Alfven eigenmode (RSAE) and EGAM frequencies. This frequency drop suggests rapid change in the rotational transform profile. Turbulent density fluctuations in the plasma central region measured by CO2 laser phase contrast imaging are not suppressed during the Ti(0)-increase, but are slightly enhanced in the range of k_⊥ ρ_i ˜ 0.7 (k_⊥: perpendicular wavenumber, ρ_i: bulk ion gyro radius). Density fluctuations in plasma edge region remain unchanged. In this RS plasma, less than 5% of NBI absorbed power is transferred to bulk ions by collisional process. Bulk ion heating power density estimated from experimental data is comparable to the power density generated by ion Landau damping of EGAM excited. In the estimation of EGAM damping rate, the rotational transform at the plasma center is inferred from the observed frequencies of fundamental and 2nd order RSAEs. This ion-temperature-increase observed in the LHD RS plasma is thought to be a clear example of energy channeling from energetic ions to bulk ions via EGAMs.
[1] K. Toi et al., Phys. Rev. Lett. 105, 145003 (2010).
[2] G.Y. Fu, Phys. Rev. Lett. 101, 185002 (2008).

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