Heat confinement improvement in the electron component has been found in the initial stage of Ohmic discharge in the TUMAN-3M [1]. The improvement lasts 7 – 10 ms and is observed in the central part of plasma ($r < 8$ cm). The characteristic feature of the regime is a non-monotonic behaviour of electron temperature $T_e(0)$ and $I_{SXR}(r=0)$ detector signal. After a slow rise during the phase of improved confinement a relatively fast decrease follows. The degradation takes place approximately at the moment when $q=1$ surface appears in plasma. Maximum $T_e(0)$ value before the confinement degradation exceeds maximum $T_e(0)$ value in the following stationary phase by 50%. In the experiments ion temperature is low, $T_e >> T_i$.

The results of numerical modeling of the discharge and experimental study of plasma fluctuation sheared rotation are presented in this paper. The factors contributing to ITB formation are analyzed.

**Modeling**

The aim of the modeling was to study effective electron heat diffusivity $\chi$ evolution in the initial phase of the discharge and to know whether low or negative magnetic shear formation is possible in the investigated regime. Astra code was used. To simulate the plasma current density $j(r)$ and power input in electrons $P_e(r)$ the equation for current diffusion was solved. Experimental values of $T_e$, $n$, $I_p$, $U_L$ were used as input parameters. Since the direct measurements of effective charge $Z_{\text{eff}}$ were not available, we tested four various $Z_{\text{eff}}(r)$ distributions. It was found that skinned and monotone $Z_{\text{eff}}(r)$ resulted in similar $j(r)$ and $P_e(r)$ evolution. $Z_{\text{eff}}(r)$ sharpening slowed down current penetration to the center, which could result in non-monotone $j(r)$ and negative $s$ values. To perform qualitative analysis we used the skinned $Z_{\text{eff}}(r)$ giving the highest estimations of $\chi$ and $s$.

Values of $\chi$ inside (6 cm) and outside the improved confinement region (11 cm) are shown in Fig.1. The $\chi$ value at $r=6$cm, low during the improved confinement phase, grows up to $\sim 12 - 15$ m$^2$/s after the confinement degradation. Outside ITB the $\chi$ variation is less pronounced. Magnetic shear $s$ evolution is presented in Fig. 2. The figure demonstrates low $s$ values ($s = 0.05 - 0.08$) during the improved confinement phase at $r < 8$ cm.

The simulations
show that Te increase due to the ITB formation can prevent the current penetration to the plasma center conserving the low s values.

**Sheared rotation and density factors**

Anomalous electron heat transport can be also reduced by sheared plasma rotation because of microturbulence decorrelation. The plasma fluctuation velocity has been measured by the Doppler reflectometry (DR) method in this work. The method is based on backscattering of the probing microwave beam, inclined to the plasma surface [2,3]. In the experiment a monostatic antenna scheme was used to probe plasma from the low magnetic field side by the O-mode radiation. The antenna was tilted at 6.8° in poloidal direction with respect to plasma boundary. The Doppler shift of the scattered radiation is proportional to the plasma fluctuation poloidal velocity. The probing frequency was chosen in the range of 38 to 52 GHz to put the cutoff position in the core, the positions are correspondingly 4 - 10 cm. The backscattered radiation spectrum was analyzed in a frequency band ±1 MHz. The measurements at different probing frequencies were made on a shot to shot basis. The velocities measured at 3 different microwave frequencies are shown in Fig.3a. The cutoff position evolution is shown in Fig.3b, l_{SXR}(r=0) detector signal is also shown. The plot demonstrates essential (up to 1.5 km/s) increase in V_θ corresponding to 50.1 GHz starting at approximately t=33 ms, there is no such an increase at other frequencies. In other words, there is a layer at r = 6 – 7 cm near the radial position of ITB, where fluctuations rotate faster than in neighbouring plasma. The values of the shear of rotation \omega_θ, estimated as a ratio ΔV_θ/Δr_c, are shown on Fig. 3c. Here ΔV_θ - difference of the velocities, Δr_c - corresponding difference in cutoff positions, data for F=49, 50.1, 52.5 GHz were used. The sheared rotation exists during all the improved confinement phase. The actual shear is possibly higher, because of the finite spatial resolution of the DR method [4]. SXR signal derivative averaged over the same discharges is shown in Fig.3d. One can see a rise by 1.5 – 2 times of the derivative approximately at the same time as the time of rotating layer formation. The rotation shear may be caused by different processes [5,6] in the vicinity of magnetic islands. For all the cases to produce magnetic islands MHD activity is necessary. Mirnov probes register burst of oscillations of the m=4, n=1 mode approximately at the same moment t=33 ms in the described experiment, see Fig. 3d. Central SXR detectors also register oscillations at the same moment at the same frequency. Thus, a correlation between rotation shear, rise of the SXR signal derivative and MHD oscillations has been observed in the improved confinement regime.

The value of plasma density n significantly effects formation of the improved confinement regime. SXR signals in discharges with different n values are shown in Fig.4. The lower the density, the less pronounced is the signal peak. It means that the difference between hotter center and colder neighbouring plasma becomes less before the moment of confinement degradation. At densities n < 0.9 10^{19} m^{-3} the peak and consequently ITB
disappear completely. An assumption, that excitation and damping of TEM mode plays a role in the experiments does not contradict our observations. The estimated $\gamma$ value of the mode at the ITB position at $t=33\text{ms}$ is $2.2 \times 10^5 \text{sec}^{-1}$ for the regime with improved confinement. The rotation shearing rate within experimental uncertainty is the same (Fig. 3c), that is the necessary condition for the process of the mode damping to become effective. The density dependence of microinstability growth rate possibly accounts for the observed $n$ effect on the phenomenon.

Plasma rotation velocity measurements by the Doppler reflectometry method show that in the discharges with low background plasma density ($n = 0.8 \times 10^{19} \text{m}^{-3}$) the poloidal velocities are approximately equal in the radial interval from 5 to 6.5 cm. The shear of rotation velocity has not been observed.

Conclusions

The performed analysis has demonstrated a substantial reduction in anomalous electron transport at $r < 8 \text{ cm}$ at the initial stage of the Ohmic discharge. Simulations demonstrate that there is a low magnetic shear region in the plasma center. A correlation between the improved confinement, the core fluctuation sheared rotation and MHD activity is found in the investigated regime. The ITB formation seems to be a result of a combined action of the plasma sheared rotation and the reduced magnetic shear at sufficiently high density.

References

6. E.Kaveeva, V.Rozhansky, this conference, P3.150

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Fig. 1. Evolution of the experimental central electron temperature $T_e$ (Thomson scattering), and simulated effective electron heat diffusivity $\chi_{e,eff}$ inside (6 cm) and outside (11 cm) the ITB region.

Fig. 2. Evolution of magnetic shear $s$ profiles.

Fig. 3. Temporal evolution of poloidal velocities $V_\theta$ (a), cutoff radii $r_c$ and $I_{SXR}(0)$ signal (b), shear of plasma fluctuation rotation rate $\omega_E$ (1 - 49 – 50.1 GHz, 2 – 50.1 – 52.2 GHz) (c), Mirnov probe signal (MHD) and $dI_{SXR}(0)/dt$ (d).

Fig. 4. $I_{SXR}(0)$ evolution in the discharges with various plasma density:
#25 - $<n> = 1.38 \times 10^{19} \text{ m}^{-3}$
#26 - $<n> = 1.1 \times 10^{19} \text{ m}^{-3}$
#27 - $<n> = 0.95 \times 10^{19} \text{ m}^{-3}$