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High Performance OH regimes in the Globus-M Spherical Tokamak

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Vessel conditioning improvement during 2001-2003 year together with upgrade of power sources and plasma control systems lead to increase of plasma purity and discharge duration. Plasma current in excess of 300 kA and duration of ~100ms (separately) were achieved. Confinement estimate on the basis of available instruments (EFIT, magnetic measurements, 0-D simulations) indicated also gradual (from campaign to campaign) ultimate energy confinement time increase. It was noted first that energy confinement time increases with plasma average density rise and second that at lower densities "experimental" confinement time is closer to neo-Alcator (NA) scaling, than at higher ones. Plasma-wall interaction intensity and MHD activity are among main factors influencing confinement properties and strongly dependent on technology of vessel conditioning and plasma column generation and control. To specify and separate the most significant reasons influencing on global variation of plasma confinement properties in different experimental campaigns, it was decided to establish reference point. Such a point could be energy confinement time measurements in clean wall non-boronized vessel. The impetus for performed experiments gave also the commissioning of novel plasma diagnostics, extending experimental possibilities of Globus-M. The first are collimated monitors of D-alpha with the line of sight directed to upper/lower divertor plates and to the equatorial section of poloidal limiter, thus localizing possible sources of neutral generation. The second one is Thomson scattering system, consisting of 5 spatial recording channels and periodically switched Nd-glass laser, producing up to 20 laser pulses during one discharge. The system is on the final stage of tuning, but already begins to produce first results. Fig. 1 shows laser pulse train, its synchronization with plasma current and electron temperature profile variation in discharge # 8838.

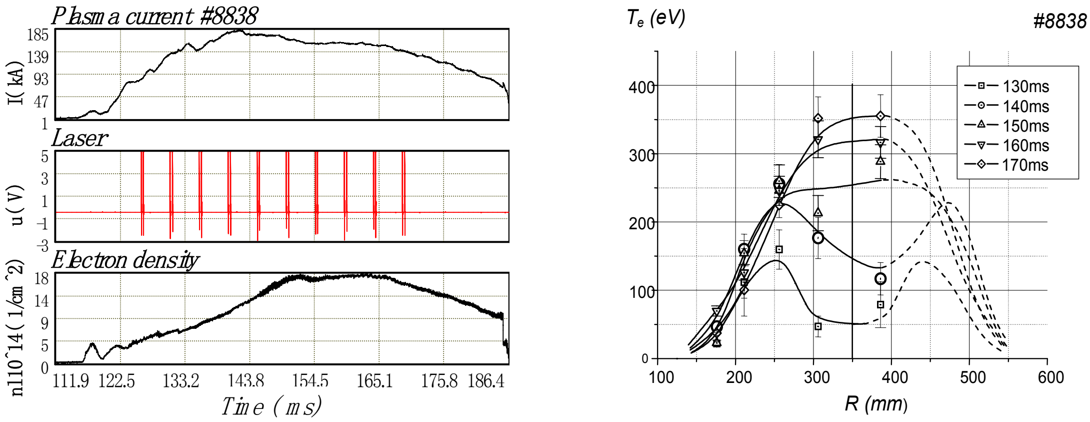

Fig. 1 Plasma current, laser pulse train and line integrated density (left). Electron temperature profile variation (right) in discharge #8838

Experiments on plasma energy confinement dependence investigation on plasma density were performed in clean non-boronized vessel. During preparation for experimental campaign of May-June 2004 all in-vessel parts (graphite tiles, loops, probes, etc.) were extracted and specially treated to remove all deposited films. The vessel with stainless steel bare walls was exposed for many days glow discharge cleaning in different gases (He, Ar, O). After achieving of good vacuum conditions and proper mass-spectrum of residual gas, all in-vessel components were installed back. Such a procedure gives possibility to prepare vessel for new auxiliary heating experiments with high wall power loads and establish desired reference point in plasma confinement properties of Globus-M. Experimental discharge parameters were: B_T=0.38T, R≈0.35m, a≈0.23m, κ≈1.6, δ≈0.2 in different discharges. Plasma current was about I_P ≈180kA and nearly constant (when it's possible) in the density range ($1.7 \div 2.6 \cdot 10^{19} m^{-3}$), but fell down to ~140 kA at higher densities, due to the absence of plasma current stabilization. Fig. 2 shows changes in plasma energy content (kinetic data) with plasma density in ohmically heated discharge in Globus-M tokamak in clean non-boronized vessel.

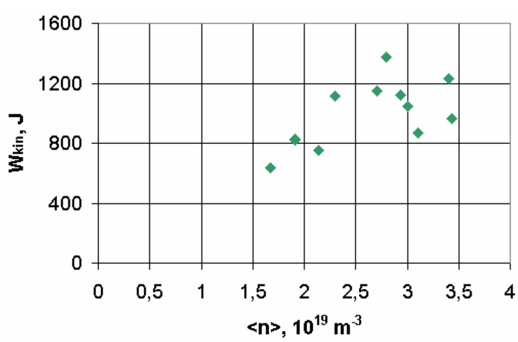

Fig.2 Plasma energy content (kinetic) versus average plasma density in OH deuterium discharge.

A kind of saturation and even degradation is seen at the densities over $3 \cdot 10^{19} m^{-3}$. Degradation in plasma stored energy with density rise manifests itself like plasma current decrease at densities higher

$\sim 2.8 \cdot 10^{19} m^{-3}$ and impossibility to overcome absolute density limit of $3.5 \cdot 10^{19} m^{-3}$ in non-boronized vessel with any kind of gas puffing method (internal or external) in OH regime. Comparison with the saturation density of NA scaling gives the value $n_{sat} \approx 0.65 \cdot B_T \cdot A_i^{0.5}/qR \approx 2.1 \cdot 10^{19} m^{-3}$, which is below experimental one. Another specific limit for OH regime is well known Murakami-Hugill limit. It usually manifests itself with fatal increase of the peripheral radiation losses over critical value and ends with disruption. For experiments in non-boronized vessel Murakami-Hugill limit is, $n_{crit} \leq 2 \cdot B_T \cdot /qR \approx 3.2\text{-}3.7 \cdot 10^{19}$ m^{-3} for $(6<q<7)$. In spite of close number to the experimental saturation density value, Globus-M density limit is not hard and do not lead to the disruption.

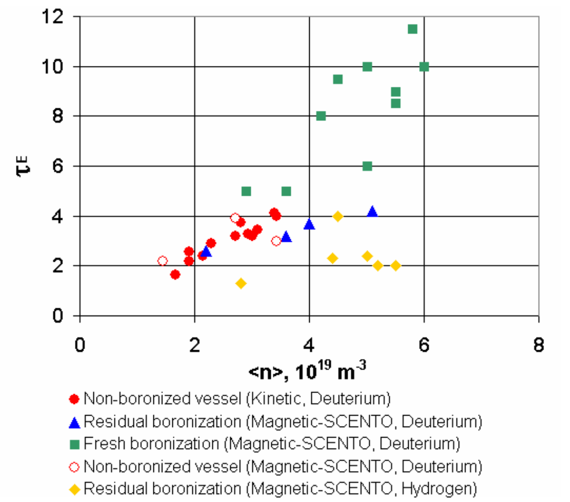

Fig.3 Energy confinement time in boronized and non boronized vessel versus average density

These experiments together with selected measurements from previous experimental campaigns (2001-2003) create a data base, which is presented in Fig. 3.

In the left down corner kinetic data obtained in clean non-boronized vessel are shown as filled circles. Also data picked up from EFIT measurements together with 0-D SCENTO simulations are plotted as open circles. One could see that satisfactory agreement between kinetic and simulated data is achieved, taking into account some uncertainties in simulations. Maximum energy confinement time reached in clean non-boronized vessel in Globus-M doesn't exceed 4 ms, with maximum density below $\sim 4 \cdot 10^{19}$ m^{-3}, which could be taken as the reference point for discharge performance increase. Triangles represent data obtained in the vessel with residual boronization [1] (after a long time and vessel opening to atmosphere). Such a poor boronization is influencing on the density limit extent, but not on confinement improvement. Shown by rhombus are confinement data in the same vessel conditions, but with hydrogen, as working gas. Comparison to triangles demonstrates isotope effect on confinement ($\sim\sqrt{2}$). Rectangles represent best shots achieved in the freshly boronized vessel. Most of the shots demonstrate indirect features of improved confinement transition. D-alpha drops at constant or increased density rate rise, peripherial density profiles pedestal build-up, SXR sawteeth amplitude and period drop indicate features of L-H transition previously reported [2,3]. Rarely, some density profile peaking (not high) were observed, which quit ambiguously may witness about IOC regime [4]. It's worth noting than in clean, non-boronized vessel our attempts to reach IOC regime with gas puffing rate change failed. It's challenging task to declare pure OH H-regime in the absence of ELMs. Anyway other data prevail. One possible reason for observation of L-H transition in freshly boronized vessel could be redistribution of input power into thermal energy of particles, rather than into radiation losses and density limit increase. Both simulations and experiment showed increase of radiating power in non-boronized vessel which is the main reason of observed density limit. It's quit obvious that boronization decrease radiating power due to minimization of impurity content. Fig.4 shows survey spectra of non-boronized clean vessel plasma discharge (left) and boronized vessel (right) discharge picked up by multichannel optical analyzer (OMA).

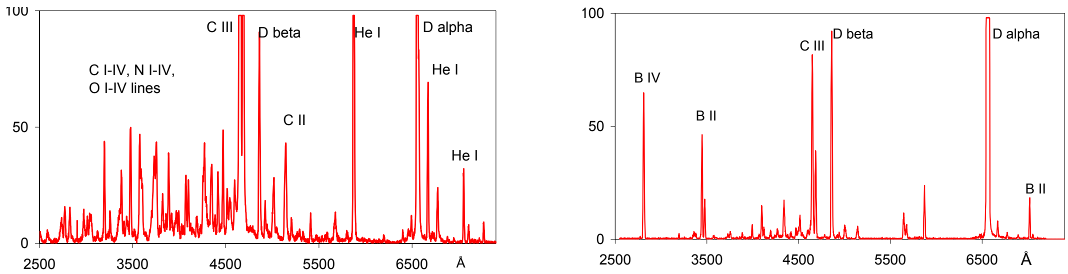

Fig.4 OMA Spectra in Globus-M discharge before (left) and after boronization (right)

Another reason simplifying L-H transition is lower plasma surface area in experiments shown by rectangles in Fig.3. Plasma column elongation doesn't exceed $\kappa \approx 1.3$, decreasing significantly plasma column surface area and increasing peripherial power density flux. Estimate of the ratio $P_{Loss}/P_{Thr} \approx 4 \div 6$, for P_{Loss}-power flux through the boundary and $P_{Thr} = 0.041 \cdot n_{e20}^{0.69} \cdot B_T^{0.91} \cdot S^{0.96}$ [4] – threshold power for L-H transition, gives 2-3 times higher values than in MAST [5]. In summary: preliminary conditions for achievement of high performance OH regime (improved confinement transition) in Globus-M were formulated, which include minimization of radiation losses by boronization and increase of density together with peripherial power flux increase through the plasma boundary.

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