# Axial electron conductivity in open magnetic trap

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**Introduction**

This work is dedicated to fundamental investigations concerning the problem of controlled thermonuclear fusion in open magnetic traps. An interest to such systems is caused by development of powerful neutron sources that are necessary for controlling hybrid fusion-fission reactors with following development of thermonuclear reactor for energy producing [1, 2]. Key parameters from application point of view is energy effectiveness of the system that is rapidly increases with electron temperature growth. One of factors that limit electron temperature can be high plasma thermal conductivity along force lines of magnetic field that is determined by complicated kinetic processes in expanders (region with expanding magnetic flux beyond magnetic mirrors). The most crucial issue is detailed investigation of this loss channel and determination of conditions, when this channel can be suppressed up to acceptable level for thermonuclear applications of open traps. Theoretical investigations about this problem were carried out before [3, 4]. It was predicted that the heat flux from an open trap during direct contact of the plasma with the cold end plate can be drastically reduced compared to the limit of classical (Spitzer) thermal conductivity due to the barrier of ambipolar potential. This barrier arises in the region between the mirror plug and the plasma absorber; it reflects most of the electrons leaving the trap back into the trap. Under these conditions, the main channel of energy loss is associated with the penetration of cold electrons from the expander into the trap, which arise due to ionization of the neutral gas and secondary emission from the surface of the plasma absorber. According to the theory [5, 6], efficient suppression of cold electron flux into the trap is realized if the degree of expansion for the magnetic field in the region behind the magnetic plug exceeds about $\sqrt{(m_i / m_e)}$, where $m_i$, $m_e$ – ion and electron mass. The theoretic limit for longitudinal losses is close to 8 electron temperatures ($8T_e$) for every electron-ion couple, leaving the trap.

There is a danger, that in real hot (thermonuclear) plasma potential drop in Debye sheath near the wall will be higher than the threshold of appearing an unipolar arc, and when arcs emerge, potential difference possibly disappears. Experimental research was performed only for low electron temperatures ~ 20 eV [7]. The main task of present work is detailed experimental research of physical processes that define longitudinal energy and particle transport in plasma with parameters close to reactor ones in axially symmetric open magnetic trap like GDT in Budker Institute of Nuclear Physics [8, 9]. Previously plasma parameters in the GDT expander had been investigated [10]. As the next step it is important to measure an amount of energy loss per one electron-ion pair upon condition that electron temperature of plasma is quite high.

**Experimental setup**

Gas Dynamic Trap is an axially symmetric magnetic mirror machine. The main part of the device is a 7 m long solenoid, with a magnetic field at the midplane up to 0.35 T and a mirror ratio R = 35. The GDT facility confines plasmas with two ion components. One component is deuterium plasma with an isotropic Maxwell velocity distribution. This plasma has electron and ion temperatures of up to 250 eV and a density of ~ $1–3\cdot10^{19}$ $m^{-3}$ and is confined in a gas dynamic mode, which means that it is similar to a gas in a bottle with a small hole. The particle lifetime in the GDT is about $\tau_{||} = L\cdot R/V_i$, where L is the trap length, R is the mirror ratio, and $V_i$ is the ion thermal velocity. Another component consists of fast deuterons with an average energy of ~ 10 keV and density up to $5\cdot10^{19}$ $m^{-3}$. These ions are produced by intense deuterium neutral beam injection (NBI) of 5 ms duration, 22-25 keV particles energy and 5 MW power. This component is confined in adiabatic mode. Additional ECR heating allows the increase of the background electron temperature up to 900 eV [9]. The ECRH system is built upon two 54.5 GHz gyrotrons with a total incident power of up to 0.7 MW, in addition to the main heating power from the neutral beams.

For the research task mentioned above a couple of probes were designed and installed in GDT expander on the moving plate (fig. 1).

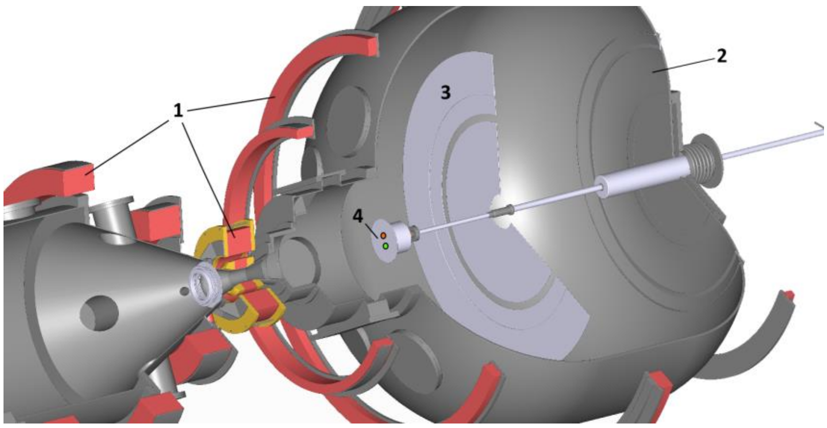


Fig.1. Layout of GDT expander: 1 – magnetic coils, 2 – western expander tank, 3 – end plate, 4 – central movable part of end plate with embedded probes

The first probe is ion flux detector, which is a three-electrode system (fig. 2a). The input electrode (1) with a hole of 2 mm in diameter is under the potential of the body, at a distance of 1 mm from there is the pulling electrode (2) with a hole of the same diameter and at a high potential of about –1.5 kV. It pulls ions out of the plasma, reflecting electrons. A negative voltage is applied to the collector (3) by several hundred volts less than to pulling electrode - to eliminate the influence of secondary electron emission from the collector. Electrodes and collector have a streamlined shape to avoid edge breakdowns. Insulators (4) are made of ceramic.

Figure 2b shows a cross section of the energy flow detector - a bolometer. Its main detail is a thin silvered tablet of lithium niobate, a pyroelectric ceramic, which generates current when an energy flow hits its surface. The tablet is shielded from plasma potential fluctuations with metal grids (1). To minimize electrical induced noises, the pyroelectric (2) is located on the same board as the signal amplifier (3), directly in the detector's body. To dampen acoustic noise, the board is clamped between two rubber rings (4).

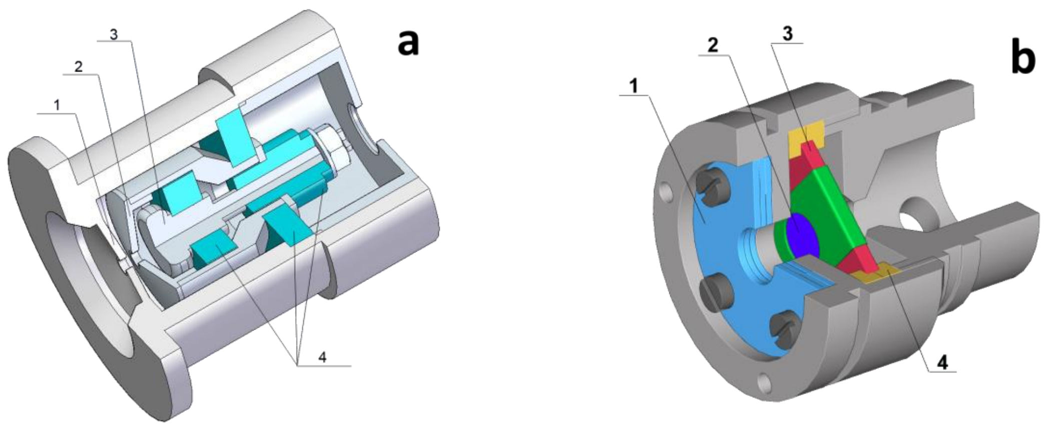


Fig. 2. a – ion flux detector, b – bolometer

A bolometer and an ion flux detector, operating simultaneously, are capable of measuring the amount of energy per electron-ion pair leaving the trap along a magnetic field. We use a dimensionless parameter A, characterizing the amount of energy in units of electron temperature. To calculate it, the power density measured by a bolometer (P) is divided into the ion flux density according to the ion flux detector ($j_i$), and the electron temperature ($T_e$) measured at the center of the trap by Thomson scattering system: $A = P/(j_i * T_e)$. Moving the probes along the expander axis, we obtained the dependence of the parameter A on the magnetic field expansion degree K (Fig. 10), which is the ratio of the magnetic field in the plug (12 T) to the current magnetic field. In this series of experiments, the averaged electron temperature in the central part of the trap was about 180 eV at a density of $2 \cdot 10^{13}$ cm$^{-3}$. Figure 3 represents the results of these measurements.

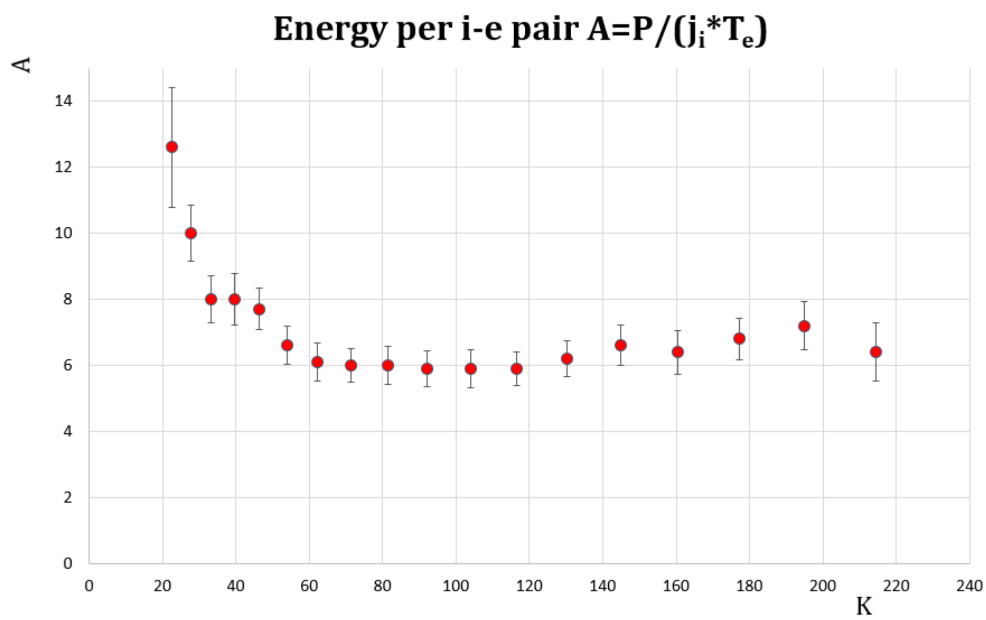


Fig. 3. The energy removed from the trap by the electron-ion pair, depending on the degree of magnetic field expansion of behind the plug

It can be seen that in a wide range of expansion ratios the energy carried by the e-i pair is in the range of values from 6 to 8 electron temperatures and rises at K < 60. These facts are in a good agreement with theoretical estimations for deuterium plasma.

**Conclusions**

It was successfully shown that axial losses from the open trap do not exceed $8T_e$ per electron-ion pair in the range of magnetic field expansion K > 60 for plasma with temperature about 200 eV. In the nearest future, we are planning to check this law for temperatures up to 500 eV.

The research is supported by Russian Science Foundation, project № 18-72-10084 from 31.07.2018.

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