Intensive Molecular Diagnostic Beam on the Basis Microchannel Plate

S.V.Murakhtin[1,2,a)], A.T.Chernyavsky[1,3], O.A.Korobeynikova[1],
D.I.Skovorodin[1,2].

[1]*Budker Institute of Nuclear Physics of Siberian Branch Russian Academy of Sciences, Novosibirsk, Russia.*
[2]*Novosibirsk State University, Novosibirsk, Russia.*
[3]*Novosibirsk State Technical University, Novosibirsk, Russia.*

a)S.V.Murakhtin@inp.nsk.su

Abstract. We have created an intense molecular source based on microchannel plates. The source forms a helium beam with divergence angle of 50 mrad, current (equivalent) density on the axis 100 mA/cm^2 with an average particle beam energy 0.025 eV. The paper shows experimental measurements of the molecular source current density profile. The result was compared with the theoretical model.

INTRODUCTION

The main problem in open magnetic traps is a longitudinal energy transport through a magnetic mirror. Heated target plasma in the central cell of the Gas Dynamic Trap (GDT) is limited by reverse flow of cold electrons from the expander region. The interaction of cold electron space charge and ambipolar potential can lead to deformation of the electrostatic potential and the emerging of the "trapped" electrons. In the GDT device we study the influence of the neutral gas in the expander on the basic parameters of the plasma in the central cell. An artificial local target of the neutral gas will be formed on the axis of the expander. The grid energy analyzer for detecting ions accelerated in the ambipolar potential will be set on the plasma target plate. Moving the artificial target along the axis one can measure an ambipolar potential profile. The experimental scheme is shown in Fig. 1.

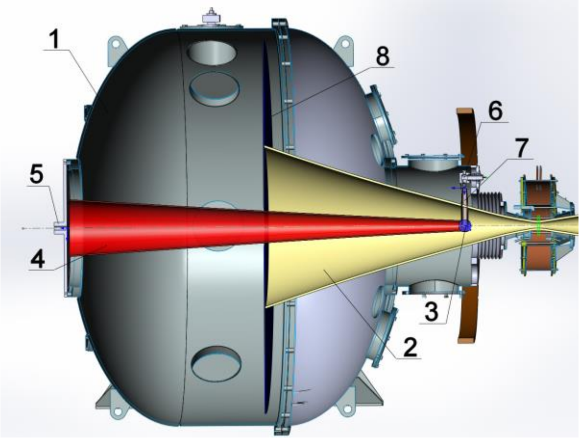

FIGURE 1. The experimental setup for the measurement of ambipolar potential in the GDT expander.
1 – Expander tank, 2 – plasma, 3 – He artificial target, 4 – He ions, 5 – scanning end-loss energy analyzer, 6 – molecular source, 7 – narrow sensing He-beam, 8 – plasma target plates.

The Molecular Source Design and Principle of Operation

The design of the beam shaper is shown in Fig. 2. A helium puff enters (gas valve in Fig.2 not shown) via a pipe (4) to the microchannel plate (MCP) (1). The gas flow in the molecular regime is determined by the concentration in the receiver volume (6). The adjusting unit (3) determines the direction of the gas jet.

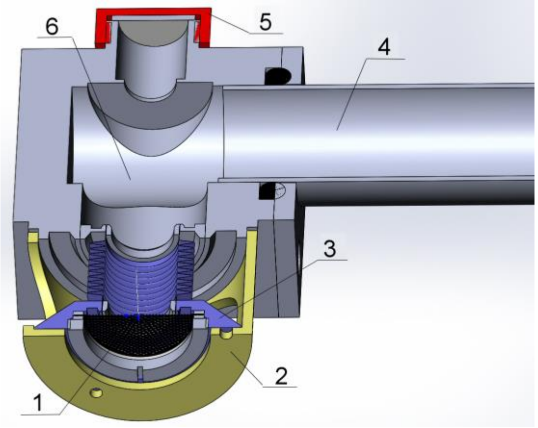

FIGURE 2. The molecular source design.
1 – Micro-channel plate, 2 – adjustment assembly, 3 – bellows unit, 4 – mobile bar, 5 – adjustment port, 6 – receiver volume.

The principle of molecular source is the formation of a narrow directional gas jet. The narrow jet is created by the interaction of a large number of elementary beams generated by each channel MCP. In our experiment, we used the MCP channel density 2×10^{6}cm^{-2}. If the mean free path λ of the molecule is more than the length L of the channel MCP, the narrow beam is formed. According to the results of numerical modeling obtained in [1], an angular distribution $F(\Theta)$ of elementary particles in a beam is determined by the relationship:

$$F(\Theta)=\cos(\Theta)\left\{1-\frac{2}{\pi}\left(1-0.6\frac{d}{L}\right)\left(\arcsin(V)-\frac{1}{3}\left(\frac{2}{V}+\sqrt{1-V^{2}}\left(\frac{2}{V}+V\right)\right)\right)\right\}, \tag{1}$$

where $V=\frac{L}{d}\tan(\Theta)$, L – capillary length, d – capillary diameter.

The angular distribution of the hydrogen flow from the capillary (L/d=20) obtained in [2] is shown on Fig.3. The solid line is the angular distribution calculated from the equation (1), points - experimental data. A more narrow angular distribution using the MCP (L/d=60) in our experiment we obtained.

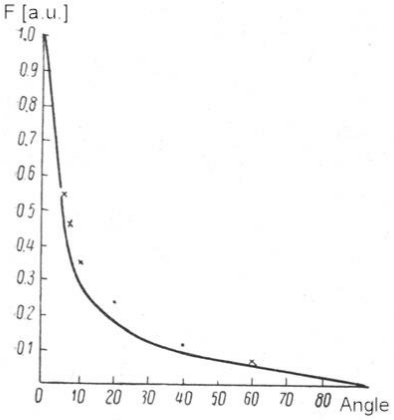

FIGURE 3. The angular distribution intensity of a single capillary.

Integrating equation (1) in the area of MCP one obtains beam current density distribution of the angle α as a function of distance along z:

$$
\begin{aligned}
j(z,\alpha) &= \frac{I_{tot}}{A(z)} \int_{0}^{r_0} \int_{-\sqrt{r_0^2 - y^2}}^{\sqrt{r_0^2 - y^2}} F(\varphi(x,y,z,\alpha))\,dxdy \\
A(z) &= 2\pi z^2 \int_0^{\frac{\pi}{2}} \sin(\varphi) \int_{0}^{r_0} \int_{-\sqrt{r_0^2 - y^2}}^{\sqrt{r_0^2 - y^2}} F(\varphi(x,y,z,\alpha))\,dxdyd\alpha, \\
\varphi(x,y,z,\alpha) &= \arccos\left(\frac{z}{\sqrt{(z \cdot tg(\alpha) - x)^2 + y^2 + z^2}} \right)
\end{aligned}
\qquad (2)
$$

where r_0 – MCP range, I_{tot} – total current.

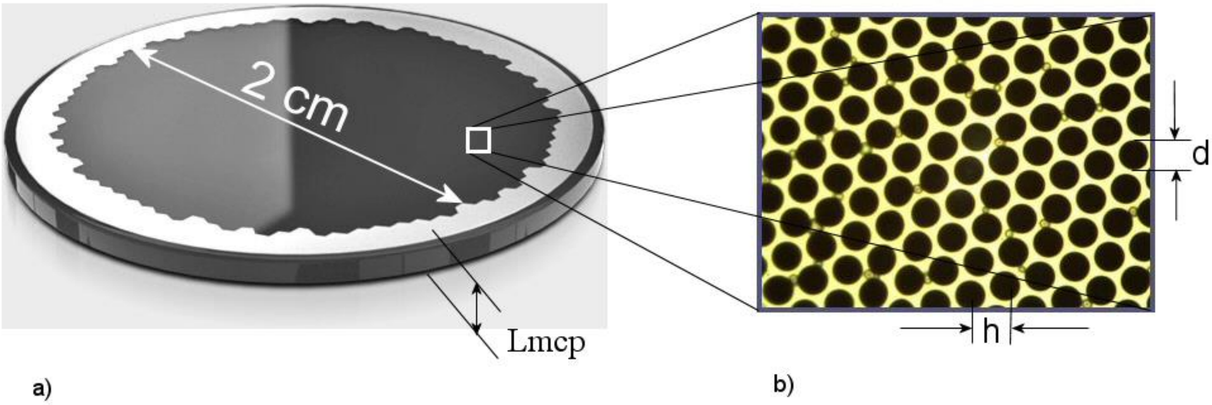

FIGURE 4. The microchannel plates - a basic element of a molecular source.
a) General view of the MCP, b) the MCP appearance in a microscope. h=7μ – structure step, d=5μ – channel diameter, L_{mcp}=300μ - thickness.

The geometry of the plates (see Fig.4) and the necessity of molecular flow channel limits the maximum current density j_{mcp} at the surface of a MCP:

$$
\left.
\begin{aligned}
\lambda &= \frac{1}{n_{He}} \frac{4}{\pi\sqrt{2} d_{He}^2} > L_{mcp} \\
F_{mcp} &= \frac{8}{3} c s N_{mcp} \sqrt{\frac{T}{M_{He}}}
\end{aligned}
\right\} \Rightarrow j_{mcp} < 10^3 q \frac{c}{L_{mcp}} \frac{k^2}{d_{He}^2} \sqrt{\frac{T}{M_{He}}}
\qquad (3)
$$

where λ – the mean free path of helium atoms, n_{He} – the concentration of helium atoms, d_{He} – the diameter of helium atoms, L_{mcp} – MCP thickness, F_{mcp}–MCP conductance, N_{mcp} – the total number of MCP channels, s – channel area, $c=L_{mcp}/d_{mcp}$, d_{mcp} – channel MCP diameter, $k=d_{mcp}/h_{mcp}$, h_{mcp} – MCP structure step, q – elementary charge.

Equation (3) limits the maximum equivalent current density at the surface of a MCP value j_{mcp}=1 A/cm^2 in our conditions. This is done when the gas concentration in the receiver volume (see Fig.2) source is up to P_{max}=2000 kPa.

Experimental Results

The measurement of the angular distribution of the molecular beam intensity on the vacuum stand was carried out. Comparison of experimental data with the results of numerical modeling (2) are shown in Fig.5.

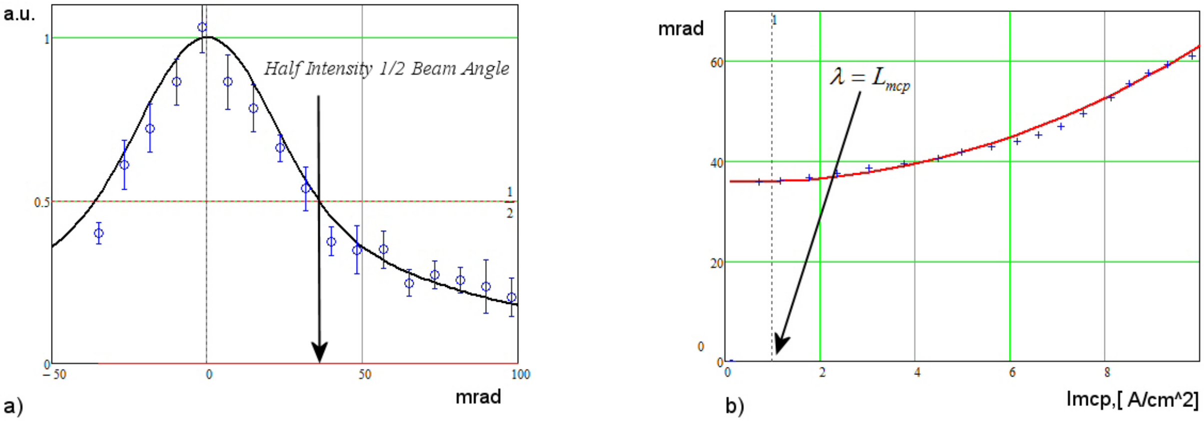

FIGURE 5. The quality of the Helium beam.
a) The angular intensity distribution. Points – experiment, solid line – numerical simulation. b) The dependence of the angular half-width level of the beam current density (experiment), solid line – spline.

The experimentally measured angular distribution of the diagnostic beam intensity in comparison with the results of numerical simulations is presented on the left figure. The good agreement between the values presented can be noted. At an equivalent current density on the beam axis up to 100 mA/cm^2 (z = 20 cm) the angular half-width at the ½ level divergence of the beam is less than 50 mrad. This value is limited by a violation of the molecular mode of gas flow through the channel MCP. The angular divergence half-width of the beam as a function of current density on the surface of the MCP is shown in Fig.5 (b). A vertical bar shows the boundary between the molecular flow regime and its viscosity, when the mean free path λ of molecules becomes comparable to the channel length L of the MCP. Predicted by the theory of the beam broadening excess of the equivalent current density on the surface of MCP more than 1 A/cm^2 is confirmed experimentally.

Summary

We have created a diagnostic beam with average energy of particles 0.025 eV, the angular divergence better than 50 mrad and an equivalent current density on the axis up to 100 mA/cm^2. In the planned experiment to measure the ambipolar potential profile in the GDT-expander it would create an artificial target with a particle density on the axis up to 10^{13} cm^{-3}.

REFERENCES

[1] V. S. Troitckiy, JTF 32, 488 (1962);
[2] B. S. Ivanov, V. S. Troitckiy, JTF 33, 494 (1963).