Modelling the magnetic field of the acceleration channel End-Hall ion source

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In recent decades, the End-Hall ion sources have been used in the optical coating industry for ion-assisted deposition and surface pre-cleaning operations e.g. /1, 2/. The employ of gridless ion sources based on magnetoplasmadynamic thrusters and Hall effect has been beneficial for many applications, because they have a relatively high ion flux density, wide spatial distribution, moderate beam energy levels of approximately 60-200 eV, and its ability to handle either inert or reactive gases. However, as modern manufacturing processes scale to larger systems, higher rates, and larger substrate areas, it has become necessary to increase power capacity of the End-Hall ion sources, reduce form-factor sand significantly improve their service ability and maintenance requirements and, thereby, reduce cost of ownership.

In Hall-effect ion sources, the magnetic field **B** is perpendicular to the discharge current forms a barrier to electron transport from the cathode to the anode at a specific location in space, leading to the increase of the electric field **E** in the plasma at that location, in a direction perpendicular to the magnetic field. This electric field accelerates ions away from the source.

The resulting cross-field configuration generates a current (the Hall current) that direction is perpendicular to the **E**×**B** fields e.g /3, 4/. Most Hall-effect ion sources have an axially symmetric design in which the applied magnetic field and the resulting electric field are such that the Hall current is generate in the azimuthal direction. In this configuration, the anode is at the end of the channel and the exhaust (and acceleration region) is at the other end. In the End-Hall ion configuration, the anode has a conical shape, the acceleration region is close to the anode surface, and the beam divergence is larger.

Magnetic field simulation

For the study of the magnetic field of an ion source (Figure. 1), it is assumed that the field is generated by cylindrical permanent magnets; therefore, the solution will be given by the equations

$$\nabla \cdot B = \nabla \cdot (\nabla \phi) = 0 \qquad (1)$$

where **B** is the magnetic induction field and $\boldsymbol{\phi}$ is the magnetic potential.

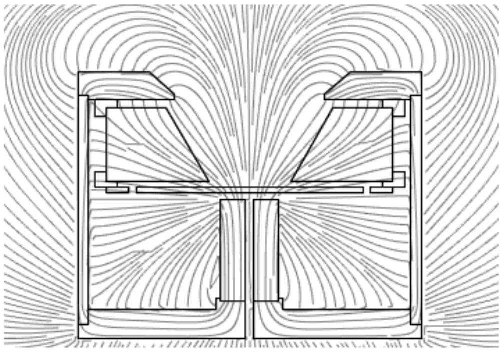

Figure 1. Magnetic field lines configuration in End-Hall ion sources

Rather than being calculated directly from the configuration of permanent magnets, the magnetic field in the discharge channel is obtained from a set of boundary values specified on the domain boundaries. This allows the direct implementation of measured magnetic field data or the deliberate adjustment of the field, which is useful for studying its influence.

The magnetic field lines are described by the stream function $\lambda\ (x, r)$ e.g. /5, 6/, calculated from

$$B_a = \frac{1}{r}\frac{\partial\lambda}{\partial r}, \qquad B_r = \frac{1}{r}\frac{\partial\lambda}{\partial x}, \qquad (2)$$

where a and r are the axial and radial position coordinates and $\boldsymbol{B_a}$ and $\boldsymbol{B_r}$ are the axial and radial components of the magnetic field. This λ is constant along magnetic field lines ($B \cdot \nabla\lambda\ = 0$) and usually diverged from anode to cathode. Substituting λ in Equation. (2) in the Maxwell-Ampere, we have

$$\frac{\partial}{\partial x}\left(\frac{1}{\mu}\frac{\partial\lambda}{\partial x}\right) + \frac{\partial}{\partial r}\left(\frac{1}{\mu r}\frac{\partial\lambda}{\partial r}\right) = -rJ_{magnet} \ (3)$$

where μ is the magnetic permeability and $\boldsymbol{J_{magnet}}$ is the azimuthal current source of the magnet. The solution for this equation is solved numerically.

It is possible to increase the efficiency of ion generation in End-Hall ion source by decreasing the value of the magnetic induction component B_r in the region above the anode. This makes it possible to increase the efficiency of the magnetic trap and to ensure the entry of electrons from the filament-cathode into the plasma formation zone. The value of the component B_a in the plasma formation region should remain high to enhance the ionizing ability of the electrons located there.

Simulations results

In this section presents the magnetic field simulation between reference and developed End-Hall ion sources. The simulation was performed using the free trial version COMSOL Multiphysics software package. The calculation of the magnetic field was carried out in a stationary mode using the Maxwell equation. It is considered that the field distribution is uniform throughout space and is not affected by external fields. During our simulation we were variation the permanent magnets dimension and shape of magnetic poles.
As a result of the simulation, graphs were constructed which show the variation of the values of the magnetic field induction components B_a, B_r on the cylinder surface located at r_1, r_2 and r_3 from the central axis as it shown on the Figure 2.

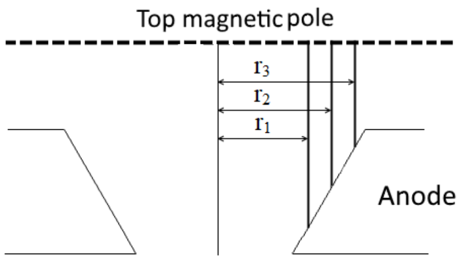

Figure. 2. Schematic of the magnetic field measurements from the central axis at a distance r_1, r_2 and r_3

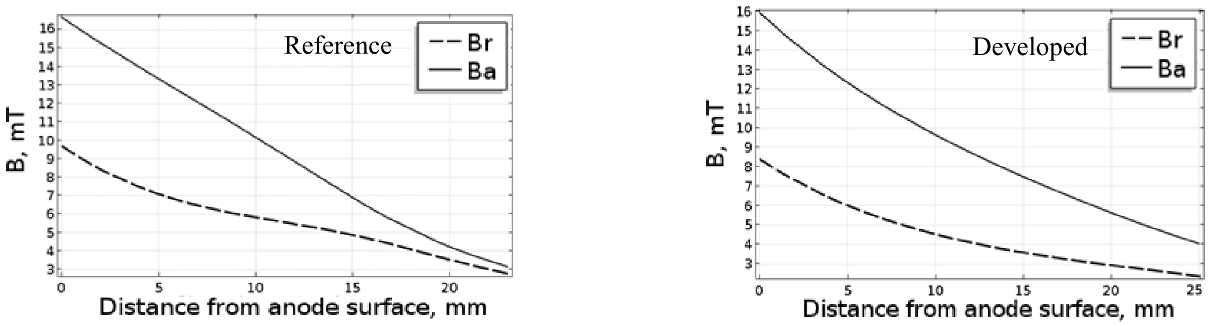

Figure 3. The values of the B_a and B_r magnetic field components for the reference and developed ion sources at the r_1

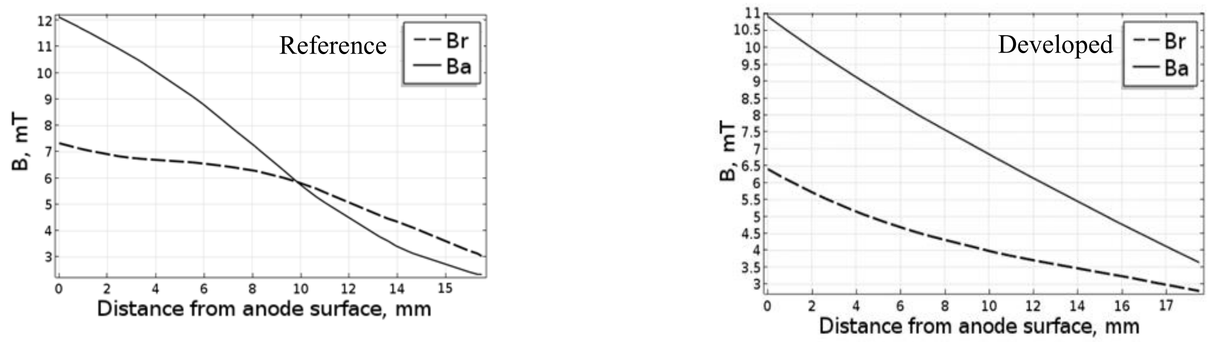

Figure 4. The values of the B_a and B_r magnetic field components for the reference and developed ion sources at the r_2

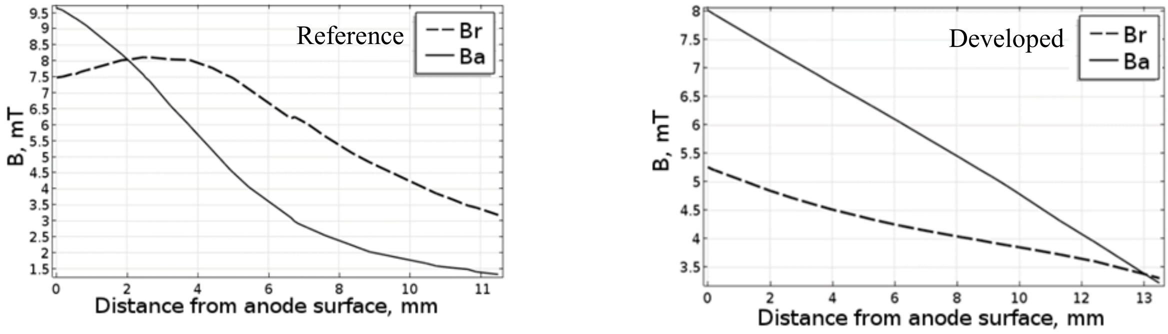

Figure 5. The values of the B_a and B_r magnetic field components for the reference and developed ion sources at the r_3

As can be seen from the figures 3,4 and 5, the values of the B_r component in the region above the plasma formation region decreased by 10-40% without a significant decrease in the B_a component. Moreover, a decrease in the values of the B_r component with a distance from the anode surface occurs more intensively.

Conclusions

The magnetic fields of the reference and developed magnetic system of the End-Hall ion sources are simulated. The values of the magnetic field induction component B_r in the region above the plasma formation zone are decreased. The results obtained indicate expansion of the "channel" for electrons that follow to the anode, increase in "effective surface" of the anode, and, as a consequence, increase in the discharge region. So, there is an increase in the efficiency of the magnetic electron trap for developed End-Hall ion source and, accordingly, an increase in the efficiency of ion current generation.

References

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