acta physica slovaca vol. 55 No. 4, 361 – 366 August 2005

DESIGN OF THE MAGNETIC STRUCTURE OF ECR ION SOURCE NANOGUN-10B [1]

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Received 11 February 2005, in final form 6 May 2005, accepted 9 May 2005

The magnetic structure of new 10 GHz ECR ion source NANOGUN-10B is described. Small permanent magnets are used for construction of suitable hexapole and axial magnetic field structure. Permanent magnets are made from FeNdB with a remanence of 1.1 T and a coercivity of 800 kA/m. The hexapole consists of 24 trapezoidal segments. The axial magnetic structure is designed of 7 slices of FeNdB permanent magnets defining a magnetic field of 0.58 T in the extraction and 0.77 T near the injection of the UHF area. The magnetic structure internal diameter is 36 mm and the external diameter is 200 mm. The total weight of the magnetic structure is about 36 kg.

PACS: 52.50.Gj, 52.55.Jd, 02.70 Rw

1 Introduction

The magnetic structure of every ECR ion source consists from radial and axial minimum magnetic field B. The radial magnetic multipole is usually a hexapolar one made of permanent magnets. The plasma of the ECR ion source (ECRIS) is kept together by the magnetic field inside a magnetic bottle. The field consists of a longitudinal one, made by coils or permanent magnets and a transversal one, made by the hexapole. The magnetic bottle is the region surrounded by a closed surface of a constant magnetic field B. The magnetic field inside the plasma region is lower than that on the surface of the magnetic bottle. The stronger is the magnetic field inside the magnetic bottle the higher is the frequency of the resonance electrons. Hence, we can obtain larger plasma density, which results in larger ionization possibility.

The electrons in the ECRIS plasma are heated by interacting with waves at cyclotron resonance on one of the closed $|\mathrm{B}|$ surfaces of such magnetic configuration, where the equal $|\mathrm{B}|_{ECR}$ surface is defined by $\omega_c = \mathrm{e}|\mathrm{B}|_{ECR}/\mathrm{m}_e = \omega_f$, where B is the magnetic field in the region where

[1] Presented at SSSI-IV (Solid State Surfaces and Interfaces IV) Conference, Smolenice, Slovakia, 8–11 Nov. 2004.
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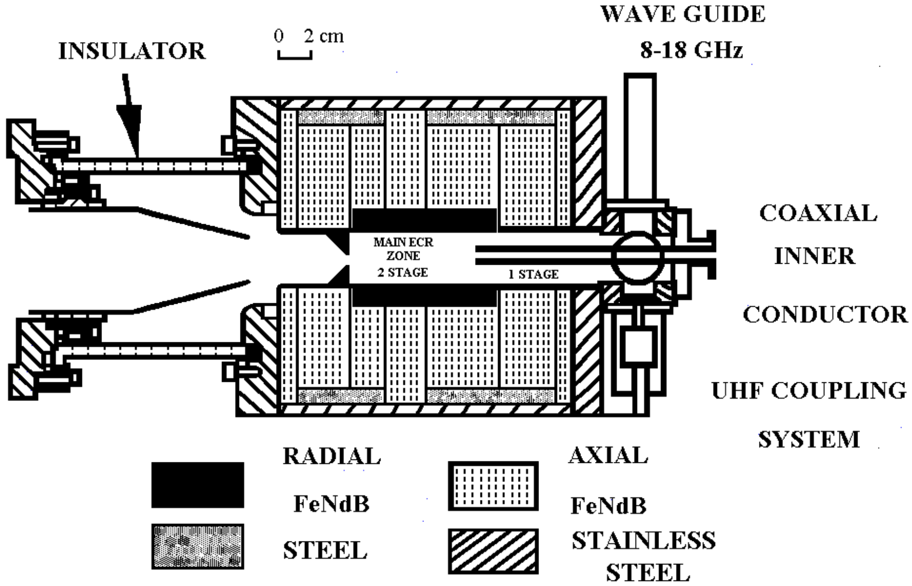

Fig. 1. Layout of the NANOGUN-10B.

plasma is kept, e the charge of the electron, m_e the mass of the electron and ω_f ($\omega_f = 2\pi f$) the microwave frequency matching the electron cyclotron frequency ω_c ($\omega_c = 2\pi f_c$). For $f_c = 10$ GHz we need $|B|_{ECR} = 0.36$ T.

Basically an ECRIS has the property of confining hot electron plasma, and its main components are: i) a magnetic configuration, i.e. a plasma container, ii) a UHF power input, i.e. a source of energy that heats up and sustains the plasma electrons in a magnetic trap, iii) internal (ionization) and external sources of electrons, which allow electron density to be built up, iv) injected gases or metals, i.e. the fuel injected in order to compensate the loss and to control the neutral pressure.

The maximum ion beam current extracted from an ECRIS is given by the following scaling law [1]: $(I_q)_{max} \sim B^2 sL$, where $(I_q)_{max}$ is the maximum current of the ions of charge state q, B the resonance magnetic field, s the extraction area and L the plasma length, which determines the main plasma volume. The scaling low also indicates that the magnetic structure should be designed to form strong B with long L. According to this concept, the configuration of the NANOGUN-10B (NANOGUN-10 GHz from Bratislava) magnetic structure has been designed.

The permanent magnet measures are: 157 mm length, and 36 mm and 200 mm in inner and outer diameter, respectively. The maximum mirror field is 0.8 T and the mirror ratio M = 2.7 (M = B_{max}/B_{min}).

2 Magnetic structure of the NANOGUN-10B

The scheme of the ECR ion source NANOGUN-10B is shown in Fig. 1. The magnetic structure of the ECR ion source is cylindrical symmetric. The full magnetic structure of the NANOGUN-

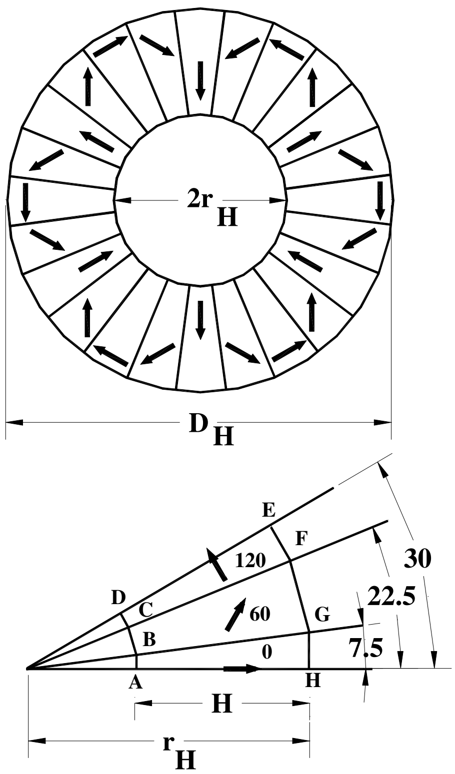

Fig. 2. Cross section of the hexapolar structure of the NANOGUN-10B ion source. Here, r_H is the radius, H the thickness, $2r_H = d_H$ the inner diameter, D_H the external diameter of the hexapole and ABCDEFGH is a characteristic segment of the hexapole.

10B (see Fig. 1) is made of permanent magnets, which saves cooling and electric power consumption. The radial magnetic multipole is hexapolar and is made of permanent magnets FeNdB. The body of the source can be subsequently reduced to an outer diameter of 200 mm, the plasma chamber can have diameter 36 mm and length about 80 mm (the second stage). A multipolar permanent magnet of ϕ 64 mm outer diameter forms the radial field around this plasma chamber. The UHF coupling is designed to connect a rectangular to co-axial wave-guide transition, where the inner conductor can be a ϕ 6-8 mm copper tube. This tube will be also used for gas injection. The introduction of the micro-oven on the axis of the source could also be possible.

The plasma electrode is placed at the maximum of the magnetic mirror field and can be made of an 8 mm extraction hole. The extraction electrode will be a conic one with the Pierce angle of 22.5^o. The extraction gap will be adjusted.

Fig. 2 shows the cross section of hexapolar structure of the NANOGUN-10B. We have chosen the thickness of the hexapole $H = 1.4$ cm (see also Fig. 1). In order to find the maximum of the magnetic field B_{max}, the region of $r_H \in< 1.3, 6 >$ cm has been investigated. It was shown that suitable radius of the hexapole can be from the region $r_H \in< 1.7, 3.2 >$ cm. It was also shown

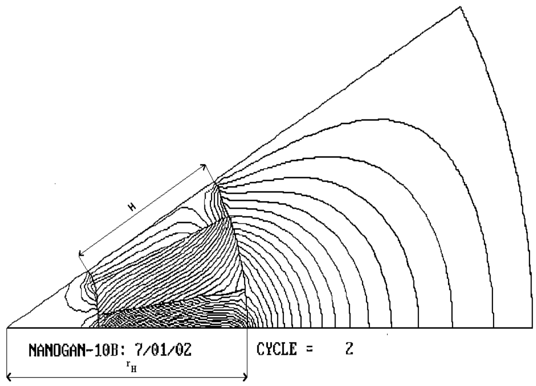

Fig. 3. Calculated magnetic flux lines inside the hexapole. The radius r_H, the length l_H and the thickness H of the hexapole are: r_H = 1.8 cm, l_H = 7.5 cm and H = 1.4 cm, respectively.

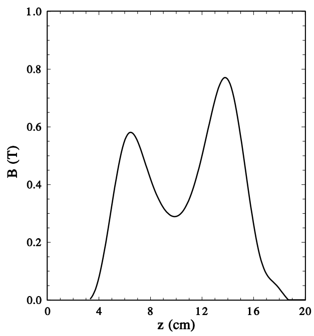

Fig. 4. Axial magnetic field.

that the magnetic field at the plasma surface of the NANOGUN-10B is 0.45 T ($r_H = 1.8$ cm). It is assumed that the plasma chamber will be constructed using a non-magnetic stainless steel tube 1.77 mm thick [2].

The FeNdB with a remanence field of 1.1 T and a coercivity of 800 kA/m has been used in our calculations. The calculated hexapole consists of 24 trapezoidal segments, where the angle of magnetization varies by 60° from one segment to the next one.

The magnetic field inside the hexapole is shown in Fig. 3. The PANDIRA two-dimensional magnetic field code has been used to calculate the magnetic flux lines inside the hexapole [3].

The whole magnetic structure is formed by the superposition of the hexapolar field and the mirror field. The higher is the hexapolar field, the stronger is the confinement of the plasma in the radial direction.

A well-known rule of plasma physics says that the higher is the mirror ratio M of a magnetic structure, the smaller is the number of particles lost from the confined plasma. In the NANOGUN-10B, the values are (see Fig. 4): M = 2.7, B_{max}/B_{ECR} = 2.2, B_{max} = 0.8 T, B_{min} = 0.29 T and B_{ECR} = 0.36 T.

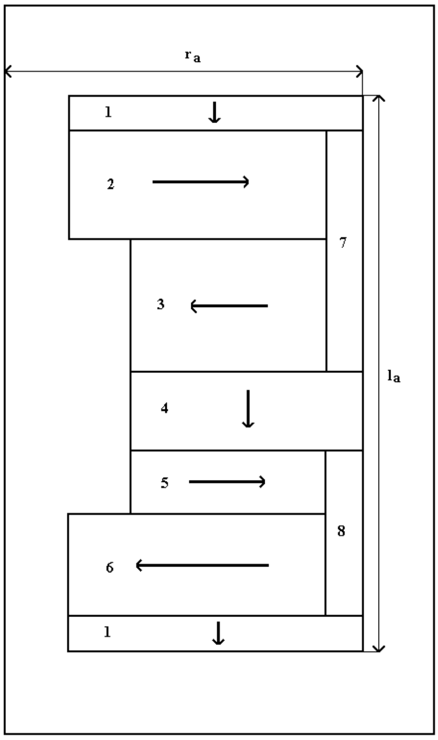

Fig. 5. Axial magnetic structure of the NANOGUN-10B. The radius r_a and the length l_a of the magnetic structure are: r_a = 10 cm and l_a = 15.7 cm, respectively.

The axial magnetic mirror field is also designed with FeNdB permanent magnets instead of solenoidal coils. The shape of the axial magnetic structure is shown in Fig. 5. The PANDIRA two-dimensional code has also been used to calculate the axial magnetic field. Every result of the calculation is shown in the file OUTPAN. It contains constant values (CON) in the solutions, a table giving the magnetic properties of used materials, the history of the iteration, and an edit of the solution in the defined regions as well as radial and total magnetic fields in the determined points. The calculated values are used at making of the picture of the magnetic field. Other output from the axial magnetic field calculation can also have the shape, which is shown in Fig. 6.

3 Conclusions

The results obtained here show that the magnetic fields B(r) inside hexapole with thickness of $H = 1.4$ cm have the highest value for the highest radii r_H. It was shown that the magnetic field at the plasma surface of the NANOGUN-10B is 0.45 T ($r_H = 1.8$ cm).

The calculated compact magnetic structure of the ECRIS will be installed inside the NANOGUN-10B. The permanent magnet technology is utilized at the design of the magnetic structure with the reduced dimensions of the source. We expect that the source will produce tens of μAe

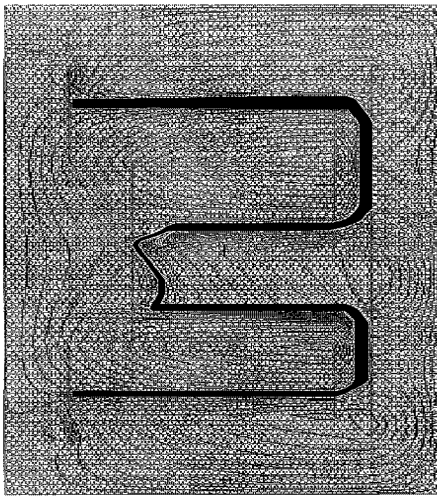

Fig. 6. Calculated magnetic flux lines inside the axial magnetic structure.

of Ar^{4+} with such magnetic structure by optimizing the operation parameters, the extraction system, and the gas pressure in the plasma chamber.

It has been shown that it is possible to build such ECRIS with performances relatively similar to the classical one but for a total cost 5 to 10 times smaller. This aspect is also used in our design. Because of the optimized magnetic structure of the NANOGUN-10B we can await that the generated yields of ions will be higher as in the Pantechnik NANOGAN ion source [4].

Acknowledgement: The authors wish to thank E. Běták for his understanding in this work but also for his help concerning the language correction of the paper. They are also indebted to V.B. Kutner, S.L. Bogomolov, A.N. Lebedev, V. Pivarčová, I. Turzo and V. Matoušek for help discussions. The work has been partially supported by VEGA grant No. 2/1124.

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