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Analysis of possible designs of processing units with radial plasma flows

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Analysis of possible designs of processing units with radial plasma flows

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Abstract Analysis of plasma-ion methods of obtaining thin-film coatings shows that their development goes along the path of the increasing use of sputter deposition processes, which allow one to obtain multicomponent coatings with varying percentage of particular components. One of the methods that allow one to form multicomponent coatings with virtually any composition of elementary components is the method of coating deposition using quasi-magnetron sputtering systems [1]. This requires the creation of an axial magnetic field of a defined configuration with the flux density within the range of 0.01-0.1 T [2]. In order to compare and analyze various configurations of processing unit magnetic systems, it is necessary to obtain the following dependencies: the dependency of magnetic core section on the input power to inductors, the distribution of magnetic induction within the equatorial plane in the corresponding sections, the distribution of the magnetic induction value in the area of cathode target location.

1. Introduction

The following is required from magnetic systems [3-8]:

- forming closed space configurations of a magnetic field with a desired form between pole pieces, ensuring the required flux density;
- stability of flux density in the conditions of continuous operation and effect of temperature;
- simplicity of design and manufacturability of the magnetic system;
- minimum cost of producing the required value and configuration of a magnetic field.

As a rule, a magnetic system consists of pole pieces, magnetic cores, and magnetic sources, which, as a rule, are either inductors or permanent magnets. Permanent magnets have a number of advantages over electromagnetic devices: simplicity, low cost, high reliability, absence of power supply systems. In their turn, electromagnetic devices have the capability to change the flux density value during the operation of a processing unit, thus ensuring the optimal mode of the unit's operation. For a laboratory-grade processing unit, the most acceptable magnetic system is the one based on electromagnetic devices since it possesses the possibility of varying the magnetic flux density within a broad range and can ensure the stability of the flux under continuous operation and the effect of temperature.

2. Analysis of methods of creating magnetic fields in processing units

In existing designs, pole pieces and magnetic cores, upon which inductors are fixed, are made of mild steel. It is difficult to consider all features of material during design of a magnetic field configuration because the properties of mild steel, just like those of any material, are heterogeneous. It is reasonably hard to factor in the process of mild steel aging depending on the operating conditions [9]. As a result, in order to simplify the calculation, an equivalent model of calculation is used [10].

Creating a desired value and configuration of a magnetic field in the processing chamber (PC) of a quasi-magnetic sputtering system is possible by using various designs of processing unit magnetic systems with one or several inductors. Possible design layouts of the magnetic systems are shown in Figures 1–3.

Pole pieces (4), terminal magnetic cores (1), and the radial magnetic core (5) are made of steel 3. The inductor (2) is installed on the radial magnetic core (5) gaplessly. A magnetic lens is formed between the pole pieces (4) that allows one to increase the number of ion collisions between the electron and the plasma gas atoms. The main ionization occurs within the zone that does not exceed the pole piece (4) diameter by 10% [11].

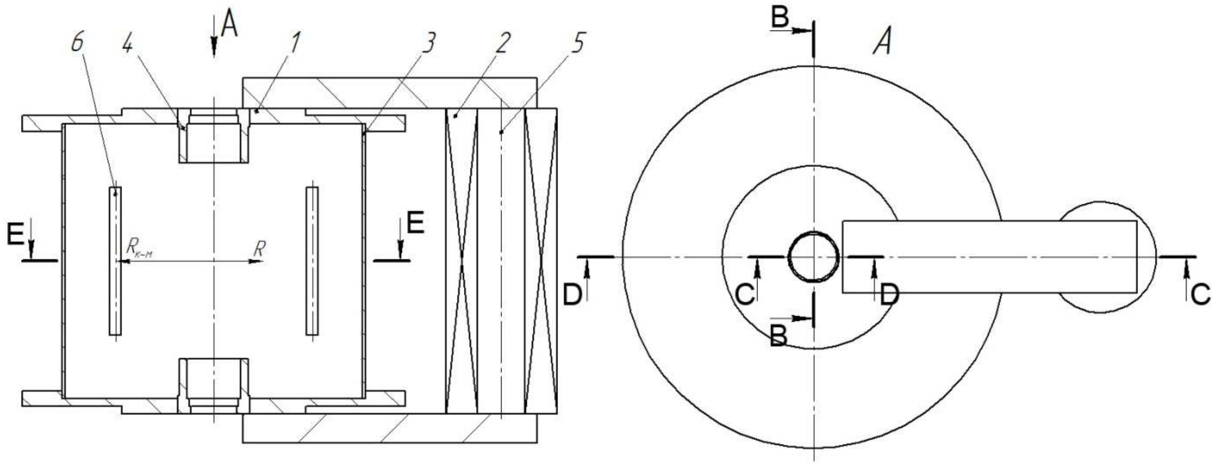


Figure 1. Design of a magnetic system with one inductor. 1 – terminal magnetic core; 2 – inductor; 3 – PC; 4 – pole piece; 5 – radial magnetic core; 6 – cathode target

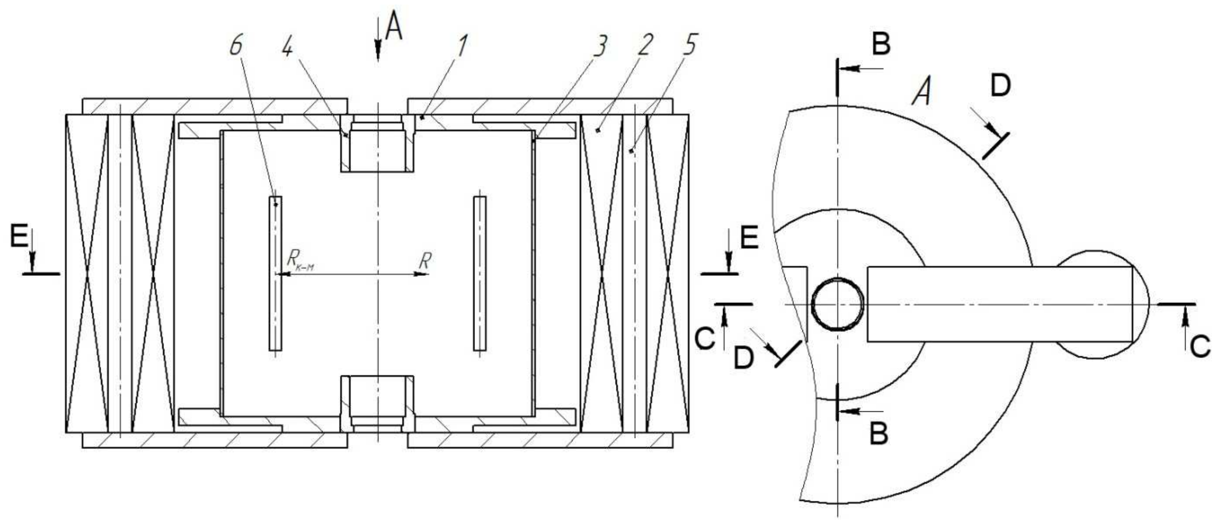


Figure 2. Design of a magnetic system with two inductors: 1 – terminal magnetic core; 2 – inductor; 3 – PC; 4 – pole piece; 5 – radial magnetic core; 6 – cathode target

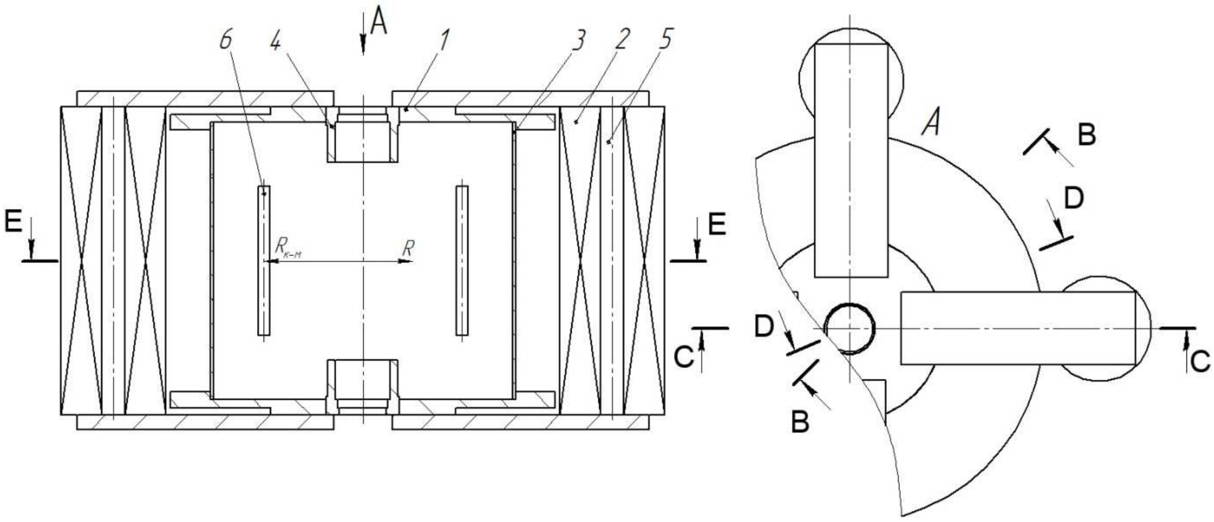


Figure 3. Design of a magnetic system with four inductors: 1 – terminal magnetic core; 2 – inductor; 3 – PC; 4 – pole piece; 5 – radial magnetic core; 6 – cathode target

3. Analysis of a processing unit magnetic system with one inductor

As a result of solving the magnetostatic problem for a magnetic system with one inductor, the magnetic field vector distribution in sections C-C and B-B was obtained, as shown in Figures 4 and 5 respectively.

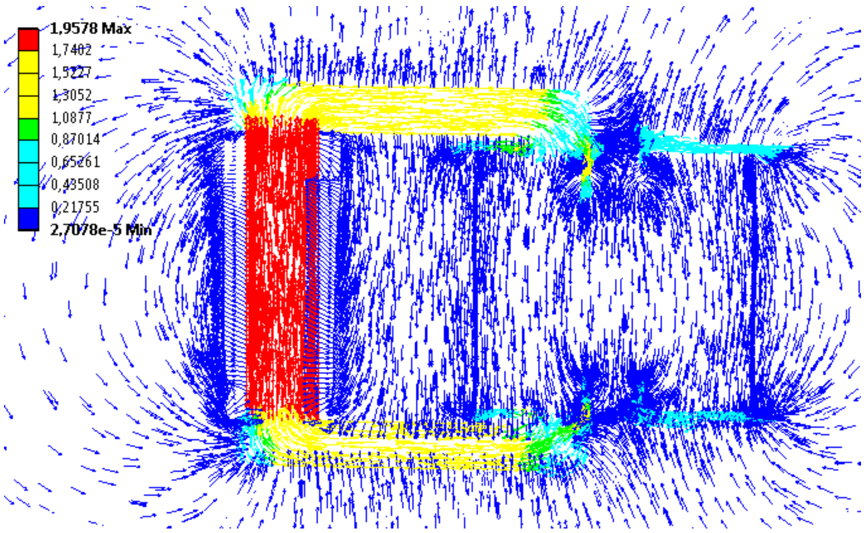


Figure 4. Magnetic field vector distribution in section C-C

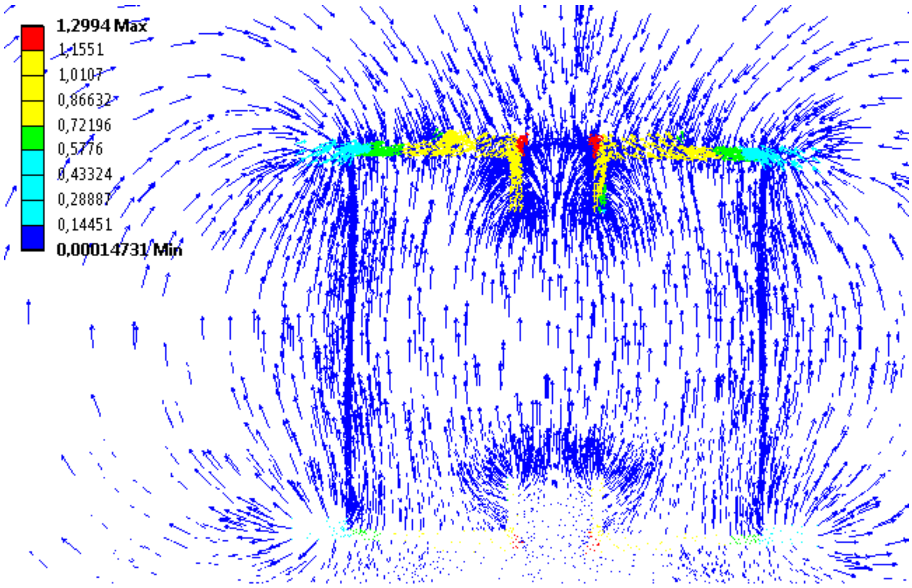


Figure 5. Magnetic field vector distribution in section B-B

Figures 4 and 5 show that a lentoid magnetic field is formed between the pole pieces that ensures the existence of a magnetic trap; and the pattern of magnetic field vector distribution in sections C-C and B-B is identical.

After analyzing Figure 4, it can be concluded that the radial magnetic core is saturated since the magnetic flux value in the radial magnetic core corresponds to the maximum of the magnetization curve of steel 3. From the previously performed series of experiments, the flux density value of around 25 mT in the processing chamber can be taken for the purpose of the analysis.

A study was carried out to select the optimal magnetic core section for the inductor input power to ensure the desired flux density value. The results of the study are presented in Figure 6.

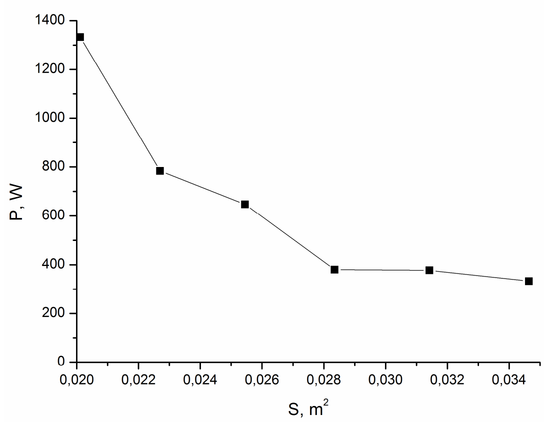


Figure 6. Dependence of magnetic core section on the inductor input power

It can be seen in Figure 6 that increasing the section to 0,028 m^2 leads to a significant decrease in the input power to the inductor. This is related to the decrease in magnetic flux leakage outside of the core, i.e. increase of magnetic permeability with the corresponding values of magnetic field strength. Further increase of the section does not lead to a significant decrease of the power put into the inductor due to the insignificant effect of the magnetic field strength on permeability.

Figure 7 shows the distribution of the flux density value for the optimal magnetic core section (0.028 m^2) in sections C-C, B-B, D-D in the equatorial plane (section E-E, Figure 1).

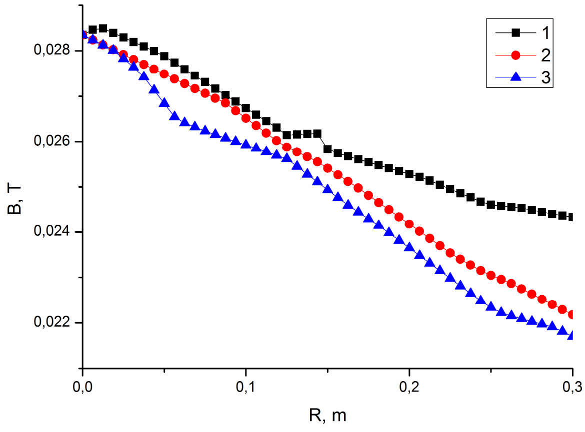


Figure 7. Distribution of the flux density value in section C-C (1), section B-B (2), and section D-D (3)

After analyzing Figure 7, it can be concluded that in the plasma generation area, the irregularity of distribution of the flux density value by sections does not exceed 5%. The irregularity of the flux density value distribution from the chamber axis to its wall does not exceed 30%.

Figure 8 shows the circumferential distribution of the flux density value in the equatorial plane in the cathode target location area ($R_{c\text{-}t}$ = 0.2 m).

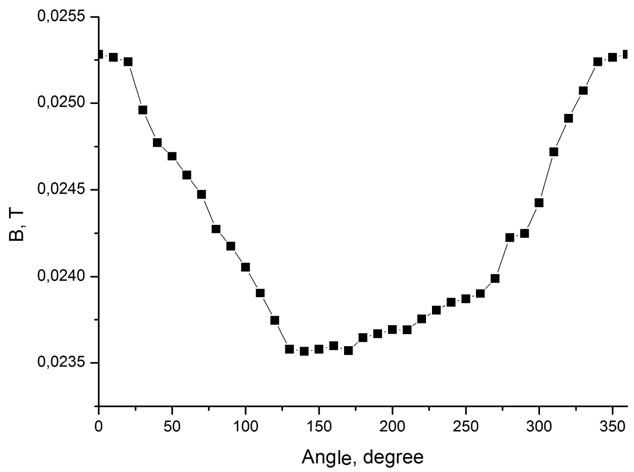


Figure 8. Distribution of the flux density value in the cathode target location area

It follows from Figure 8 that the irregularity of distribution of the flux density value in the equatorial plane in the cathode target location area comprises the value of around 7%. This can lead to uneven sputtering of cathode targets and, correspondingly, to maldistribution of components in the multicomponent coating. The sputtering pattern of cathode targets located in different locations on the substrate requires additional study.

It should also be noted that the system with one inductor has the following advantages: the possibility to install an observation window of a desired diameter, and the possibility to install an ion source.

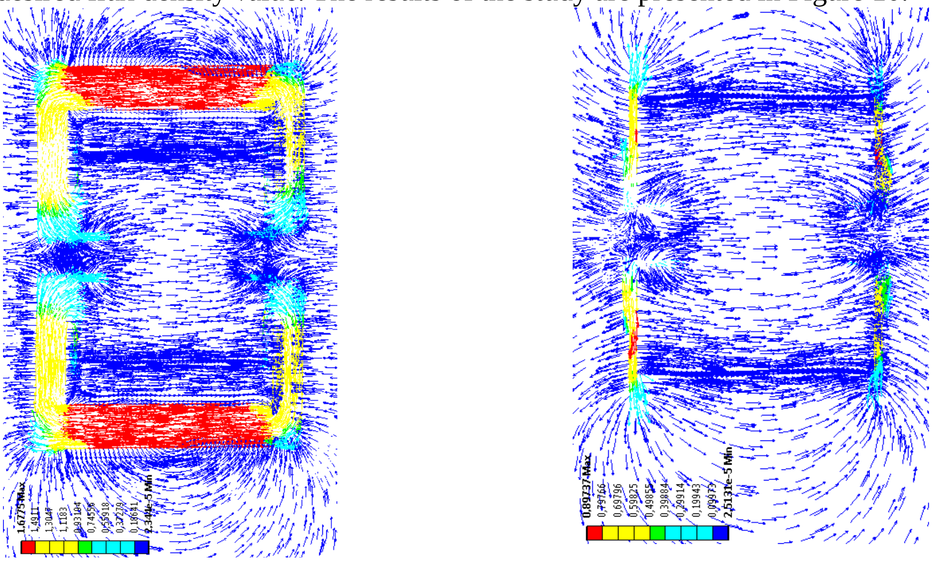
4. Analysis of a processing unit magnetic system with two inductors

A system with one inductor has a number of disadvantages: the high irregularity of distribution of the flux density value in the cathode target location area; in the plasma generation area, the irregularity of distribution of the flux density value by sections is 5%. Increasing the regularity of the flux density value distribution in the processing chamber and, correspondingly, increasing the regularity of cathode target sputtering is possible by using two or more inductors.

As a result of solving the magnetostatic problem for a magnetic system with two inductors, shown in Figure 5, the results shown in Figure 9 were obtained.

Figure 9 shows that a lentoid magnetic field is formed between the pole pieces that ensures the existence of a magnetic trap; and the pattern of magnetic field vector distribution in sections C-C and B-B is identical.

A study was carried out to select the optimal magnetic core section for the inductor input power to ensure the desired flux density value. The results of the study are presented in Figure 10.



a b

Figure 9. Magnetic field vector distribution in section C-C (a), B-B (b)

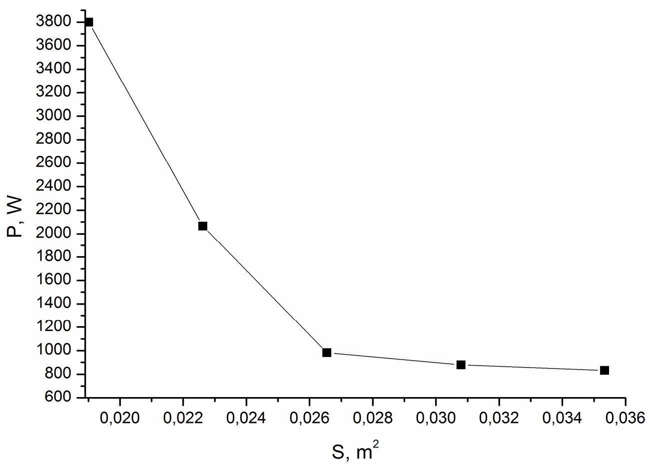


Figure 10. Dependence of magnetic core section on the inductor input power

Figure 10 shows that the optimal section is 0.027 m^2 because a further increase of the section does not lead to a significant decrease of the power put into the inductor (see point 2.2).

Figure 11 shows the distribution of the flux density value for the optimal magnetic core section (0.027 m^2) in sections C-C, B-B, D-D in the equatorial plane (section E-E, Figure 2).

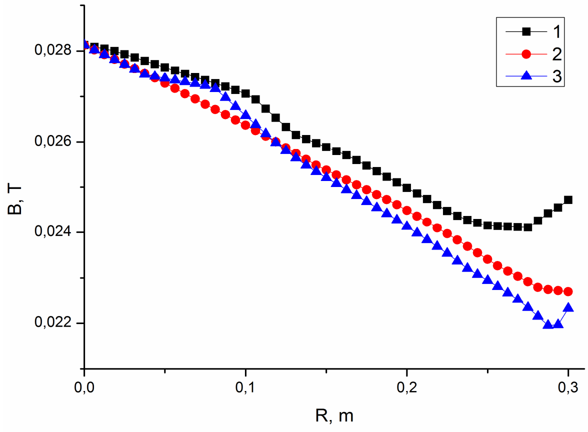


Figure 11. Distribution of the flux density value in section C-C (1), section B-B (2), and section D-D (3)

After analyzing Figure 11, it can be concluded that in the plasma generation area, the irregularity of distribution of the flux density value by sections does not exceed 3%. The irregularity of the flux density value distribution from the chamber axis to its wall does not exceed 29%.

Figure 12 shows the circumferential distribution of the flux density value in the equatorial plane in the cathode target location area (R_{c-t} = 0.2 m).

It follows from Figure 12 that the irregularity of distribution of the flux density value in the equatorial plane in the cathode target location area comprises the value of around 4%. This can lead to uneven sputtering of cathode targets and, correspondingly, to maldistribution of components in the multicomponent coating.

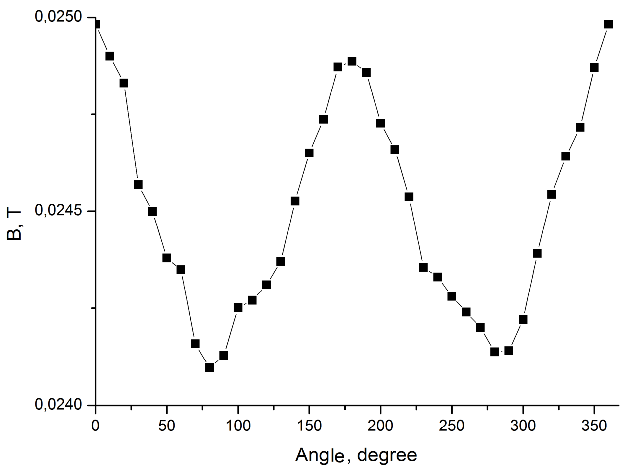


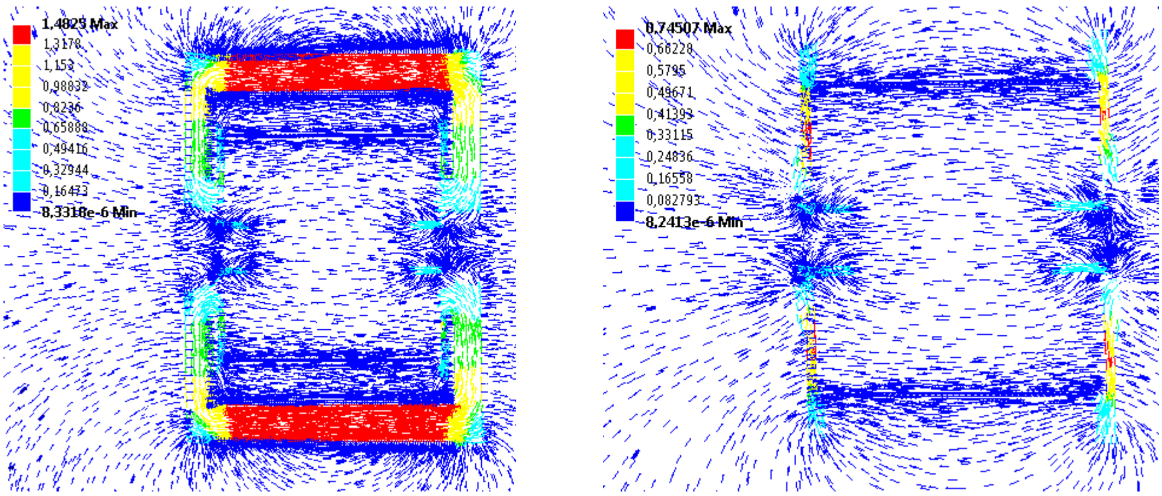
Figure 12. Circumferential distribution of the flux density value in the equatorial plane in the cathode target location area

The sputtering pattern of cathode targets located in different locations on the substrate requires additional study.

5. Analysis of a processing unit magnetic system with four inductors

Increasing the regularity of the flux density value distribution in the processing chamber of a system with two inductors and, correspondingly, increasing the regularity of cathode target sputtering is possible by increasing the number of inductors to four.

As a result of solving the magnetostatic problem for a magnetic system with four inductors, shown in Figure 6, the results shown in Figure 13 were obtained.



a b

Figure 13. Magnetic field vector distribution in section C-C (a), B-B (b)

Figure 13 shows that a lentoid magnetic field is formed between the pole pieces that ensures the existence of a magnetic trap; and the pattern of magnetic field vector distribution in sections C-C and B-B is identical.

A study was carried out to select the optimal magnetic core section for the inductor input power to ensure the desired flux density value. The results of the study are presented in Figure 14.

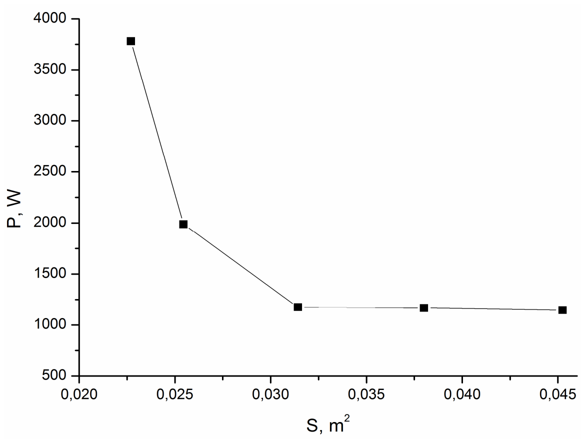


Figure 14. Dependence of magnetic core section on the inductor input power

Figure 14 shows that the optimal section is 0.031 m^2 because a further increase of the section does not lead to a significant decrease of the power put into the inductor (see point 2.2).

Figure 15 shows the distribution of the flux density value for the optimal magnetic core section (0.031 m^2) in sections C-C, B-B, D-D in the equatorial plane (section E-E, Figure 3).

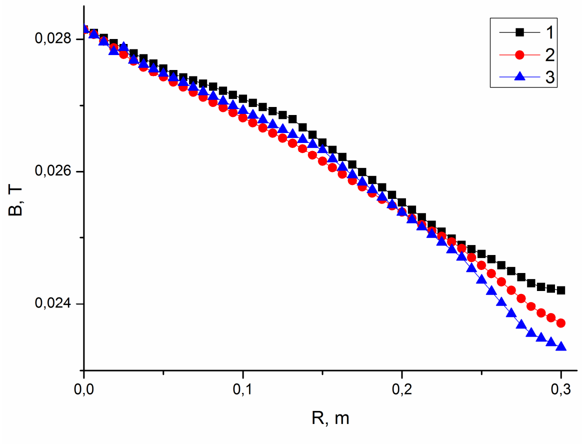


Figure 15. Distribution of the flux density value in section C-C (1), section B-B (2), and section D-D (3)

After analyzing Figure 15, it can be concluded that in the plasma generation area the irregularity of distribution of the flux density value by sections does not exceed 1.5%. The irregularity of the flux density value distribution from the chamber axis to its wall does not exceed 21%.

Figure 16 shows shows the circumferential distribution of the flux density value in the equatorial plane in the cathode target location area (R_{c-t} = 0.2 m).

It follows from Figure 16 that the irregularity of distribution of the flux density value in the equatorial plane in the cathode target location area comprises the value of around 1.2%, which is acceptable in multicomponent coating sputtering.

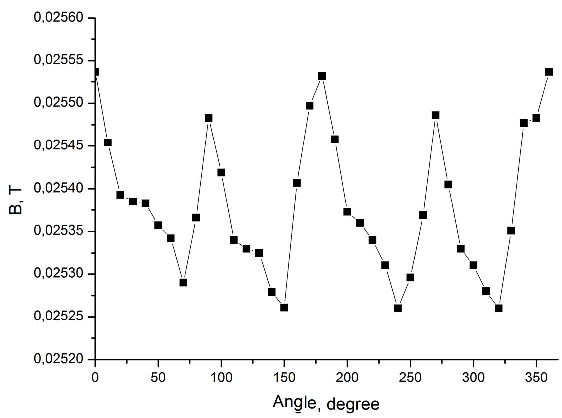


Figure 16. Circumferential distribution of the flux density value in the equatorial plane in the cathode target location area

The results stated above indicate that it is necessary to carry out additional research of the sputtering patterns of cathode targets located in different areas of the substrate.

6. Comparative analysis of methods of creating magnetic fields

By analyzing the methods of creating magnetic fields considered above, it can be concluded that a magnetic system with four inductors allows one to achieve the irregularity of sputtering cathode targets below 1.2%.

When designing magnetic systems, it is necessary to pay attention to the power put into the inductors. Let us consider Figure 17.

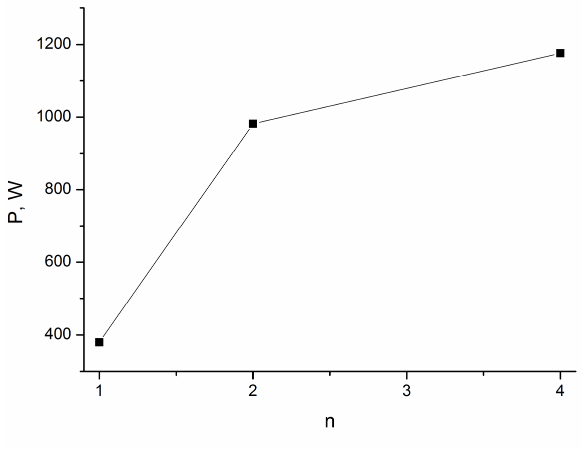


Figure 17. Dependence of inductor input power on the number of inductors

Increasing the number of inductors causes an increase in the power put into them, which leads to increased energy costs. Study of Figure 17 reveals that this chart lacks the optimum, which leaves us without a consensus between the number of inductors and energy costs, as well as between the material intensity and design specifications (Table 1).

Table 1. Research results

n	S, m^2	P, W	Flux density value distribution irregularity		
			in the cathode target location area	in the plasma generation area	from PC axis to PC wall
1	0.028	380	7 %	5 %	30 %
2	0.027	980	4 %	3 %	29 %
4	0.031	1170	1.2 %	1.5 %	21 %

Analyzing the optimal number of inductors requires further research, which is expected in future.

7. Conclusions

Review of available research allowed one to identify the general standards applied to magnetic systems of processing units with radial plasma flows. According to these requirements, an analysis of such magnetic systems was carried out. At the given stage of the research, it is hard to assert that a system with four inductors is the most efficient one, which is why it is necessary to carry out further study of the optimal number of inductors relative to input power, material intensity, power costs, and design specifications.

Irregularity of cathode target sputtering will be analyzed in further work.

8. Acknowledgments

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