OPTIMIZATION OF THE COLLECTING MIRROR LOCATION IN THE PLASMA SOURCE OF EXTREME ULTRAVIOLET RADIATION

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The paper is devoted to searching the optimal location of first collecting mirror in the extreme ultraviolet radiation plasma sources. It is shown that the system efficiency can be increased by 1.5…2.5 times in the case of elliptical plasma radiation pattern and the optimal location of the first collecting mirror. In this case the first collecting mirror should cover the plasma on lateral side.

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INTRODUCTION

One of the important problems in the field of the nano-electronic production is increasing the radiation power of extreme ultraviolet plasma source for scanner-steppers. However the low conversion efficiency of the input energy into the radiation energy and the impossibility to collect all the plasma radiation by the first collecting mirror lead to that a power consumption of modern sources is hundreds kilowatts. This makes actual to search the additional ways to increase the efficiency of such systems. The problem can be solved by increasing the radiation power collected by the first mirror without increasing the input power into the discharge. Using the plasma source with directional radiation [1], it is possible to collect more plasma radiation in the same solid angle.

1. CALCULATION PART

To optimize the shape and location of the first collecting mirror in the case of the directional radiation one has identify the areas where the main part of the radiation stands out. If the mirror is set relative to the radiation source (RS) as shown in Fig.1, then the angle $\gamma_{1/2}$ can be calculated, that corresponds to a half radiation collected by the first mirror. Angle $\gamma_{1/2}$ is a convenient value for the expert evaluation of the various options of sizes and location of the first mirror, depending on the direction radiation. In this paper the angular distribution of the radiation flux, depending on the coefficient of radiation direction $\alpha = j_{\|} / j_{\perp}$ of the point plasma source is investigated. Here $j_{\|}$ is radiation flux density in the longitudinal direction and $j_{\perp}$ – in the transverse one.

The elliptical radiation pattern (RP) is adopted in the calculations. The radiation flux $dI(\varphi)$ into the angle φ in the ring surface element dS (Fig. 2) is determined by the expression

$$dI(\varphi) = 2\pi R_0^2 j_{//0} \frac{\sin\varphi \cdot d\varphi}{\sqrt{\cos^2\varphi \cdot \left(1-\alpha^2\right)+\alpha^2}},$$

here R_0 is the distance from the radiation source to the

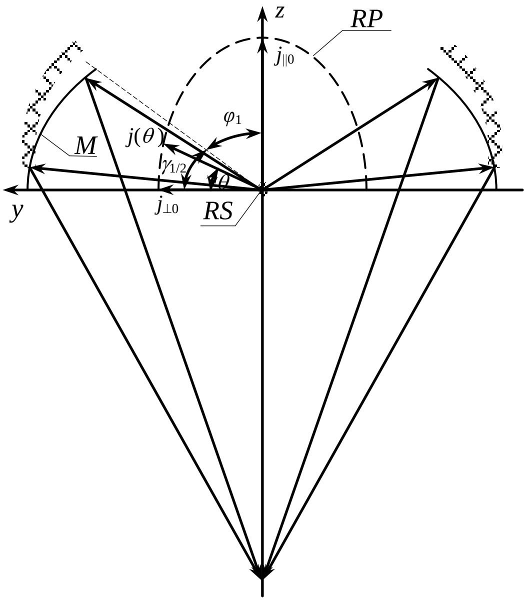

Fig. 1. Location of the collecting mirror (M) relative to the radiation source with an elliptical radiation pattern

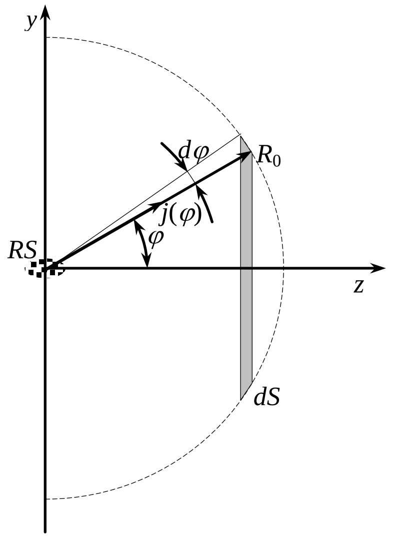

Fig. 2. Radiation intensity in the annular surface element: RS – the radiation source; dS – the annular surface element

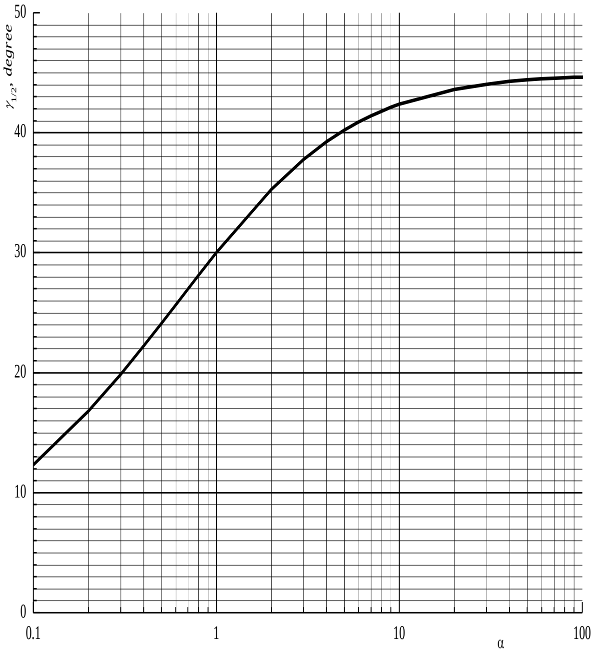

Fig. 3. The angle $\gamma_{1/2}$ versus the coefficient of radiation direction α

detector RS, $j_{||0}$ is radiation flux density in the longitudinal direction

2. RESULTS OF CALCULATIONS

On the Fig. 3, the dependence of the angle $\gamma_{1/2}$ on the directivity α is shown. The plot shows that in the case of the transverse radiation orientation ($\alpha < 1$), an angle $\gamma_{1/2} < 30°$ is sufficient to collect half of the radiated power. It is also shown that the picture is almost the same even in the case of a very strong longitudinal radiation direction ($\alpha \sim 100$): the main part of the radiation is emitted in the transverse direction. The latter is explained as follows. Despite the huge longitudinal radiation intensity, the solid angle of the collection is a very, very small. As a result the low intensity radiation emitted into the large solid angle provides the collection of the more intense radiation.

The following important conclusion can be done from these relatively simple arguments. If due to the design features, it is impossible to collect all the radiation and to increase the output power collected by the first mirror, then the mirror should cover the plasma from the lateral side (as it is shown in the Fig. 1). This is a particularly relevant issue in the presence of transverse radiation patterns.

The scheme of the nanolithograph SoCoMo [2] produced by a group XTREME technologies is analyzed in which a frontal arrangement of the first collecting mirror is applied. A considerable gain in output radiation power can be obtained in the case of a lateral arrangement of the first collecting mirror with the same surface but at the transverse direction of the radiation which can be achieved by a slight change in the design of a plasma source. It is appropriate to assess the correctness of the approach to the choice of the collecting mirror location used by the designers of the system SoCoMo (see Fig. 3). In the latest version of the nanolithograph, the solid angle of radiation collection is 3.24 str and the radiation is collected in a longitudinal direction. This scheme is quite acceptable one in the case of an isotropic radiation. But if one uses a source with the transverse direction of the radiation, then this system is completely unsuitable one. This can be seen from the comparison of the two cases: the first case - the one that is used in the system SoCoMo, the second case - a mirror of the same area but located as shown in Fig. 1.

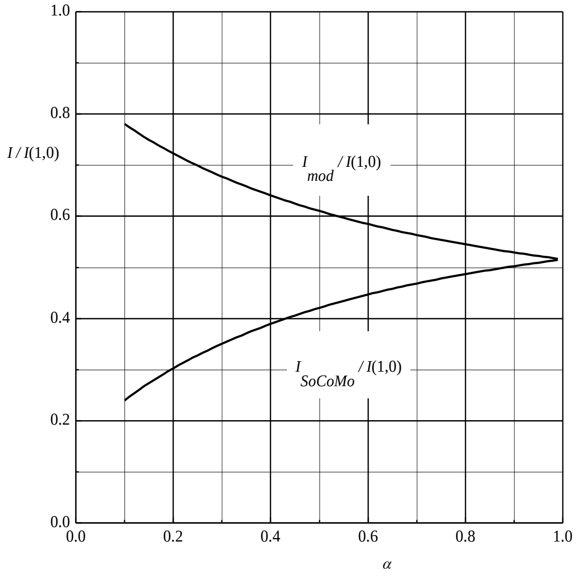

Fig. 4. Dependences of collected flows on the radiation coefficient α for SoCoMo system and the modified system

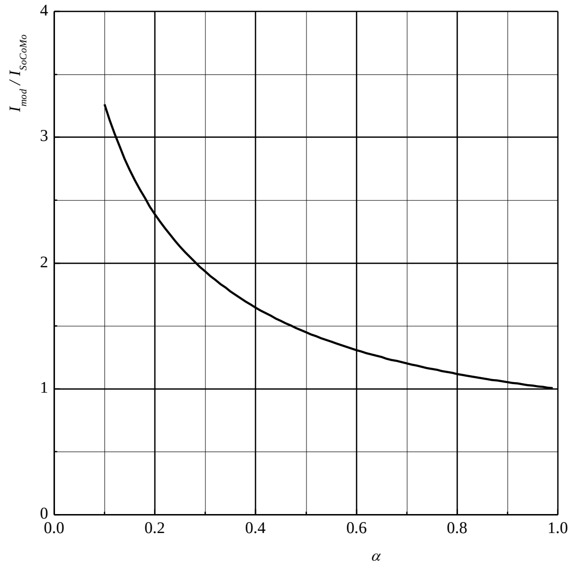

Fig. 5. Dependence of efficiency ratio of modified system to system SoCoMo on the coefficient of radiation direction

Fig. 4 shows the dependences of collected flows on the directional radiation coefficient α for SoCoMo system and for the modified system with a cross-collecting radiation. It is clear that in the case of transverse direction of the radiation the first mirror location at the side of discharge axis is more advantageous one as compared to the frontal arrangement. Thus, more radiation flux can be focused in the case of a lateral mirror arrangement for the same surface area and the same input power.

The ratio of the system efficiency with lateral radiation collection to the system SoCoMo is shown in the Fig. 5. The efficiency of collection from lateral side is 45% higher even for a slight transverse radiation direction $\alpha \sim 0.5$. This is a good result providing that the input power of SoCoMo system can reach up to 500 kW. And the transverse direction coefficient of radiation observed in the experiments [1] was up to $\alpha \sim 0.2$!

CONCLUSIONS

Theoretical calculations show that the required power output can be achieved in nanolithography based on plasma radiation source not only by increasing the input energy but also by improving the radiation collection. In the case of an elliptic radiation pattern (i.e., if the radiation is anisotropic one) optimizing the location of the first mirror provides the 1.5…2.5 times more radiation that can be collected in the same solid angle at the same input electrical energy.

It is shown that if due to the design features of the plasma radiation source it is impossible to use the elliptical mirror, then the increase of the output power can be reached by lateral arrangement of the first collecting mirror. The more radiation flux can be focused for the lateral location of the mirror with the same area and for the same power inputted into the discharge.

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ОПТИМИЗАЦИЯ ПОЛОЖЕНИЯ СОБИРАЮЩЕГО ЗЕРКАЛА В ПЛАЗМЕННЫХ ИСТОЧНИКАХ ВАКУУМНОГО УЛЬТРАФИОЛЕТА

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Работа посвящена поиску оптимального расположения первого собирающего зеркала в плазменных источниках экстремально ультрафиолетового излучения. Показано, что в случае эллиптической диаграммы направленности излучения плазмы и оптимального расположения первого собирающего зеркала можно в 1,5…2,5 раза повысить эффективность системы. В этом случае первое собирающее зеркало должно охватывать боковую поверхность плазмы.

ОПТИМІЗАЦІЯ ПОЛОЖЕННЯ ЗБИРАЮЧОГО ДЗЕРКАЛА В ПЛАЗМОВИХ ДЖЕРЕЛАХ ВАКУУМНОГО УЛЬТРАФІОЛЕТУ

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Роботу присвячено пошуку оптимального розташування першого збираючого дзеркала в плазмових джерелах екстремально ультрафіолетового випромінювання. Показано, що в разі еліптичної діаграми спрямованості випромінювання плазми та оптимального розташування першого збирального дзеркала можна в 1,5…2,5 рази підвищити ефективність системи. У цьому випадку перше збиральне дзеркало має охоплювати бокову поверхню плазми.