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Study of Extraction Property of RF Ion Source*

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Abstract Effects of geometry parameters of extraction electrode, extraction voltage and oscillator power on the extraction property of RF ion source are measured and the experimental results are analyzed. It turns out that the RF ion source has a good extraction property. There is the best D/d on condition that other parameters don't change. The D/d rising is beneficial to the ion beam focusing from over focusing. Focusing degree increases and extraction beam intensity drops with b/D increasing. Focusing degree rises with B/d decreasing and the rising tendency slows down when B/d is smaller than 4. The suitable ranges of D/d, b/D and B/d are respectively 1.6—2.1, 0.7—1.1 and 4—7 when considering comprehensively the focusing degree, the extraction beam intensity and the pressure. Change of extraction voltage and oscillator power has opposite effect on the ion source performance and they have respectively best operation values.

Key words ion source, ion beam, focusing degree

1 Introduction

Ion source is a crucial part of electrostatic accelerator[1, 2]. Its property affects directly the performance of electrostatic accelerator. So the working state of RF ion source used was studied in the process of developing electrostatic accelerator. The former article studied the factors influencing the RF ion source discharging and the effects of plate voltage of oscillator, gas pressure and extraction voltage on the intensity and the proton ratio of ion beam[3]. The work ensures that the property of ion beam can satisfy the requirements of electrostatic accelerator. But the article didn't consider whether the extraction state of RF ion source was the best. The extraction property of RF ion source wasn't touched on. Ion source in the best working state has not only a strong intensity and a high proton ratio but also a fine focusing degree. If the extraction property of ion source is bad, the efficiency of extracting ions is low and extraction electrode is quickly damaged for ion bombardment. Electrostatic accelerator can't be ensured to work steadily. So the factors influencing the extraction property of RF ion source are studied in this article so that the technological parameters of RF ion source can be selected rationally to make RF ion source work in the best state.

The physical quantities expressing the extraction property of ion source are focusing degree α and extraction beam intensity $I_{\mathrm{M}} \cdot \alpha$ is defined to be the ratio of the current intensity I_{M} of the ions going through extraction electrode to the current intensity I_{K} of the ions striking extraction electrode. I_{M} and α are related to the geometry parameters of extraction electrode, extraction voltage, pressure and oscillator power[2, 4]. The extraction voltage, the pressure and the oscillator power can be adjusted when ion source works, but the geometry parameters of extraction electrode cannot be changed generally after ion source is designed and machined. So it is obvious

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that the geometry parameters of extraction electrode affect I_M and α most greatly. Moreover, the geometry parameters of extraction electrode influence the pressure and the extraction voltage to some extent.

In studying the geometry parameters of extraction electrode, most engaged in computing and simulating by theories of ion optics and plasma[5—8]. This article studies the effects of the geometry parameters of extraction electrode, extraction voltage and oscillator power on focusing degree α and extraction beam intensity I_M by experiment to provide direct data for designing extraction electrode of RF ion source.

2 Experiment

The extraction electrodes used in experiments (Fig. 1) are made of aluminum. Their inner diameters are respectively 1mm, 1.5mm and 2mm. Experiments are carried out on the table experimental system[3]. Faraday box 1 is far from focusing electrode in the system, so I_M can't be measured accurately for ions scattering and annihilating when focusing voltage doesn't exist. However, it isn't convenient to measure I_K if focusing voltage exists. So another moveable Faraday box is installed at the base of focusing electrode to be able to measure precisely I_M without focusing voltage.

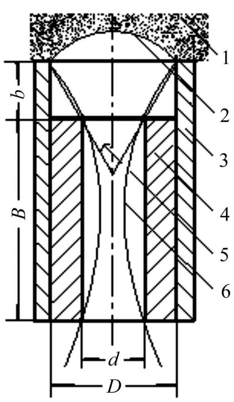

Fig. 1. Geometry parameters of extraction electrode.
1–plasma; 2–emitting surface; 3–quartz pipe; 4–extraction electrode; 5–assembling angle θ; 6–waist.

Firstly, effects of D/d, B/d, plate voltage V_a of oscillator (oscillator power is determined by its plate voltage) and extraction voltage V_b on α are measured with the extraction electrode of inner diameter 1.5mm. Fig. 2 shows that D/d and b/D greatly influence α so that α has the greatest value with D/d rising, ion beam begins to focus when b is equal to $0.5D$ and that α quickly rises with b/D increasing. At the same time, it is observed in experiments that I_M promptly decreases and the best extraction voltage rises when b/D increases. Fig. 3 indicates that α rises in a line with B/d decreasing and that the tendency of α rising slows down when B/d is smaller than 4. This is consistent with the experimental results of Сербинов . Fig. 4 and Fig. 5 make clear that there are the best extraction voltage and the best plate voltage for α. The best extraction voltage increases and the best plate voltage decreases with D/d rising. It is found that pressure has similar property to oscillator plate voltage.

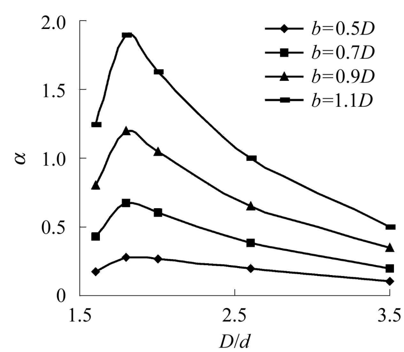

Fig. 2. Effect of D/d on focusing degree α ($B = 5d$, V_a=600V, V_b=1.8kV, $P = 6\times10^{-4}$Pa).

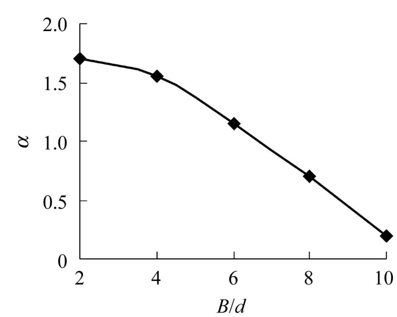

Fig. 3. Effect of B/d on focusing degree α ($D = 1.8d$, $b = 0.9D$, V_a=600V, V_b=1.8kV, $P=6\times10^{-4}$Pa).

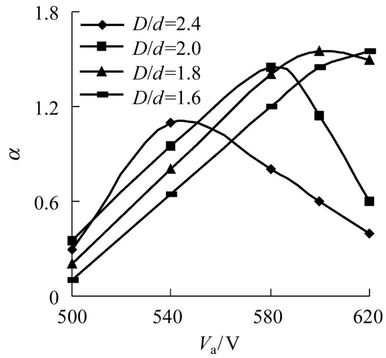

Fig. 4. Effect of oscillator voltage V_a on focusing degree α ($b = 0.9D$, $B = 5d$, V_b=1.8kV, $P = 6\times10^{-4}$Pa).

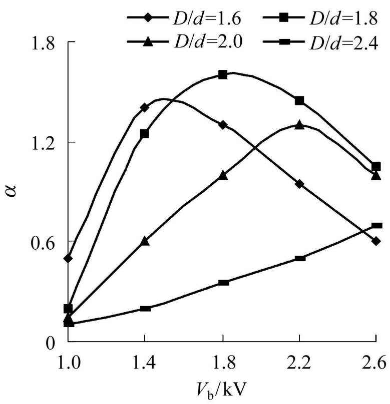

Fig. 5. Effect of extraction voltage V_b on focusing degree α ($b=0.9D$, $B=5d$, V_a=600V, $P=6\times10^{-4}$Pa).

Secondly, the effects of the inner diameter of extraction electrode on α and I_M are measured with extraction electrodes of different inner diameters by adjusting other parameters to the best values. Table 1 shows that α doesn't basically change with d and that I_M roughly increases in proportion to the square of d.

Table 1. Effects of inner diameter d of extraction electrode on extraction voltage I_M and focusing degree α ($D=1.8d$, $b=0.9D$, $B=5d$, V_a=600V, V_b=1.8kV, $P=6\times10^{-4}$Pa).

	d/mm		
	1	1.5	2
I_M/μA	55	132	229
α	1.47	1.62	1.54

3 Analysis

In the action of electric potential, the edge of the plasma in ion source presents concave shape and forms emitting surface (Fig. 1). The extraction efficiency of ion source is related with the shape of emitting surface. The curved electric field makes ions assemble before they enter extraction electrode. Assembling angle is θ. The appearance of ion beam is approximately like a taper. Because the entrance of extraction electrode and space charges disperse ions, ion beam has a waist in extraction electrode. The distance between the waist and the upper end of extraction electrode is determined by the geometry parameters of extraction electrode. The best emitting surface should make the waist be in the middle of extraction electrode to make ion beam just shave the edges of the entrance and the exit of extraction electrode (Fig. 6(b)). In this case, those are evident that the ions striking the extraction electrode are the least, the focusing degree is the largest and the extraction efficiency is the highest. D/d is the best in this case. Adding b can reduce the probability that ions strike the upper surface of extraction electrode so that the focusing degree rises. But it simultaneously makes the electric field between the emitting surface and the extraction electrode decrease so that the extraction force of extraction electrode reduces. Therefore, extraction beam weakens obviously. When the parameters except B don't change, the distance between the waist and the upper end of extraction electrode doesn't change. Reducing B is equal to only reducing the distance between the waist and the lower end of extraction electrode so that the probability that ions strike the lower part of extraction electrode becomes small. So α rises in line with B/d reducing. But when B/d decreases, the gas resistance becomes small and the pressure in discharging bottle reduces so that ion density decreases. This can make the curvature radius of emitting surface become small and ion beam over focus. So the tendency of α rising slows down when B/d is smaller than some value.

In the case that the geometry proportions of extraction electrode don't change, the shape of emitting surface and the relative position of waist in extraction electrode don't change too. I_M and I_K simultaneously increase or decrease with d rising or reducing, so the focusing degree doesn't change with d. Adding d is equal to adding the area which ion beam goes through, so I_M increases in proportion to d square.

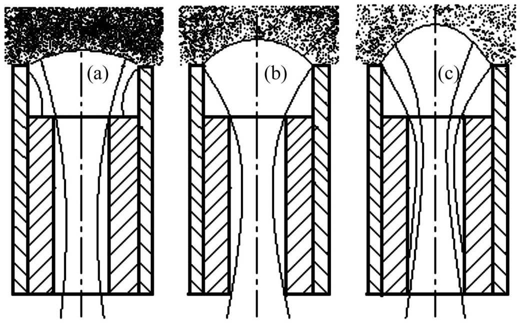

Fig. 6. Three focusing states of ion beam.
(a) weak focusing; (b) the best focusing;
(c) over focusing.

When ion beam is in the best focusing state, adding of oscillator power or pressure can make the ion density in discharging bottle rise, the curvature radius of emitting surface large, waist move down (Fig. 6(a)), ion beam weakly focus and ions striking the upper part of extraction electrode increase. On the contrary, reducing of oscillator power or pressure can make ion beam over focus. Extraction voltage is opposite to oscillator power. In the best state, continuous adding of extraction voltage can make the curvature radius of emitting surface small and ion beam over focus. On the contrary, it can make ion beam weakly focus. So there are the best oscillator power and the best extraction voltage. Those can be seen from experimental results that adding D/d is beneficial to ion beam focusing from over focusing and that reducing D/d is beneficial to ion beam focusing from weakly focusing.

The total electric current emitting from emitting surface can be gotten according to the emitting formula of concentric spherical extraction electrode

$$I_b = \frac{2}{9}\left(\frac{2e}{m_p}\right)^{\frac{1}{2}} V_b^{\frac{3}{2}} \frac{1-\cos\theta}{(-\beta)^2}.$$

In the formula, θ is the assembling angle of emitting surface (Fig. 1). β is the function of r/r_0. r_0 is curvature radius of emitting surface , and r is the distance between the curvature center of emitting surface and the upper end of extraction electrode. m_p is the mass of ion. The formula shows that the total electric current emitting from emitting surface is in proportion to three-second square of extraction voltage. In low extraction voltage, focusing degree and total beam intensity increase with extraction voltage rising, so extraction beam intensity increases evidently. In high extraction voltage, focusing degree decreases with extraction voltage rising though total beam intensity still increases in proportion to three-second square of extraction voltage, so the tendency of extraction beam intensity increasing slows down. This has been proved in the experiments. Thus, raising extraction beam intensity by adding extraction voltage when the tendency of extraction beam intensity increasing already slows down isn't beneficial to ion source. That can distinctly reduce the lifetime of extraction electrode.

4 Conclusion

Geometry parameters of extraction electrode, extraction voltage, oscillator power and pressure are the factors affecting the extraction property of an ion source. They influence one another. Change of geometry parameters influences not only the focusing ability of extraction electrode but also the pressure in discharging bottle and the distribution of extraction voltage. There is the best D/d on condition that other parameters don't change. D/d rising is beneficial to ion beam focusing from over focusing. Focusing degree increases and extraction beam intensity drops with b/D increasing. Focusing degree rises with B/d decreasing and the rising tendency slows down when B/d is smaller than 4. The suitable ranges of D/d, b/D and B/d are respectively 1.6—2.1, 0.7—1.1 and 4—7 when considering comprehensively the focusing degree, the extraction beam intensity and the pressure. Change of extraction voltage and oscillator power has opposite effect on the ion source performance and they have respectively best operation values.

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RF离子源引出特性的研究*

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摘要 为了使RF离子源具有良好的引出特性, 测试了吸极几何参数、振荡器板压、引出电压对离子源引出特性的影响, 对实验结果进行了分析. 在其他参数不变的情况下, 存在最佳的D/d; 增加D/d, 有利于过聚焦的离子束恢复聚焦状态. b/D增大时, 聚焦度上升, 引出束流下降. B/d减小时, 聚焦度增大; 当B/d小于4时, 聚焦度增加趋势变缓. 综合考虑聚焦度、引出束流和气压, D/d, b/D, B/d适宜的选择范围分别为1.6—2.1, 0.7—1.1, 4—7. 改变引出电压和振荡器功率对离子源性能的影响具有相反的方向, 两者都存在最佳工作点.

关键词 离子源 离子束 聚焦度

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