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基于 M 型电极的离子引出过程二维粒子模拟研究

摘要

改进电极结构是提高原子蒸气激光同位素分离离子引出效率的有效手段。本研究基于一维平行板电极离子引出过程解析模型，采用二维粒子模拟软件（EDIPIC-2D），对 M 型电极结构下的离子引出过程进行了理论分析和数值模拟。在此基础上，研究了不同引出区结构参数对离子引出特性的影响规律。

一方面，在 M 型电极结构下，数值模拟结果观察到了电子振荡、朗缪尔鞘层的形成与扩张、离子稀疏波的传播等过程。但与一维平行板电极不同的是，M 型电极下的离子稀疏波会在两个方向上产生并传播，二者共同对等离子体主体区的离子密度产生影响。另一方面，在保持其他参数不变的条件下，当阳极插入深度和宽度足够大时，等离子体主体区及附近区域的电势会达到与阳极相近的水平，该区域被称为虚拟阳极；阳极插入深度和宽度的增大均会导致等离子体主体区电势的上升和引出时间的缩短；等离子体边界和阴极间距离对引出时间没有明显的影响。

上述研究工作对于实际应用中离子引出装置结构参数的选择具有一定的理论指导意义。

关键词

原子蒸气激光同位素分离（AVLIS）；离子引出；M 型电极；粒子模拟（PIC）；朗缪尔鞘层

Abstract

Improving the electrode configuration has been proved to be effective to improve the ion extraction efficiency of atomic vapor laser isotope separation.

In this study, based on the analytical model of the ion extraction process of the one-dimensional parallel plate electrode, the theoretical analysis and numerical simulation of the ion extraction process under the M-type electrode structure were carried out by using the two-dimensional particle simulation software (EDIPIC-2D).

On the one hand, the particle-in-cell (PIC) modeling results show that, for the M-type electrode configuration, the physical processes such as electron oscillations, Langmuir sheath formation and expansion, and ion rarefaction wave (IRW) propagation can be observed during the ion extraction process. However, different from the 1-D ion extraction process, the IRW propagation occurs in both directions within the M-type electrode, both of which affect the ion density distributions.

On the other hand, if the insertion depth or width of the anode is large enough, the potential of the main plasma region will reach the level of the anode, forming a virtual anode. And with other parameters being unchanged, increasing in the insertion depth and width of the anode can effectively improve the potential of the main plasma region and shorten the ion extraction time; the insertion depth of the anode has a more significant influence on the ion extraction features, and simultaneously, the potential value of the anode also limits that of the main plasma region. In addition, the gap spacing between the plasma and cathode surface has no significant impacts on the overall extraction time.

The above research work has a certain theoretical guiding significance for the selection of structural parameters of ion extraction devices in practical applications.

Keywords

Atomic vapor laser isotope separation (AVLIS); Ion extraction; M-type electrode configuration; Particle simulation (PIC); Langmuir sheath

Authors: 张, 梦龙 (清华大学工程物理系); 鲁, 晟 (清华大学工程物理系); Dr 汪, 耀庭 (清华大学工程物理系); 孙, 鑫礼 (清华大学工程物理系); 罗, 岚月 (清华大学工程物理系); 李, 和平 (清华大学工程物理系); 姜, 东君 (清华大学工程物理系); 周, 明胜 (清华大学工程物理系)

Presenter: 张, 梦龙 (清华大学工程物理系)

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