J. At. Mol. Sci.
doi: 10.4208/jams.012513.042013a

Vol. **5** , No. 1, pp. 26-33
February 2014

Geometric optimization of hybrid ion trap

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Received 25 January 2013; Accepted (in revised version) 20 April 2013
Published Online 18 November 2013

Abstract. In this study we determined the effect of geometry of ring electrode on the operation of a new ion trap with cylindrical ring electrode and hyperbolical end cap electrode. This model indicated how adjusting the geometric cell parameters could reduce the impact of presence of higher order fields. Our work also illustrated the possibility of improving other desired properties of a trap. For example we found how these adjustments could minimize the non-linear effects. We also noticed the possibility of increasing the time of ion storage in a trap by the effect of one field in a hybrid ion trap. In this study we have obtained all of the equations of motion in a trap analytically.

PACS: 37.10.Ty, 07.75.th

Key words: hybrid ion trap, quadrupole, equation of motion, coefficients of field, geometric parameters

1 Introduction

An ion trap is a device which confines ions in a particular area of a space. Hybrid ion trap is a combination of two ion traps, quadruple and cylindrical traps which both of them are well known traps and also have numerous uses. In this study, we grounded the end cap electrode and connected the ring electrode to the v_0 potential as common for the standard hyperbolic trap. And then in similar theoretical case, we have calculated the equations of motion for a single ion too [1].

$$v_0 = v_{dc} + v_{rf} \cos\Omega t \tag{1}$$

Ions follow the different trajectories under the influence of the applied field. If ions oscillate on the x-y plane with limited amplitude, they will be revealed at end. Otherwise

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the amplitude of motion increases exponentially and thus ions will be destroyed due to the collision with electrodes. We will study these conditions in our work. On the other hand deviation of hyperbolic geometry leads to nonlinear effects that we will also discuss it later. We have replaced the standard hyperbolic ring electrode with a cylindrical ring electrode in this study and also we have calculated the motion equations for a single trapped ion as mentioned earlier.

2 Calculation of the electric field and potential inside the trap

The following equations govern in the Hybrid ion trap:

$$\begin{cases} \frac{z^2}{z_0^2}-\frac{r^2}{r_0^2}=1 \\ r=r_1 \end{cases} \tag{2}$$

Where r is radial displacement and z is axial displacement. r_1 is inner radius of the ring electrode and z_0 is vertex of the end cap electrode. Also θ is the asymptotic angle.

In the Eq. (1) V_{dc} is direct current component of the applied potential, V_{rf} is amplitude of the oscillating component of the applied potential, the parameter Ω is frequency of the oscillating potential and t is time. We assumed that electrodes have been extended to infinity. Also the trap is free from any background ion gas.

$$\nabla^2\phi=0 \tag{3}$$

The separating method of variables and riddance from azimuthal dependency leads to following equation:

$$\phi(r,z)=\phi(r)\phi(z) \tag{4}$$

Boundary conditions says that potential of trap is v_0 where $r=r1$ and potential is Zero where points belong to hyperbolic electrode. The separating technique of variables leads to the following equation eventually:

$$\phi(r,z)=\sum_{n=0}^{\infty}A_n I_0(p_n r)\cos(p_n z) \tag{5}$$

Where I_0 is modified Bessel function in the zero order which is also a first kind function. The potential value is being obtained by applying the Boundary conditions:

$$\phi(r,z)=4v_0\sum_{n=0}^{\infty}\frac{(-1)^n}{(2n+1)}\frac{I_0(p_n r)}{I_0(p_n r_1)}\cos(p_n\frac{z}{\rho}) \tag{6}$$

$$\rho=\sqrt{1+\frac{r^2}{z_0^2 tg^2\theta}} \tag{7}$$