Simulation of Microfabricated Linear Ion Trap

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Abstract

1. Introduction

Recent studies have shown a great potential of application of trapped ions in quantum information processing [1]. Due to the stability of ion oscillation frequencies, ion traps also play a fundamental role in optical frequency standards [2]. In turn, new fabrication methods enable the realization of compact integrated ion traps, which can simultaneously operate with multiple ions. Consequently, in order to effectively use a large number of trapped ions, new scalable and feasible designs are required.

In this work, we present a model that simulates the operation of the linear microscale integrated ion trap. We study trapping conditions and stability of a single Sr+ ion. The confinement in all three dimensions is provided by the application of the specific AC and DC voltages to the corresponding trap electrodes. The AC voltage confines the ion in radial direction of the trap while the DC voltage provides the trapping in axial direction. Together they form a potential well that prevents the ion from leaving the trap and at the same time makes it oscillate in all three dimensions.

2. Use of COMSOL Multiphysics®

The 3D geometry of the simulated trap employs a set of metalized electrodes, which are formed on top of an insulator layer on silicon substrate (cross section is shown in Figure 1). The general concept of trap geometry is close to the one described in [3], however, it was simplified and reduced to the model containing only the electrodes and the surrounding vacuum areas.

The operation of the ion trap was simulated as follows. The distribution of the trapping potential was calculated utilizing the Electrostatic interface (DC) and the Electric Currents interface (AC) with the corresponding applied voltages. The obtained field distributions were used for the simulation of ion trajectory in the Charged Particle Tracing interface.

3. Results

The determined ion trajectories provided the data for the calculation of the frequency spectra of ion oscillations along each principal axis. The analytical description of these frequencies [4] indicates the two different types of oscillations: secular motion with lower frequency and micromotion at the trap drive frequency. Our results for secular frequencies correspond well with the analytically calculated numbers. With the optimized mesh and geometry, the difference between the calculated and simulated values was less than 5%. We also observed a micromotion component at the trap drive frequency as suggested by theory. The amplitude of these oscillations was verified to be dependent from the ion offset from the potential node and from the applied voltages. With the proper parameters, this micromotion amplitude can be reduced to be below 10 nm for the particular cases.

4. Conclusion

In this work, we created a model for an ion trajectory simulation in a linear ion trap. The model can be used to identify the achievable secular frequencies for a specific set of voltages, to monitor micromotion amplitude and stability of the trapping. The model can be further expanded by including additional multiphysics such as the simulation of the trap heating via the Joule Heating interface.

Reference

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Figures used in the abstract

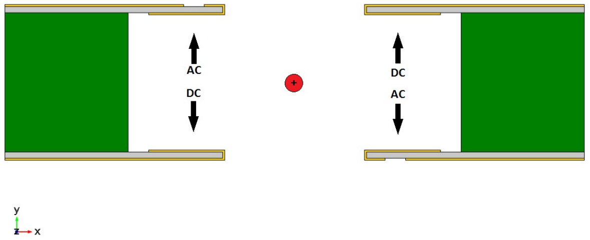

Figure 1: Cross section of one electrode segment in the xy-plane of the ion trap. Green domains are silicon substrate, grey domains are insulator, and orange domains are gold electrodes. The black arrows indicate where the AC and DC potential are applied and the red circle shows where the ion is confined.