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Simulation of Microfabricated Linear Ion Trap

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Motivation:

Trapped ions play a fundamental role in quantum information processing and optical frequency standards due to the stability of their oscillation frequencies. Novel fabrication methods allow for realization of compact integrated ion traps, which can simultaneously operate with multiple ions. In order to effectively handle a large number of trapped ions, new scalable and feasible designs are required.

In this work:

We present a simplified 3D model that simulates the operation of a microscale linear ion trap similar to the concept introduced in [1]. The model enables the estimation of trapping conditions and stability of an ion. We apply it to study secular and micromotion frequencies of a single ^{88}Sr^{+} ion.

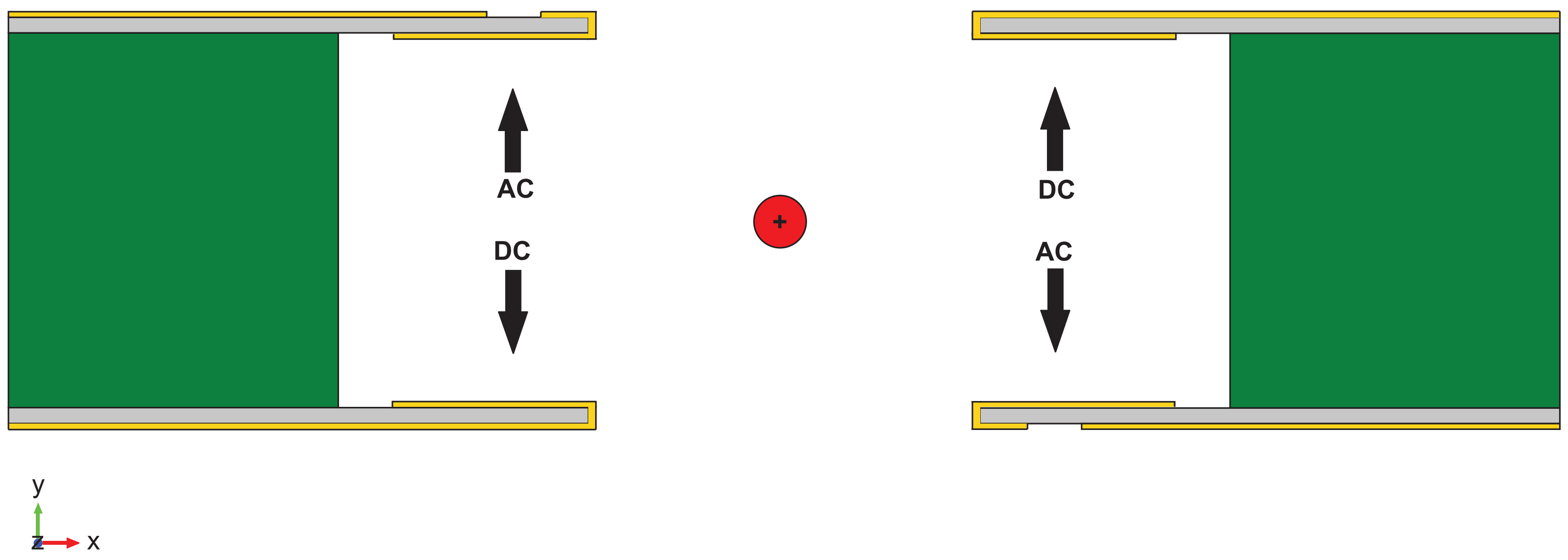


Figure 1. Cross section of one electrode segment in the xy-plane of the ion trap. Green domains are silicon substrate, grey domains are insulator, and orange domains are metal. The black arrows indicate where the AC and DC voltages are applied and the red circle illustrate where the ion is trapped.

Trap physics:

The confinement in all three dimensions is provided by the application of the specific AC and DC voltages to the corresponding trap electrodes. 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.

Modeling steps:

- Creation of the 3D model of the trap geometry
- Simulation of the DC potential distribution with the *Electrostatic* module
- Simulation of the AC potential distribution with the *Electric Currents* module
- Based on the aquired solutions, calculation of the ion trajectory with the *Charged Particle Tracing* module
- Application of the Fast Fourier Transform (FFT) to calculate the frequency spectra from the trajectory data

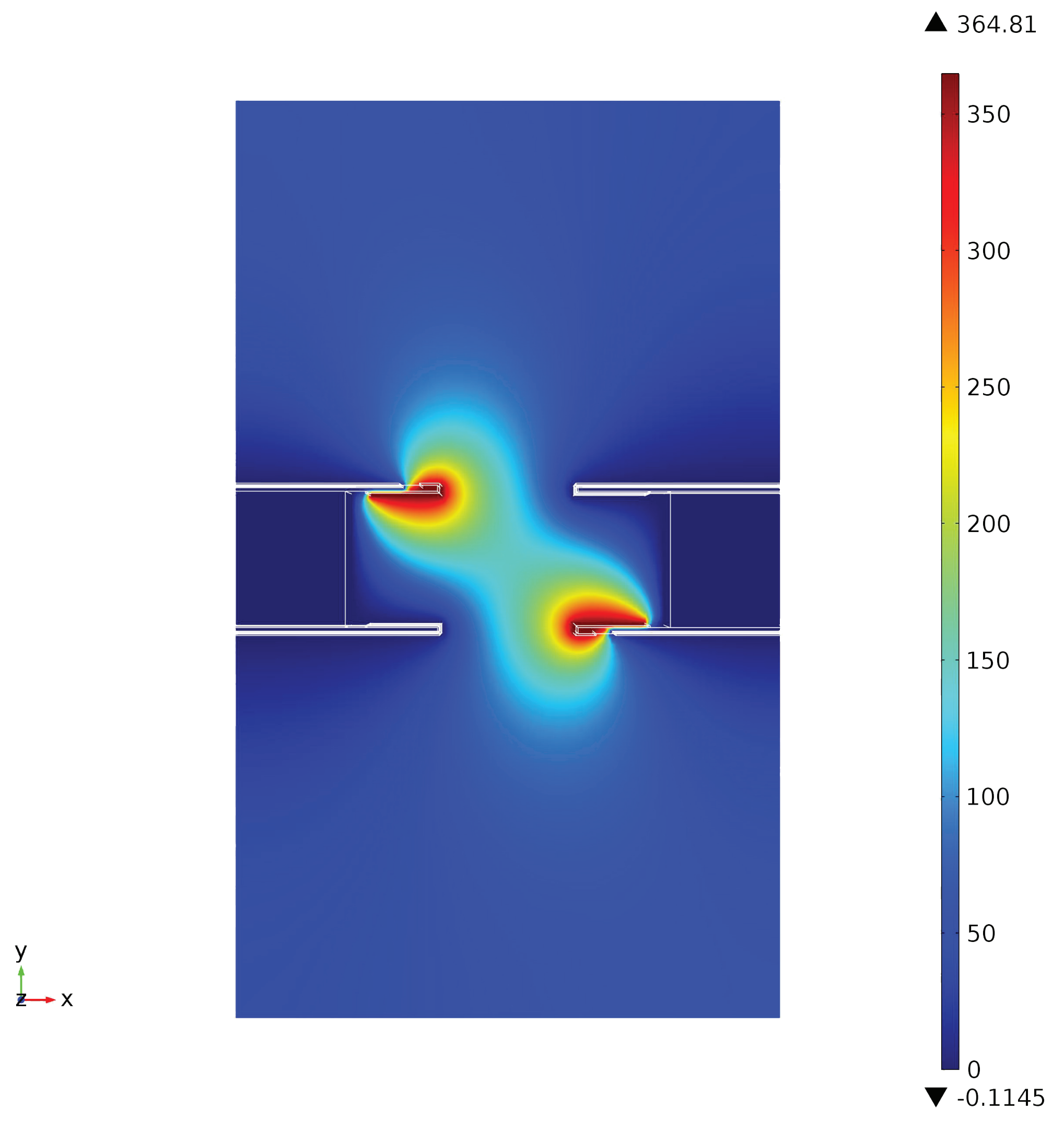


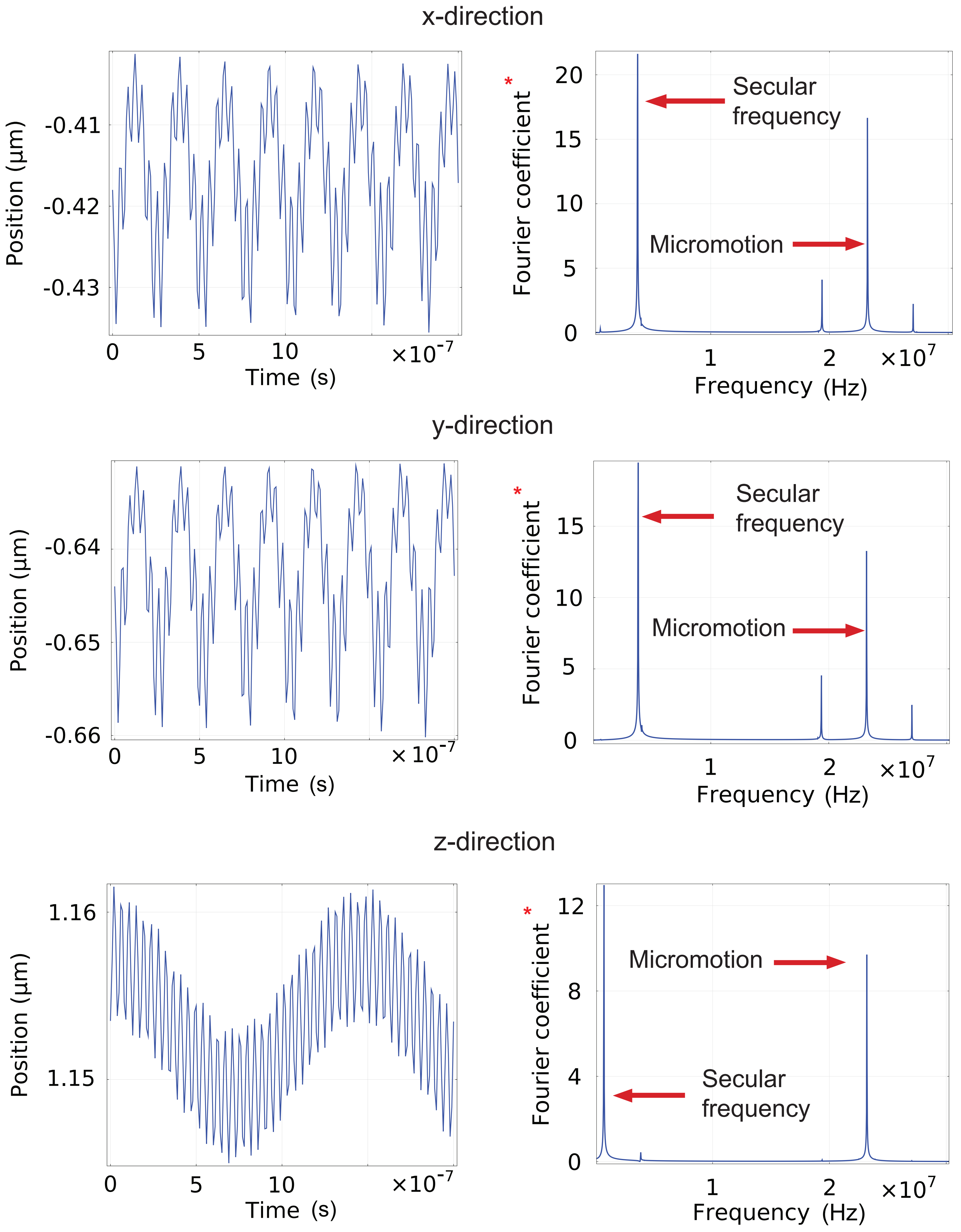
Figure 2. Resulting AC potential in the xy-plane when 365 V is applied to the AC electrodes.

Optimized features:

- Density of the mesh
- Size of the surrounding vacuum domain
- Starting location of the ion
- Time stepping of the solver
- Permittivity of the metal in the RF frequency region

With these optimizations the differences between calculated and simulated secular frequencies were minimized to be less than 5%. Equations presented in [2] were used to calculate analytical values for secular frequencies.

Results:


x-direction

y-direction

z-direction

Figure 3. Ion trajectories and the corresponding frequency spectra in each dimension.

* Fourier coefficient indicates how often some particular oscillation frequency appears in the studied ion trajectory.

Conclusions:

We created a model of a linear ion trap that can be used to identify achievable secular frequencies, oscillation amplitudes, and trapping stability with a particular set of voltages. In the future, the model will be expanded to include trap heating simulation via the *Joule Heating* module.

References:

1. G. Wilpers et al. A monolithic array of three-dimensional ion traps fabricated with conventional semiconductor technology, *Nature Nanotechnology*, **7**, 572-576 (2012).
2. M. J. Madsen et al. Planar ion trap geometry for microfabrication, *Appl. Phys. B*, **78**, 639-651 (2004).

Acknowledgments:

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