Simulating Ion Source - custom cooling method

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Introduction

The goal of this project was to create simulation of the Ion source, test it's parameters, and provide cooling method for Ions trapped inside.

Trap geometry

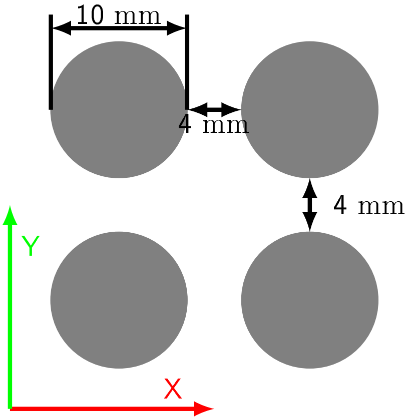

Figure: Trap geometry - perpendicular to trap's main axis

Trap geometry

The trap is built from 4 cyllindrical electrodes, cut into 5 segments each, creating two trapping centers. The main axis of the trap will be called Z axis, while the two perpendicular will be X and Y, as shown on diagrams. Electrodes along the Z axis will be numbered from 1 to 5.

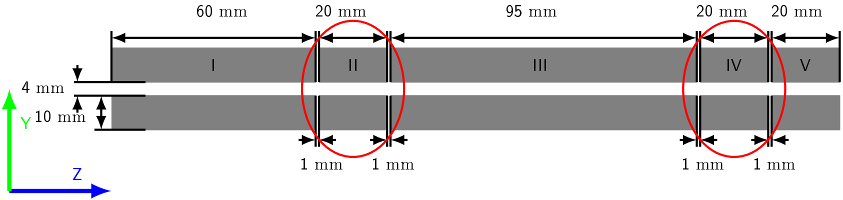

Figure: Trap geometry - paralel to trap's main axis - trapping centers are marked in red

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Calculating fields

In order to be able to simulate trap's behaviour, electric potential inside needs to be calculated. At first it was decided to use potential calculated by "CST Studio" program for every electrode in the trap.

Calculating electrostatic potentials - CST Studio

Potentials calculated by CST Studio proved however to be of unsatisfactory quality.

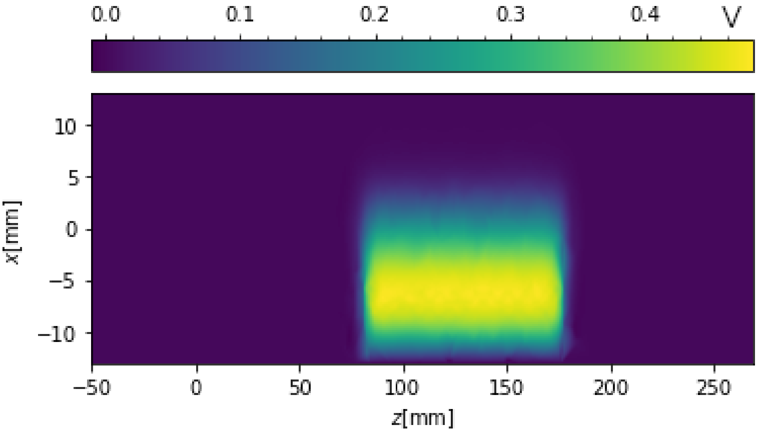

Figure: Electric potential on XZ plane in the center of the trap, when only one of the middle (III) electrodes is turned on. The field changes rapidly, even though

Calculating electrostatic potentials - CST Studio

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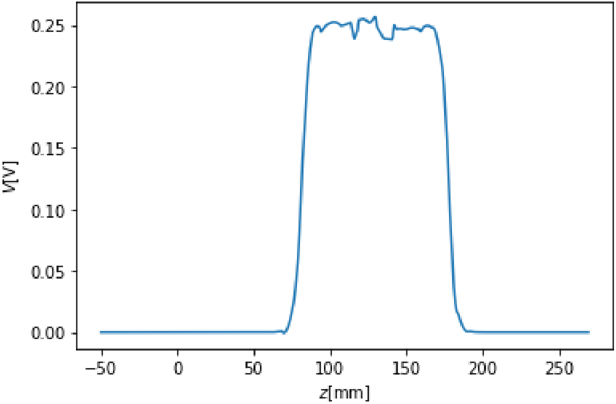


Figure: Electric potential along the Z axis, in the center, when only one of the middle (III) electrodes is turned on. The field changes rapidly, even though there is no change in voltage along the electrode.

Calculating electrostatic potentials - CST Studio

Rapid change of potential generates impulse force along electrode, where no force should be applied

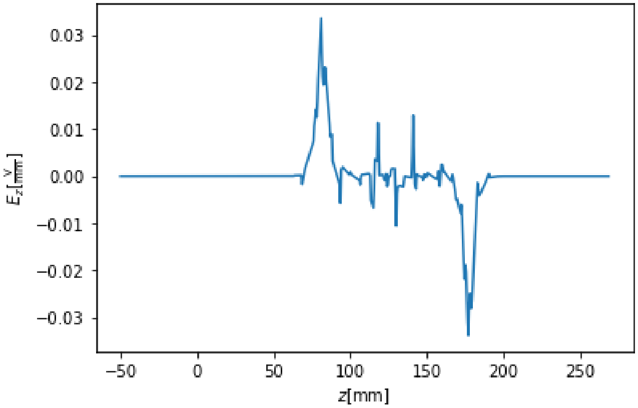


Figure: Electric field along Z axis, in the center, when only one of the middle (III) electrodes is turned on.

Relaxation of the fields

In order to refine given fields, relaxation method was used [1]. After around 50 000 iterations, there were no glaring numerical artifacts.

Field comparison

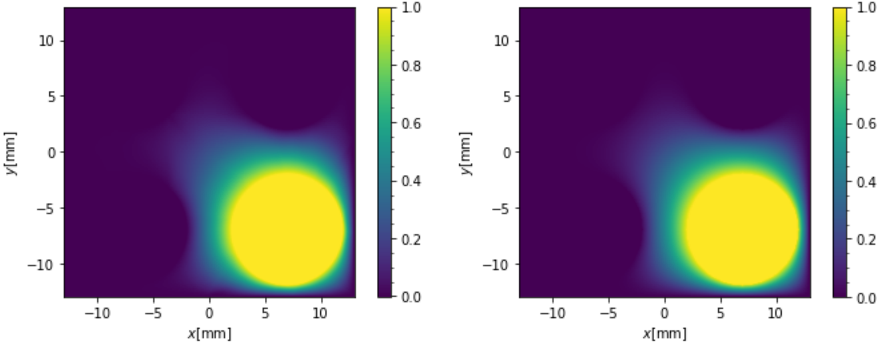


Figure: Electric potentials on XY plane, cutting through the center of the middle (III) electrode, when only one of the middle (III) electrodes is turned on. To the left output from CST Studio, to the right field after relaxation.

Field comparison

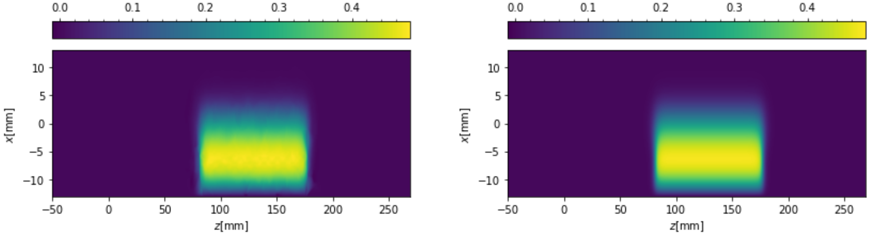


Figure: Electric potentials on ZX plane, going through the center of the trap, when only one of the middle (III) electrodes is turned on. To the left output from CST Studio, to the right field after relaxation.

Field comparison

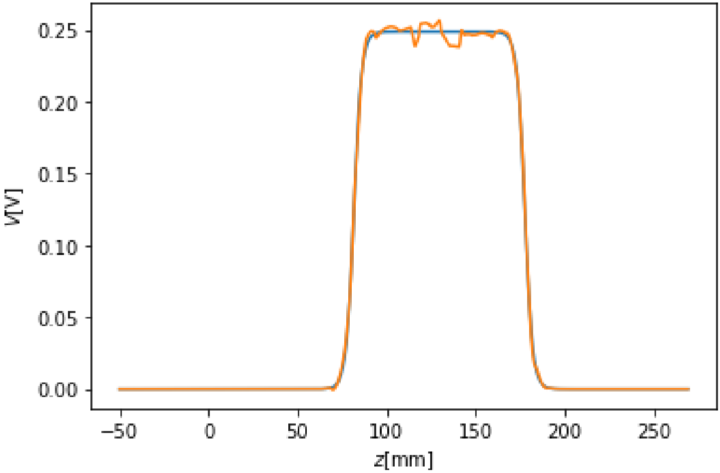
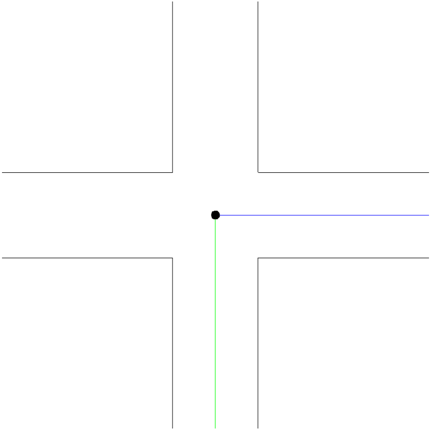


Figure: Electric potentials along the Z axis, in the center of the trap, when only one of the middle (III) electrodes is turned on. Orange line shows output from CST Studio, blue shows after relaxation.

Simulation

These potentials were then used for simulation. The software generates real-time 3d image of particles inside trap, as well as some charts, such as average energy of particles during specific time.

Animation



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Principle of cooling

One of the more important tests conducted with this software, are tests of our cooling method. High energy particles are pushed from deep potential well, to shallow one, with high potential barrier between them. Particles loose significant amount of kinetic energy while crossing barrier, and cannot regain all of it when entering second well.

Potentials inside the trap

In the beginning particles were Trapped in the first center of trapping, between electrodes II. First, third and last electrodes were set to 10 V, stopping particles from leaving the trap.

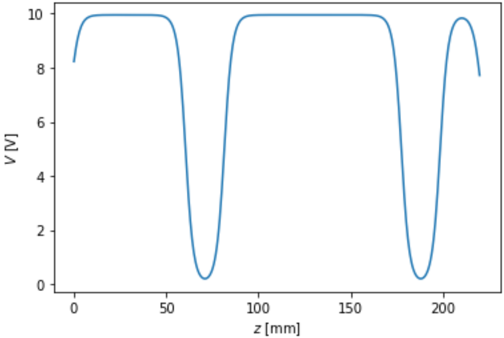

Figure: Electric potential along te Z axis, in the center of the trap, at $t = 0$.

Potentials inside the trap

Later the middle (III) electrode's potential was lowered, so that the some particles may move through it, loosing most of their energy. Potential in the second trapping center, near electrodes IV, is raised, so particles may get trapped, but won't regain all of their energy.

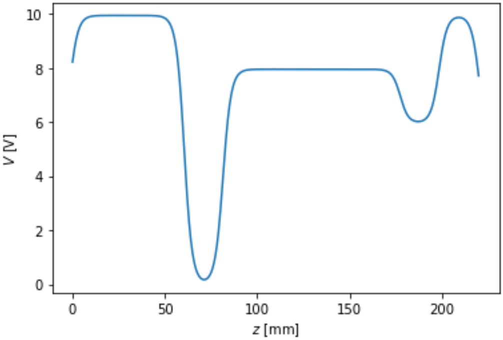

Figure: Electric potential along te Z axis, in the center of the trap, at $t = 201$ μs.

Potentials inside the trap

Particles were given some time to move between the two trapping centers.Finaly, middle barrier was raised again. Some particles were trapped inside the second trapping center.

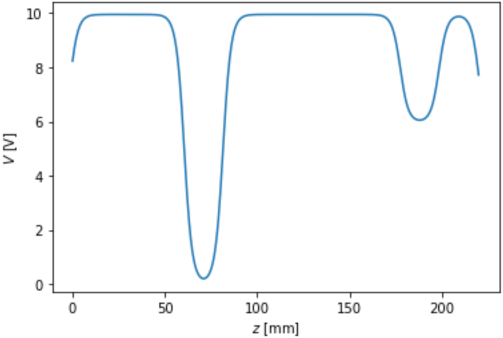

Figure: Electric potential along te Z axis, in the center of the trap, at $t =???\ \mu s$.

Result

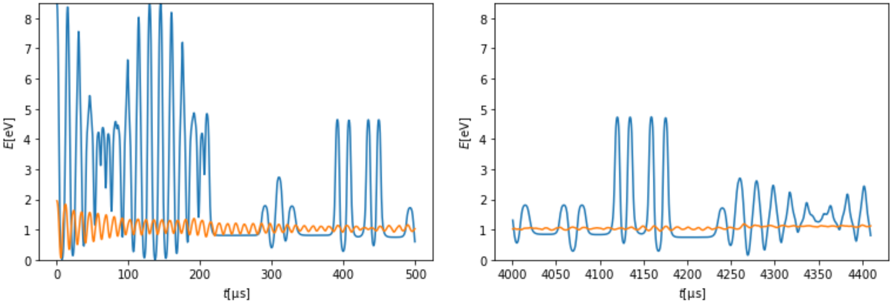

Figure: Average kinetic energy of particles along the Z axis. Blue chart shows particles which ended up cooled inside the second center, orange shows those which stayed in the first trapping center.

Result

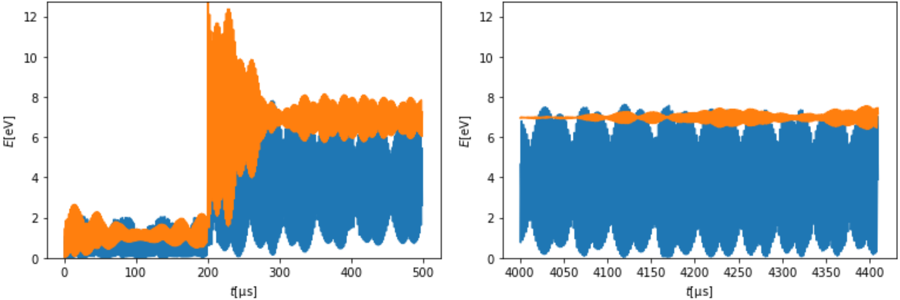

Figure: Average kinetic energy of particles on XY plane. Blue chart shows particles which ended up cooled inside the second center, orange shows those which stayed in the first trapping center.

Result

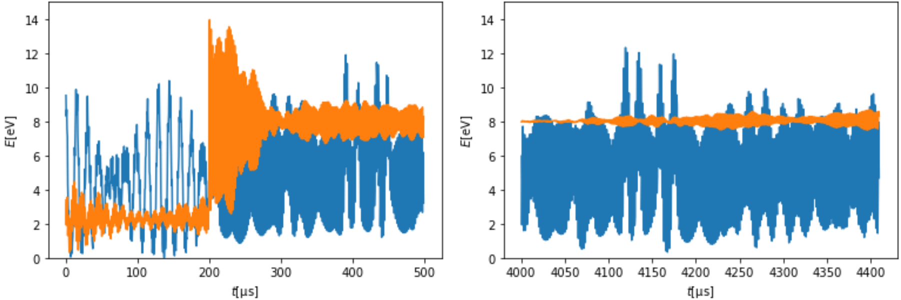

Figure: Average kinetic energy of particles along the Z axis. Blue chart shows particles which ended up cooled inside the second center, orange shows those which stayed in the first trapping center.

Results

In the end, particles which were transfered to the second center ended up with smaller kinetic energy along Z axis, but higer energy on XY plane. The total average energy hasn't changed much. The energy of other particles has raised significantly, with many of them beeing ejected from the trap.

Problem

Particles which are able to move through the barrier tend to be distributed along the whole trap, so only a few of them can be trapped at any time, ending with very small number of praticles cooled. When the barriers are lower, while energy along Z axis is lowered, the XY axis energy rises.

Changing well's depth

The final effect important for cooling, is seeing how changing potential well's depth, while particles are in it, changes energy of the system, to see if well's floor can be lowered again in the end.
Simulation was conducted, where particles were simply trapped inside the first trapping center, with the floor of the well beeing raised and then lowered again.

Changing well's depth

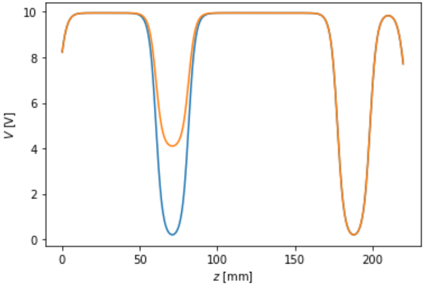

Figure: Potential in the middle of the trap along main axis. Blue shows initial and final potential, orange shows raised potential.

Changing well's depth - results

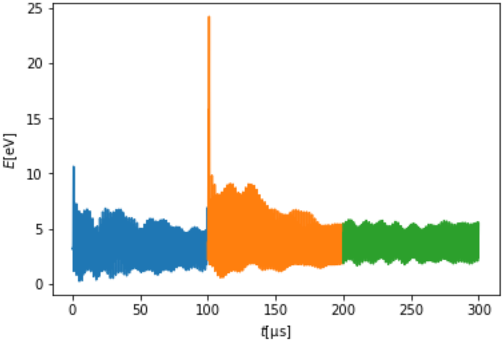

Figure: Average kinetic energy of particles in trap. Colors show stages of experiment, with blue beeing initial, orange raised potential, and green final, lowered potential.

Results

After initial burst of high energy particles leaving trap, kinetic energy oscillates around 3.36 eV. When voltage on middle electrodes is raised, 44% particles are thrown away from the trap, and the rest oscilates around 3.76 eV. After lowering voltage again, no particle is lost, and energy drops to 3.38 eV. There is visible difference in energy, but nowhere near potential difference of 4 V.

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Spreadsheets in Education (eJSiE), 8, Marzec 2015.