A Surface Electrode Trap for the Sympathetic Cooling of Molecular Ions

I.M. Georgescu and S. Willitsch

Department of Chemistry, University of Basel, Klingelbergstrasse 80, 4056 Basel, Switzerland

Background

Surface Electrode (SE) ion traps [1-5] are nowadays used in quantum information processing [1], the study of cold collisions between ions and neutrals [2] and cold-chemistry.

Their open geometry and flexibility in manipulating the trapping potentials are important advantages for realizing novel experiments with translationally cold molecular ions, e.g., cold ion-neutral chemistry [6] or precision spectroscopy on cold molecules.

The first step towards such experiments always consists of the sympathetic cooling of molecular ions by laser-cooled atomic ions, which is theoretically investigated in this work.

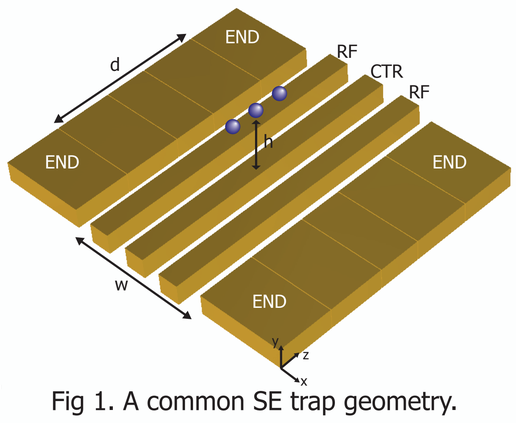


Fig 1. A common SE trap geometry.

SE trap pseudopotential

$$\Phi(x,y,z) = \frac{Q^2}{4m\Omega^2}\left|\nabla \Phi_{RF}(x,y,z)\right|^2 + Q\Phi_{DC}(x,y,z)$$

Unlike traditional linear Paul traps the trapping potential of SE traps is anharmonic and asymmetric and the trap depths are considerably smaller (< 1 eV).

Increased controllability of the positions of the ions is possible through the DC control electrodes. Moreover, DC potentials can increase/decrease the trapping height (h) and effective trap depth.

Numerical simulation of the dynamics of ions in SE traps

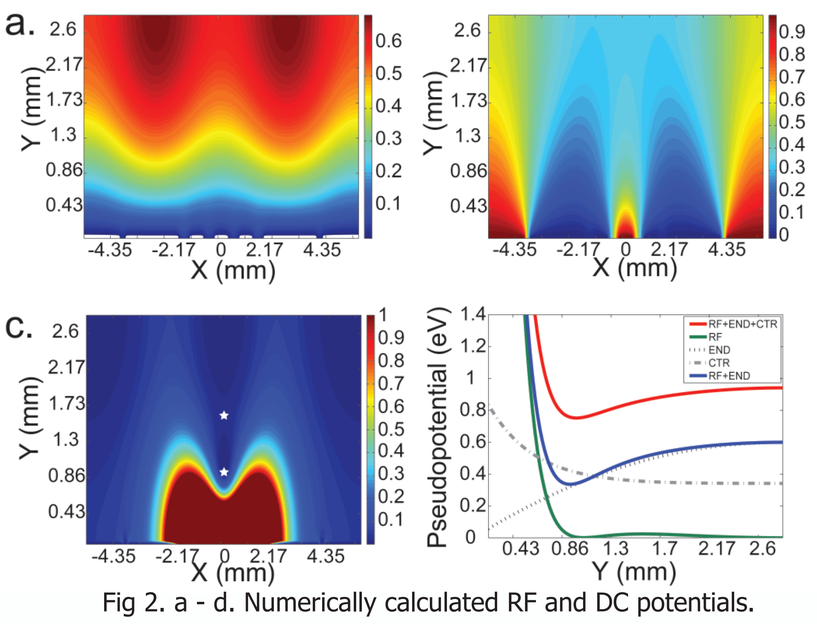


Fig 2. a - d. Numerically calculated RF and DC potentials.

Numerically calculated potentials are used to compute the trajectories of the ions using standard Molecular Dynamics algorithms (ProtoMol [7])

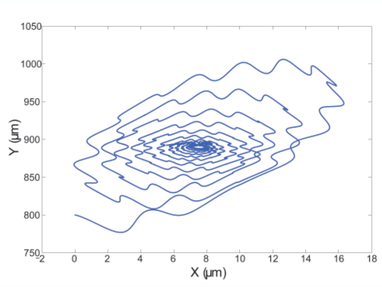
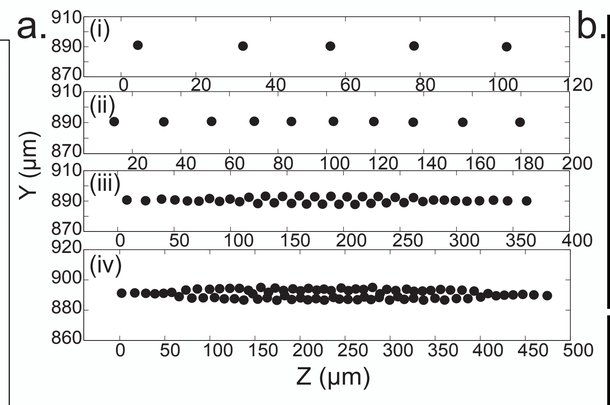


Fig 3. Trajectory of a single Ca ion over the first 50,000 time steps.



From the calculated ion trajectories the average effective and secular kinetic energies can be obtained. Furthermore, by averaging the ion positions, fluorescence images similar to the ones observed in experiment can be reconstructed.

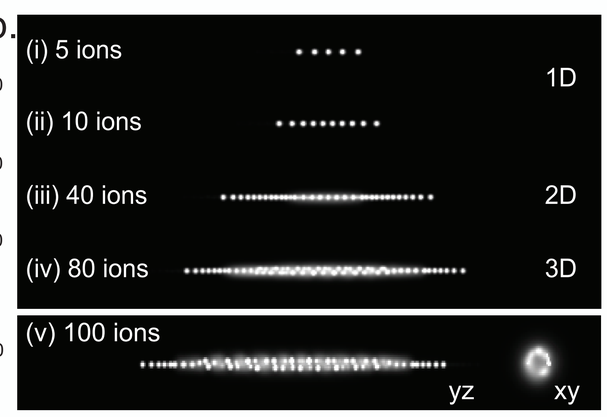


Fig 4. a. Snapshots of the ion positions at the end of the simulation; b. Reconstructed fluorescence images of simulated calcium Coulomb clusters in the SE trap in [3-5].
Simulation conditions:
RF 700 V, 11.2 MHz, END 1.22 V, CTR 0 V.

Laser- and sympathetically cooled ions

Bi-component Coulomb clusters of laser- and sympathetically cooled ions in SE traps are highly asymmetric and do not exhibit the spheroidal shapes observed in linear Paul traps [8]. Heavy ions are more weakly confined and therefore the ions are trapped higher above the trap surface.

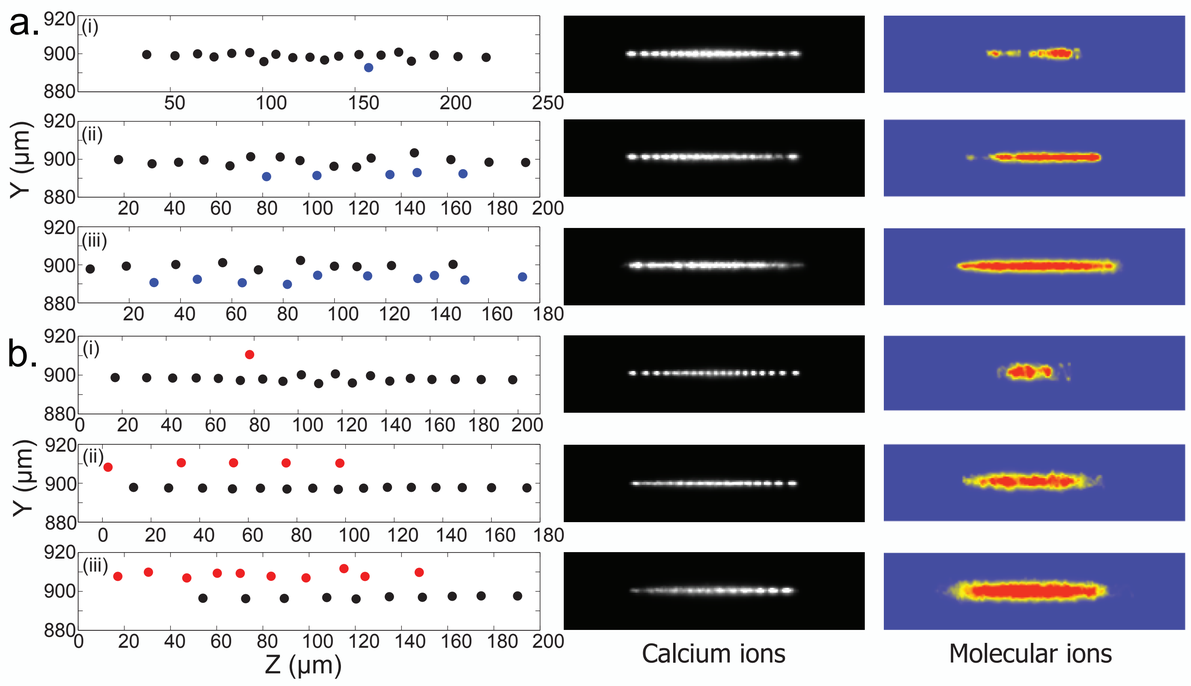
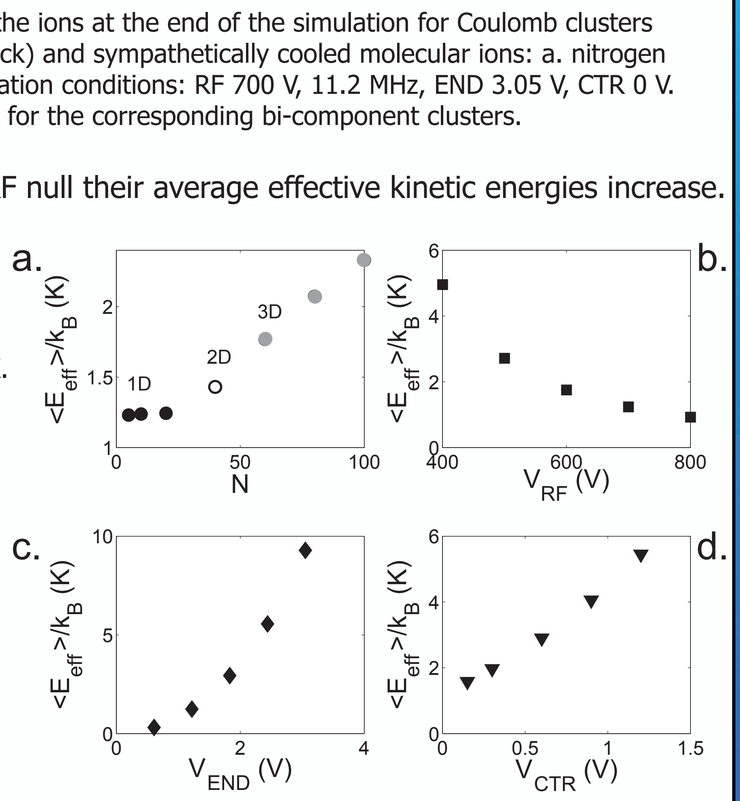


Fig 5. (left) Snapshots of the positions of the ions at the end of the simulation for Coulomb clusters with directly laser cooled calcium ions (black) and sympathetically cooled molecular ions: a. nitrogen (blue) and b. calcium fluoride (red). Simulation conditions: RF 700 V, 11.2 MHz, END 3.05 V, CTR 0 V. (right) Reconstructed fluorescence images for the corresponding bi-component clusters.

As the ions are displaced from the RF null their average effective kinetic energies increase.

Fig 6. a - d. Dependence of the average effective temperature on differerent operating parameters (number of ions, RF amplitude, END and CTR voltages). The average secular temperatures are ~10 mK.

Simulation conditions: as in Fig 3, ten calcium ions.



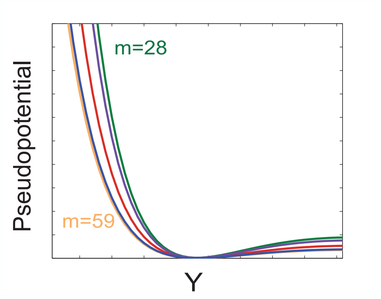


Fig 7. SE trap pseudopotential for ions of different masses in the same trapping conditions.

Experimental setup

Trap: laser cut, gold coated stainless steel foil glued on an insulating macor frame; no exposed insulator present near the trap center

Electrode width: a = 750 μm; inter-electrode gap: g < 50 μm
Control electrodes width: 700 μm; electrode thickness: 250 μm

Operation: RF 200-400 V, 8 MHz, END 5-60 V

Loading: non-resonant photoionization of an atomic beam with a 355 nm Nd:YAG laser

Laser cooling: 397 nm, 866 nm diode lasers

Detection: microscope lens and CCD camera

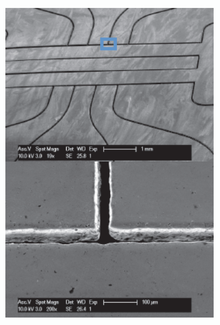
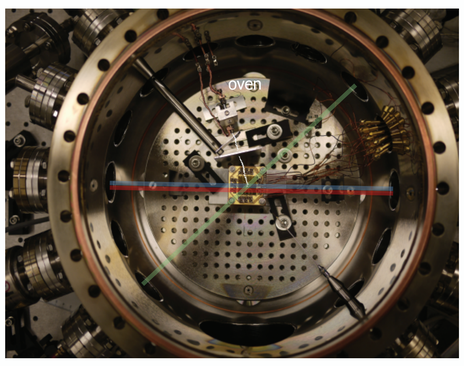


Fig 8. Microscope images of the SE trap:

before gold coating

after gold coating



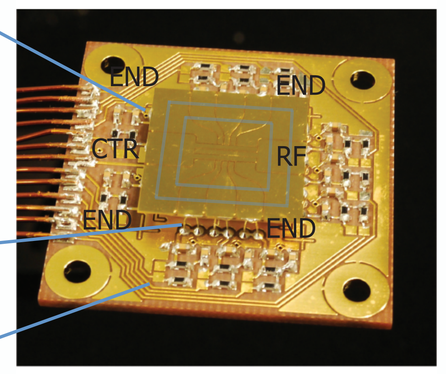


Fig 9. SE trap and electronic circuit.

Fig 10. Chamber setup in the current experiment:
SE trap (center) and electrical connections (upper right);
Atomic oven and mechanical shutter(upper left);
Cooling (blue) and repumper (red) laser crossing the chamber at the center, 700-800 μm above the trap surface;
Allignment fiber (lower right);
The lens-CCD camera system is situated on top (not in image).

Conclusions

In SE traps the asymmetry of the trapping potential is reflected by the asymmetry of the Coulomb clusters. Ion kinetic energies are dominated by micromotion and hence the distance of the ions from the RF null line. Ion energy distributions can be shaped by the application of suitable control electric fields.

References & Acknowledgements

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