PROJECT FINAL REPORT

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MolI microTrap project: Sympathetic cooling of molecular ions in microstructured ion traps on chips

Background

The study of trapped, cold atomic and molecular ions is an exciting new interdisciplinary research area with many practical and theoretical applications (e.g., frequency standards, mass spectrometry, fundamental tests of quantum mechanics, ultra-cold chemistry or quantum information). Microstructured ion traps on chips open the perspective of realizing portable mass spectrometers, scalable quantum information processors and other miniaturized devices for metrology and fundamental studies.

Goals

The MolI microTrap project aims at developing a flexible, compact, microstructured trapping device for conducting various precision experiments with single cold (i.e., mK temperatures) molecular ions. The first stage of the project consists in the design and construction of a novel type of ion trap, tailored towards the sympathetic cooling of molecular ions, with an open geometry and increased controllability of the trapping potentials. Here we report on the finalization of the first stage of the project.

Summary of results

In this work we have theoretically investigated the properties of laser- and sympathetically-cooled ions in surface-electrode microstructured ion traps. Following detailed numerical simulations we have designed, constructed and tested a surface-electrode microstructured ion trap. The main results are summarized below:

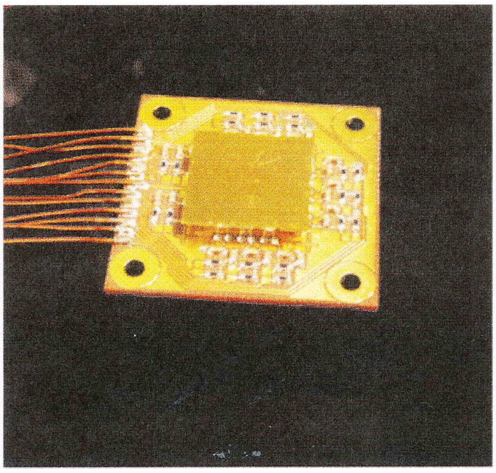
- ✓ Characterization of the effect of static electric fields on the trapping potential;
- ✓ Study of the shape, structure and thermal properties of laser-cooled atomic ions in surface-electrode traps using molecular dynamics simulations;
- ✓ Study of the shape, structure and thermal properties of sympathetically-cooled molecular ions in surface-electrode traps using molecular dynamics simulations;
- ✓ Design, construction and testing of a surface-electrode microstructured prototype ion trap, featuring a cheap and flexible production method.

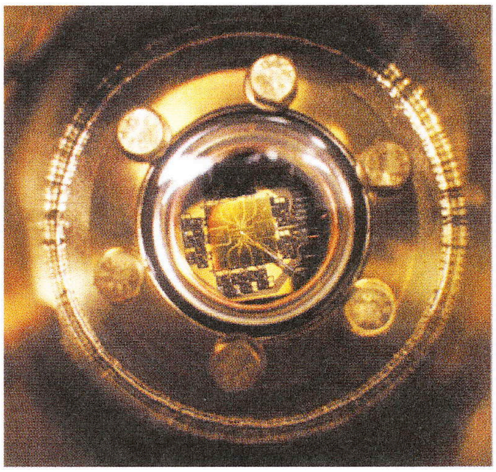
In surface-electrode ion traps, charged particles are trapped above the trap electrodes using a combination of static and radio-frequency electric fields. We characterized the electric potential given by these fields for a specific electrode configuration and the effect of the static fields on trapping height and trapping depth. The calculated fields were used in molecular dynamics simulations to compute the trajectories of trapped, laser-cooled ions which localize to formed ordered structures called Coulomb crystals. We studied the thermal properties of these crystals and investigated the sympathetic cooling of molecular ion species trapped together with the laser-cooled ions.

A surface-electrode microstructured prototype ion trap was constructed and tested. The fabrication method is laser-cutting, which is cheap and flexible. Furthermore, our design eliminates the problem of charged dielectrics near the trap center, which has been frequently reported in literature. The results of testing showed the strengths and weaknesses of this first prototype. The fabrication method proved to work, but electrical instabilities prevented the successful trapping of ions. Based on the experience gained, an improved second-generation prototype will be built.

Impact

To our knowledge the current study is the first numerical investigation of sympathetically-cooled ions in a surface-electrode ion trap. A publication is in preparation.These results are relevant for the ion-trap community and will hopefully contribute to the further development of microstructured ion trap technology. The methods that have been developed here can be easily generalized to other types of traps.





Left: close-up view of the microstructured surface-electrode ion trap (dimensions: 19 mm x 19 mm) mounted on an electronic chip. The laser-cut electrodes are micrometer-sized. Right: view of the trap from outside the vacuum chamber.

Conclusions

The first part of the project (i.e., the design and construction of a prototype microstructures ion trap) has been successfully completed.

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