Cryogenic microfabricated ion traps: Explorations of surface physics with ions

J. Labaziewicz, Y. Ge, D. Leibrandt, P. Antohi, S. X. Wang, R. Shewmon, K. R. Brown, I. L. Chuang

Center for Ultracold Atoms, Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

The surface of a metal is ideally an electrical equipotential, but in reality it may exhibit significant potential variations, up to hundreds of millivolts over micrometer distances. These "patch potential" variations generate local electric fields, with a static component thought to originate from differences in the work function between crystal facets, further modified by adsorbates. The noise due to temporal fluctions of these patch fields is of considerable interest, due to broad practical implications for trapped ion quantum computation, single spin detection, and measurements of weak forces. However, surprisingly little is known about this noise, or its physical origin.

Recent experiments demonstrate that ions can be trapped with electrodes on the surface of microfabricated chips, providing a superb system for exploring the surface physics of patch potentials. [1] We present experimental results [2,3] from a family of surface-electrode ion traps, made of silver and gold metal on quartz, operated in a liquid helium cryostat. Using a single trapped $^{88}\mathrm{Sr}^{+}$ ion, loaded by photoionization and sideband cooled to its motional ground state with fidelity $> 99\%$, heating rates are measured, quantifying electric field fluctuations arising from nearby trap surfaces. The ion-surface distance is varied from 75 μm to 150 μm, and the surface temperature is varied from 7 to 100 K. The noise amplitude is observed to have an approximate $1/f$ spectrum around 1 MHz, and grows rapidly with temperature as T^{β} for β from 2 to 4. Measured in units of motional phonons, the heating rate is found to be as low as ~ 2 quanta/sec at 6 K, which is more than 2 orders of magnitude lower then the best traps of comparable size, operated at room temperature; an identical trap operated at 300 K exhibits noise which is 7 orders of magnitude worse than at 6 K.

These results indicate that the patch fields may originate from surface fluctuators with a continuous spectrum of thermal activation energies, and suggest further experiments for trapped ions as highly sensitive probes of the physical behavior of condensed matter systems, possibly including the surface physics of superconductors.

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[1] S. Seidelin, et al, "A microfabricated surface-electrode ion trap for scalable quantum information processing," Phys. Rev. Lett, v96, 253003, 2006.

[2] J. Labaziewicz, Y. Ge, P. Antohi, D. Leibrandt, K. Brown, I.L. Chuang, "Suppression of heating rates in cryogenic surface-electrode ion traps", Phys. Rev. Lett, v100, p13001, 2008.

[3] J. Labaziewicz, Y. Ge, D. Leibrandt, S. X. Wang, R. Shewmon, and I.L. Chuang, "Temperature dependence of electric field noise above gold surfaces", arXiv preprint quant-ph/0804.2665, 2008.