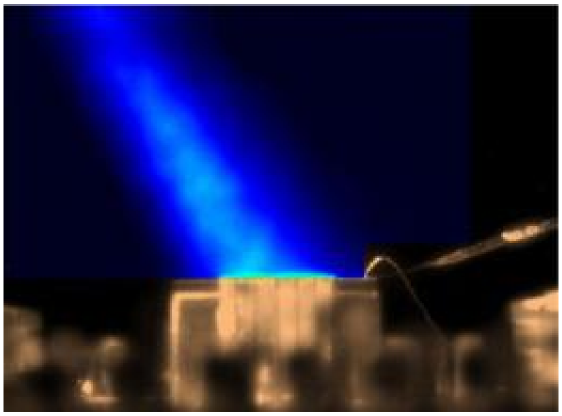
Argon cleaning helps trapped ions chill out

February 28 2012, by Dustin Hite



This colorized photo shows trap cleaning in progress. The trap (shown from the side) is atop the gold-colored pedestal in the center and measures 8 mm across. The vertical stripes on the pedestal are the gold ribbons used to make contact the trap. The blue beam from the top left is fluorescence from argon ions that are used to scrub the trap surface. The argon is accelerated to 500 - 2000 volts before it hits the trap surface. This cleaning process is similar to bead-blasting or a stream of water, but is relatively gentle. It removes the atoms in a layer-by-layer fashion. The process is also very clean because it is conducted at ultra-high vacuum with very pure argon. Photo: Y. Colombe/NIST

(PhysOrg.com) -- The reliability of trapped-ion quantum information systems – a promising candidate technology for an eventual quantum computer – can be dramatically improved by giving the trap electrodes a good scrub.

That’s the conclusion of PML researchers who found that cleaning the electrode surfaces of a room-temperature, gold-film trap with a beam of argon ions produced a 100-fold decrease in thermal jitter of the trapped ions, a phenomenon often called “anomalous heating” because the exact origin is unknown. That heating is a serious problem for ion trappers worldwide and is impeding progress in the use of ions as dependably controllable qubits, the quantum counterparts of digital bits.

The situation is critical, the scientists report because “deterministic entanglement and multi-qubit logic gates require precise control of the ions’ collective motion.” But the frequency of the noise typically overlaps the frequencies of the ions’ motional modes, causing errors.

“The most difficult operations occur in multi-qubit quantum gates,” says coauthor David Wineland of PML’s Time and Frequency Division. “If there’s even a single quantum of motion absorbed during this gate operation, the gate becomes useless.” There are ways to reduce the heating rate, such as cryogenic cooling; and because the rate scales inversely with trap size to the fourth power, bigger traps would reduce the problem. “But what we need are smaller traps,” Wineland says, “and if we could kill this anomalous heating, then it would be a huge step for everybody.”

The researchers focused on the apparent cause of the heating: electric-field noise emanating from contaminants on the surfaces of the trap electrodes. “The notion that the noise is probably coming from the surface has been around for a long time,” says PML physicist and co-author Dietrich Leibfried, “but it has only really evolved in the last few years. Before then, you’d go to an ion-trapper meeting, and you’d hear people saying ‘Have you tried gold?’ or aluminum or superconducting niobium. But they never talked much about the stuff that sits on the electrodes.”

To investigate the problem, the group began by baking a set of traps –

fabricated with 5 micrometer gaps in a 10 micrometer thick film of gold electroplated to a quartz substrate – at 475 K (about 200 °C) in a high vacuum. After baking, they measured the heating rate of a trapped beryllium ion. When they analyzed duplicates of the electrode surfaces using a technique called Auger electron spectroscopy, they determined that the gold was contaminated by two or three monolayers of adsorbates.

Rectifying that situation fell to coauthors Dustin Hite and David Pappas of PML's Quantum Electronics and Photonics Division. "When we heard about the heating problem," Pappas says, "it was clear that this is a surface science problem that we could address with the capabilities here in the Boulder surface science laboratory. We routinely clean surfaces to the atomic level and conduct measurements of basic physics of these ideal surfaces. The challenge in this experiment was to combine the cleaning techniques in-situ with the ion-trapping experiments."

After several successive cleaning cycles with an argon ion mill, Hite and colleagues conducted measurements on a trapped beryllium ion, and found that the heating rate had been reduced by two orders of magnitude, from about 7000 motion quanta per second to about 60 per second. A trap failure prevented continuation of the experiments. But "we're certainly going to pursue the subject," Wineland says. "Even without understanding the detailed mechanism that produces the heating, if we can reliably reduce it by a factor of 100, then with apparatus that will allow us to do cleaning, we may make much more progress."

For example, the results to date indicate that the amount of ion heating varies in a power law relationship with ion motion frequency, and the specific details of that power-law relationship may yield insights into the physical mechanism responsible for the electric-field noise and associated heating. "Different mechanisms have different scaling laws," Leibfried says, "so, for instance, we can probably rule out Johnson noise as the origin because its scaling would be different.”

In coming months, the group expects to learn much more. “This work represents a truly collaborative and synergistic effort of two fundamentally different disciplines,” Pappas says. “It has been exciting working with the ion-trapping group, and we are now building a combination surface science-ion trap system that will allow us to interchange the surfaces that the ion sees. This will allow us to not only optimize ion traps, but to investigate new surface physics phenomena such as charge and defect migration up to very high frequencies, which has never been done before.”

In addition, the work might lead to a valuable technique for surface analysis. “Measurement of the heating of ions located near surfaces might be a new probe of electric fields from surfaces in an as-yet unexplored frequency regime,” the researchers write.

The research, conducted at NIST’s Boulder, CO campus, was supported by the Intelligence Advanced Research Projects Activity, the National Security Agency, the Office of Naval Research and the NIST Quantum Information Program.

Provided by National Institute of Standards and Technology

Citation: Argon cleaning helps trapped ions chill out (2012, February 28) retrieved 20 May 2024 from https://phys.org/news/2012-02-argon-ions-chill.html