Electric-field noise and carbon diffusion on Au(110)

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Synopsis The decoherence of trapped-ion quantum gates due to heating of their motional modes is a fundamental science and engineering problem. This heating is attributed to electric-field noise arising from the trap-electrode surfaces. We have investigated the origin of this noise by focusing on the diffusion of carbon-containing adsorbates on the Au(110) surface. We show how the carbon adatom diffusion on the gold surface changes the energy landscape, and how the adatom dipole moment varies with the diffusive motion. A simple model for the diffusion noise, which varies quadratically with the variation of the dipole moment, predicts a noise spectrum, in accord with the measured values.

Trapped ions are a promising platform for demonstrating coherent operations for quantum information applications [1]. However, heating of their motional modes remains a major obstacle to continued progress [2]. In particular, motional heating caused by electric-field noise originating from the trap-electrode surfaces has proven to be a difficult problem to mitigate, ever since it was first observed more than two decades ago. This decoherence mechanism scales strongly with the inverse of the distance separating the ion from the nearest electrode, and, therefore, is a barrier to scalability through miniaturization. The origin of this noise source has been suspected to arise from surface processes, based on experimental evidence on scaling with ion-electrode distance [3], electrode temperature [4], and spectral-density frequency dependence [5–6]. However, the exact mechanism that gives rise to electric-field noise at the location of the ion still remains elusive.

In this work, we have investigated diffusion of a carbon adatom on gold surfaces to gain better understanding of electric-field noise. Electron spectroscopy indicates that carbon is a dominant contaminant on gold trap-electrode surfaces [7], and scanning tunneling microscopy (STM) images (see Fig. 1) reveal ordered Au(110)-(2×1) like structures after trap electrodes have been treated with ion bombardment. Density functional theory (DFT) calculations provide the first detailed values for the energy and dipole landscapes of the adsorbed carbon atoms on Au(110), and are used subsequently in an analytical derivation of noise due to classical diffusion. The model shows how the electric-field noise varies in a non-monotonic fashion as a function of the degree of carbon-adatom coverage. The electric-field noise spectral density is a function of the variation in the adatom dipole moment, the surface diffusion constant, and patch size with different work functions. Using realistic parameters, the theory predicts an electric-field noise spectral density consistent with experimental measurement.

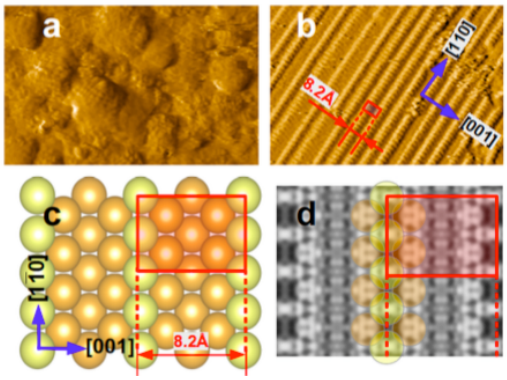

Figure 1. Derivative STM images (17 nm × 10 nm) of (a) untreated and (b) treated ion-trap surfaces by ion bombardment; (c) Top view of the Au(110)-(2 × 1) reconstructed structure and (d) its simulated STM image.

References

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