Rb adsorbate-induced negative electron affinity on quartz

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Synopsis We have investigated Rb adsorbates on the SiO_2 (0001) surface. Using Rydberg atom electromagnetically induced transparency, we investigate the electric fields resulting from Rb adsorbed on the quartz surface, and measure the activation energy of the Rb adsorbates. We show that the adsorbed Rb induces a negative electron affinity (NEA) on the quartz surface. The NEA surface allows low energy electrons to bind to the surface and cancel the electric field from the Rb adsorbates. Our results are important for integrating Rydberg atoms into hybrid quantum systems and the fundamental study of atom-surface interactions, as well as applications for electrons bound to a surface.

Due to recent technological advances in fabrication and trapping, hybrid quantum systems (HQS) consisting of atoms and surfaces, as well as electrons and surfaces, are fast emerging as ideal platforms for a diverse range of studies in quantum control, quantum simulation and computing, strongly correlated systems and microscopic probes of surfaces [1–3]. Miniaturization of chip surfaces is necessary to achieve large platform scalability, but decoherence and noise emerge as serious challenges as feature sizes shrink [4–6]. Mitigating noise is a fundamental step in realizing the full potential of HQSs.

In this work, we show that adsorption of Rb atoms on a quartz (0001) surface, contrary to prevailing assumption, can reduce the E-field near the surface, using spin-polarized density functional theory (DFT). On the surface of quartz, the Rb atom is bound to two oxygen atoms. Total-energy calculations for the quartz (0001) surface with various Rb coverage indicate that the lowest bound state for one monolayer (ML) has a binding energy of E_b = 0.35 eV. For the lower experimentally investigated coverages, our DFT calculations show an increase of E_b by about 1.4. The calculated E_b is comparable in magnitude with the measured activation energy, E_a, and is consistent with the expectation $E_b \leq E_a$ [7]. We demonstrate, by appealing to theoretical arguments and ab initio calculations, that the reduction in E-field is caused by a transformation of the quartz into a negative electron affinity (NEA) surface via adsorption of Rb atoms on the surface (see Figure 1). The repulsion on quartz occurs because the surface vacuum level dips below the conduction band minimum. We find that the binding of electrons to the surface substantially reduces the E-field above the surface. Reducing E-fields on a quartz surface by making quartz a NEA surface by Rb adsorption is a promising pathway for coupling Rydberg atoms to surfaces.

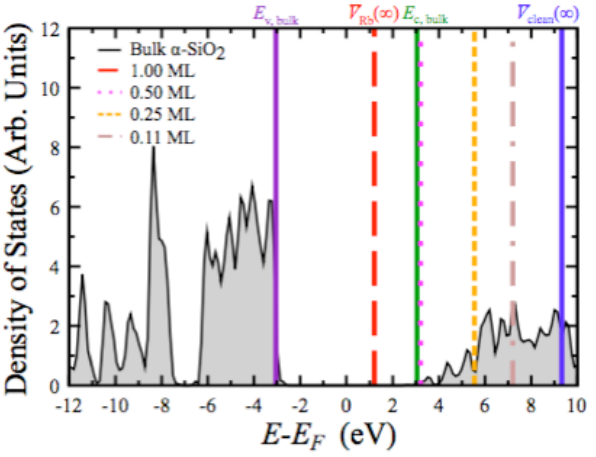

Figure 1. Density of states of bulk α-quartz. The Fermi level, E_F is at E = 0. The valence band maximum, $E_{v,bulk}$, conduction band minimum $E_{c,bulk}$ of bulk α-quartz, and the vacuum levels of the SiO_2 (0001) surface without and with Rb adsorbates, respectively, $V_{clean}(\infty)$ and $V_{Rb}(\infty)$ are labelled.

References

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