Quantum dots created by atom manipulation with the scanning tunneling microscope

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Atom manipulation with the scanning tunneling microscope (STM) makes it possible to create ultimately small structures at surfaces. We extended this technique to III-V semiconductor surfaces [1,2] and found that their electrostatic potential landscape can be precisely designed by the controlled positioning of charged adatoms. In this way, quantum dots with identical, deterministic sizes can be created one atom at a time. By using the lattice of the InAs(111)A surface to define the allowed atomic positions, the shape and location of the dots is controlled with effectively zero error. The dots are assembled from +1 charged indium adatoms, leading to the confinement of intrinsic surface-state electrons [3,4]. This approach enables one to construct quantum dots with a perfectly defined level structure, as well as dot assemblies whose quantum coupling has no intrinsic variation but can nonetheless be tuned over a wide range.

In a related experiment, we found that the tunneling conductance of a single organic molecule adsorbed on InAs(111)A can be controlled by the adatom-induced gating potential, with the STM tip and substrate acting as source and drain contacts, respectively [5]. Depending on the potential, the molecular charge state can be tuned from neutral to −1, as well as to bistable intermediate states. Moreover, the molecule changes its orientational conformation upon charging. This coupling between charge and conformation induces a conductance gap more than one order of magnitude larger than normally found, for example, in electron transport through single molecules in the regime of strong electron-vibron coupling. The observed behavior can be rationalized within the framework of charge transport through a gated molecular quantum dot with strongly coupled charge and orientational degrees of freedom.

The discussed results illustrate that atom manipulation in combination with scanning tunneling spectroscopy provides detailed insight into the quantum-physical properties of artificial surface structures at the smallest size scales. Understanding and controlling these properties – and the new kinds of behavior to which they can lead – will be crucial for integrating atomic-scale devices with existing semiconductor technologies.

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