Forces during Controlled Manipulation of an Organic Molecule

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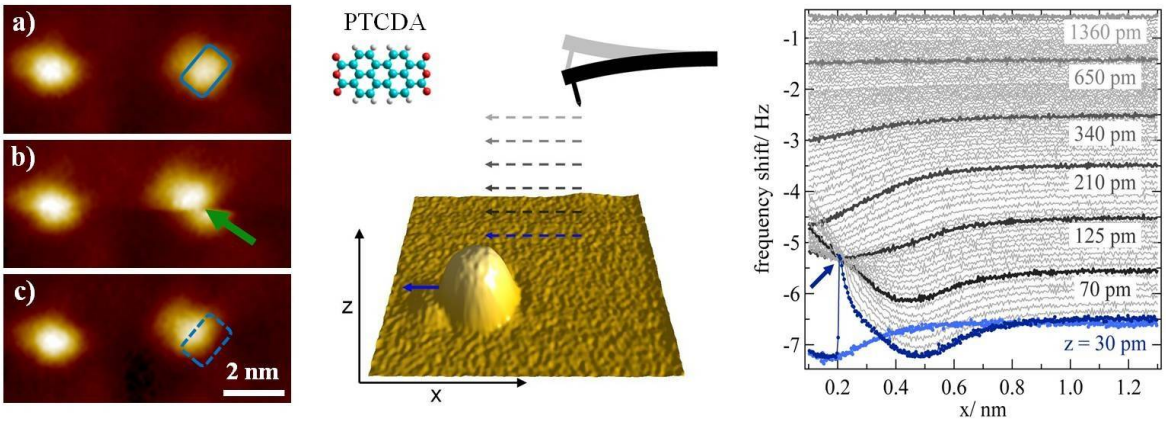
Scanning Tunneling Microscopy (STM) based lateral and vertical manipulation of single atoms up to large organic molecules has become an established technique. In contrast, controlled manipulation by NC-AFM seems to be more challenging, since no continuous contact between oscillating tip and adsorbate is maintained. Nevertheless, over the last decade, procedures for lateral and vertical manipulation by NC-AFM have been developed [1], focusing mainly on semiconductor surfaces, but including also atoms and small molecules on conducting and insulating substrates. A major advantage of NC-AFM over STM is its capability to measure directly the tip-sample forces inducing the adsorbate's motion and, thus, to provide a detailed insight into the underlying processes. However, only in a few cases reported so far this unique ability was exploited to determine the manipulation threshold of vertical forces. Not until recently also the lateral manipulation forces were quantified [2], and found to play an important role for a successful manipulation of surface adsorbates.

Motivated by these results and the many open questions regarding controlled manipulation of large organic molecules by NC-AFM, we performed lateral manipulation experiments using a low temperature tuning fork AFM. Individual PTCDA molecules where moved with the AFM tip on a Ag(111) surface, exhibiting discrete jumps along the [$\bar{1}$10] direction. Starting at a large enough height above the surface, where no tip-molecule interaction could be detected, we recorded the frequency shift along a lateral manipulation path while stepwise decreasing the tip-surface distance up to the point where the molecule hopped to the adjacent adsorption site (see figure). This was done repeatedly with the same molecule. The hopping events could clearly be identified in the two dimensional frequency shift maps, which were converted into lateral and vertical tip-sample forces. Based on this analysis we determined the lateral manipulation threshold forces, allowing us to identify the manipulation mechanism as 'pushing' mode. Furthermore we found an increase of the energy dissipation signal at the onset of manipulation, which may be correlated to molecular relaxations during the initial hopping attempts.



References

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[2] M. Ternes et al., Science 319, 1066–1069 (2008).