

Coupled Peeling and Sliding of Ladder Phenylenes on Au(111) Studied by nc-AFM Force Spectroscopy

Mengxi Liu,[#] Xiaohui Qiu

National Center for Nanoscience and Technology, 100190 China,
[#] liumx@nanoctr.cn

In 1975, K. Kendall proposed a model describing that the force required to peel an elastic film from a rigid substrate depends not only on the adhesive surface energy but also on the elastic deformation [1]. More recently, L. Gigli et al. extended this concept in the context of graphene nanoribbons (GNRs) on Au(111), where vertical lifting leads not to a retracting detachment point, as in Kendall's model, but to a forward-moving tail, indicating a coupled peeling and sliding motion [2]. Given that GNRs on Au(111) typically form incommensurate interfaces, their lateral motion can be interpreted within the framework of structural superlubricity [3]. However, GNRs with finite length are usually atomically pinned to the substrate at the head (detachment point) and tail, even if they are incommensurate with the underlying substrates. The influence of these pinned regions on the interfacial mechanics of GNRs adsorbed on metal surfaces remains insufficiently explored.

Here, we employ nc-AFM force spectroscopy to study the peeling and sliding of dimethyl ladder phenylene (DM-LP) nanoribbons adsorbed on Au(111). The DM-LP nanoribbon is lifted from the Au(111) surface by vertical manipulation with an AFM tip. The simultaneously recorded $\Delta f(z)$ curve shows oscillations with a period of ~ 0.38 nm, consistent with the lattice constant of DM-LP. By measuring the lateral friction of the DM-LP at various lifting heights, we construct a 2D $\Delta f(x, z)$ map to demonstrate the interplay between vertical peeling and lateral sliding motions. Our results reveal that the peeling force is primarily determined by the segment at the detachment point, while the lateral slip is governed by the motion of the moiety at the tail end. Moreover, the friction force profiles vary with lifting height, enabling the identification of distinct chemical moieties at the atomic scale. These findings provide direct experimental evidence of peeling-sliding coupling in the system of nanoribbons adsorbed on metal surface, offering an extended perspective on the classical Kendall model.

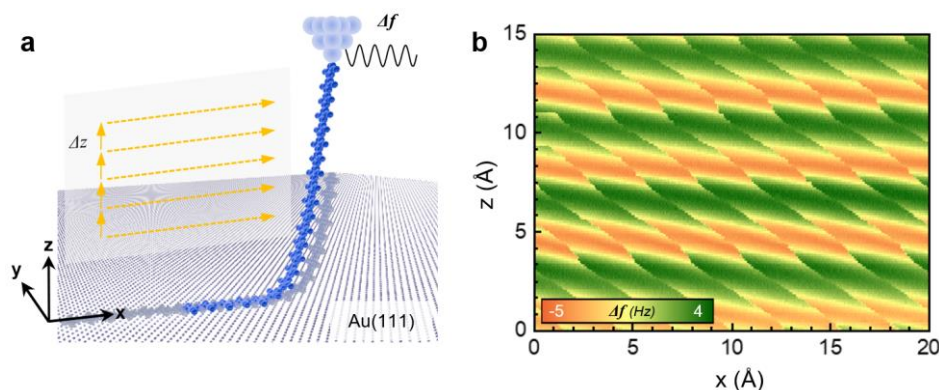


Figure 1. (a) Schematic illustration of the controlled manipulation of DM-LP on Au(111) by nc-AFM. (b) Experimental 2D $\Delta f(x, z)$ color map recorded during the manipulation.

References:

- [1] K. Kendall J. Phys. D: Appl. Phys. **8**, 1449 (1975)
- [2] L. Gigli, et al. Nanoscale **11**, 17396 (2019)
- [3] S. Kawai, et al. Science **351**, 6296 (2016)