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NANOMECHANICAL INVESTIGATIONS OF GRAPHENE BY FRICTION FORCE MICROSCOPY

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Abstract: Nanotribology experiments are performed on graphene and related materials. Graphene and hydrogenated graphene are compared by friction force microscopy. Superstructures of graphene on ruthenium are investigated by force microscopy, where nanodomains are observed and indications are found that the nanodomains collapse under the application of local pressure. Graphene nanoribbons (GNR) are studied by high resolution forces with CO-terminated tips. GNRs and polymeric chains are pulled by the action of the probing tip, where quantitative information about the sliding of the ribbons/chains across surfaces are determined.

Keywords: friction force microscopy, nanotribology, graphene.

1. INTRODUCTION

Nanotribology is a subject of intensive research. Novel instruments, such as quartz microbalance, surface force apparatus or atomic force microscopy, are used to investigate the mechanisms of friction and wear on the nanometer scale. In this paper the emphasis is on the investigation of graphene related investigations by friction force microscopy and high resolution force microscopy.

2. NANOTRIBOLOGY INVESTIGATIONS OF GRAPHENE AND RELATED MATERIALS

Friction force microscopy is used to investigate thin layers of lubricants to deduce the reduction of friction on the adsorbate

covered surfaces compared to the bare substrate. High resolution force microscopy with CO terminated tips can be used to investigate the atomic structure of single molecules or molecular aggregates. Local manipulation experiments of nanoribbons or molecular chains give information about the sliding of ribbons/chains on surfaces and of the detachment of molecular subunits from the surfaces.

2.1 Graphene vs. hydrogenated graphene

Frictional properties of graphene and hydrogenated graphene are investigated by tapping force microscopy, Kelvin force microscopy and friction force microscopy [1]. The initial friction forces are found to be larger on graphene compared to the hydrogenated

part. However, the friction contrast changes during subsequent imaging, which is related to the removal of an adsorbate film by the action of the probing tip. After prolonged imaging the frictional forces are equal within the experimental error [2].

2.2 Graphene superstructures and nanodomains

A second study is related to graphene on Ru(0001) prepared under ultrahigh vacuum conditions. Here, a superstructure is observed due to the mismatch between the two lattices. Local force spectroscopy shows, that the elevated part of the superstructure, called graphene nanodome, can be deformed by the probing tip. This elastic deformation has dramatic influence on the imaging conditions, revealing an inversion of the contrast at elevated forces [3].

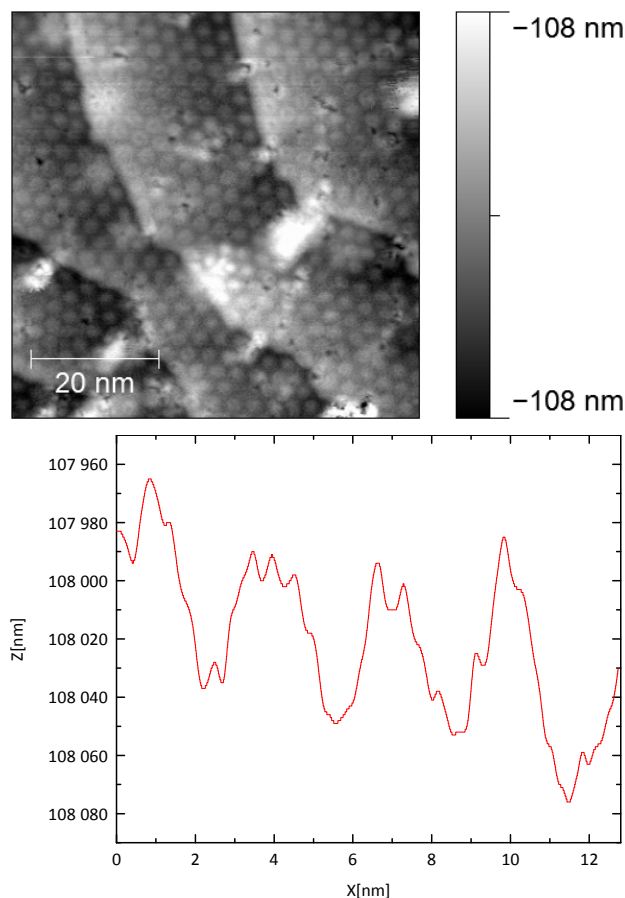


Figure 1. Graphene on Ru(0001) imaged by nc-AFM. Nano-dome structures are observed due to the mismatch between substrate and graphene layer (top: topography image; bottom: profile across 4 nano-domes)

2.3 High resolution imaging of graphene nanoribbons and nanomanipulation

The third example is related to graphene nanoribbons, which are grown under ultrahigh vacuum conditions. Using CO-terminated probing tips at low temperatures the nanoribbons can be imaged with high resolution, where individual atoms are observed [4]. The ribbons are found to be nearly defect free. Only in rare cases, the passivation of the borders of the ribbons are non-ideal, e.g. an additional hydrogen atom is observed at some sites.

Manipulation experiments, such as the pulling of nanoribbons and lateral movement, give further information about the interactions with the gold substrate [5]. An example of the pulling of a polymeric chain is shown in Figure 2. Though the frequency shift of tuning fork force microscopy is primarily related to normal force gradients, there are some examples of experiments, which provide valuable information about lateral forces or energy barriers in the lateral direction. Either 2d- or 3d-frequency data are acquired and transferred into force or energy fields by integration, where instabilities limit the applicability of this method.

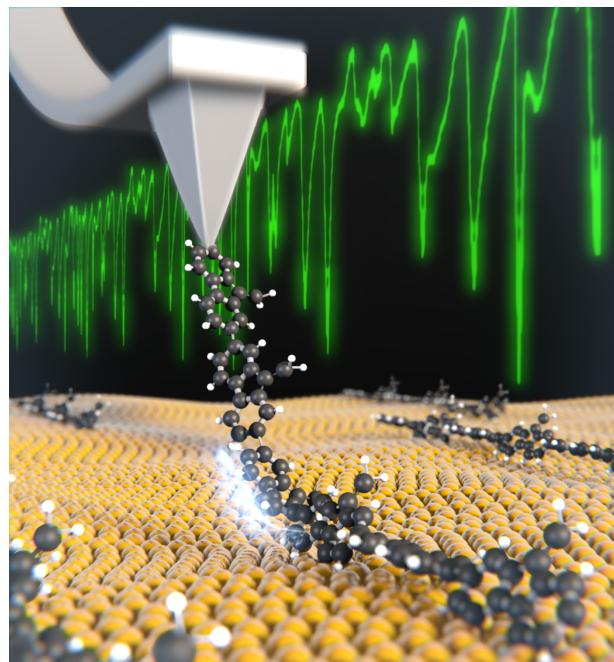


Figure 2. Pulling of a polymeric chain by the action of a probing tip. The measured frequency shift gives information about the bonding of molecular subunit to the gold surface

Alternatively, models are used, where the essential parameters are included to simulate the frequency shift data. The example given by the pulling of polymeric chains on Au(111) [5] shows that the detachment of the chain leads to oscillations of the normal and lateral forces. The comparison with the model allows determining the adhesive energy per subunit of the molecular chain. Lateral manipulation gives insight about the movement of one-dimensional chains on surfaces, which is close to the ideal of the Frenkel-Kontorova model.

3. CONCLUSION

Graphene layers provide an efficient lubrication for various surfaces. As long as the local forces are not large enough to shear complete layers, the films are found to be intact. Superstructures on metallic surfaces are found to be deformable under the application of local forces. The deformation seems to be completely elastic. The pulling of nanoribbons is an alternative way to quantify the interaction of graphene with substrates. Important parameter, such as the angle orientation or the sliding direction can be controlled with high accuracy.

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