AFM pattern formation in a compliant surface

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Atomic Force Microscope (AFM) is an experimental technique that has played a key role in the flowering of the new research field of nanotribology. At small forces the AFM serves as a probe of the material topography at the nanoscale. Increasing the force is able to resolve the lateral force exerted by the surface over the moving tip, allowing to characterize friction at the level of a single-contact. Remarkably, in this case an atomic stick-slip dynamics is observed in many different materials and under different experimental conditions. This dynamic can be mostly understood in terms of the Prandtl-Tomlinson model, a simple model which, however, it has been proved to be instrumental in the development of the field.

Pressing further our sample, abrasion and wear effects are typically observed in hard materials. However, a new world of interesting phenomena with promising applications have been observed in the case of compliant materials as polystyrene polymer, for instance. There, material surface is moulded by effect of the tip dragged over the surface resulting in the formation of a rippled pattern.

Thus, in 1992, Leung and Goh published a pioneering work on the orientational ordering of polymers by atomic force microscope tip-surface interaction. [1] As stated in the abstract, they observed that, by action of an atomic force microscope (AFM) tip nanometer-size structures are induced, resulting in a pattern that is periodic and is oriented perpendicular to the scan direction. Such wavy patterns, later called ripples, appear as the outcome of the tip motion, which reshapes the polymer surface locally.

Nowadays, ripples can be created in a controlled way in a given area after just one surface scan. However, these structures have been elusive to a theoretical understanding for years. This relates to the fact that the complex plowing process investigated in the aforementioned references involves concepts of physics, chemistry, and material science in a rather intermixed way which makes traditional approaches to the problem quite challenging.

In our work we have introduced a mesoscopic dynamic model which allows us to reproduce the main features of the observed patterns. The model parameters were fitted to experiments performed over polystyrene films using a commercial AFM operated in contact mode and standard silicon probes. There it was showed that the surface patterns originated from the plowing process are ultimately due to the competition between two basic mechanisms: (i) viscoplastic indentation of the tip in the polymer surface caused by a constant normal force and (ii) lateral shear of the same surface caused by the tip elastically driven (at constant velocity) along a raster scan pattern. Here, we will review here our recent results on this topic [2, 3, 4, 5].

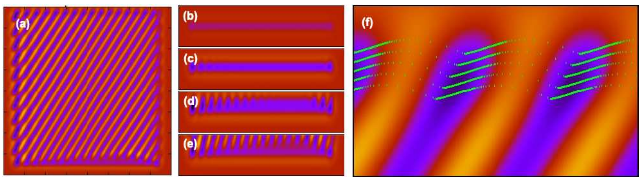

Fig. 1. (a) An example of the obtained rippled pattern. (b-e) Evolution of the same pattern after 1, 5, 10 and 20 scan lines. (f) Tip trajectories corresponding to a series of 5 consecutive scan lines (green dots) overlapped to the surface topography observed after the last one (with $y_s = 1.79\,\mu$m). Frame sizes: (a) $4{\times}4\ \mu\text{m}^2$, (b-e) 4 μm $\times$ 0.5 μm, (f) 0.5 μm $\times$ 0.3 μm.

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