Nanoscale friction on evolving surfaces

Juan J. Mazo[1] and E. Gnecco[2]
[1]Dpto. Física de la Materia Condensada and Instituto de Ciencia de Materiales de Aragón
CSIC-Universidad de Zaragoza, 50009 Zaragoza
[2] Otto Schott Institute of Materials Research, Friedrich Schiller University Jena, Germany

Introduced more than 50 years ago, the nonlinear Prandtl-Tomlinson model is broadly accepted as one of the most efficient ways to interpret the sliding friction of a nanotip on a periodic substrate. The most remarkable feature of this model is probably its simplicity. In this model, a point-mass tip scans a surface elastically pulled by a moving support. If the shape of the tip-substrate interaction potential, the scan velocity and the stiffness of the driving spring are known, one can easily distinguish between stick-slip and continuous sliding regimes and draw quantitative conclusions regarding the static and kinetic friction forces on the tip.

Furthermore, by introducing thermal vibrations and/or properly varying the model parameters, one can predict a variety of phenomena, most of which have been confirmed by dedicated AFM experiments. After a brief overview of the most prominent of those phenomena, we will focus on some intriguing aspects which we are currently studying, theoretically and experimentally, also in collaboration with other groups.

Specifically, in the *standard* PT models constant tip-surface and tip-support interaction are assumed. However this is not always the case. Here we will talk about three known phenomena where contact dynamics plays a crucial role. First, the tip may be oscillated at high frequency while the support is displaced laterally on a crystal surface. Two independent actuation schemes can be introduced: out-of-plane and in-plane, which show important differences from the point of view of contact dynamics, but result in a similar amplitude dependence of the average friction force [1, 2].

While in this case the tip-surface interaction changes periodically with time, this does not occur in the second example that will be discussed. i.e. the formation of wavy patterns observed when scanning a compliant surface. Assuming that the indentation depth increases logarithmically with time, the PT model can be used to predict different types of structures, the orientation of which is related to the scan path [3].

A similar approach, applied to a locally deepening tip-surface potential, has been also applied to crystal surfaces, and used to interpret contact ageing effects. The experimental velocity and temperature dependencies of friction force and lateral contact stiffness are in good agreement with the extended PT model that we propose [4].

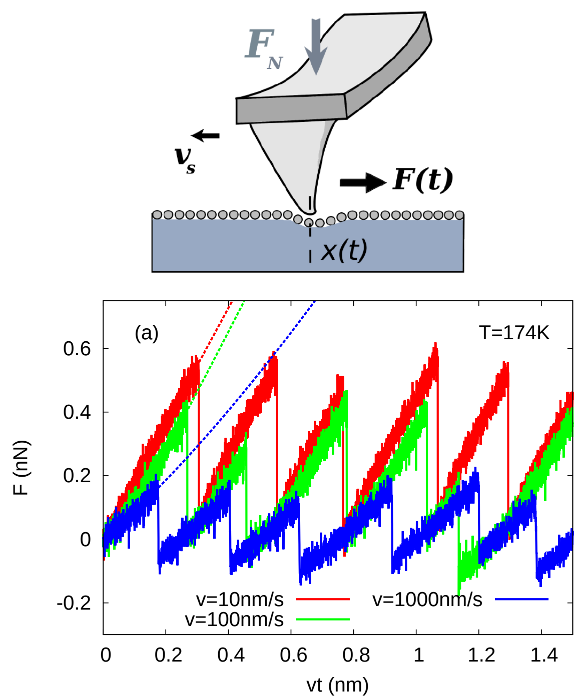

Figure 1: (Top) Simple representation of the AFM scanning of a material surface. (Bottom) Stick-slip cycles at different scan velocities.

[1] R. Roth, O. Y. Fajardo, J.J. Mazo, E. Meyer, and E. Gnecco. *Lateral vibration effects in atomic-scale friction*. Applied Physics Letters **104**, 083103 (2014).

[2] O. Y. Fajardo, E. Gnecco, and J.J. Mazo. *Out-of-plane and in-plane actuation effects on atomic-scale friction*. Physical Review B **89**, 075423 (2014).

[3] I. Bailera, P. Pedraz, E. Gnecco, and J. J. Mazo. *Nanolithography of polymer: The puzzling rippling process*. In preparation.

[4] J.J. Mazo, D. Dietzel, A. Schirmeisen, and E. Gnecco. *Time strengthening of crystal nanocontacts*. Submitted.

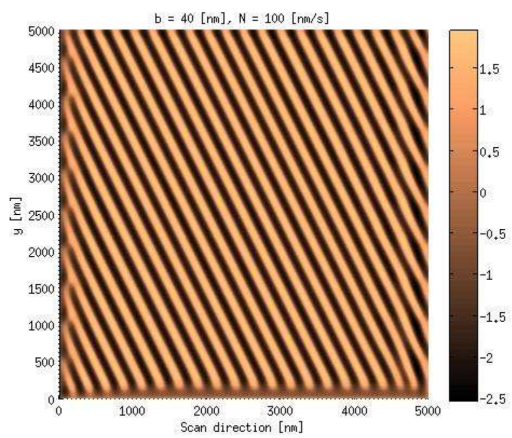

Figure 2: Simulation of the ripple surface patterns generated by a sharp tip scanning a compliant surface.