Energy dissipation over structural and electronic phase transitions

Prof. Dr Ernst Meyer, Prof. Dr Martino Poggio, Dr Marcin Kisiel
University of Basel, Department of Physics, Klingelberstr.82, 4056 Basel, Switzerland

Understanding friction or mechanism of energy dissipation is nowadays among few priorities in nanoscience. The concepts of friction control, wearless sliding or superlubricity are now successfully examined down to the atomic level by means of Atomic Force Microscope (AFM) [1]. Controlling the nanoscale friction is cruicial in nanotechnology, where moving elements are extremely important. Bodies in relative motion, separated by few nanometers gap experiences a tiny friction force [2], whose nature is not yet fully understood. This non contact form of friction can be successfully measured by highly sensitive cantilever oscillating like a tiny pendulum over the surface [3,4]. In pendulum geometry we employ very soft cantilevers with spring constant $k = 10^{-3}$ N/m. The force sensitivity in this configuration is typically few orders of magnitude better as compared to the standard AFM geometry. The enhanced sensitivity recently allowed to distinguish between electronic and phononic contribution to non-contact friction while working over metal-superconductor phase transition [5].

A significant scientific interest, triggered by recent discovery of graphene [6], is focused on 2 dimensional (2D) materials. Owing to breaking of translational symmetry quasi-2D materials exhibit a variety of electronic and structural peculiarities such as Charge Density Waves (CDW) and accompanied periodic lattice distortion (PLD). The problem of friction in those systems still remains unexplored.

Within the project we will perform energy dissipation measurements across critical temperature of charge density wave (CDW) transition metal dichalcogenide compounds – $NbSe_2$ and TaS_2. Due to electron's organization into CDW on the surface, both systems exhibits “self organized” response to the applied force. The ultimate goal is to study energy dissipation while coupling the cantilever either to electronic (CDW) or phononic (PLD) degrees of freedom. The obtained results might be next compared to non-contact friction measurements on NbS_2, which in contrast to $NbSe_2$ shows only superconducting phase transition.

2D layered transition metal dichalcogenides in form of single atomically thin layers are extremely intriguing. Among them MoS_2 – a new direct band gap semiconductor attracts a lot of attention, because of its potential application in future atomically thin electronics [7]. Although

MoS_2 in bulk form is a good lubricant there is still not much known about its friction at the atomic level. Within the project we will perform the temperature dependent non-contact friction measurements on exfoliated MoS_2 with thickness up to few monolayers.

The idea of replacing passive substrate with "active" material hosting phase transition came recently from E. Tosatti and co-workers [8]. Their calculations showed that there should be a measurable amount of order parameter dependent friction while sliding over a structural phase transition. In a second part we will perform dissipation measurements on $SrTiO_3$ sample. The crystal at 105K exhibits cubic to orthorhombic structural phase transition. At the critical temperature system becomes very "soft" owing to proliferation of domain walls, defects, disorder in the distortive part of the crystal structure. Due to this softening the dissipation peak was theoretically predicted to occur [8]. It is moreover suggested that frictional response could be controlled by applying external action.

The Ultra high vacuum (UHV) system already exists. The temperature of the microscope is controlled in the range of 5-150K. In addition to pendulum AFM system is furnished with Scanning Tunneling Microscope (STM). Certain effort would be expected concerning cantilever modification/preparation in order to perform AFM and STM measurements simultaneously.

[1] – M. Urbakh, E. Meyer, *Nanotribology: The renaissance of friction*, Nature Materials, 9, (2010), 8-10.

[2] - A.I. Volokitin, B.N.J. Persson, H. Ueba, *Giant enhancement of noncontact friction between closely spaced bodies by dielectric films and two-dimensional systems*, Journ. Exp. Theor. Phys.104, (2007), 96-110.

[3] - B.C. Stipe, H. J. Mamin, T. D. Stowe, T. W. Kenny, D. Rugar., *Noncontact Friction and Force Fluctuations between Closely Spaced Bodies*, Phys. Rev. Lett.87, (2001), 096801.

[4] - S. Kuehn, R. F. Loring, J. A. Marohn, *Dielectric Fluctuations and the Origins of Noncontact Friction*, Phys. Rev. Lett.96, (2006), 156103.

[5] - M. Kisiel, E. Gnecco, U. Gysin, L. Marot, S. Rast, E. Meyer, *Suppression of electronic friction on Nb films in the superconducting state,* Nature Materials 10, (2011), 119-122.

[6] – A. K. Geim, K. S. Novoselov, *The rise of graphene*, Nature Materials 6, (2007), 183-191.

[7] - A. M. van der Zande, P. Y. Huang, D. A. Chenet, T. C. Berkelbach, Y. You, G. H. Lee, T. F. Heinz, D. R. Reichman, D. A. Muller, J. C. Hone, *Grains and grain boundaries in highly crystalline monolayer molybdenum disulphide,* Nature Materials, advance online publication, 2013/05/05/online.

[8] – A. Benassi, A. Vanossi, G. E. Santoro, E. Tosatti, *Sliding over a Phase Transition,* PRL106, (2011), 256102.