ABSTRACT

We present experimental results concerning the Friction Force Microscopy (FFM) investigation of smooth mica and Si surfaces lubricated by a model lubricant. We have studied the friction force as a function of normal load and sliding velocity, analyzing results in the framework of interfacial liquid structuring and drainage effects.

1. INTRODUCTION

It is well known that the frictional resistance between solids is significantly reduced if lubricated. So far few experiments, performed by FFM, addressed the role of interfacial liquid structuring on boundary lubrication. One of them [1] suggested that Si surfaces lubricated by n-hexadecane and octamethylcyclotetrasiloxane (OMCST) exhibit different dependencies of friction force on load and sliding velocity according to the molecular shape and its specific packing on the substrate. In detail they suggested that i) n-hexadecane forms a higher coordinated entropically cooled boundary layer than OMCST due to the highly anisotropic linear chain molecules and ii) such effect reduces interfacial friction in nanolubrication. More recently surface force apparatus investigations have demonstrated that lubricants rheology, under nanometer scale confinement, strongly depends on surface preparation and contamination [2].

We report in the following experimental results concerning the FFM investigation of mica and Si surfaces lubricated by OMCST. We have studied the friction force as a function of normal load and sliding velocity for the observation of significant FFM frictional effects related to the studied lubricants.

2. EXPERIMENTAL SET UP

FFM measurements have been performed by means of a commercial atomic force microscope (Explorer by Thermomicroscopes-Veeco), equipped with Si tips and operated in a low humidity environment (RH<6%) and at the temperature T = 26°C. We investigated muscovite mica and Si(110) wafers covered by a 2nm-thick native oxide layer. We have observed that as-received Si substrates have mainly a hydrophobic character and that they are only partially wetted by the lubricants. Such unusual properties have been attributed to the presence of a stable contamination layer, presumably coming from packing materials and prolonged air exposure. Despite the possibility to efficiently remove the grease layer by standard wet cleaning solution, we preferred to acquire FFM measurements on as-received samples, since the contamination layer provided a stable frictional response in air for days, together with a small capillary (adhesive) force. The lubricant we used was OMCST (Fluka, >99% purity).

3. RESULTS AND DISCUSSION

In Fig.1 we report a friction force map representing the stick-slip dynamics of the FFM tip on mica in OMCST; similar
Friction maps were obtained for the case of dry contact. In both cases it clearly appeared that the tip dynamics was dominated by elastic instabilities of Tomlinson-like type [1]. The friction force vs normal load curves (not shown) were described by a non-linear relation for both dry and wet nanojunctions, as expected for an adhesive-controlled perfectly-elastic contact [3].

In Figs. 2 we report friction force plots as a function of scanning velocity. A logarithmic increase of friction force with scanning velocity is found, followed by a saturation region above 200 nm/s, in agreement with experiments and theory for thermally-activated elastic instabilities in dry contacts [4].

The observation of stick-slip motion both in dry and wet environment, with slip lengths correlated to the mica atomic corrugation, suggests that lubricant molecules are completely squeezed out at the interface and they may eventually affect junction dynamics through drainage effects. The measured load-dependent curves, however, demonstrate a negligible difference in friction performance between the dry and lubricated case; also the velocity-dependent curves are in qualitative agreement with Ref. [3] concerning dry mica. Such evidences, despite their preliminary character and the need for further accurate investigations of temperature effects, indicate that interfacial liquid structuring may not have any detectable influence on the shearing properties of a nanolubricated junction if an atomically-smooth and clean substrate, like mica, is considered.

In Fig. 3 we report the mean friction force as a function of sliding velocity for the case of as-received Si(110) substrates lubricated by OMCTS. It appears that above a critical velocity of about 2-3 µm/s, dissipation rate is higher for lubricated junctions than for dry ones. In such case the increase in the slope of friction vs velocity curves should be due to self-diffusion motion of liquid molecules on the Si substrate, as excited by the sliding tip: therefore we are actually observing a specific signature of the molecular dissipation mechanisms involved in the sliding process. We presume that, opposed to the FFM measurements on mica, the contamination layer on as-received Si substrates is playing a crucial role in influencing the relaxation time and drainage effects of lubricant molecules.

4. CONCLUSIONS
In summary, we reported FFM measurements performed on freshly cleaved mica and as-received Si substrates in dry air and OMCTS environment. Despite the presumed squeeze out of OMCTS molecules at the contact junction in both cases, significant differences in friction performance can be appreciated according to the chosen substrate. Preliminary data indicate a crucial role of surface contaminants on affecting relaxation times of boundary layers.

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