MOLECULARLY-ASSISTED TUNING OF THE FRICTION LAWS IN A MULTI-ASPERITY TRIBOCONTACT

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ABSTRACT

The design and control of materials at the nanoscale are the foundation of many new strategies for energy generation, storage and efficiency. Besides, friction is an important limitation of energy efficiency performances in MEMS/NEMS [1]. Multi-asperity nanotribology studies are needed to develop a fundamental understanding of interfacial phenomena where frictional behaviour is controlled by interactions between nano-asperities [2]. Controlling these interactions is clearly the first *step* for designing *triboactive* surfaces – *ie*, surfaces whose frictional behavior can be controlled in *real time* by means of external stimuli [2]. A promising way consists to apply a suitable stimulus – *eg.* IR [2] or UV beam [3] – on grafted self-assembled monolayers (SAMs) in order to change their dissipated behavior in real time. However, the *real* friction laws occurring on the asperity's scale – especially their evolutions over time and over multiple asperities – need to be known to control friction when stimulus is applied. This complicated assessment is often ignored by assuming that the friction is uniformly shared on the whole *nanoasperities* which constitutes the so-called *real contact area*. Hence, the friction law is frequently supposed constant over time and well-described by various relationships – *ie*, Coulomb's dry friction, Stokes' viscous friction or Mindlin's partial slip.

However, it is also well-known – from the pioneered LFM/FFM's works – that the elemental friction law at the asperity's scale is intrinsically connected to the size of the asperity itself and especially to the ratio between the sliding amplitude and the asperity's contact radius. This is why the classical law often breaks down at the asperity's scale.

Hence, it clearly appears that friction law can *locally* changes from an asperity to another in a multi-asperity contact [4]. This is especially true for grafted self-assembled monolayers because their frictional behavior is mainly controlled by the entropy variations [5].

In this work, evolution of friction laws of alkanethiol self-assembled monolayers is studied at the nanoscale as a function of sliding amplitude and velocity by using a grafted AT-cut quartz crystal resonator (QCR, 6 MHz) which is in contact with a rough bare alumina ball (4 mm) at constant normal load (500 µN).

The surface displacement amplitudes of the AT-cut QCR – *ie*, the sliding amplitude – is controlled by means of a Vector Network Analyzer (*R&S ZNC 3*) [4, 6]. In order to study the interaction between the QCR and ball's asperities, experiments were performed over a wide amplitude range – from 40 pm to 40 nm – by changing the drive level provided by the network analyzer [6]. Thus, induced sliding velocity lies from $mm.s^{-1}$ to $m.s^{-1}$ which is actually in the range of actual MEMS one.

When the rough ball is applied at constant normal load on the QCR, the network analyzer sweeps the frequency across the resonance and measures the resonator's electrical admittance [6]. At the resonance frequency, the real part of the latter forms the well-known resonance curve which is characterized by its quality factor *Q*. Hence, any variations of resonance frequency (*dF)* and dissipation factor ($dD = dQ^{-1}$) can be studied over time as function of the sliding amplitude or sliding velocity [7]. The frictional behavior can be accurately studied – for strong bonding conditions – by fitting the evolution of *slip-time (ie. dD/dF) vs.* amplitude by power-laws [8].

As a main result, the power-law exponent continuously changes *vs.* amplitude. Since this evolution is equivalent to those of friction force *vs.* velocity [8], friction laws in a multi-asperity contact can be accurately tuned by specially designed or tailored molecules.

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