Friction of Xenon monolayers on Copper

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Superlubricity 1

Dry friction assumes very small values when the (nano)contacts between two crystalline surfaces are incommensurate:
The force coming from the mismatched atoms in the contact area point in all directions and sum up to zero.

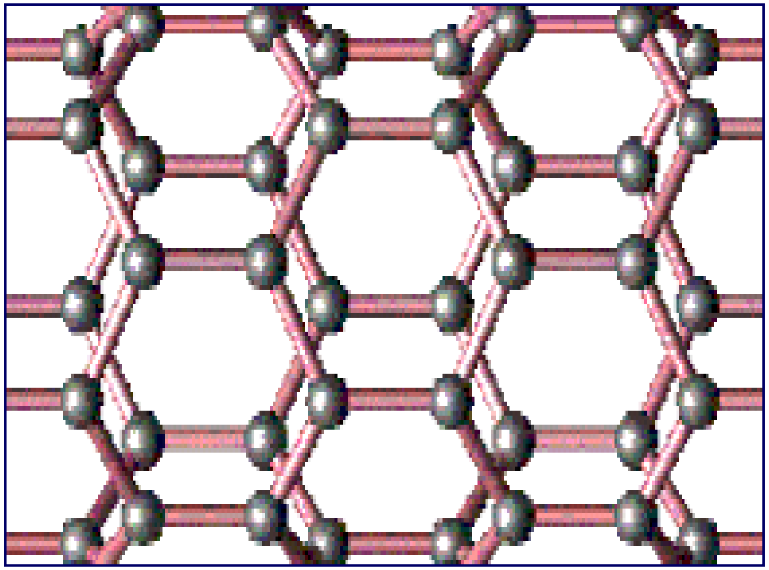
Hirano and K. Shinjo, PRB 90

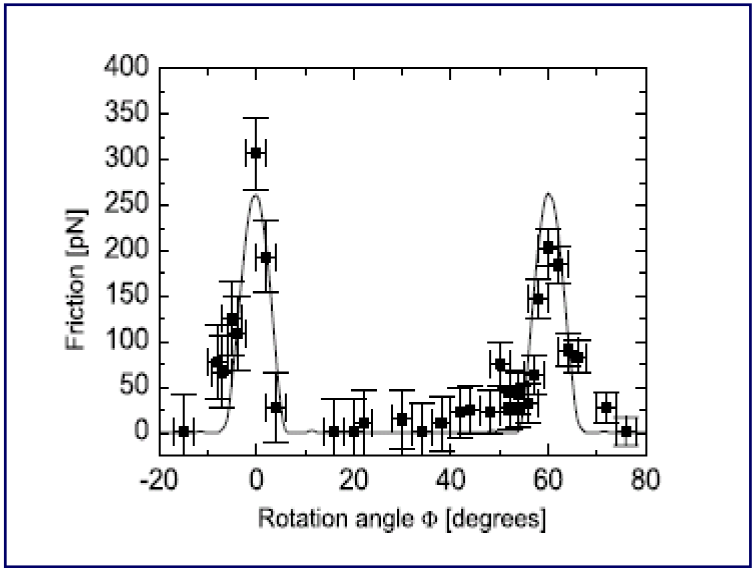
Vanishing friction on a silicon surface was observed with ultra-high vacuum (UHV) scanning tunneling microscopy

Hirano et al., PRL 97

Superlubricity 2

First direct experimental confirmation of importance of lattice mismatch on sliding friction: rotating graphite flake above a graphite surface





Dienwiebel, PRL04

Small friction -> incommensurate state

Superlubricity in atomic systems

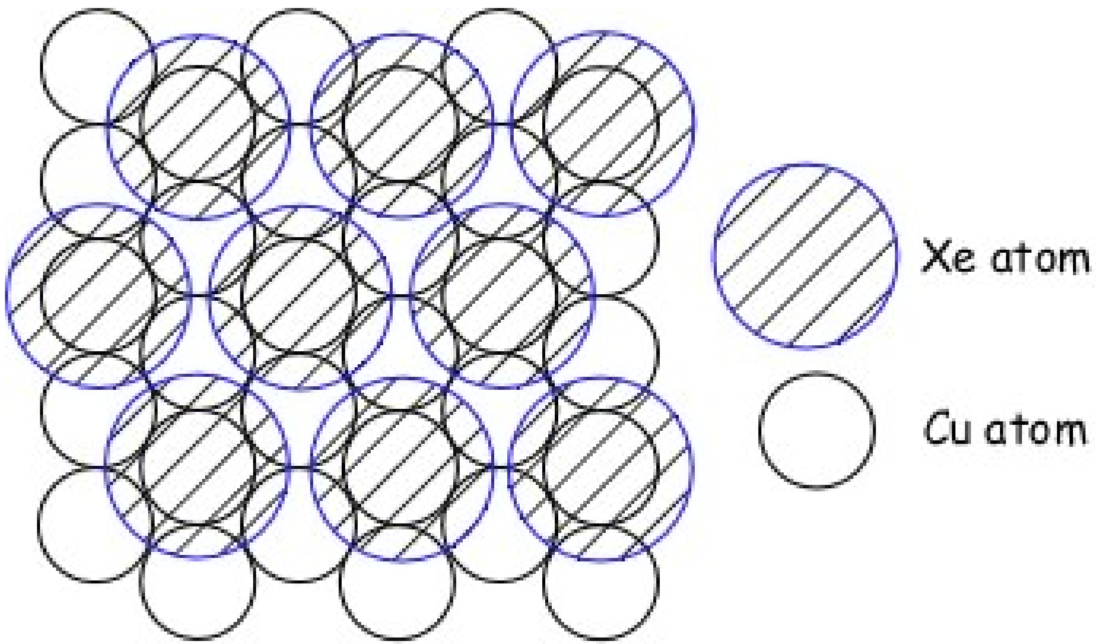
Xenon monolayers on Cu(111)

→ model system to study onset of frictional slip by domain nucleation

Reguzzoni, PNAS10

Commensurate phase Xe on Cu(111)

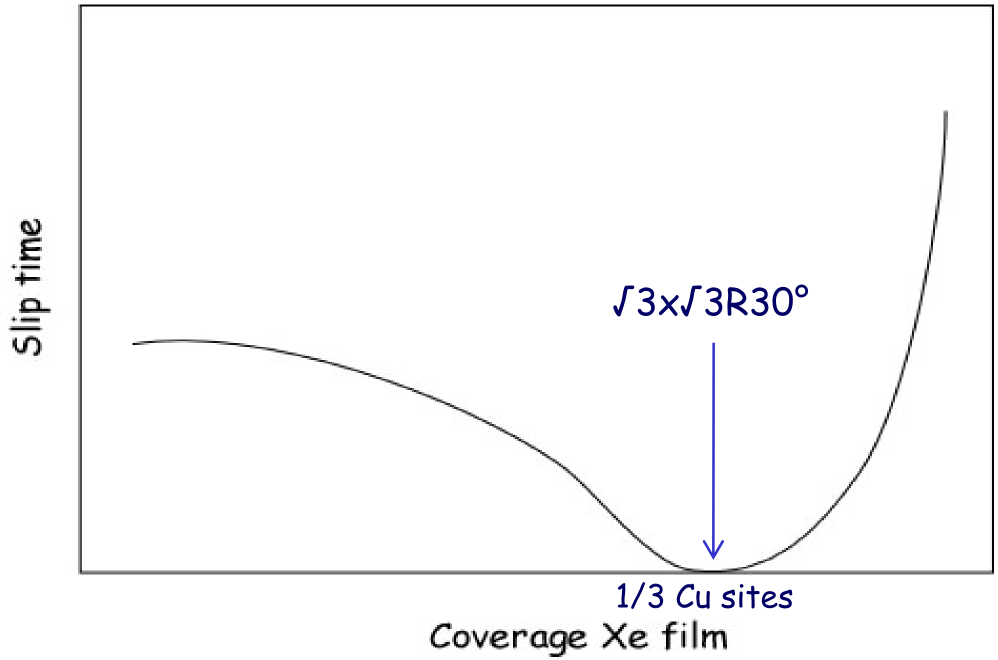
At temperatures between 50-80K Xe is found to form a $\sqrt{3}\times\sqrt{3}R30°$ registred phase on Cu(111)



Bulk Xe-Xe distance 4.38 Å
$\sqrt{3}$x(Cu-Cu spacing) 4.41 Å

Nonlinear sliding dynamics

Xe deposition on Cu(111) at a constant temperature



Calculated static friction force per Xe atom at T~0 K

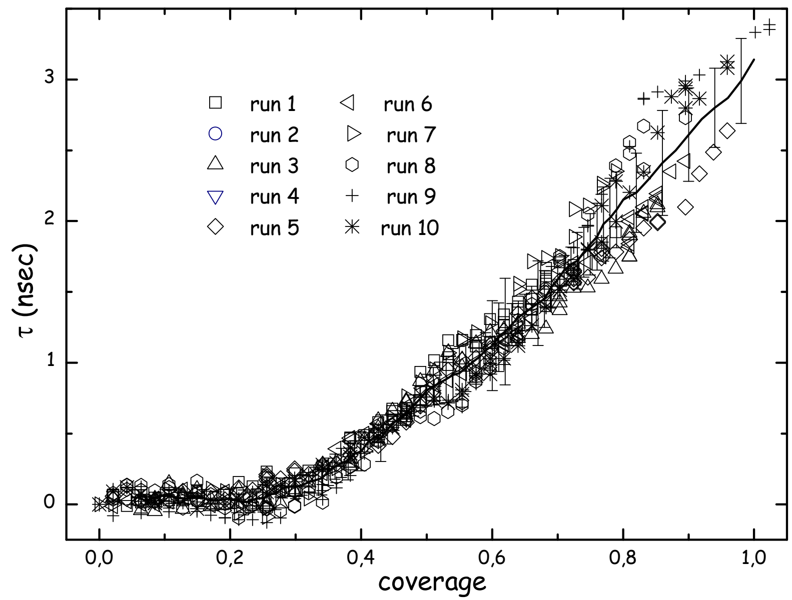
F_S=6.5meV/Å for Cov=1/3

F_S=0.021meV/Å for Cov=0.36

Franchini, to appear in JPCM

Experimental results 1

Coverage scans of Ne on Pb(111) @ 6 K
Pinning at low coverages followed by (structural?) depinning above ~ 0.3 ML



Bruschi, PRL06
Pierno, PRB10

Lack of morphological data on Ne/Pb system to validate interpretation of observed depinning in terms of superlubricity

Experimental results 2

QCM study of Xe at 77K

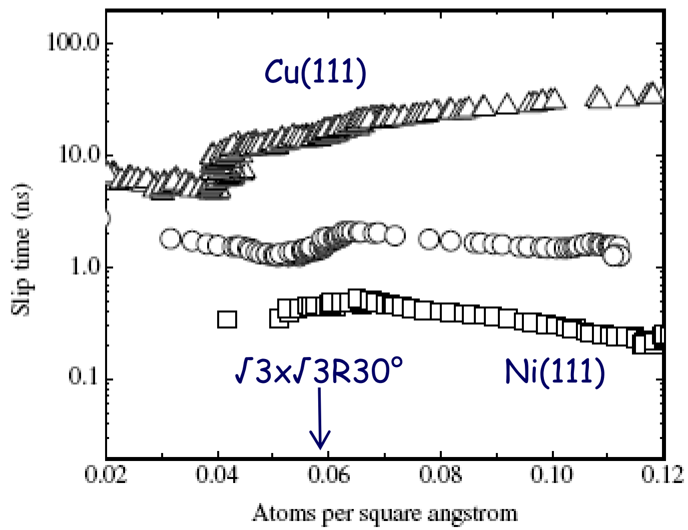


FIG. 2. The slip times for xenon on Cu(111) (triangles), Ni(111) (squares), and graphene/Ni(111) (circles) vs coverage. The coverage (corrected for slip effects) is obtained by solving the right expression in Eq. (2) for (δf_{film}) and then substituting the value into the left expression in Eq. (2). The frequency shift of a monolayer of xenon is calculated from the xenon mass and spacings (coverage) given in Table I. Compressed monolayer coverage is 6 atoms/nm^2, corresponding to 1.31×10^{-12} ng/nm^2.

Coffey, PRL05

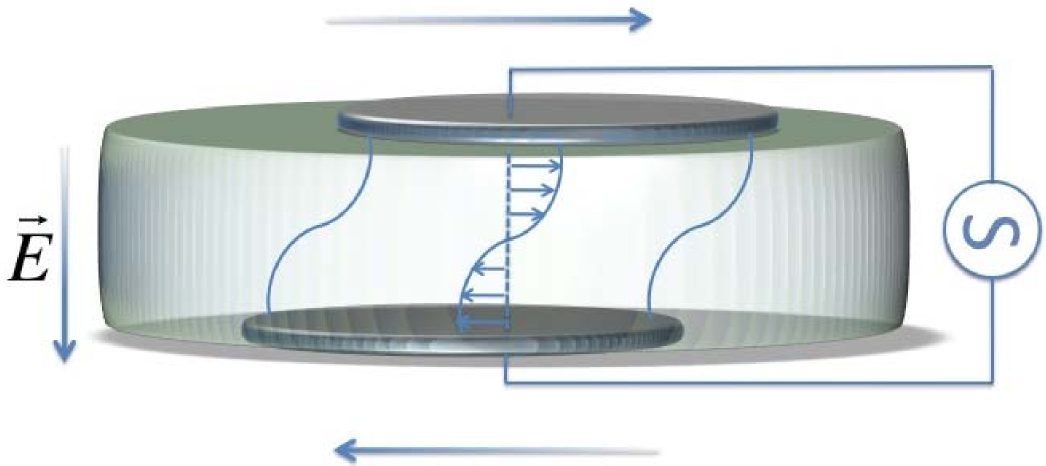
Large slip times on Cu(111) are explained as due to the displacement of preexisting domain walls caused by vacancies in the Xe film or substrate defects

Reguzzoni, PNAS10

Quartz Crystal Microbalance (QCM)

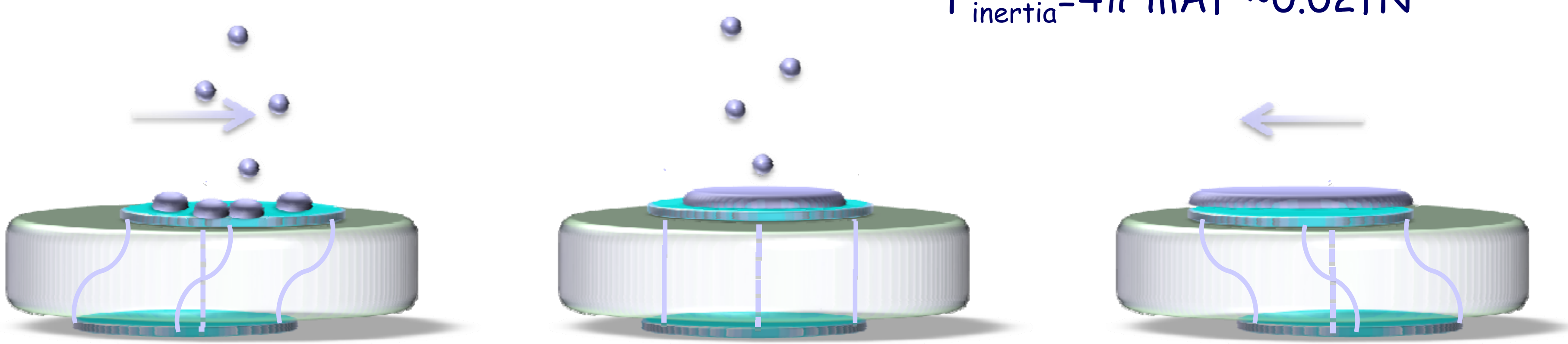
Standard technique to measure mass (e.g. thickness) in evaporators

- quartz disk (D≈10 mm, t≈0.3mm) with two metal electrodes
- parallel faces undergo a shear motion by the application of a variable voltage
- automatic track of mechanical resonance (I harmonic 5MHz), instantaneous measurements of frequency and amplitude
- high quality factor Q≈10^5 ⇒ High sensitivity



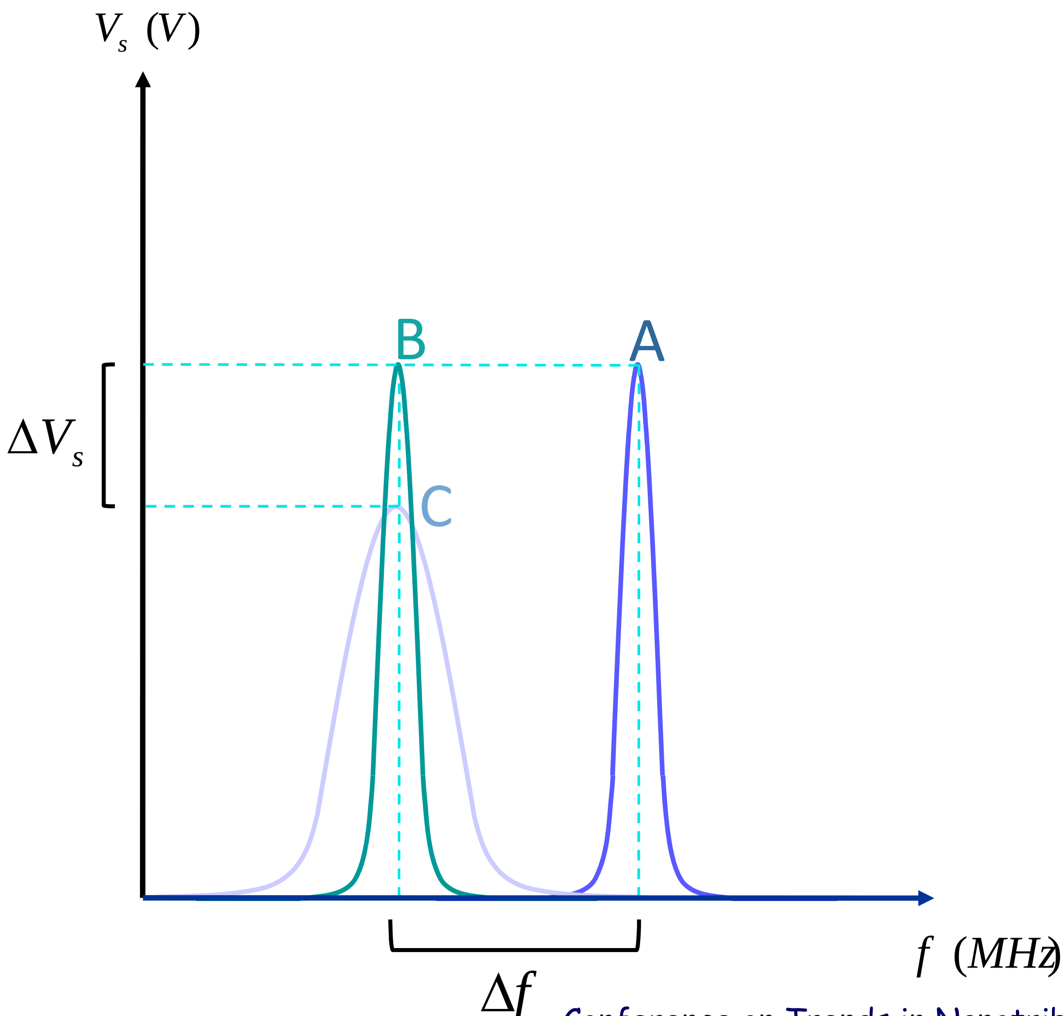
Xe atom

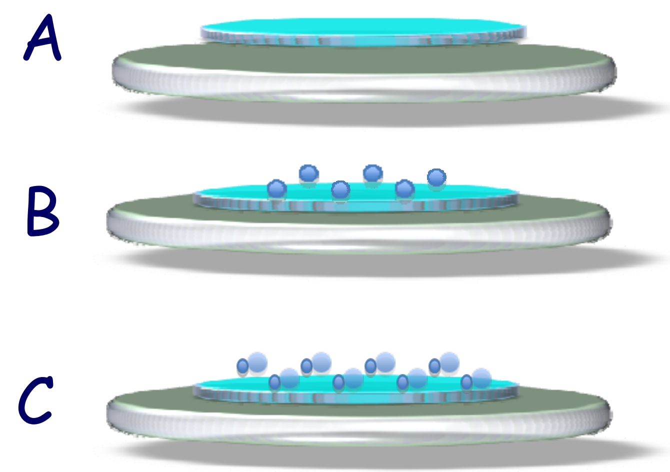
$F_{inertia}=4\pi^2 mAf^2 \sim 0.02fN$



QCM as a nanofriction probe

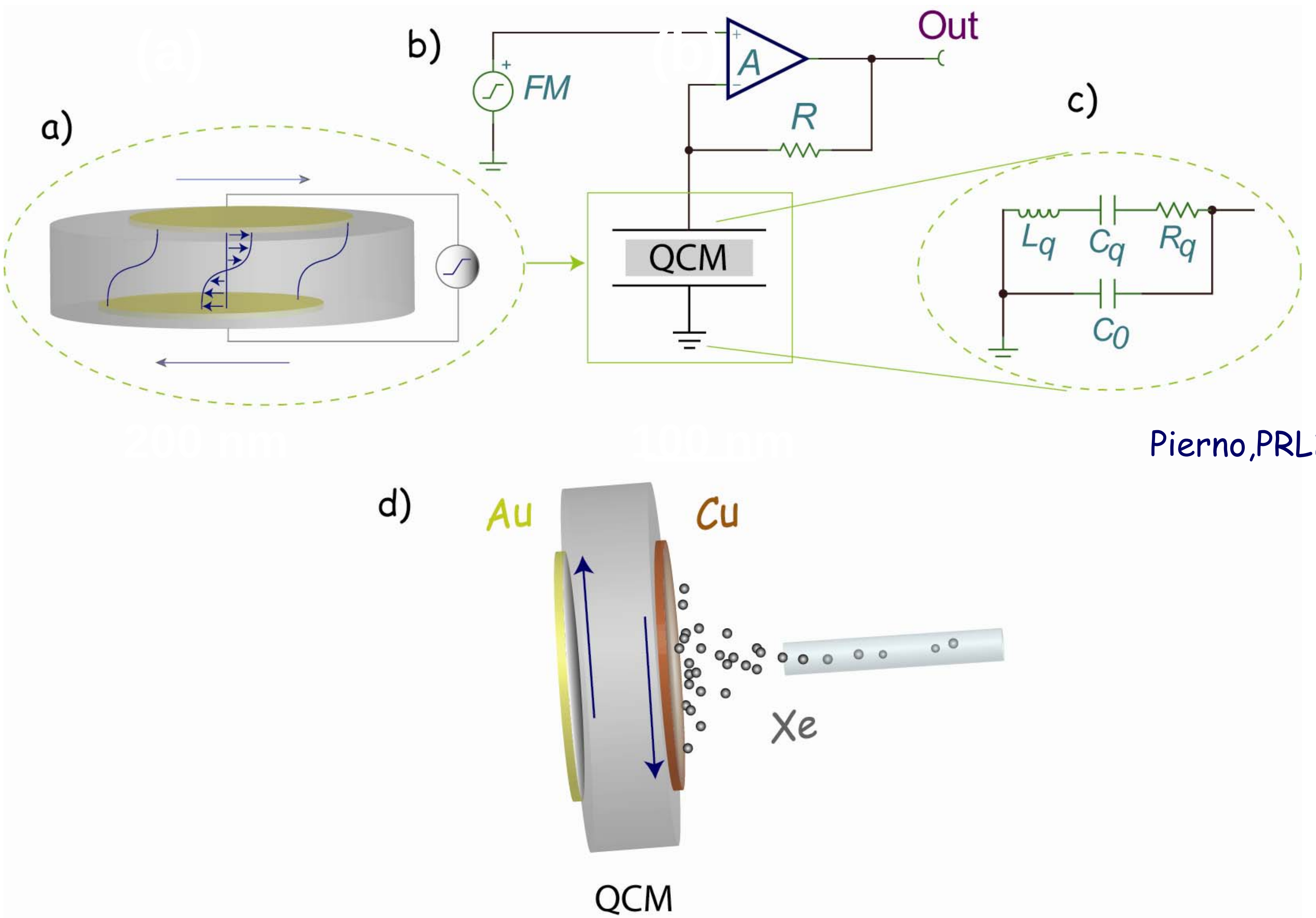
In 1988 J. Krim suggested to use QCM to study sliding of adsorbed film





Δf→adsorbed mass
(2.3 Hz/5MHz for
Ne monolayer)
ΔV_S→dissipation

Xenon deposition on Cu(111)

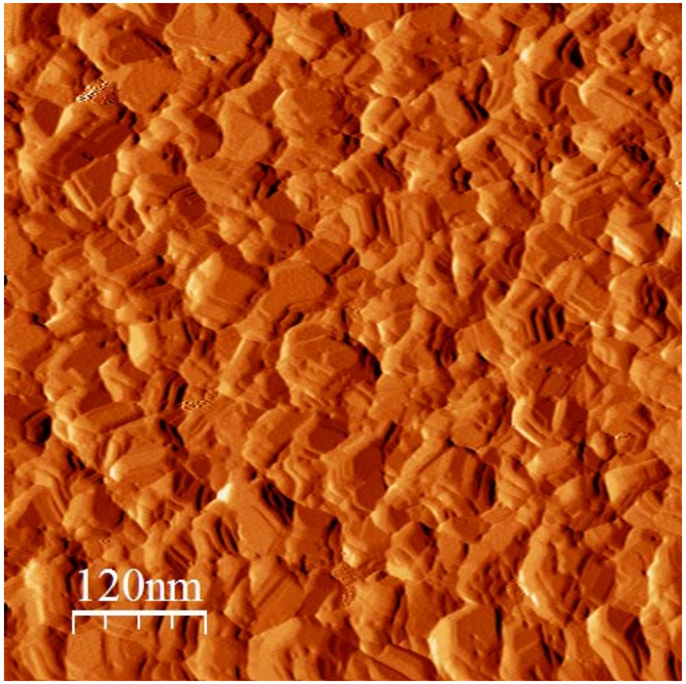


Pierno,PRL2010

Growth and characterization of Cu electrodes

Growth and characterization facilities available at SESAMO laboratory in Modena have been used to prepare crystalline copper in UHV conditions directly on a bare quartz crystal

in-situ STM scan

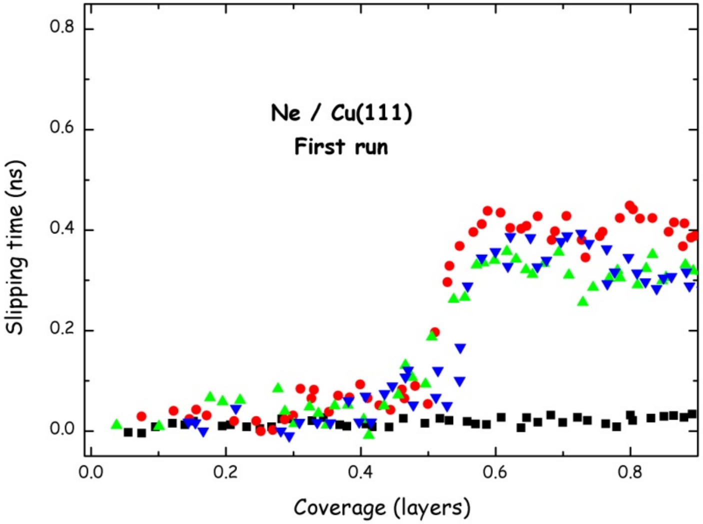


Average size crystallites ~ 50nm
(111) texture

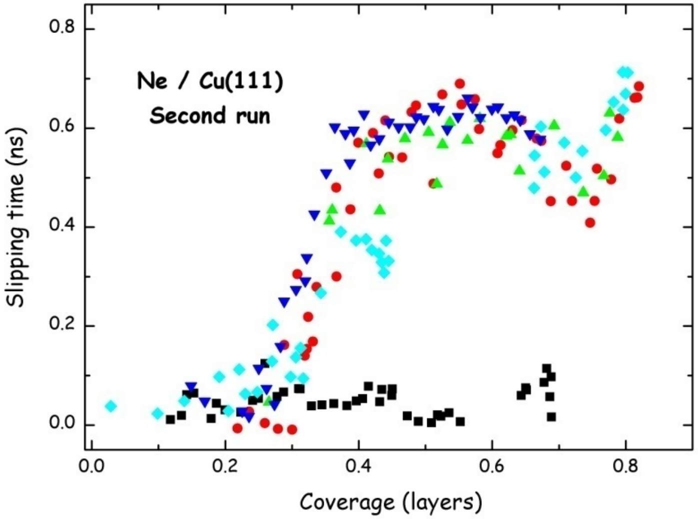
Room temperature deposition
Cr : 30 nm – rate 5 Å/min
Cu: 60 nm – rate 10 Å/min

Ne on Copper

Slip times of Ne films deposited on Cu @ 6K



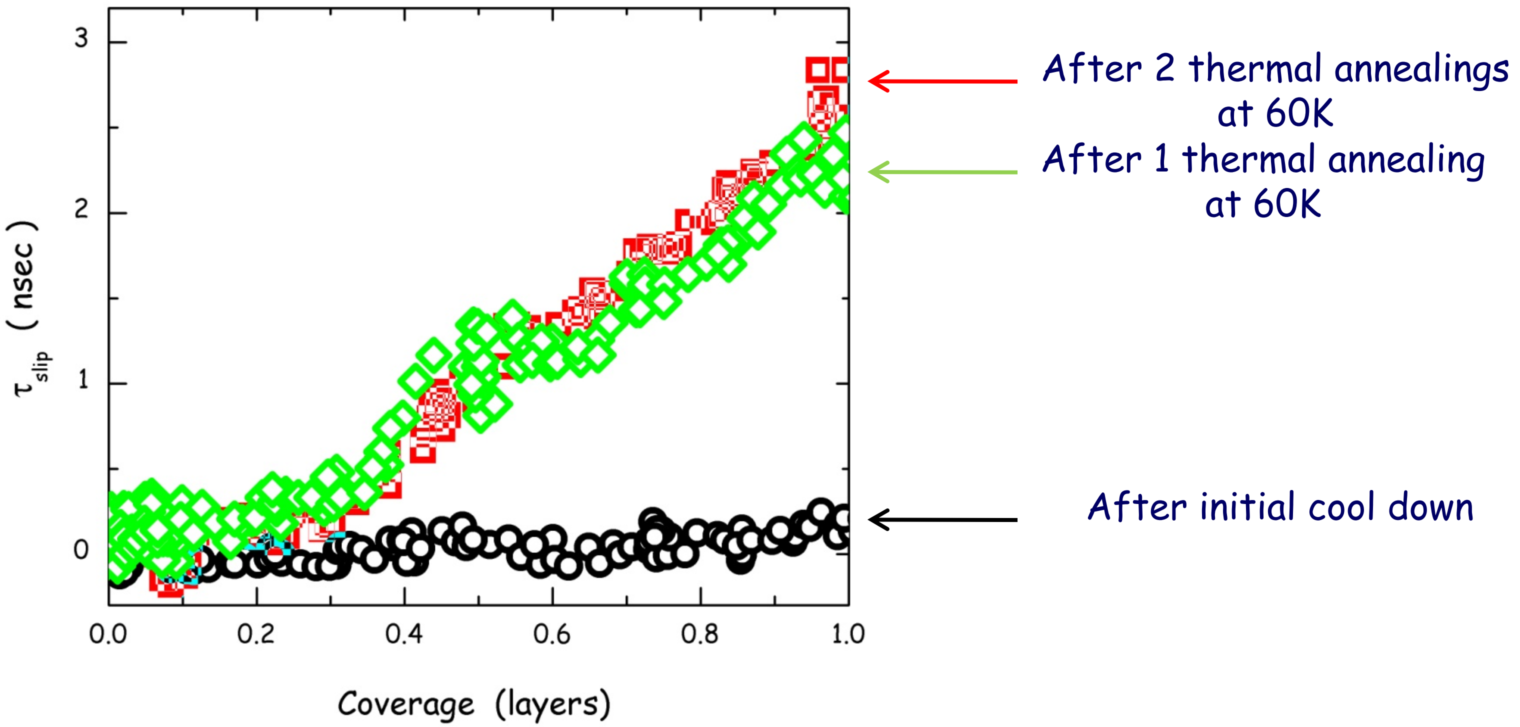
After initial cool down



After initial cool down

Annealing of QCM at low temperatures

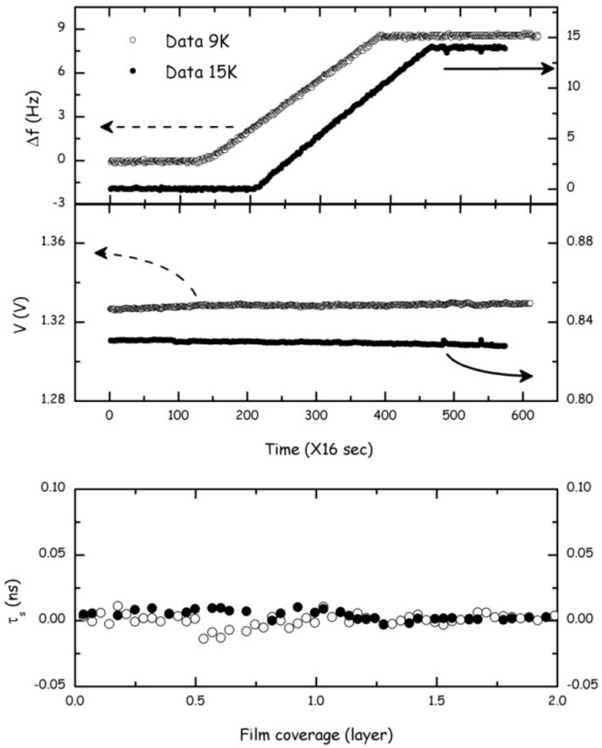
Slip times olf Ne films deposited on the Pb electrode of a QCM @ 6K



Pierno, PRB2011

Deposition of Xe on Cu(111) at low T

No sliding of Xe up to 15 K and for coverages ≤ 2 layers



At low T (e.g. T≤15 K), only Ne is found to slide. All heavier adsorbates (N_2, Ar, Kr) are always pinned to the electrodes

Pierno, PRB2010

CONCLUSIONS

- We have started a new experiment to study the sliding friction of rare gases on Cu(111) with a QCM technique

- Preliminary measurements on an oxidized Cu electrode confirm that only Ne films are found to reproducibly slide below 10K after thermal annealing of the QCM following initial cool down

OUTLOOK

- Repeat experiments with Cu electrodes of good crystalline quality transferred under vacuum at temperatures around 40-60K to search for superlubricity of Xe monolayers

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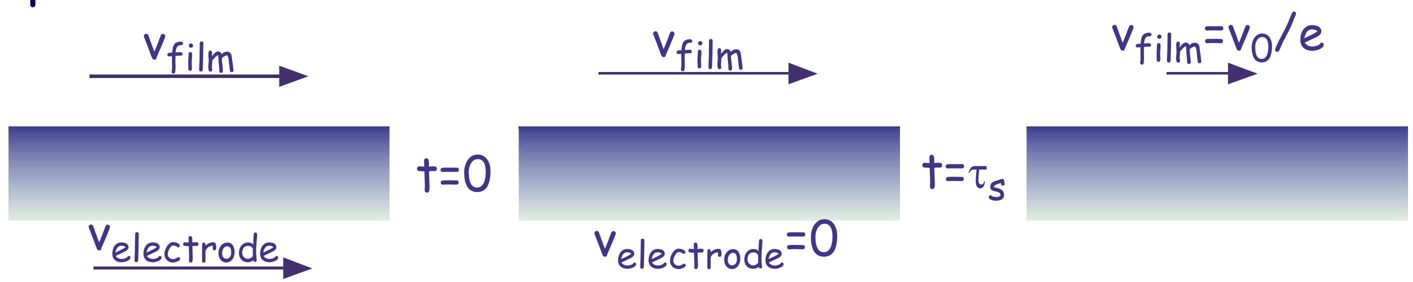
QCM as a nanofriction probe

From ΔV and Δf it is possible to determine slip time τ_s

Slip time is the time it takes the film to follow the electrode



$\tau_s = 0$	film locked to the surface
$\tau_s = \infty$	superfluid film
$\tau_s \approx 1 \div 10$ nsec	sliding Kr monolayer