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Triggering frictional slip

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Triggering Frictional slip

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Questions

☐ Mechanical triggering: can we understand the role of vibration in stick-slip and friction?

☐ Thermal triggering: How does frictional slip occur in subcritical conditions?
Part I
Vibration induced slip
Suppression of stick-slip by vibration

Langevin simulations
Repulsive particles
Normal load
Low driving velocity
Low temperature
Rigid top & bottom plates

Sinusoidal vibration of the bottom plate

\[ Z = A \sin(\omega_0 t) \]
Friction suppression

![Graphs showing friction suppression](image)
Spectral properties

\[ S(\omega) \]

\( \omega_0 = 1 \)

\( \omega_0 = 2 \)

\( \omega_0 = 3 \)

\( \frac{\omega}{\omega_0} \)
Friction suppression

To compute the frequency \( \omega_1 \) we compare the inertial force due to the vibration to the sum of the load and the damping

\[
F_{in}(\omega_1) \approx F_N(\omega_1) + F_{damp}(\omega_1).
\]

\( M \): is the total mass (particles+plates)
\( M_p \): is the mass of the particles
\( F_N \): is the load
\( \eta \): is the damping constant
\( A \): is the vibration amplitude

Using dimensionless variables:

\[
\tilde{f} \equiv \frac{F_N}{MA\eta^2}, \quad \tilde{m} \equiv \frac{M_p}{M}, \quad \tilde{\omega} \equiv \frac{\omega}{\eta}.
\]

\[
M A \omega_1^2 = F_N + M_p \eta A \omega_1
\]

\[
\tilde{\omega}_1 = \frac{1}{2} \left( \tilde{m} + \sqrt{\tilde{m}^2 + 4\tilde{f}} \right)
\]
Friction recovery

Detachment time from the bottom substrate:
\[ \Delta t \simeq \dot{Z}_b M/F_N \simeq A\omega_0 M/F_N \]

Rise time of the bottom substrate:
\[ t_{\text{rise}} = \frac{2\pi}{\omega_0} \]

When the rise time is equal to the detachment time friction is recovered:
\[ \tilde{\omega}_2 = \sqrt{2\pi \tilde{f}}. \]
Comparison with simulations
Phase diagram

\[ \frac{1}{2} < \tilde{m} \equiv \frac{M_p}{M} < 1 \]

- high friction
- low friction

\[ \tilde{m} = \frac{1}{2} \]

\[ \tilde{m} = 1 \]
Part II
Thermally induced slip
Subcritical slip: creep

According to Amontons-Coulomb, two surfaces in contact slide if the later force exceeds the static friction force:

$$F_L > F_s = \mu_s F_N$$

and when they move they are subject to the dynamic friction force:

$$F_d = \mu_d F_N$$

but real interfaces creep even below the static limit.

Onset of slip:
Xe monolayer on Cu substrate

Xe atoms interact via LJ interactions:
\[ \epsilon = 20\text{meV} \]

Xe-Cu potential obtained from ab-initio calculations:
\[ V_0 = 1.9\text{meV} \]

Constant temperature MD simulations:
\[ 25^\circ \text{K} < T < 100^\circ \text{K} \]

Apply a subcritical force to Xe atoms:
\[ F < F_s \simeq 2.4\text{meV/Å} \]

Cu (111) surface adsorbed Xe atom form a commensurate interface

\[ V_0 = 1.9\text{meV} \]
Slip activation time
Onset of slip
Nucleation theory

Energy cost of a commensurate domain:

\[ \Delta E = 2\pi r \Gamma - \frac{2\pi r^2}{\sqrt{3}b^2} Fa \]

- domain wall energy
- gain from the force

Critical domain size:

\[ r_c = \frac{\Gamma \sqrt{3}b^2}{2aF} \]

Energy barrier:

\[ U = \frac{\sqrt{3}\pi \Gamma^2 b^2}{2aF} - E_s \]
Domain wall: theory

\[ E = \int dxdy \left[ \frac{1}{2} B (\nabla u)^2 + \rho V(u) \right] \]

\[ B \simeq 57 \epsilon / \sigma^2 \]
\[ V(u) \simeq \frac{V_0}{2} (1 - \cos(2\pi u / a)) \]

\[ E_{el} \simeq B a^2 / w \]
\[ E_{sub} \simeq V_0 \rho w \]

\[ w \propto \sqrt{B a^2 / V_0 \rho} \]
\[ \Gamma \propto a \sqrt{\rho B V_0} \]
Domain walls: simulations

**DW energy**

\[ \Gamma \left[ \text{meV/Å} \right] \]

\[ (\varepsilon V_0)^{1/2} \left[ \text{meV} \right] \]

**DW shape**

\[ u(x)/a \]

\[ x(V_0/\varepsilon)^{1/2} \]
Nucleation barrier

\[ U \text{ (meV)} \]

\[ \varepsilon V_0(1/F-1/F_c) \text{ (meV Å)} \]
Comparison with QCM experiments

A typical QCM operates at the resonance frequency of $\omega_0 \simeq 10^7 \text{s}^{-1}$ with an amplitude $A \simeq 100\text{Å}$ corresponding to a maximum lateral inertial force on the monolayer $F_{QCM} = m\omega_0^2 A \simeq 10^{-7}\text{meV/Å}$.

In order for the film to slide, the nucleation time should be smaller than the experimental time scale. This would be impossible for a perfect Xe/Cu interface where $F_s \simeq 2.4\text{meV/Å}$.
The role of defects

Defects could allow commensurate interfaces to slip in the QCM!
Conclusions

- Mechanical triggering:
  Under vibration friction is suppressed in a well defined frequency range.

- Thermal triggering:
  Creep in commensurate interface can be understood as a nucleation problem.
  Disorder induced nucleation could explain QCM experiments.
Thank you for your attention!