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Role of the surface electronic structure in the enhancement of quantum friction between parallel silver slabs

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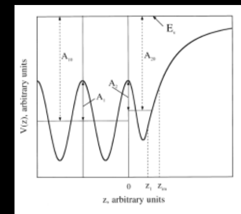
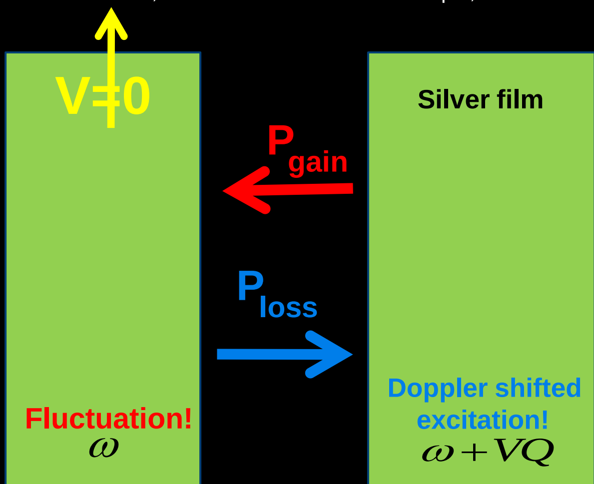
1. Fundamental concepts

Ag-thin films (jellium model and Chulkov model potential)

E.V. Chulkov, V. M. Silkin and P.M. Echenique, Surf.Sci. **437** (1999) 330-352





source of fluctuations

intensity of excitation

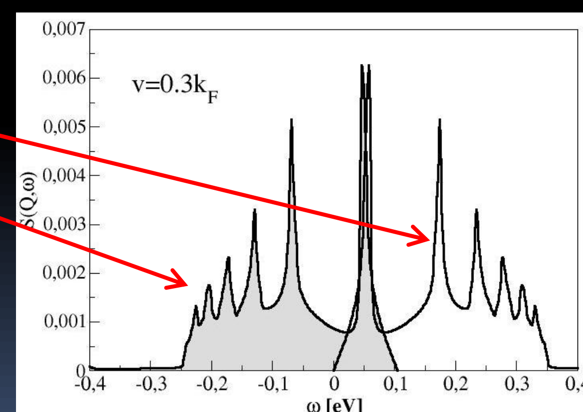
$$P_{loss} = \hbar \int d\omega (\omega + QV) S(|\omega|) \, \mathrm{Im} W(\omega + QV)$$

$$P_{gain} = -P_{loss}(V=0) = \hbar \int d\omega \omega S(|\omega|) \, \mathrm{Im} W(\omega + QV)$$

$$P_{diss} = P_{loss} - P_{gain} = \hbar Q V \int d\omega S(|\omega|) \, \mathrm{Im} W(\omega + QV)$$

$$P_{diss} = -FV$$

$$F = \frac{\hbar}{\pi^3} \int_0^\infty dQ_x dQ_y e^{-2Qd} \int_0^{Q_x V} d\omega \, \mathrm{Im} D(\omega) \, \mathrm{Im} D(VQ_x - \omega)$$



J. B. Pendry, J. Phys.: Condens. Matter **9** 10301 (1997)

B. N. J. Persson, Phys. Rev. **B 57**, 7327 (1997)

A. I. Volokitin, and B. N. J. Persson, Rev. Mod. Phys. **79**, 1291 (2007)

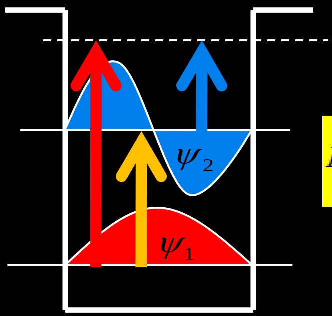
A. I. Volokitin, B. N. J. Persson, Phys. Rev. B **78**, 155437 (2008)

J. B. Pendry, New J. Phys. **12**, 033028 (2010)

V.Despoja, P.M. Echenique, M Šunjić, Phys. Rev. B (in press)

Multiple two-dimensional electron gas

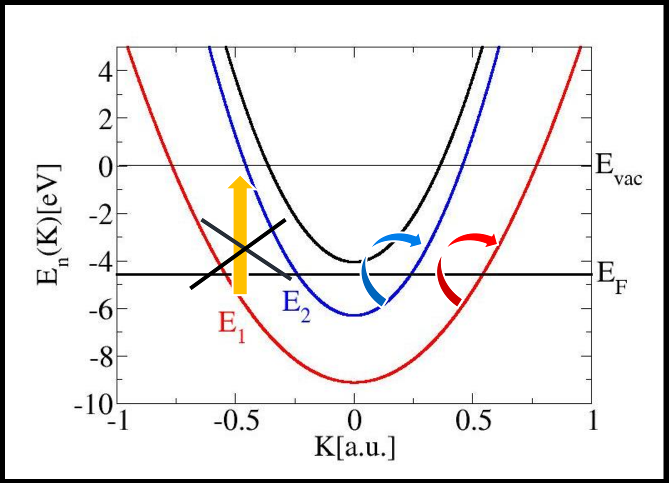
Ultra thin (L~1nm) metallic slabs - quantization in perpendicular direction



E_F

$$E_{n,\vec{K}} = E_n + \frac{\hbar^2 K^2}{2m_n{}^*}$$

2ML- Ag(111)

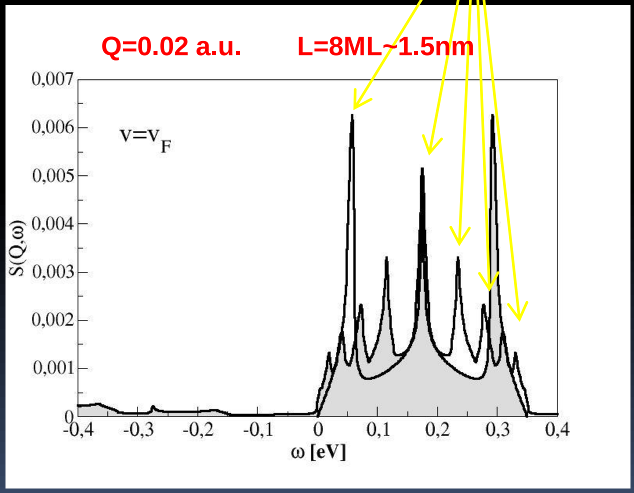


$$V_n^F = \sqrt{\frac{2}{m_n{}^*}(E_F - E_n)}$$

$$\omega_n = QV_{F_n}$$

source of fluctuations!

reservoir of electronic excitations!



$Q_C = 1/d \approx 0.01 a.u.$ $\quad V_C = V_F$ $\quad \Delta\omega_C = Q_C V_C = 0.1 eV$

$$\Delta\omega_C < \Delta E_{12} \approx 1eV$$

$$\Delta\omega_{Doppler} = Q(V_{F_n} + V_{F_m})$$

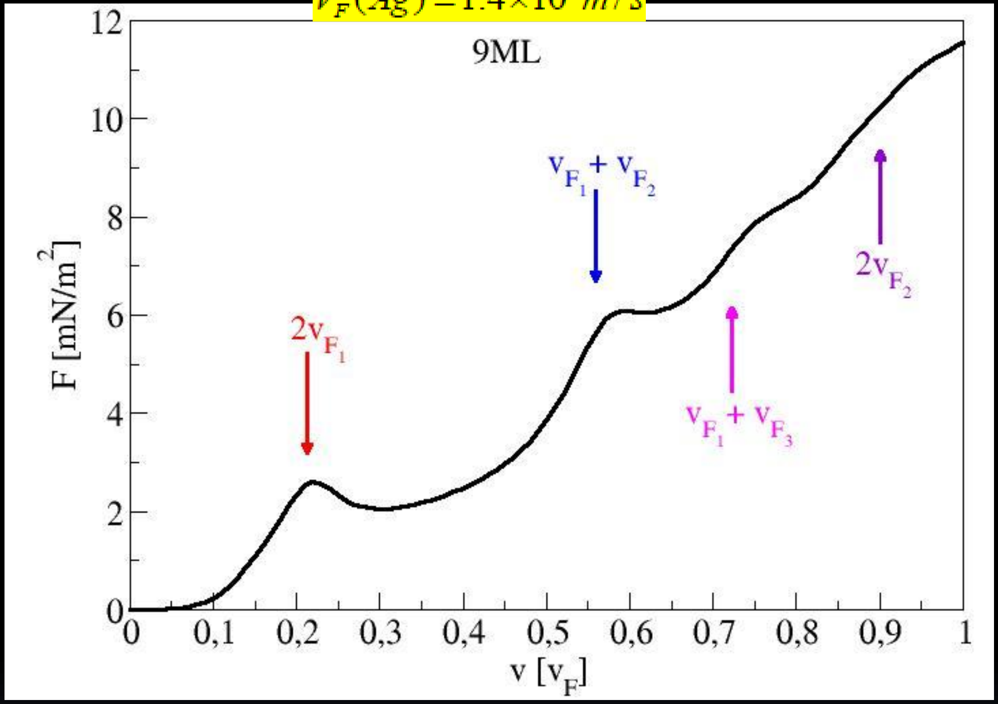
$$\Delta\omega_{Doppler} = QV$$

Resonance condition !!!

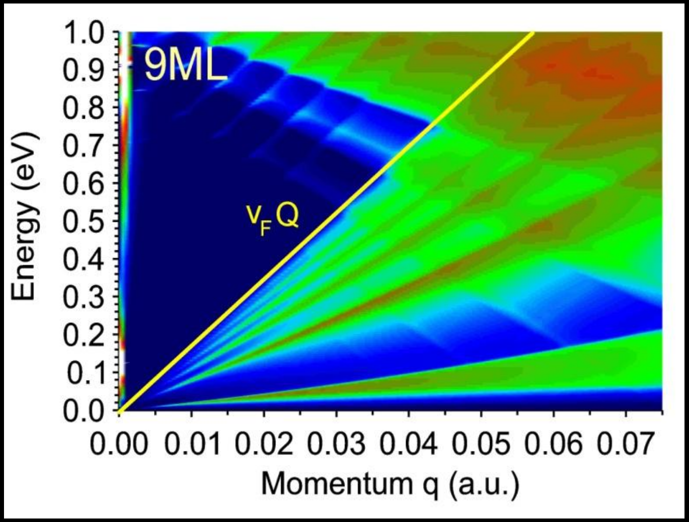
$$V_{rez} = V_{F_n} + V_{F_m}$$

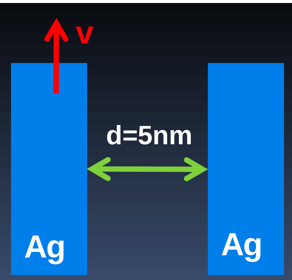
2. Friction force vs. velocity (Quantum Size effects)

$V_F(Ag) = 1.4 \times 10^6 m/s$



Loss function - Ag(jellium)

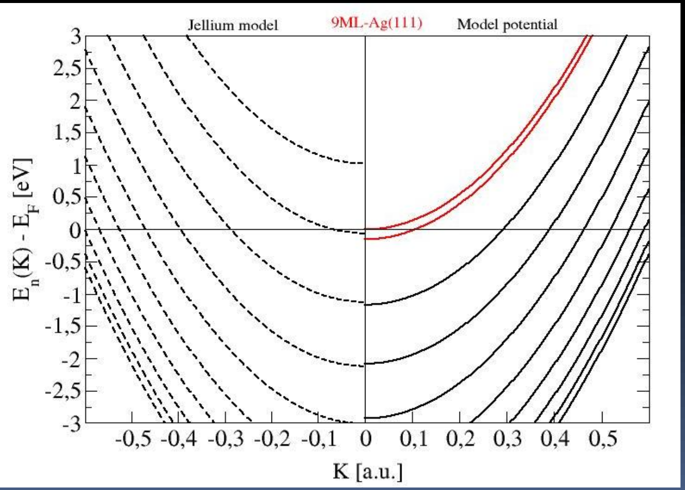


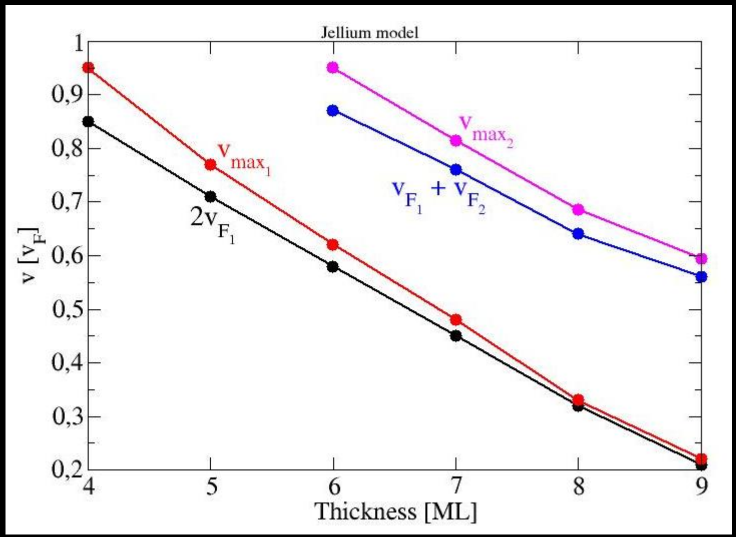


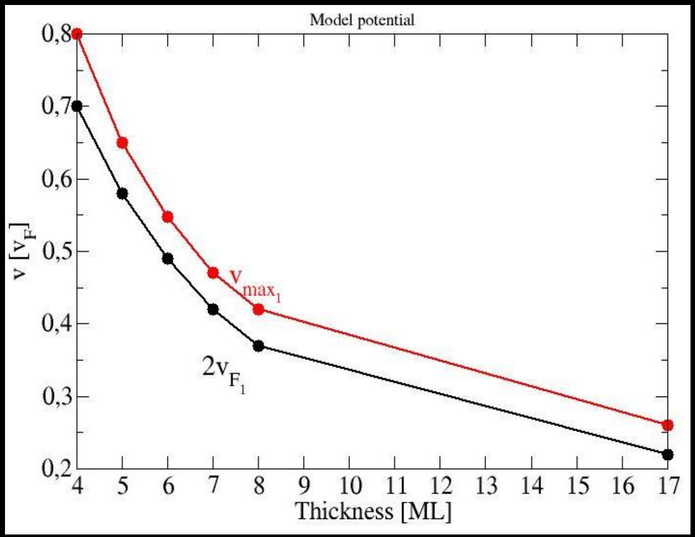
1ML~0.2nm

Resonance condition !!!

$$V_{rez} = V_{F_n} + V_{F_m}$$

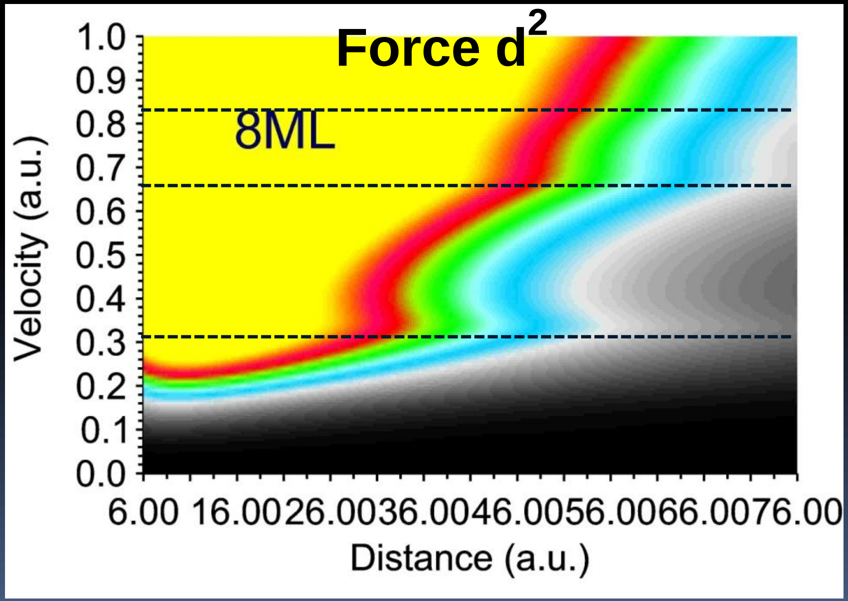






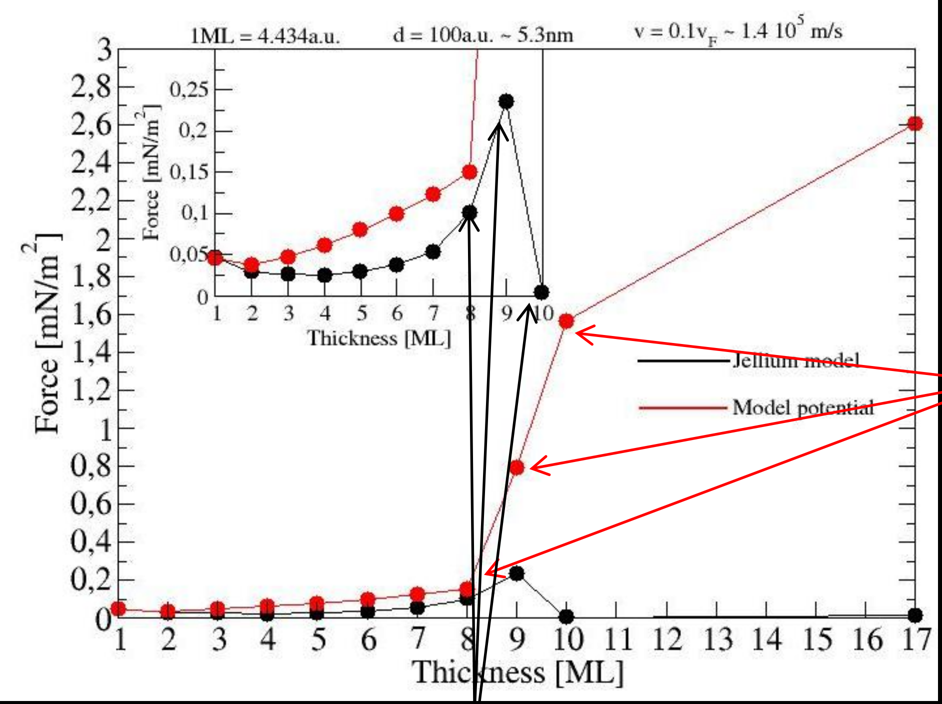
$V_{F_1} + V_{F_2}$

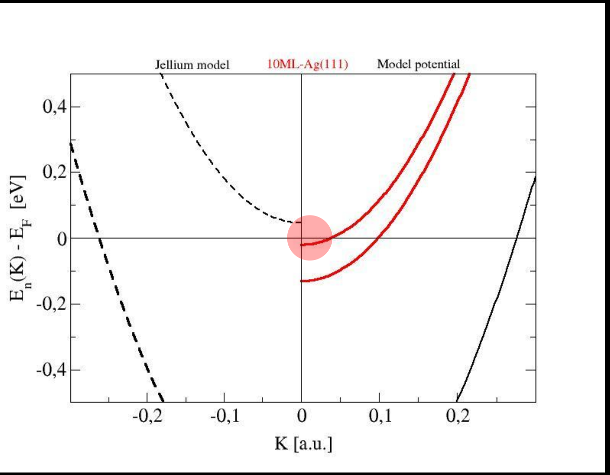
$2v_{F_1}$



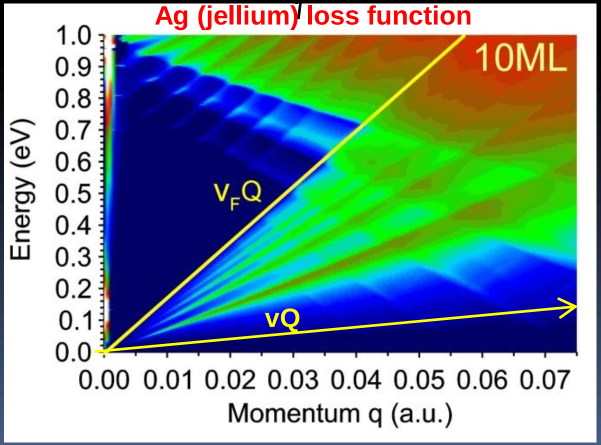
$V_{F_1} + V_{F_3}$

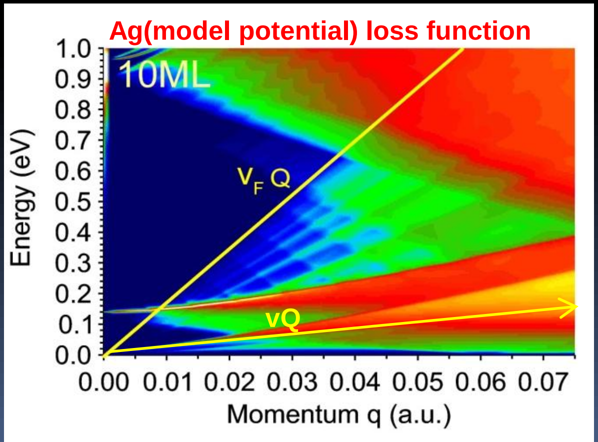
3. Friction force vs. Ag film thickness (anomaly at ~10ML)





Nocc=8



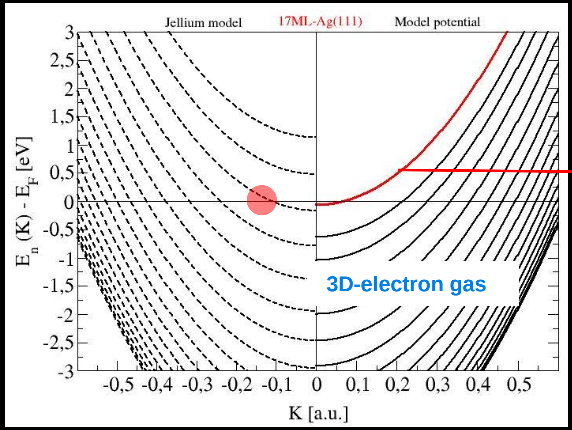


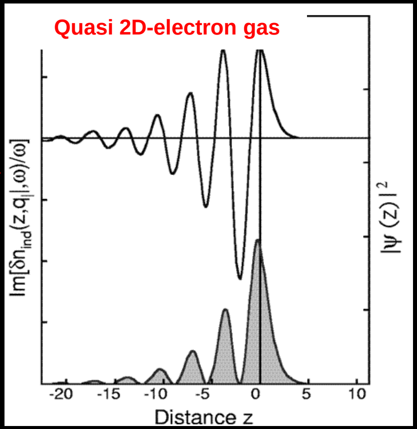
4. Friction force driven by Acoustic Surface Plasmon (ASP)

ASP theory

J. M. Pitarke, V. U. Nazarov, V. M. Silkin, E. V. Chulkov, E. Zaremba, and P. M. Echenique Phys. Rev. **B 70**, 205403 (2004)

V. M. Silkin ,J.M. Pitarke, E. V. Chulkov and P. M. Echenique Phys. Rev. **B 72**, 115435 (2005)





$$\varepsilon_{eff}^{2D} = 1 - W^{3D}\chi_{SS}^{2D}$$

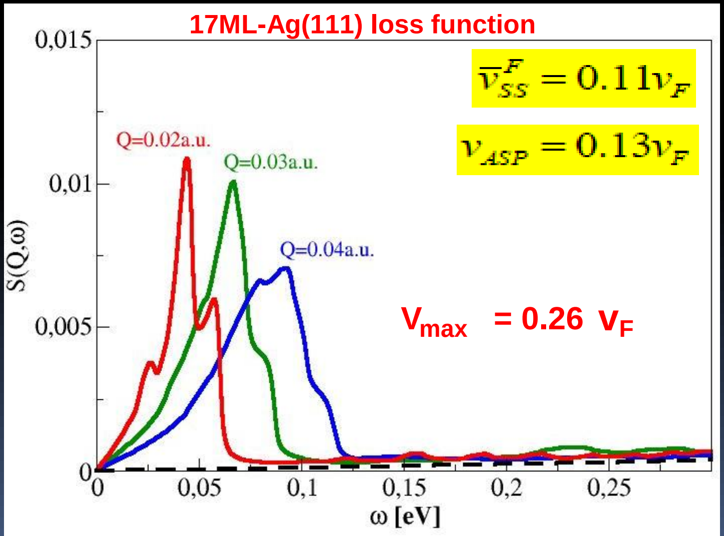
$$W^{3D} = \left\langle \psi_{SS}^2(z) \middle| W^{3D}(z,z') \middle| \psi_{SS}^2(z') \right\rangle$$

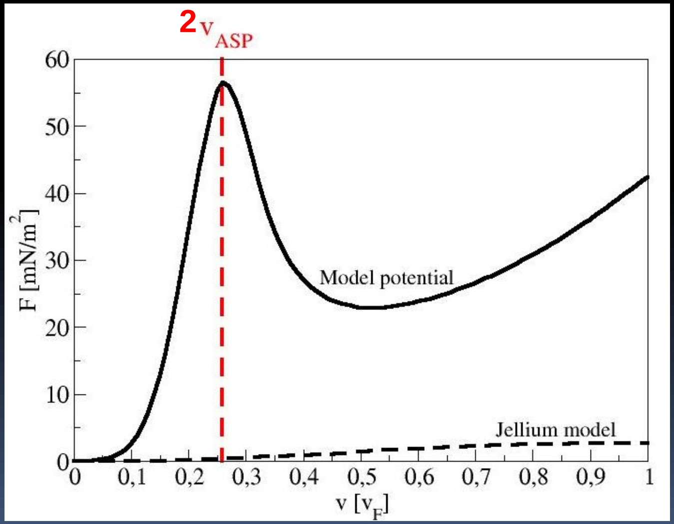
$$\varepsilon_{eff}^{2D}(Q,\omega) = 0$$

Acoustic surface plasmon!!!!

$$\omega_{ASP} = \alpha v_{SS}^F Q$$

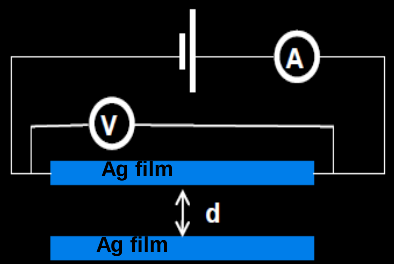
$$\alpha \approx 1$$

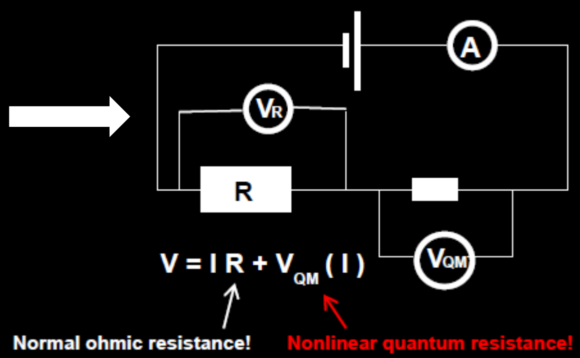


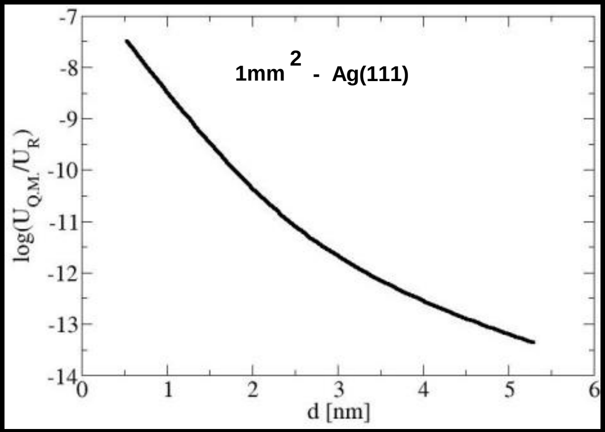


Back to reality!- Experimental measurement of the quantum friction

A) Directly by measuring the U-I characteristic



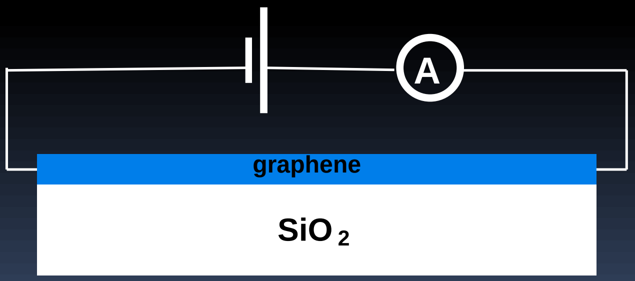




B) Coulomb drag

M. B. Pogrebinskii, Fiz. Tekh. Poluprovodn. **11**, 637 (1977) [Sov. Phys. Semicond. **11**, 372 (1977).]
P. J. Price, Physica B+C (Amsterdam) 117-118, **750** (1983).
T. J. Gramila, J. P. Eisenstein, A. H. MacDonald, L. N. Pfeiffer, and K.W. West, Phys. Rev. Lett. **66**, 1216 (1991).
U. Sivan, P. M. Solomon, and H. Shtrikman, Phys. Rev. Lett. **68**, 1196 (1992).

A. I. Volokitin and B. N. J. Persson, Phys. Rev. Lett. **106**, 094502 (2011)



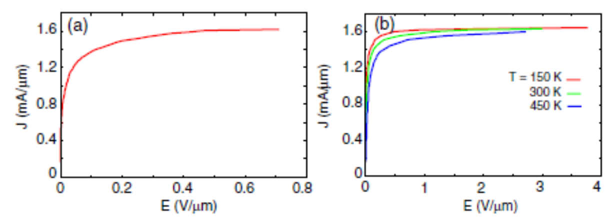


FIG. 2 (color online). The role of the interaction between phonon polaritons in SiO_2 and free carriers in graphene for graphene field-effect transistor transport. The separation between graphene and SiO_2 is $d = 3.5$ Å. (a) Current density-electric field dependence at $T = 0$ K, $n = 10^{12}$ cm^{-12}. (b) The same as in (a) but for different temperatures.

5. Conclusion

1. Friction force between thin metallic films (d~1nm) has local maximums for relative velocities which correspond to Fermi velocities within quantised 2D bands inside films-QSE

2. Quantum friction between metallic surfaces which support surface states (like noble metal (111) surfaces) is strongly enhanced-ASP enhanced friction

3. Is quantum friction macroscopic quantum phenomenon, i.e. whether the quantum friction is fact or fiction?

Thank you for your attention!