Electronic transport in graphene and metallic nanotubes the role of electron-phonon scattering

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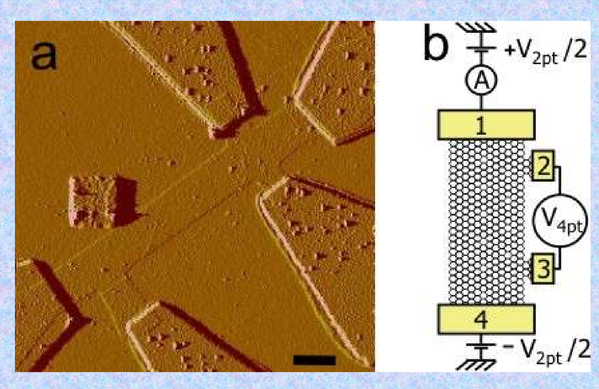
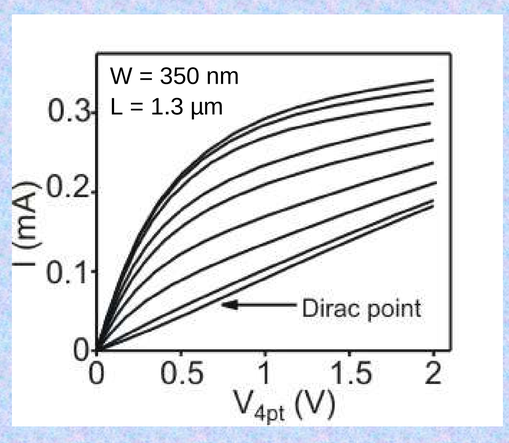
Graphene

At high-bias, the current tends to saturate because of the scattering of the carriers with the optical-phonons of graphene, but it never reaches the complete saturation because of the competition between electron-phonon scattering and electron-defects scattering.

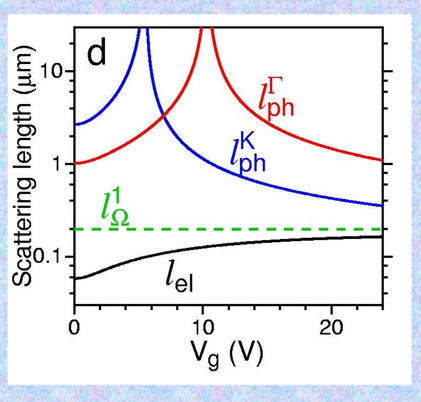
A. Barreiro *et al.*, Phys. Rev. Lett. 103, 076601 (2009).



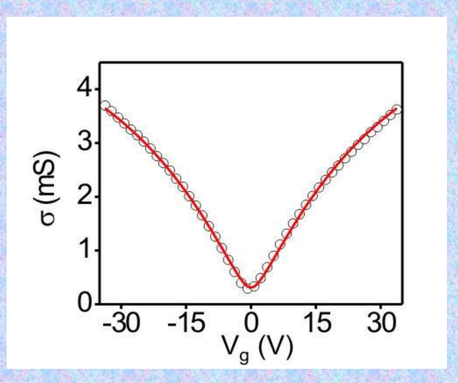
Measurements are done in a four-points configuration (in Barcellona)



The carrier concentration is varied by changing the gate-voltage (V_g). The high-bias quasi-saturation is due electron-phonon scattering.



Three relevant scattering lengths:
l_{Ω} : activation of the phonon emission
l_{ph} : electron-phonon interaction (computed from first-principles)
l_{el} : elastic scattering due to defects (obtained phenomenologically)



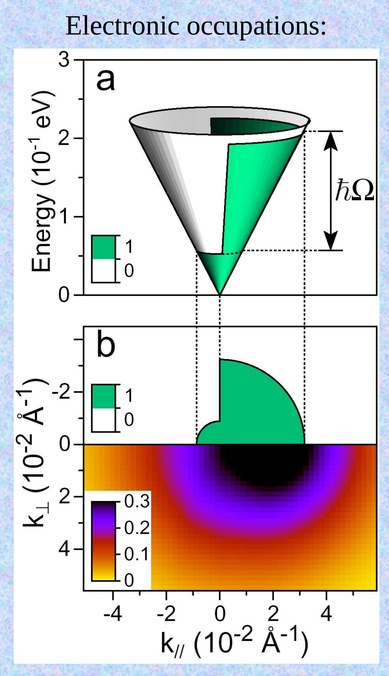
The zero-bias conductivity (σ) is fitted to obtain l_{el} with two models ("C" and "Cδ"). Both models provide σ in perfect agreement with measurements.

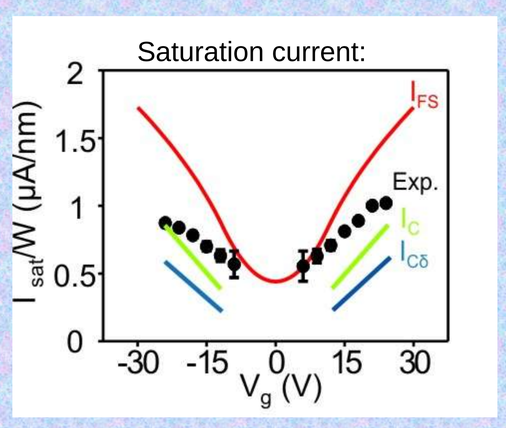
Ideal case:
full saturation (FS)

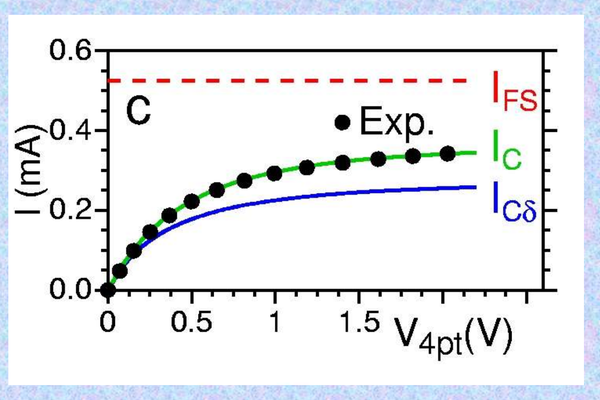
$l_{ph} << l_{\Omega}$
and
$l_{\Omega} + l_{ph} << l_{el}$

Real graphene:

Electronic occupations:







Comparison of measurements with Boltzmann-transport calculations:
Good qualitative agreement.
The results are very sensitive to the model for the elastic scattering.

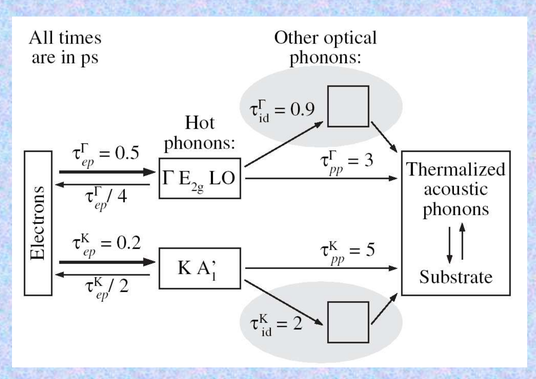
Metallic carbon nanotubes

At high-bias, the current displays a sudden increase of the resistivity and it reaches saturation, because of the scattering of the carriers with optical-phonons. The occupation of the phonons plays a crucial role (hot-phonon generation). Isotopic disorder creates additional channels for the hot-phonon deexcitation, reduces their population and, thus, can be used to improve the electrical performances.

N.Vandecasteele *et al.* Phys. Rev. Lett., 102, 196801(2009).
M. Lazzeri & F. Mauri Phys. Rev. B, 73, 165419 (2006).
M. Lazzeri *et al.* Phys. Rev. Lett., 95, 236802 (2005).

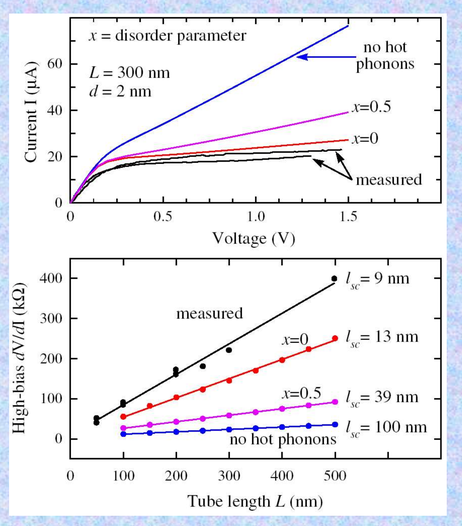
Electron-phonon dominates:
l_{el} ~ 1600 nm
l_{ph} ~ 10-100 nm

The rate at which the optical phonons are excited is faster than the rate at which they are de-excited by phonon-phonon scattering.



Three relevant scattering times:
(computed from first-principles)
τ_{ep} : due to electron-phonon
τ_{pp} : due to phonon-phonon
τ_{id} : due to isotopic disorder (x=0.5)

Boltzmann-transport calculations



An important part of the electrical resistence is due to the presence of hot-phonons. Hot-phonon population can be reduced by introducing isotropic disorder.
Measurements from:
Yao et al., PRL 84, 2941 (2000); Javey et al., PRL 92, 106804 (2004); Park et al., Nano Lett. 4, 517 (2004)

Phonon lifetimes due to isotopic disorder (x=0.5).