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ICTP Conference Graphene Week 2008

25 - 29 August 2008

EFE-Raman Study of Graphene Thin Films

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EFE-Raman Study of Graphene Thin Films

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S. Golar

P. Kim

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Columbia University and the National Science Foundation
Center for Electron Transport in Molecular Nanostructures

Outline

- Charge-tunable electron-phonon coupling in graphene

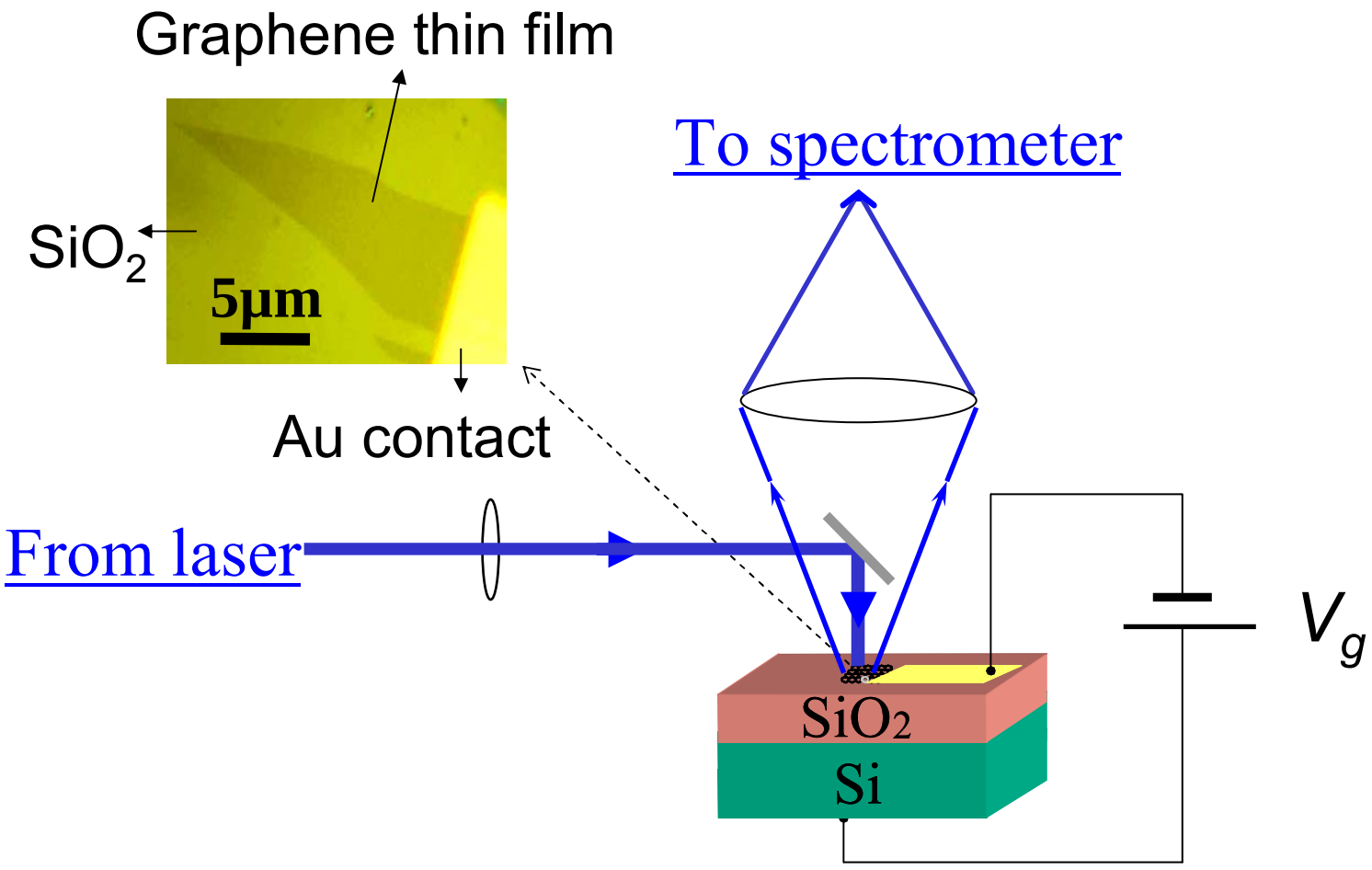
  J.Yan, Y.Zhang, P.Kim, A.Pinczuk **PRL 98, 166802 (2007)**
  J.Yan, Y.Zhang, S.Goler, P.Kim, A.Pinczuk **SSC 143, 39 (2007)**

- Observation of phonon anomaly in bilayer graphene

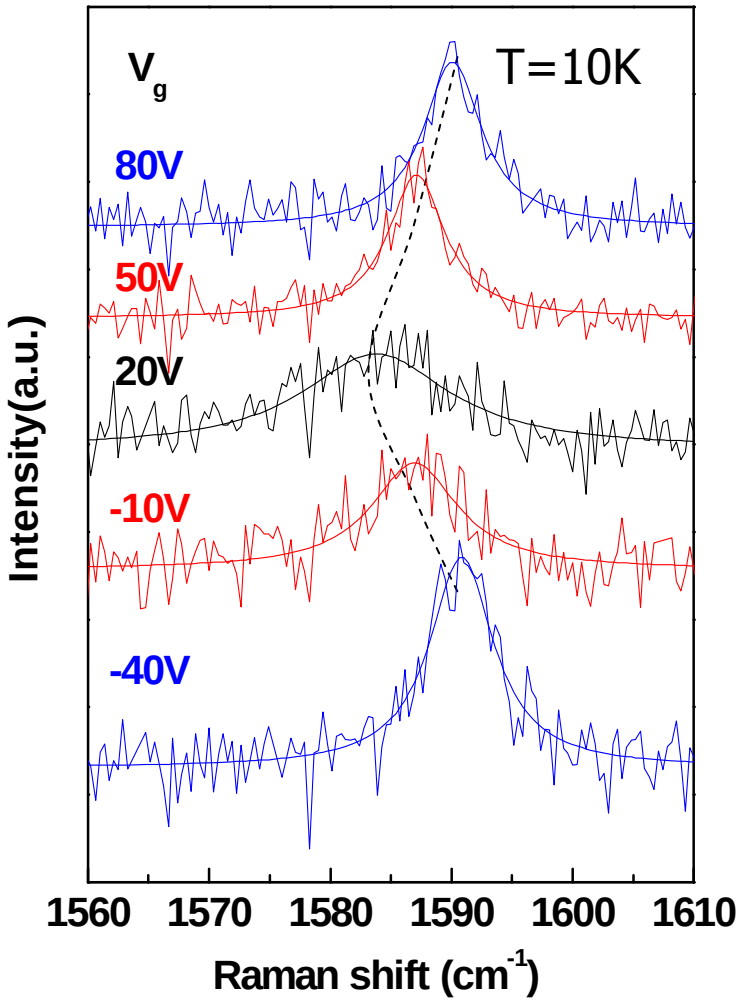
  J.Yan, E.Henriksen, P.Kim, A.Pinczuk **arXiv:0712.3879**

- On-going work of magneto-phonon resonance in graphite and graphene

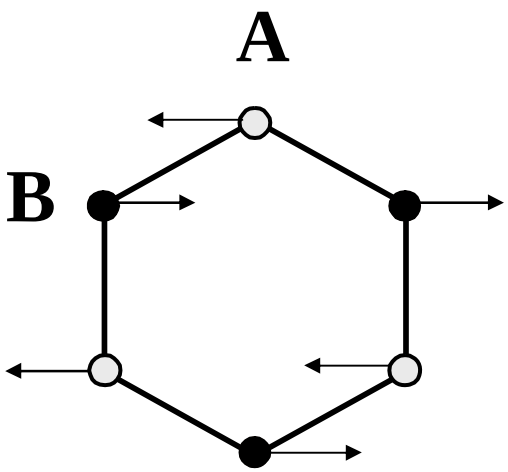
EFE-Raman investigation of graphene



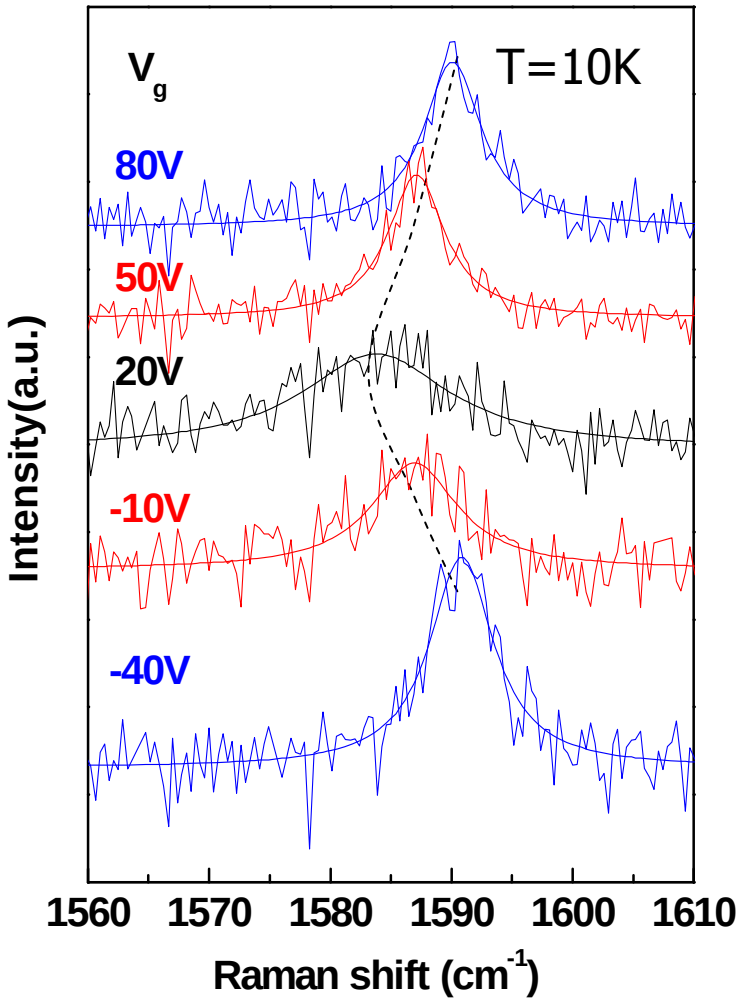
G band in gated graphene

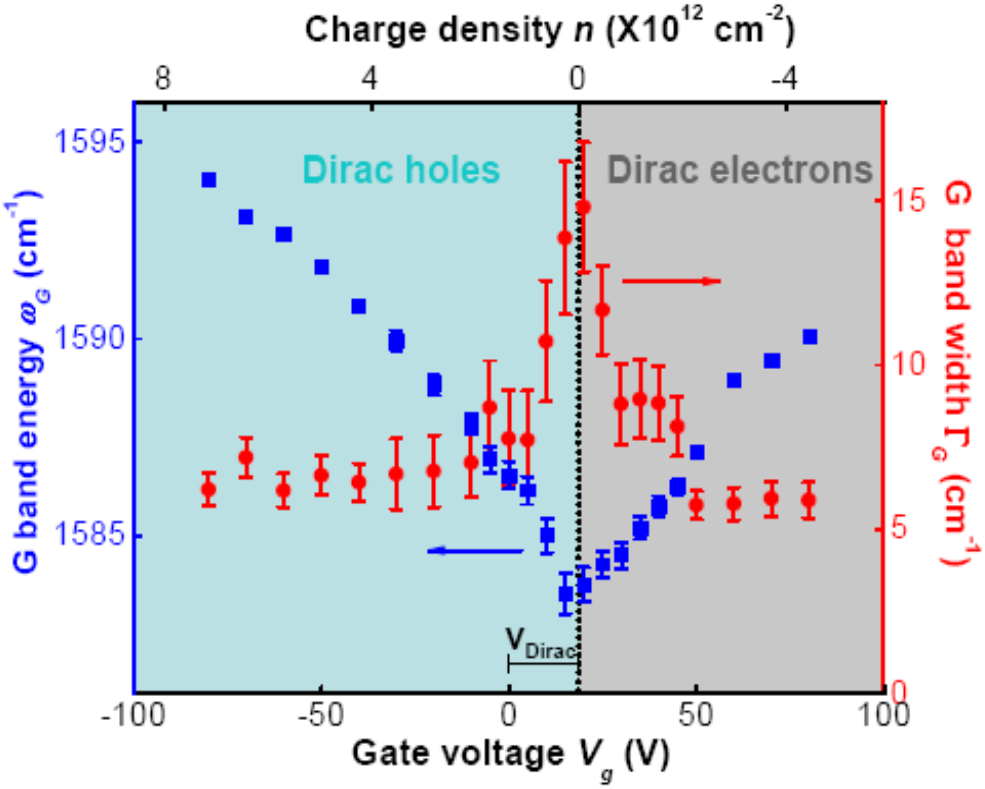


G band vibration of graphene



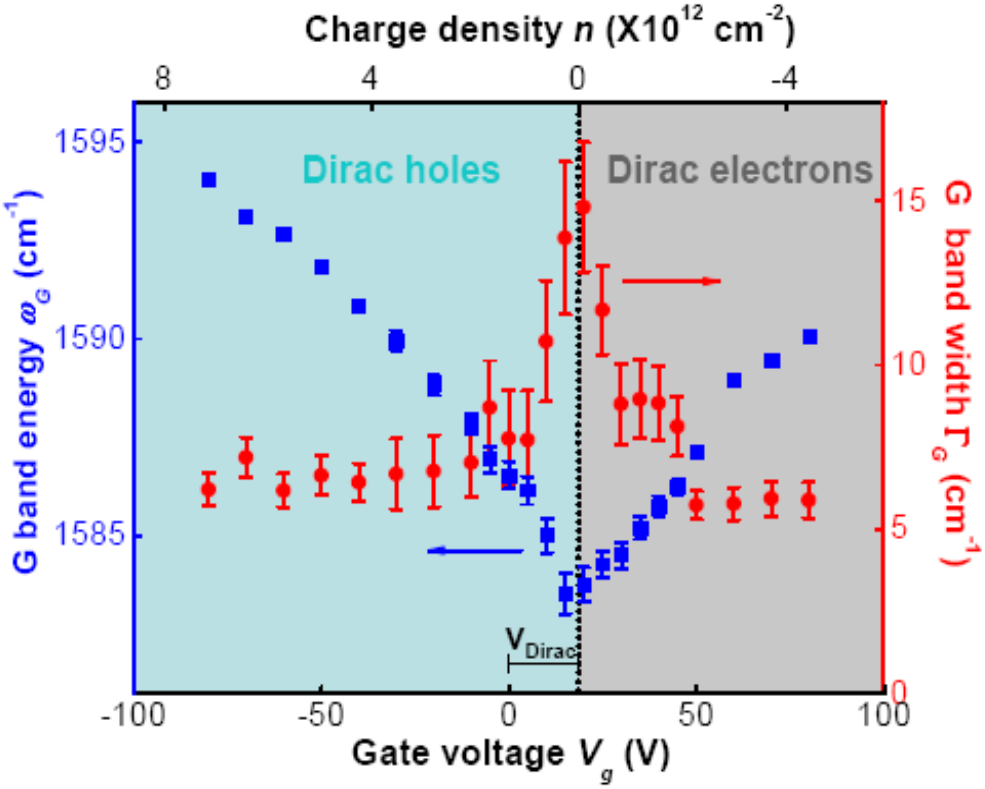
G band in gated graphene



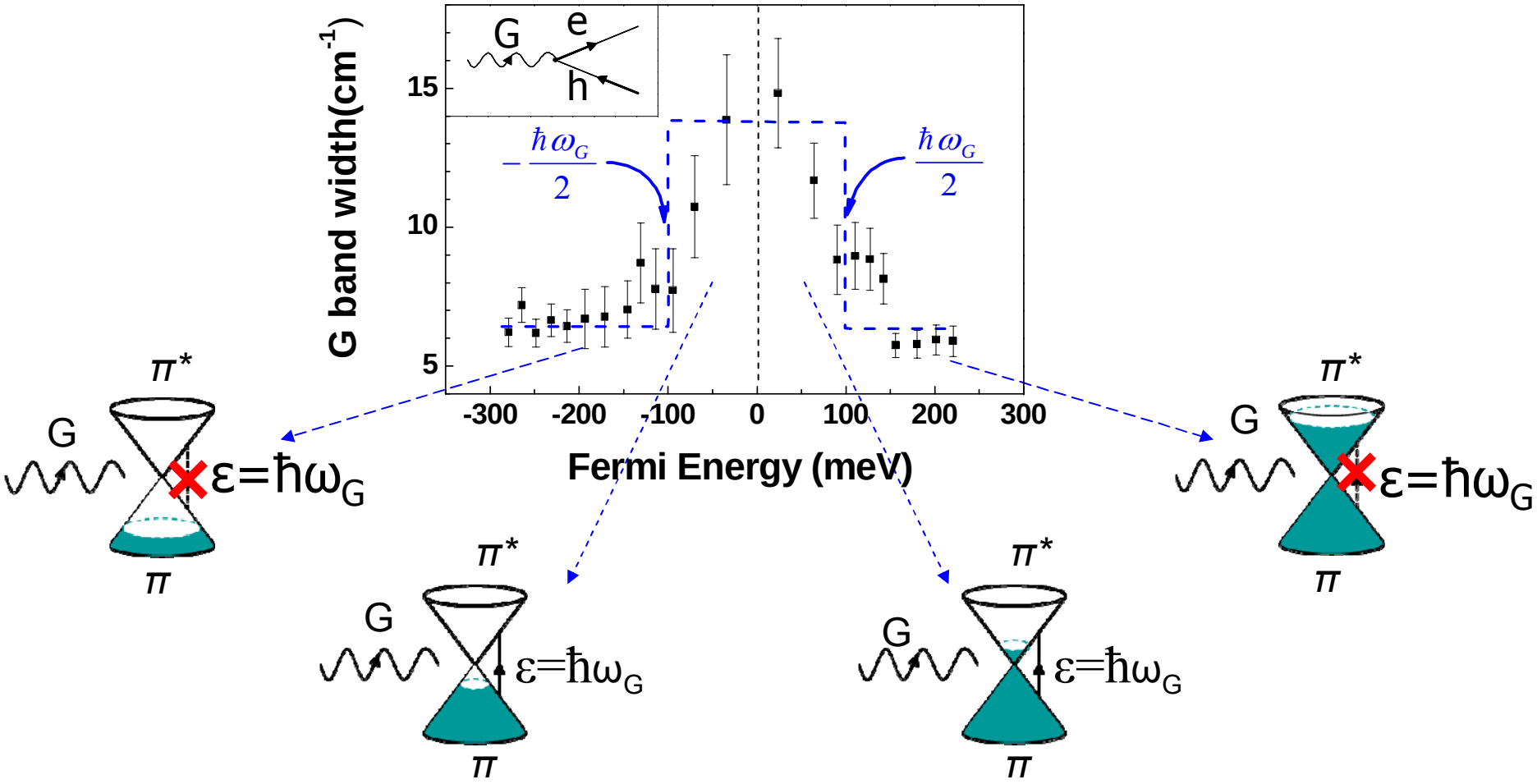


G band in gated graphene

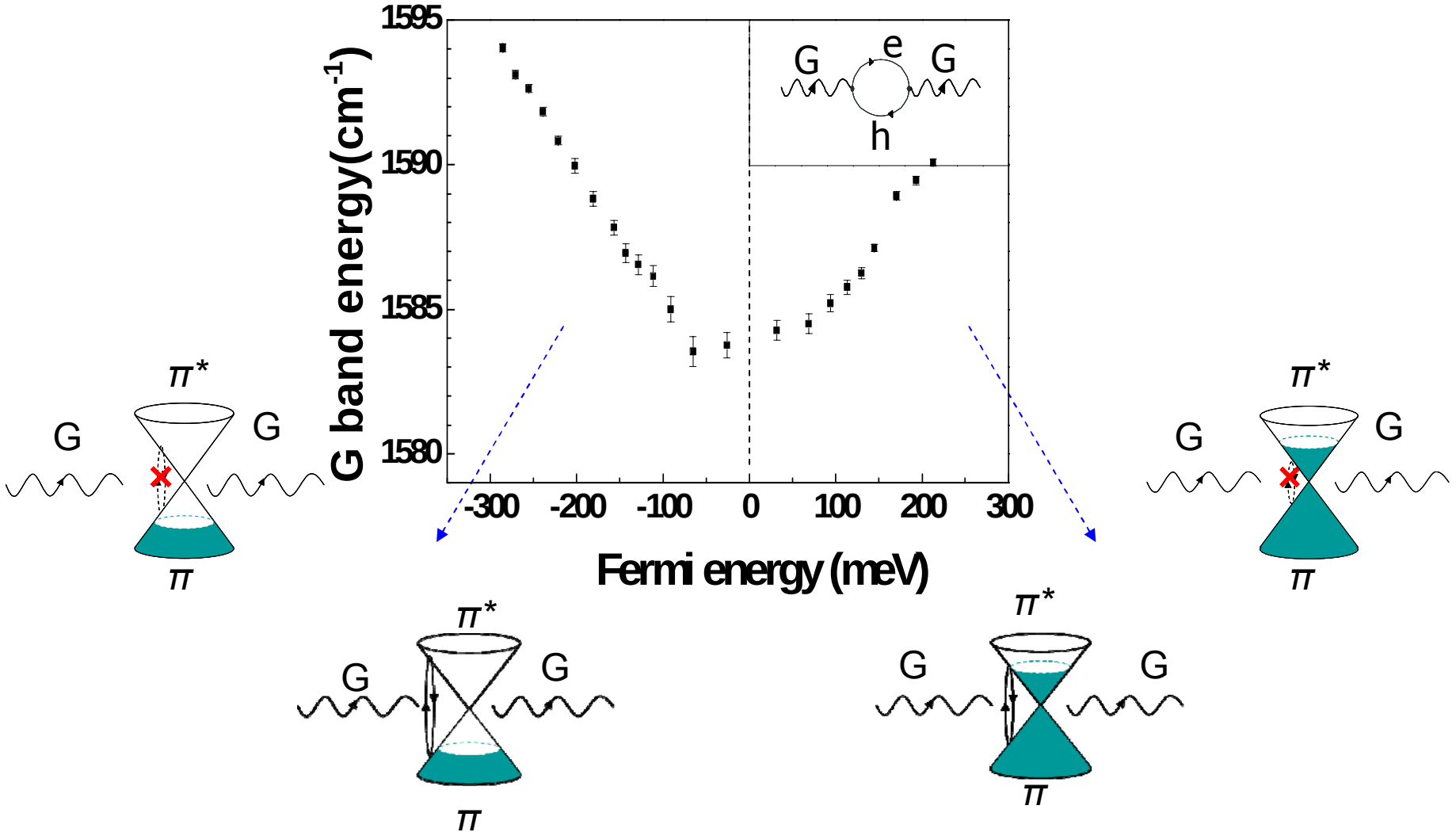
Symmetry in G band line-width and energy: optical determination of charge neutral point



G phonon life-time: Landau damping

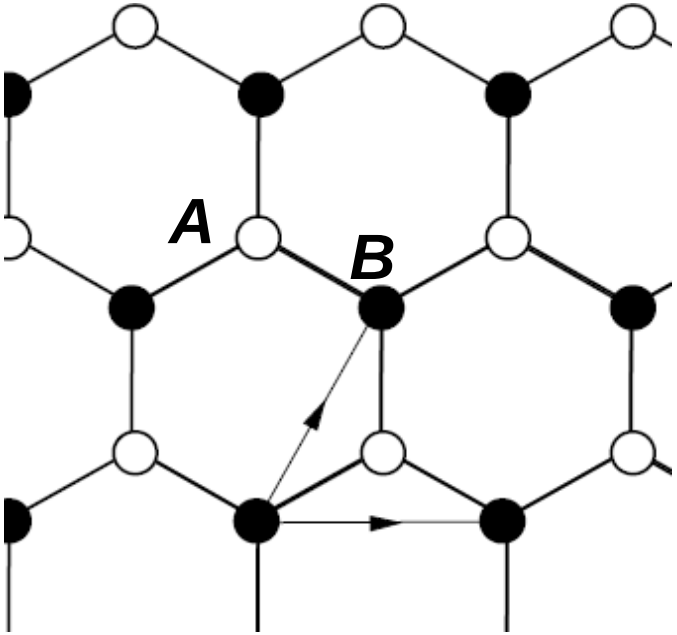


Charge-tunable G phonon stiffness

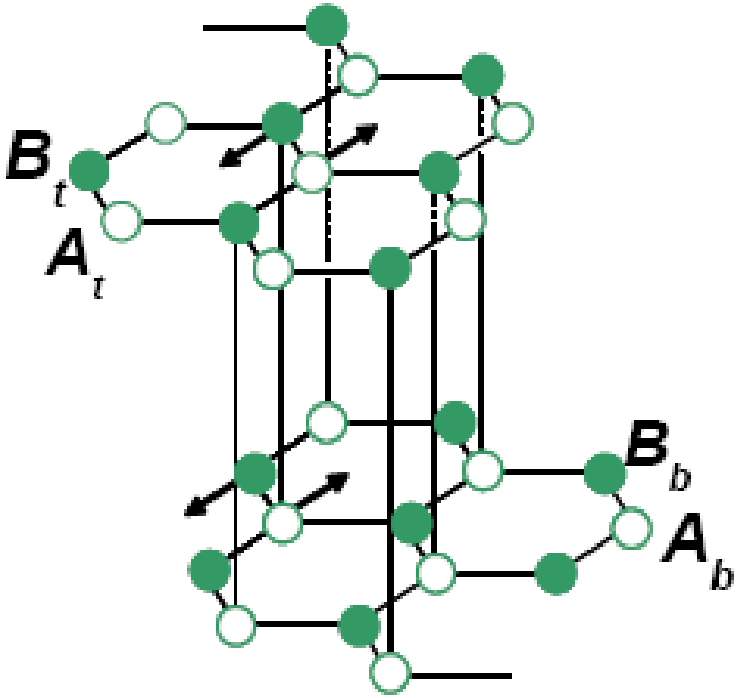


Monolayer → bilayer

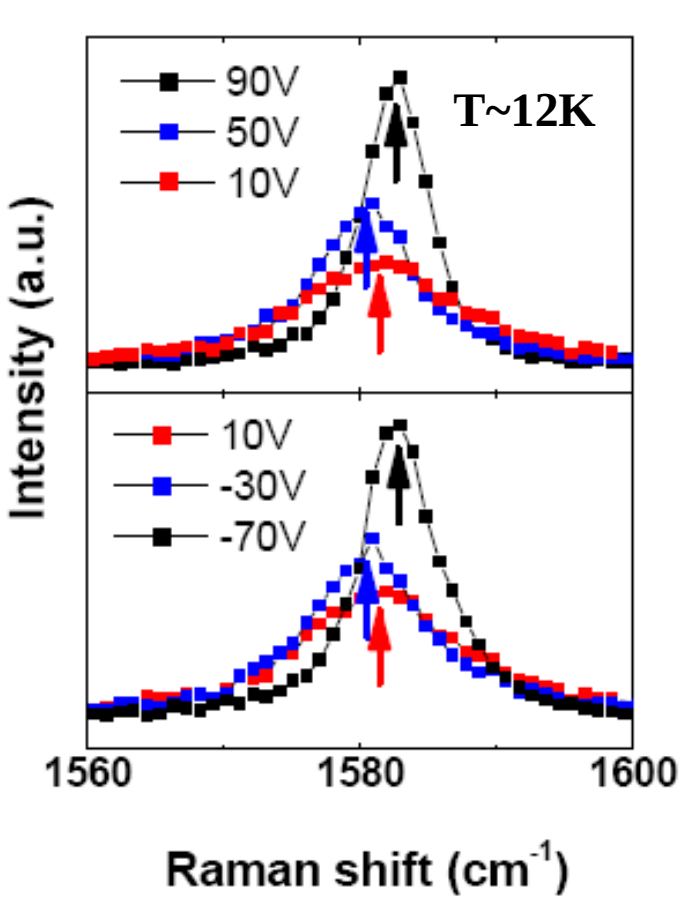
monolayer

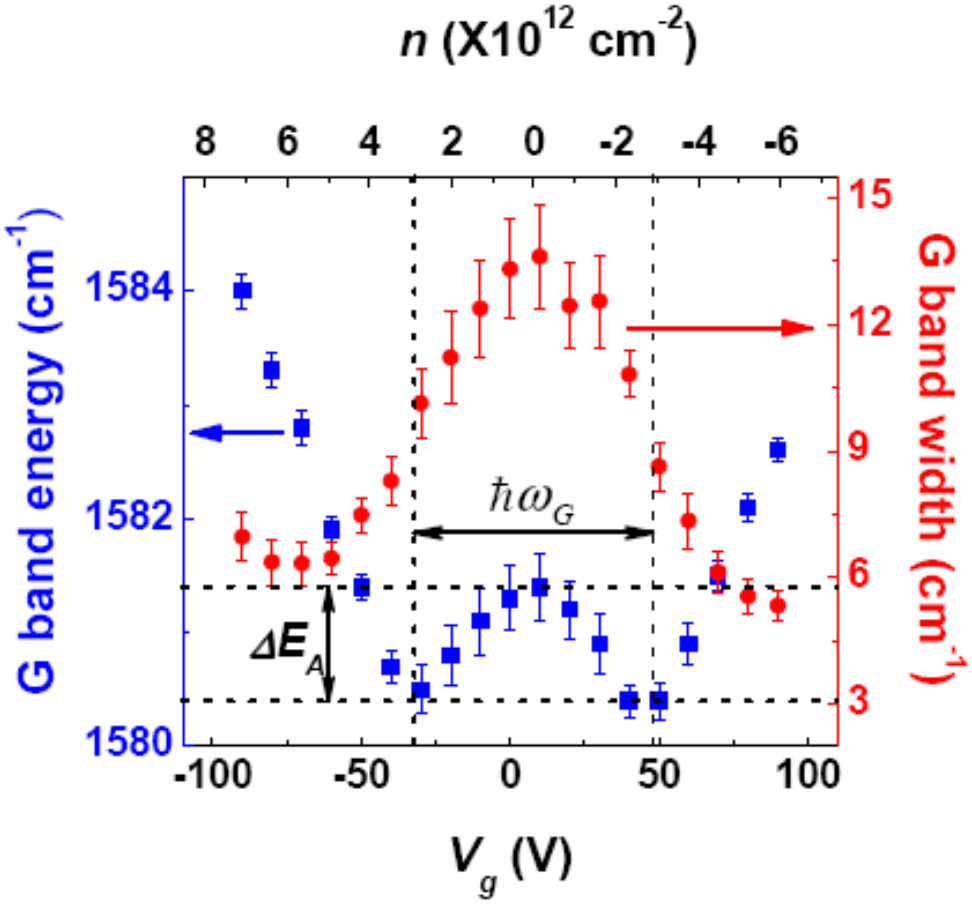


bilayer



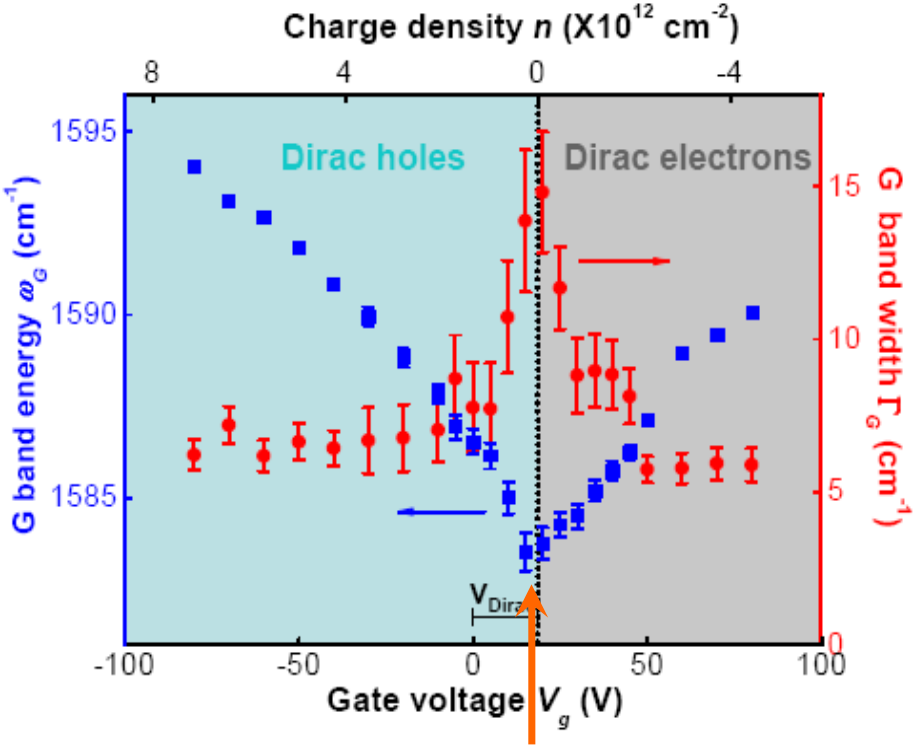
EFE-Raman result: bilayer graphene



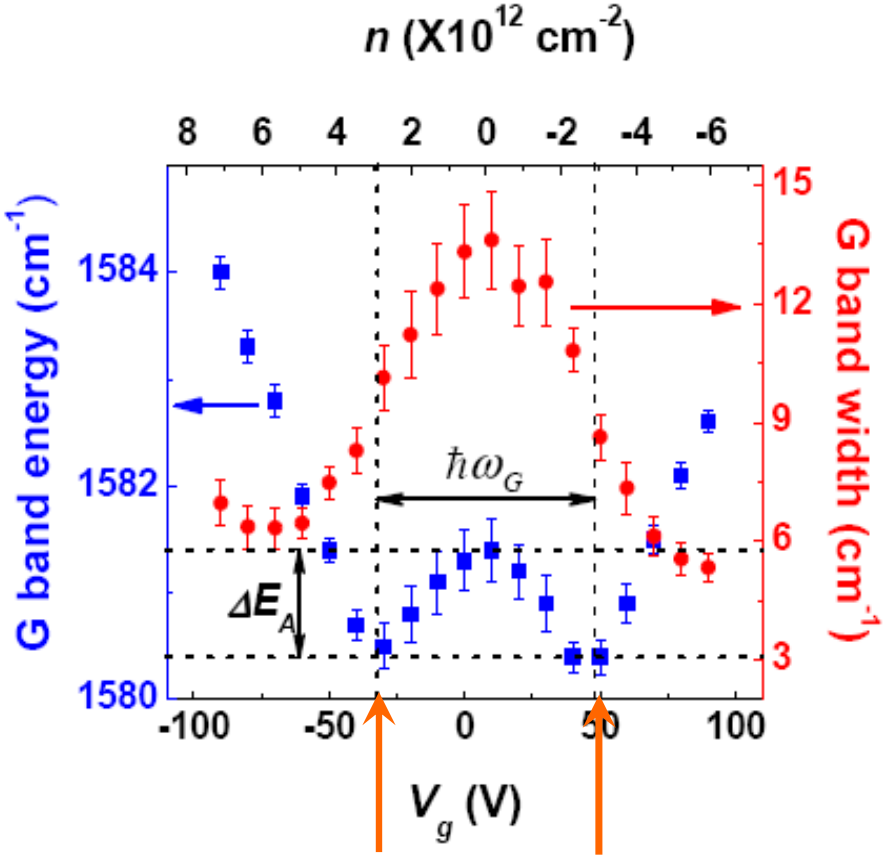


Monolayer vs bilayer

monolayer



bilayer



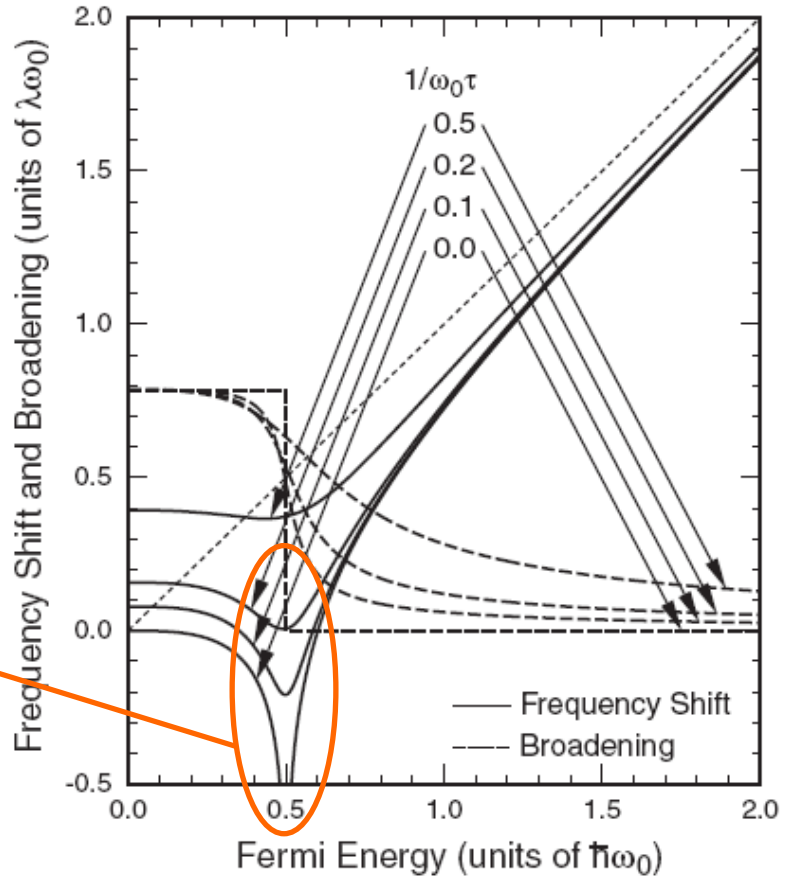
Stories from theorists: phonon anomaly

Anomaly of Optical Phonon in Monolayer Graphene

Tsuneya ANDO

Department of Physics, Tokyo Institute of Technology,
2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551

Phonon Anomaly

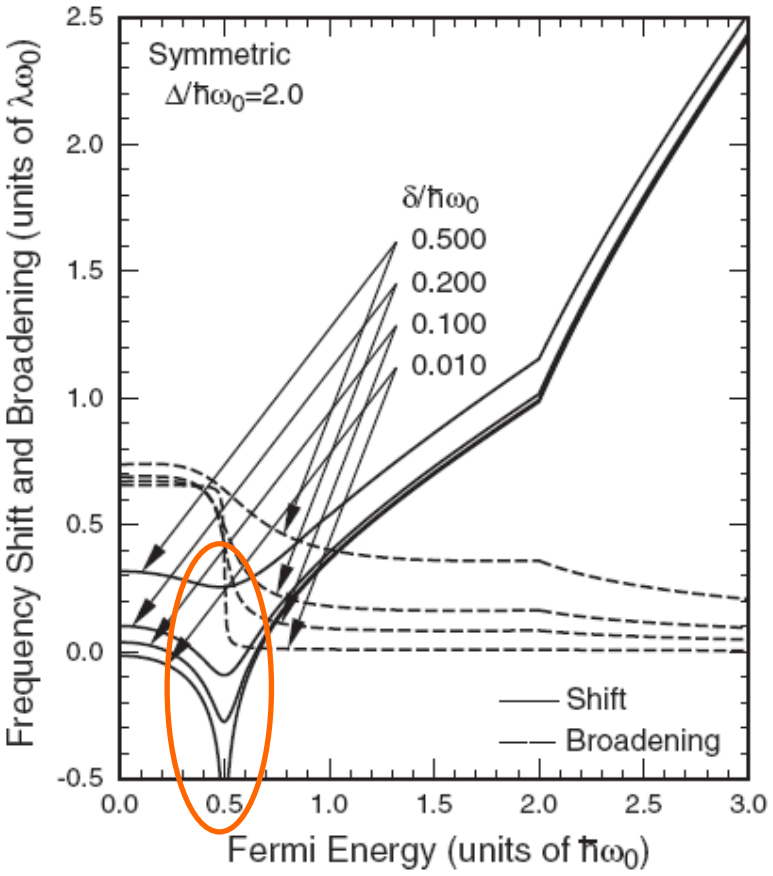


See also, e.g., Lazzeri and Mauri PRL 97, 266407 (2006)

T. Ando JPSJ 75, 124701 (2006)

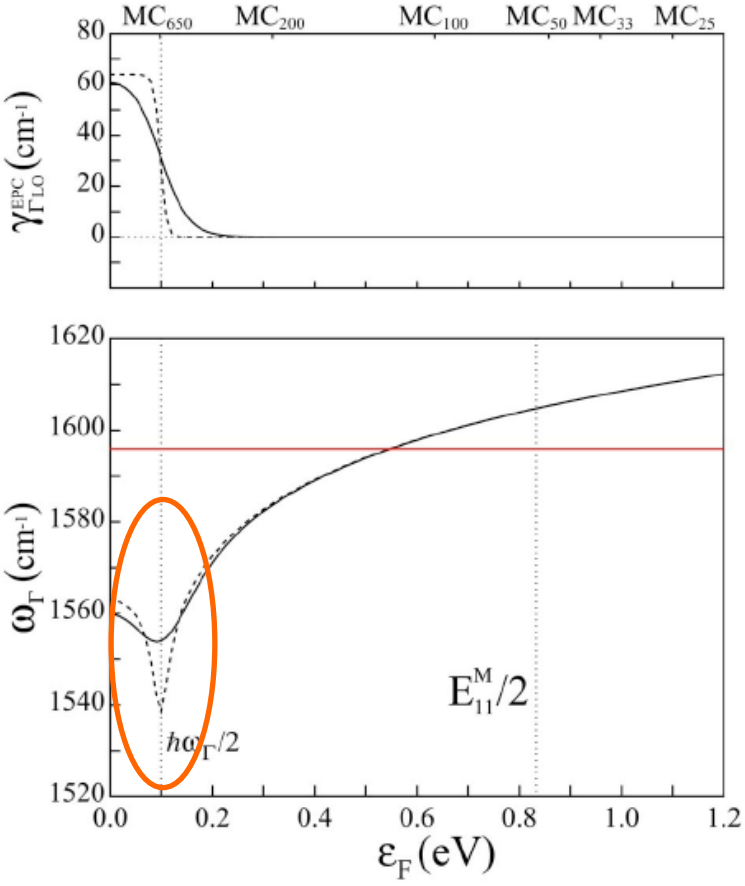
Stories from theorists: phonon anomaly

- Bilayer graphene



T. Ando JPSJ 76, 104711 (2007)

- Carbon nanotube

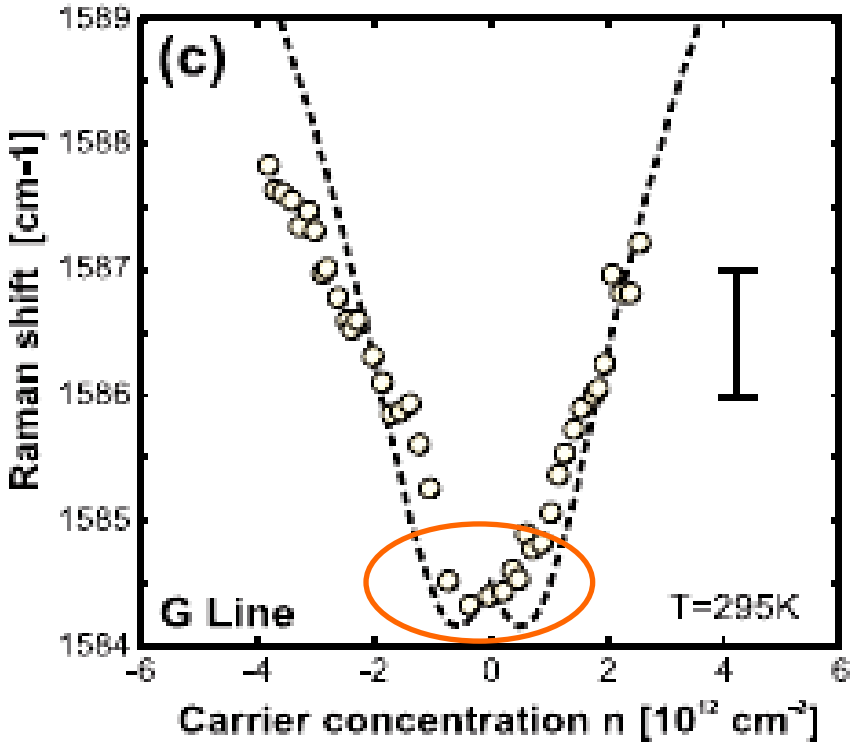


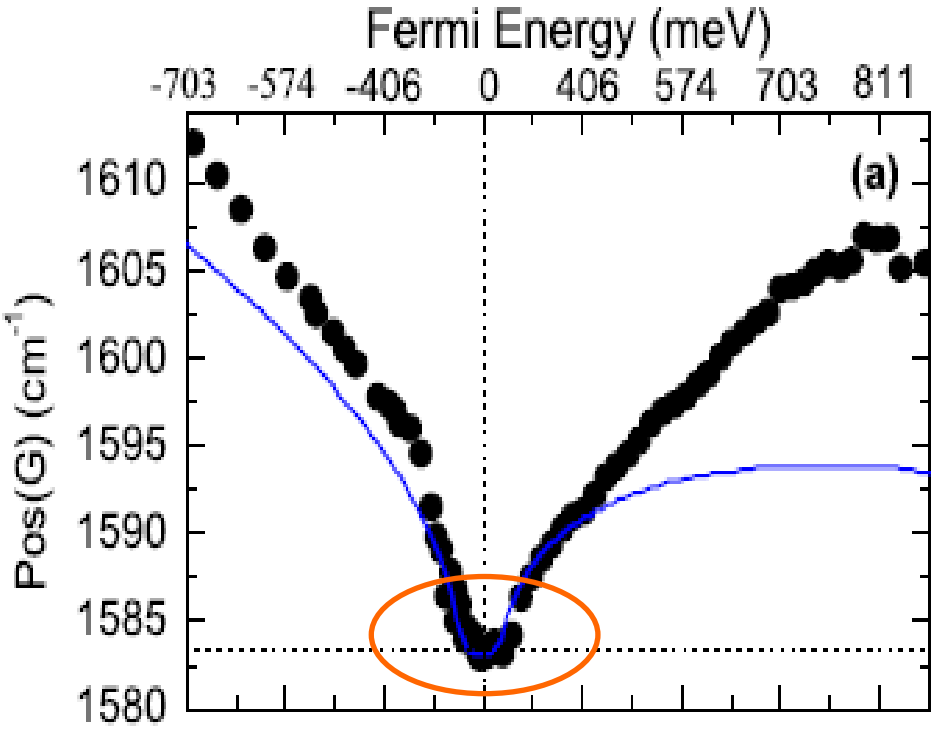
Caudal et al PRB 75, 115423 (2007)

Comparison with Kohn anomaly

	Kohn anomaly	Phonon anomaly
generality	**General phenomenon**	**General phenomenon**
Non-analytic behavior	**Log-singularity**	**Log-singularity**
Quantity of interest	**$d\omega/dk$ (phonon group velocity)**	**ω (phonon energy)**
Happens at	**$q=2k_F$**	**$E_F = \omega/2$ (~100meV for graphene)**

More results of monolayer graphene



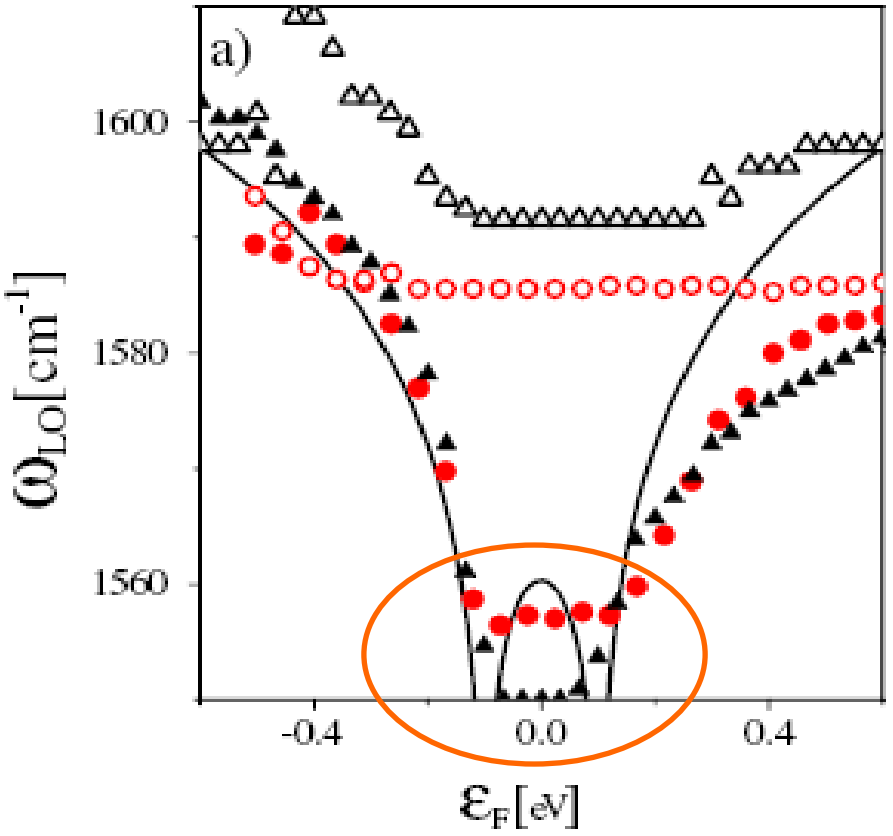


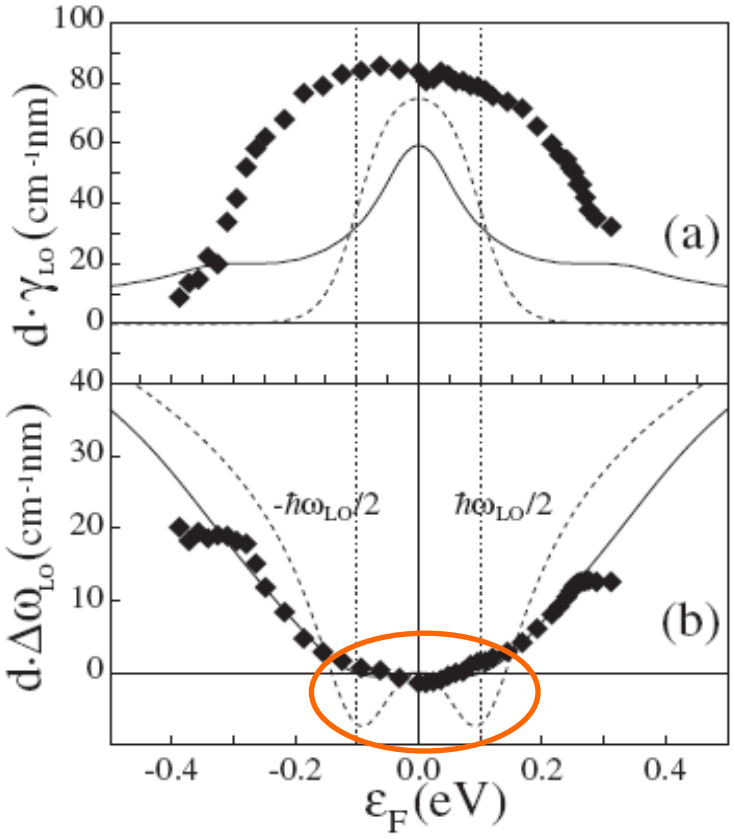
Stampfer et al. APL, 91, 241907, (2007)

Das et al. arXiv:0709.1174

See also Pisana et al. Nature Materials 6, 198 (2007)

Experimental results of carbon nanotubes





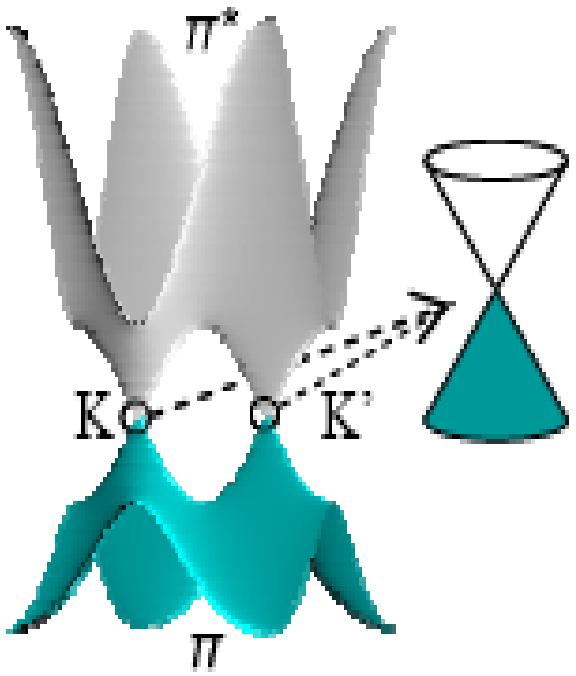
Farhat et al PRL 99, 145506 (2007)

Das et al PRL 99, 136803 (2007)

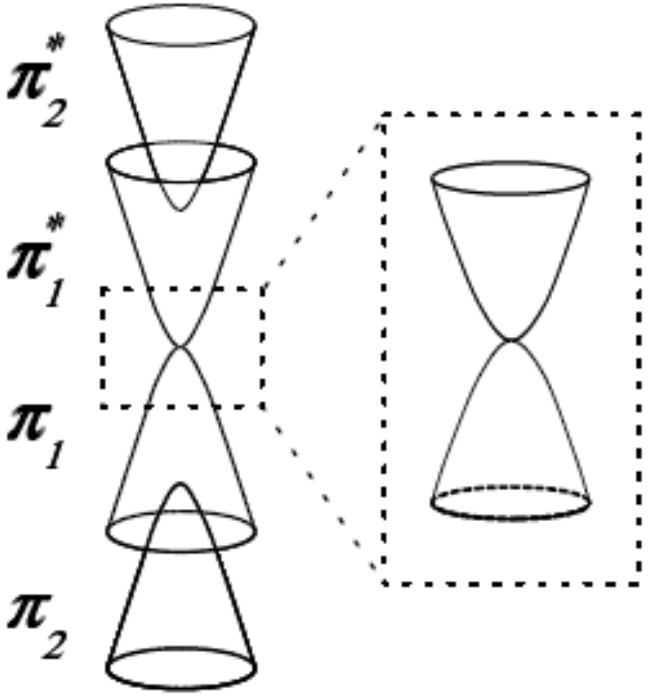
See also Tsang et al Nature Nanotech. 2, 725 (2007)

Monolayer vs bilayer: band structure

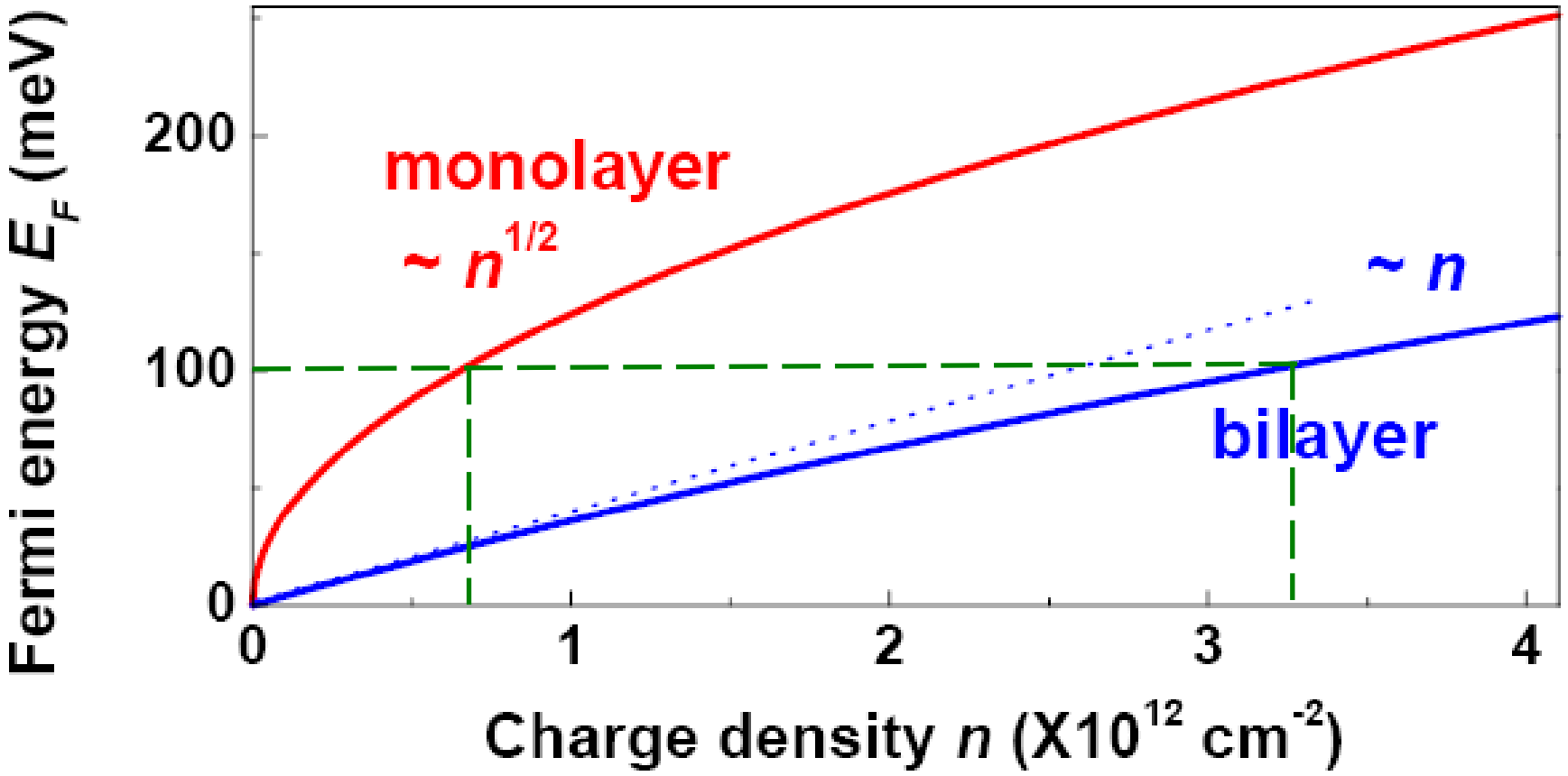
monolayer



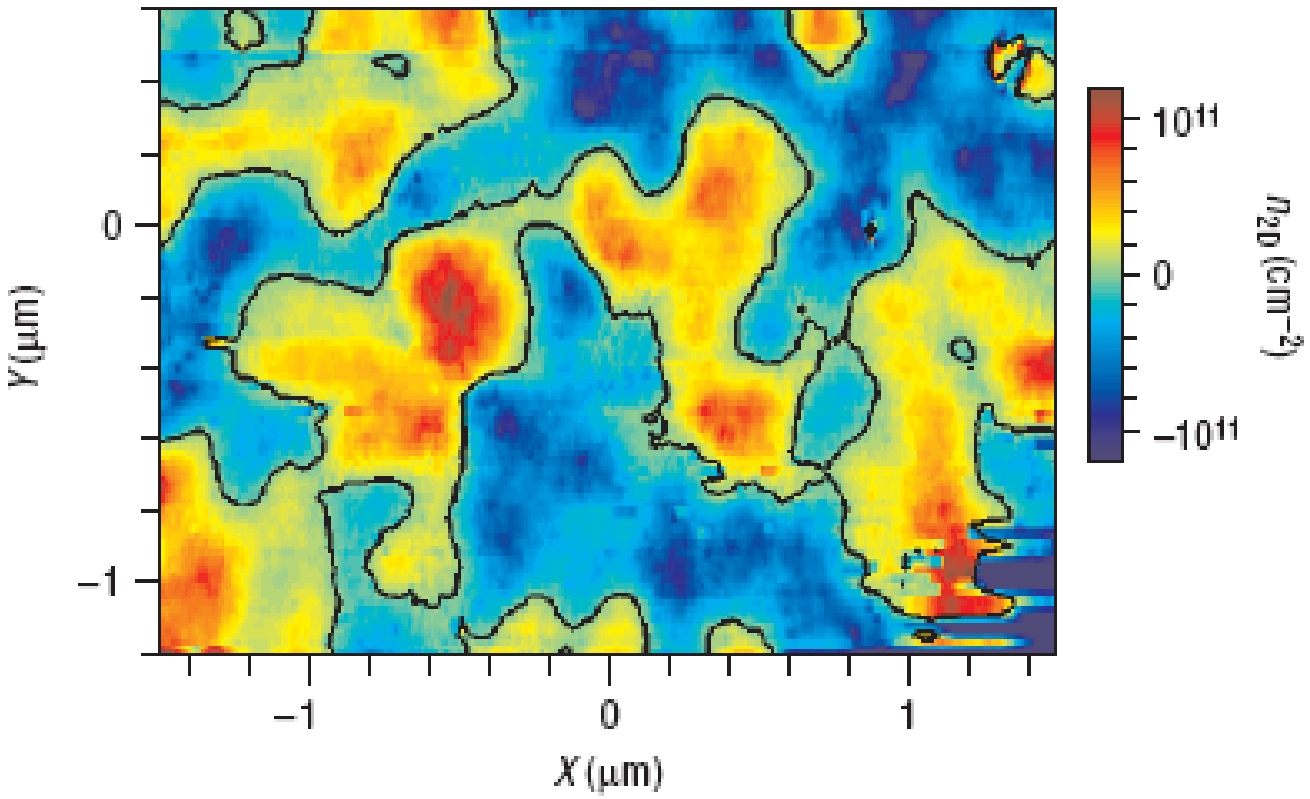
bilayer



Bilayer vs monolayer: $E_F(n)$

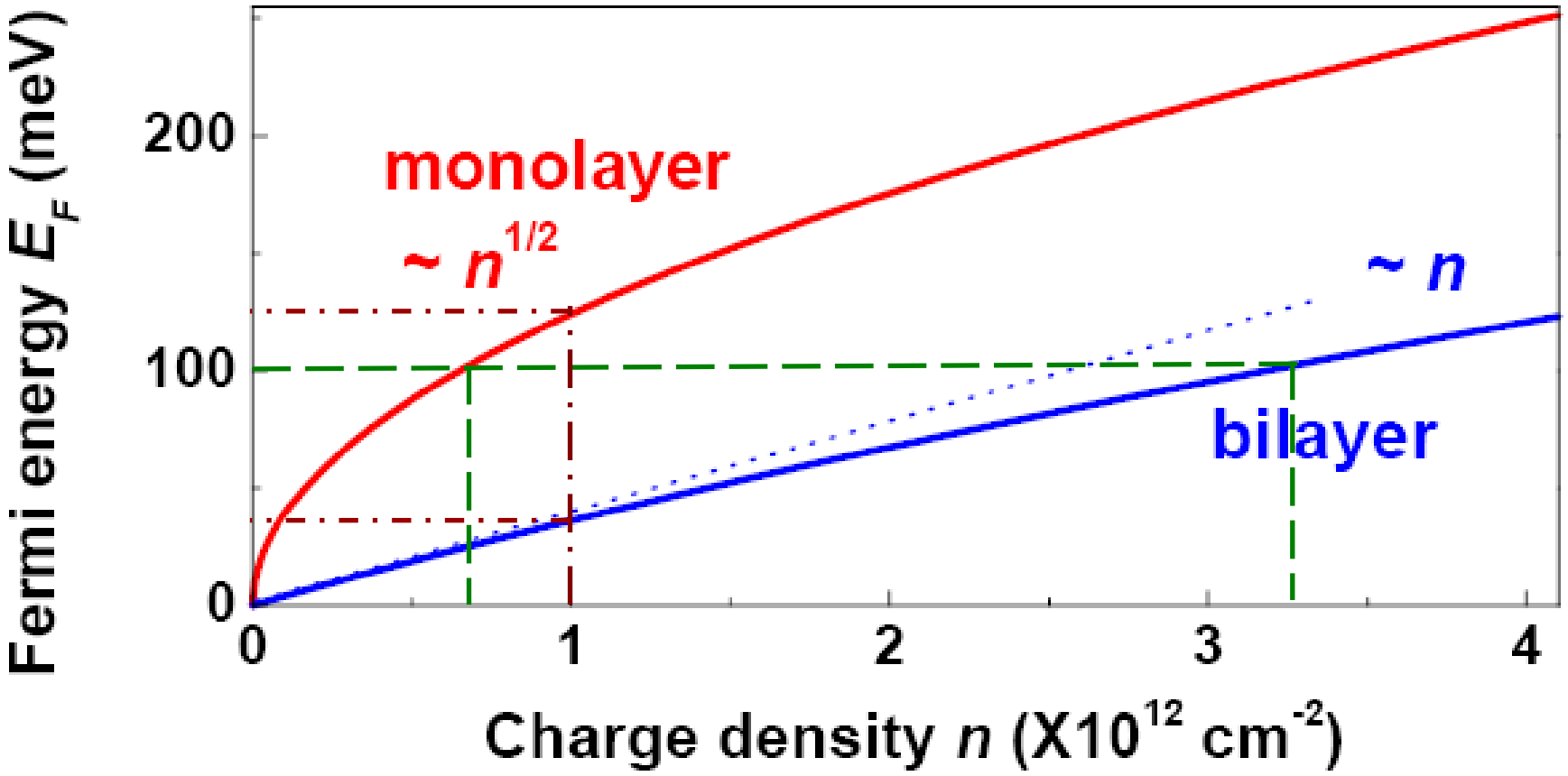


Electron and hole puddles in graphene films



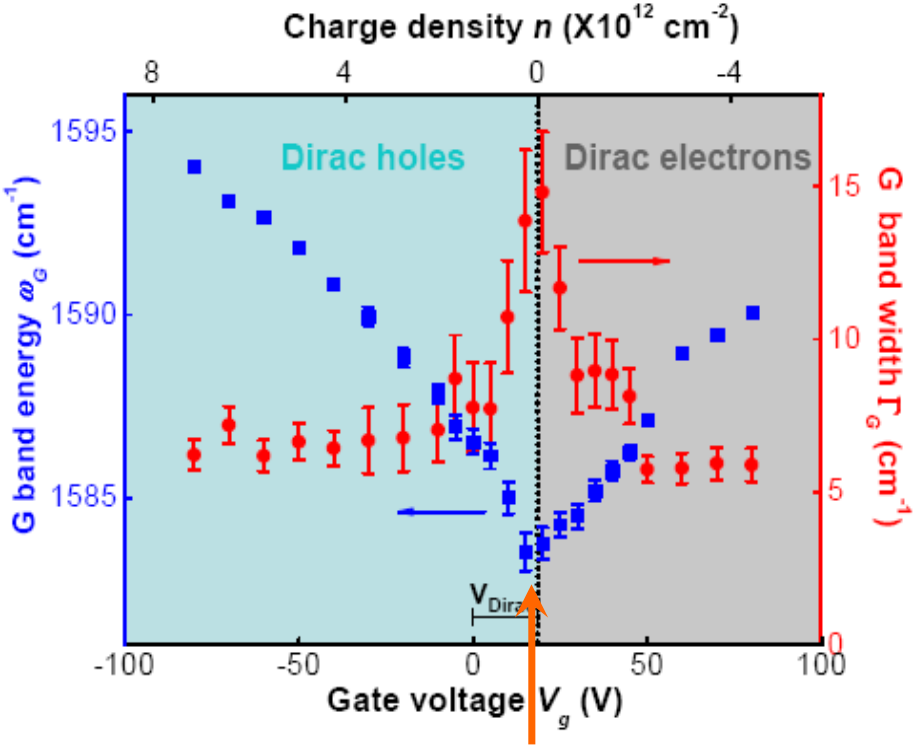
Martin et al Nature Phys. 4, 144 (2007)

Bilayer vs monolayer: $E_F(n)$

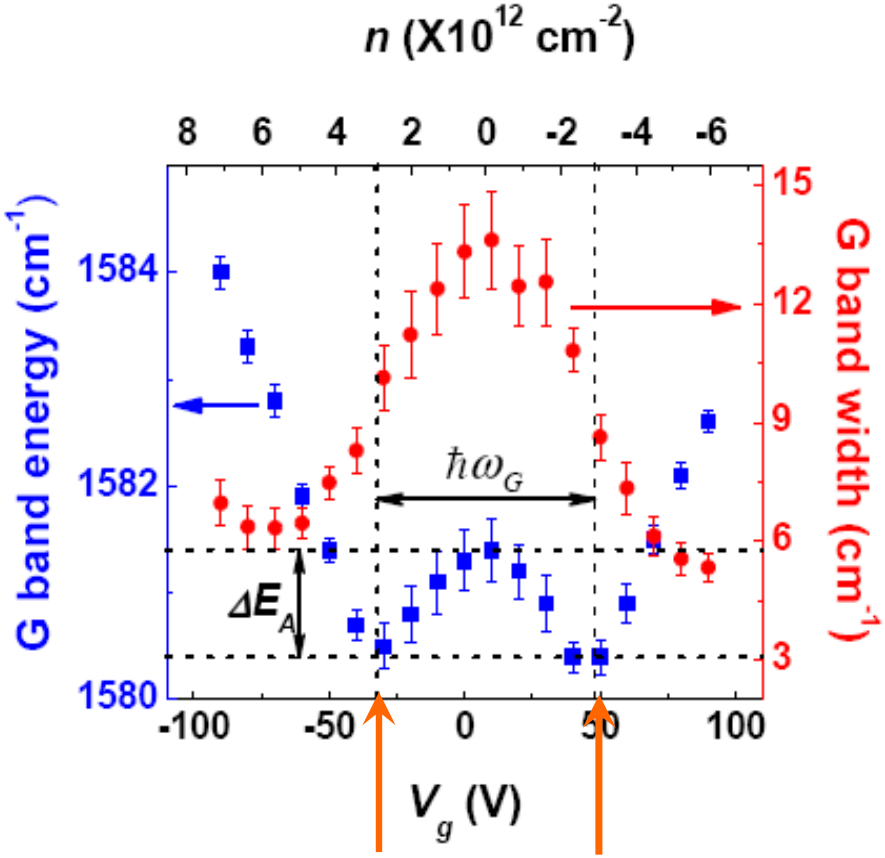


Monolayer vs bilayer

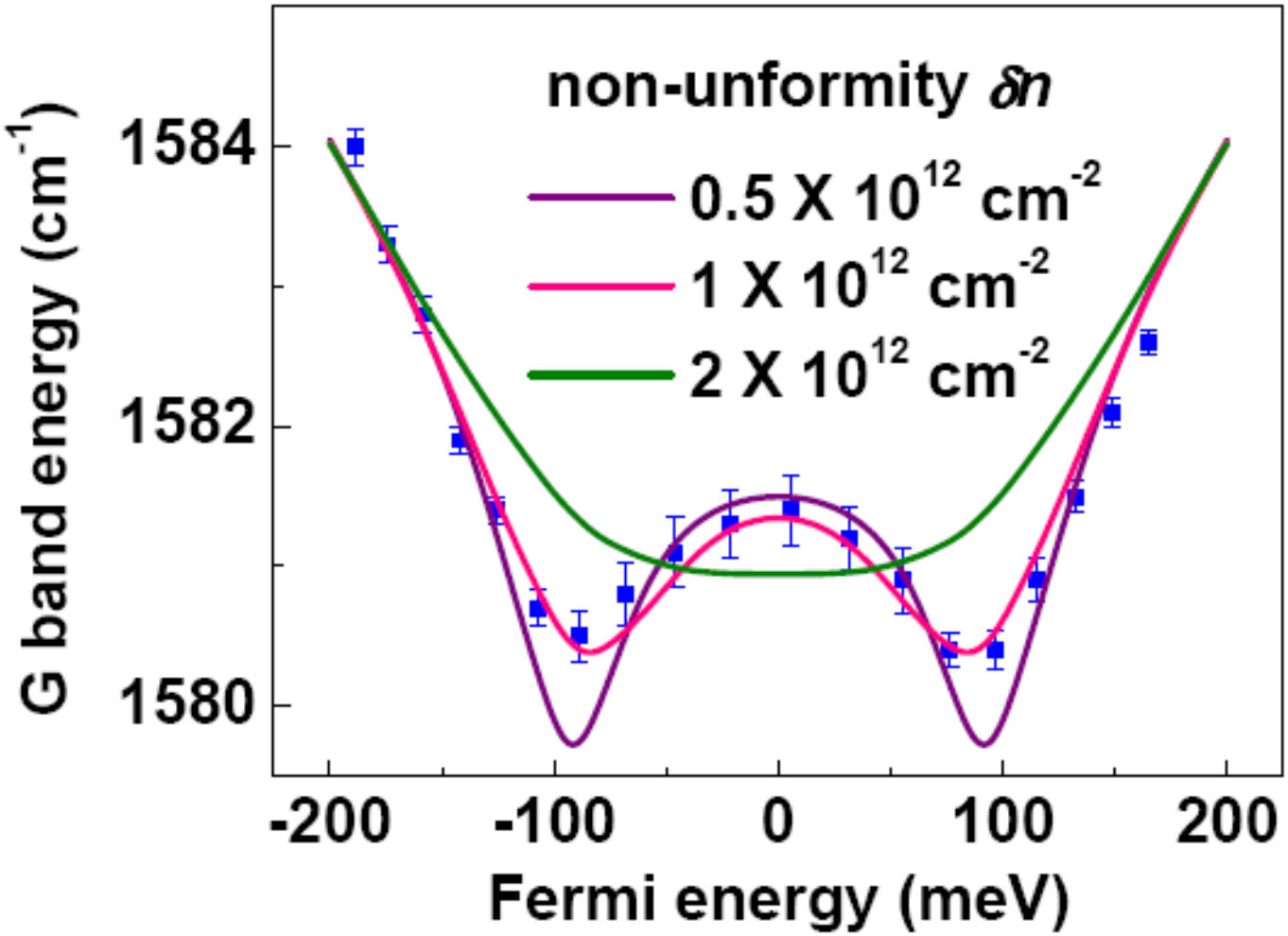
monolayer



bilayer



Phonon anomaly vs. charge non-uniformity

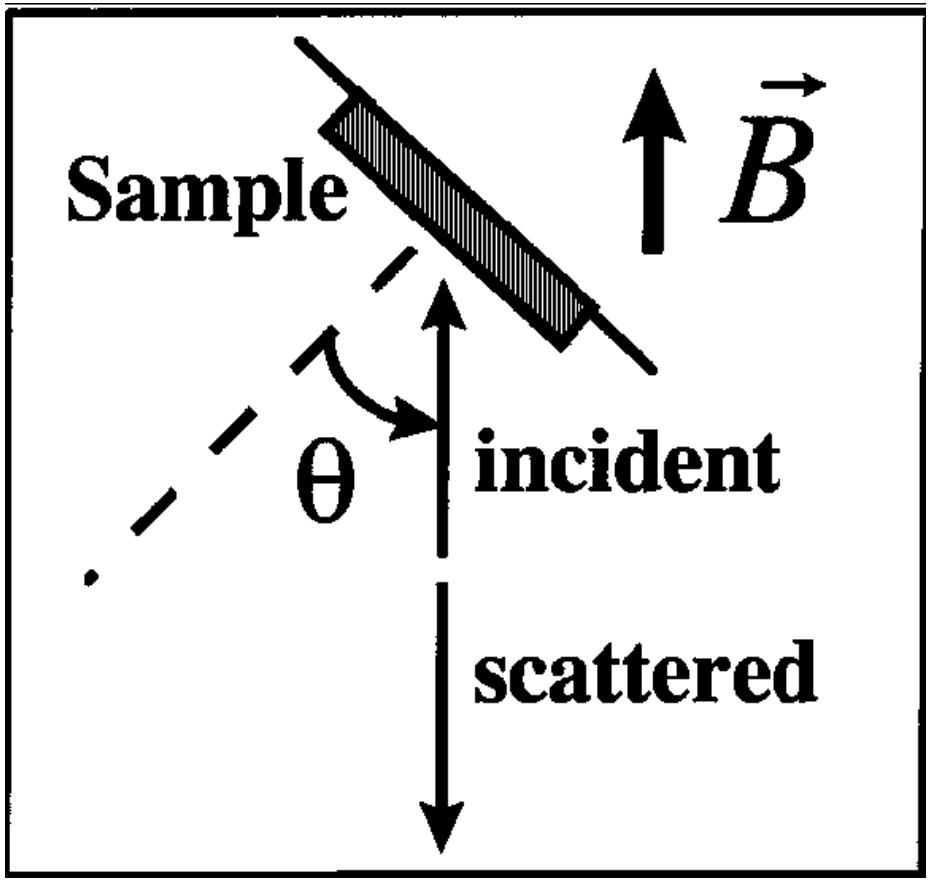


Effect of magnetic field: motivation

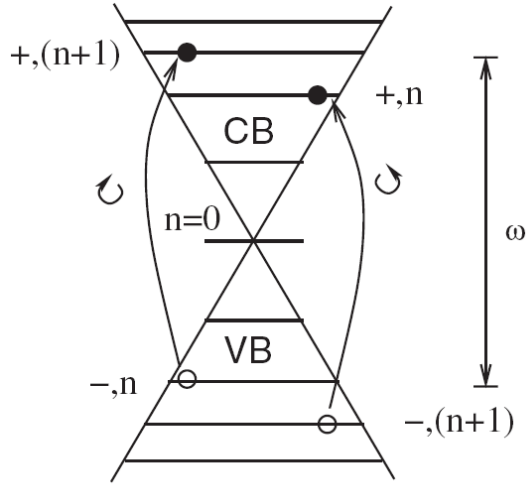
Motivation:

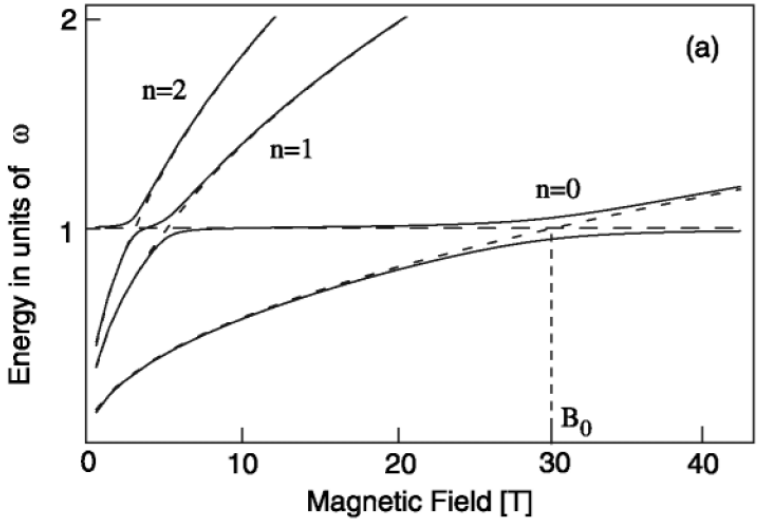
- Effect of Landau level formation on phonon spectra
- Interaction of magneto-exciton with lattice vibration

Experimental geometry:

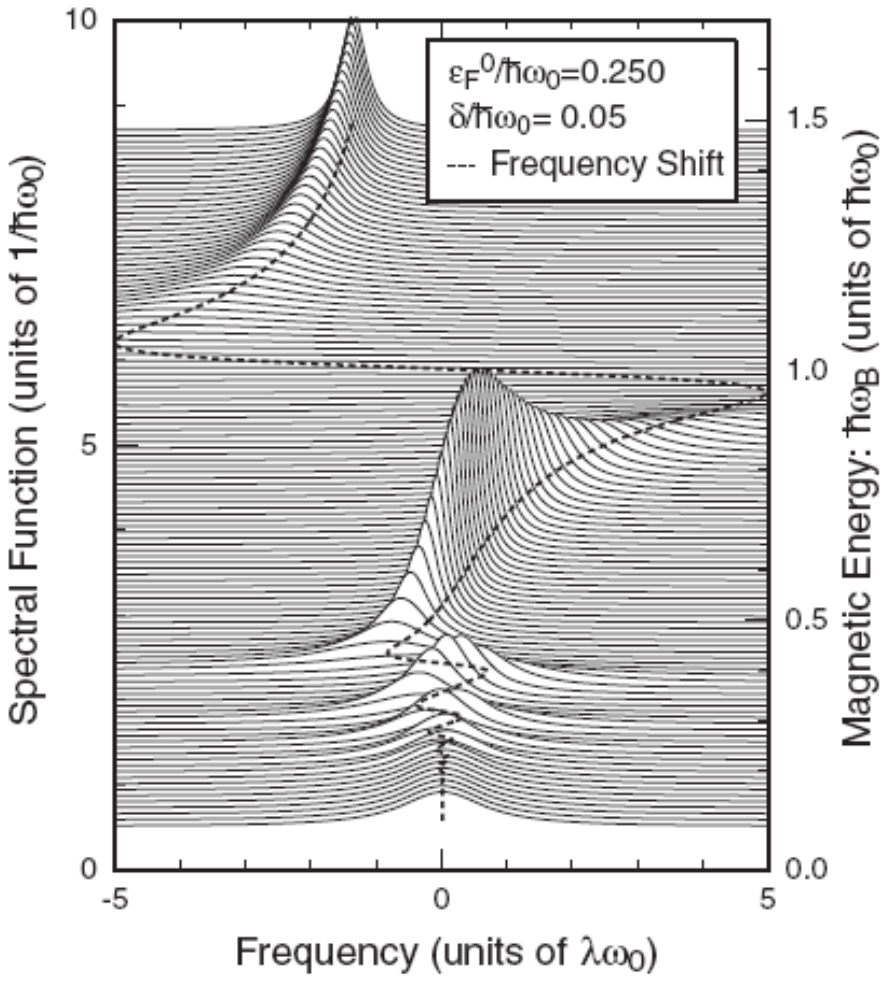


Effect of magnetic field: motivation





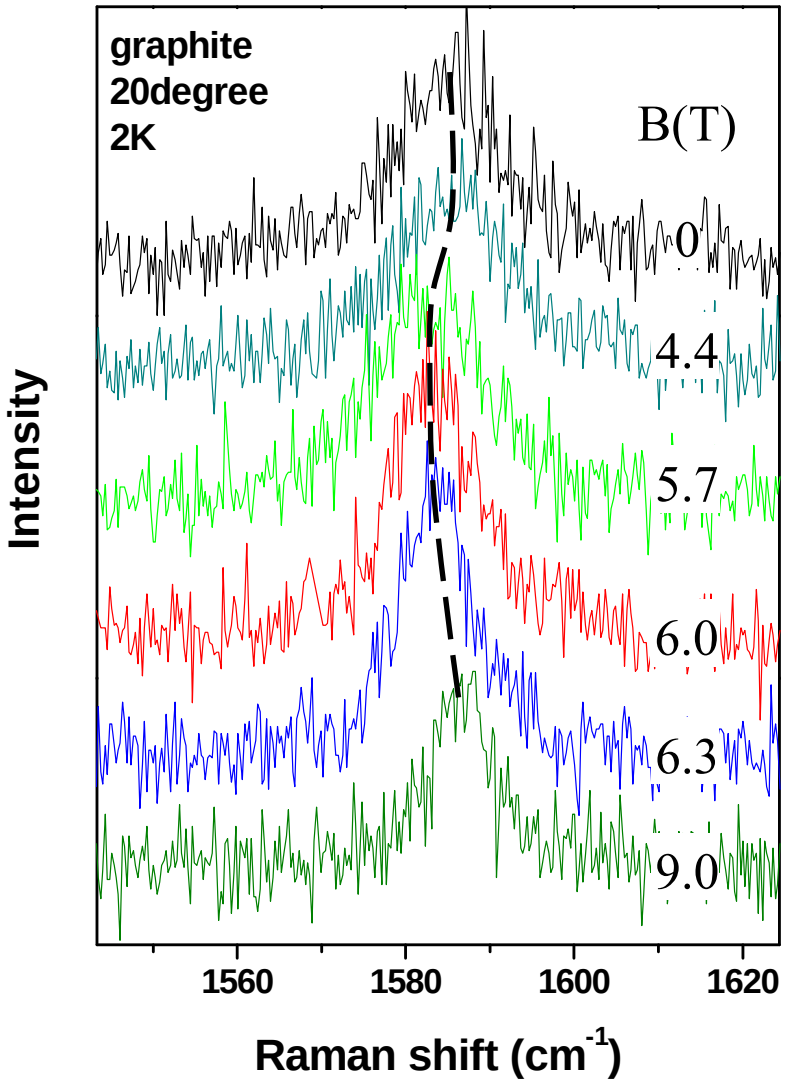
Goerbig et al PRL 99, 087402 (2007)



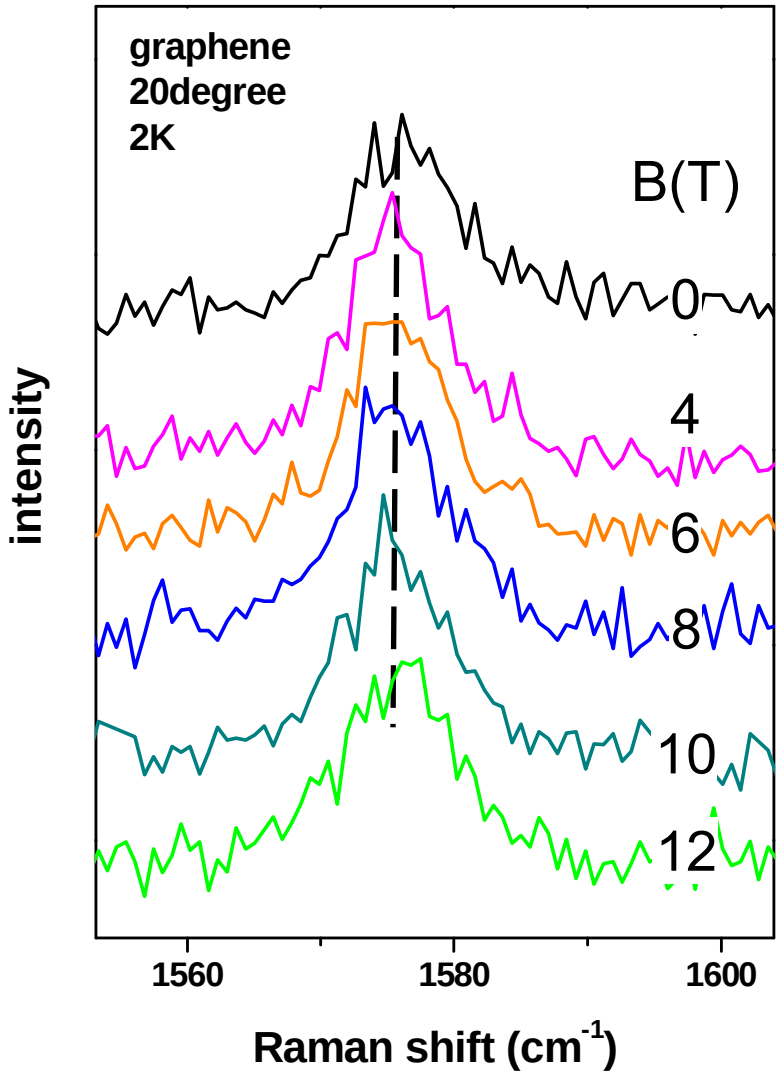
T. Ando JPSJ 76, 024712 (2007)

Preliminary results of magneto-phonon resonance

graphite



graphene



Conclusion:

- Some changes were observed in graphite phonon spectra which might be indicative of magneto-phonon resonance.

- In graphene, however, almost no changes have been observed up to 12 Tesla.

Thank you!