Abstract for an Invited Paper
for the MAR09 Meeting of
The American Physical Society

Doping, Strain, Orientation and Disorder of Graphene by Raman Spectroscopy

ANDREA C. FERRARI, University of Cambridge, Engineering Department, Cambridge, CB3 OFA, UK

Raman spectroscopy is a fast and non-destructive method for the characterization of carbons [1]. These show two features: the G and D peaks, around 1580 and 1350cm^{-1} respectively. The G peak corresponds to the doubly degenerate E_{2g}phonon at the Brillouin zone centre. The D peak is due to the breathing modes of sp^2 atoms and requires a defect for its activation [1-5]. It is common for as-prepared graphene not to have enough structural defects for the D peak to be seen [4,6], so that it can only be detected at the edges [6]. The most prominent feature in graphene is the second order 2D peak [6]. This is always seen, since no defects are required for its activation. Its shape distinguishes single and multi-layers [6]. Raman spectroscopy also monitors doping [7-9]. We report the evolution of the Raman spectra of single [7,8] and bi-layer [9] graphene as a function of doping. A Fermi level shift is induced either by applying a bottom gate [7], or by a polymeric top gate [8,9], or naturally happens as a result of charged impurities [10]. This induces a stiffening of the Raman G peak for both hole and electron doping [7]. This is explained including dynamic corrections to the adiabatic Born-Oppenheimer approximation [7]. The phonon renormalization of bilayer graphene has characteristic features compared to single layer. This allows a direct estimation of the interlayer coupling [7-9]. We then consider the effects strain. Uniaxial strain lifts the E_{2g} degeneracy and splits the G peak in two: $G^+$and G^-. The peaks downshift as a function of strain allows a direct measurement of the Gruneisen parameter [10]. The polarization dependence of the G^+/G^-modes is a probe of the crystallographic orientation of the sample [10]. Finally, we consider the effect of disorder [3,4,11] and show how to discriminate between disorder, strain and doping [11]. We will also discuss how the D peak is a signature of π electron localisation, and, thus, of gap opening in chemically modified graphene[12].

1. A. C. Ferrari, J. Robertson (eds), *Raman spectroscopy in carbons: from nanotubes to diamond*, Theme Issue, Phil. Trans. Roy. Soc. **362**, 2267 (2004). 2. F. Tuinstra, J.L. Koening, J. Chem. Phys. **53,** 1126(1970). 3. A. C. Ferrari, J. Robertson Phys Rev B **61**, 14095 (2000); **64**, 075414 (2001) 4. A. C. Ferrari Solid State Comm.**143**, 47 (2007) 5. S. Piscanec et al. Phys. Rev. Lett. **93**, 185503 (2004) 6. A. C. Ferrari et al. Phys. Rev. Lett. **97**, 187401 (2006) 7. S. Pisana et al. Nature Mater. **6**, 198 (2007) 8. A. Das et al, Nature Nano **3**, 210 (2008). 9. A. Das et al., arXiv:0807.1631v1 (2008) 10. A. C. Ferrari et al. submitted (2008) 11. C. Casiraghi et al. Appl. Phys Lett. **91**, 233108 (2007) 12. Elias et al. arXiv:0810.4706 (2008)