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 1350 cm\(^{-1}\) 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 \(\pi\) electron localisation, and, thus, of gap opening in chemically modified graphene[12].