Production of Graphene micro-ribbons to withstand large deformations

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Graphene is a crystal consisting of carbon atoms arranged in a lattice of hexagons forms the basis of all graphitic structures i.e. carbon nanotubes, graphite and carbon fibres [1, 2]. In spite of its potential as one of the stiffest and strongest material in nature [3] of high inherent ductility and strength better than steel, very little experimental verification has been provided for its extraordinary mechanical properties. Strain on the other hand, deforms the graphene lattice and has been shown to modulate graphene's electronic, magnetic and transport properties [2]. Hence is of outmost importance to understand how the thinnest membrane ever existed in nature can respond to mechanical loadings?

In general it is expected and already verified experimentally, that a thin film can withstand relatively large tensile strains in air without early fracture, whereas in compression monolayer graphene is expected to buckle at extremely low strains [4]. Furthermore, when an exfoliated monolayer graphene is stretched axially in one direction should always be accompanied by the formation of lateral (orthogonal) wrinkles or buckles which render pure axial experiments untenable, phenomenon which should be prevalent for any future 2D materials, has not as yet been fully studied, predicted or, even, exploited [5]. Recently, we have examined the mechanical behavior of several monolayer graphene flakes with various length to width ratio for small deformations, collecting simultaneously Raman spectra [4, 6, 7]. Under compression the critical strain to buckling was found to be ~ –0.6% and independent of the flake's dimensions. Also, it was found that a minimum length of about 4 μm is needed in order to have sufficient stress transfer from the surrounded polymer to the graphene [7].

In this work, we exploit the above findings by altering the geometry of the flakes, and design graphene strips (micro-ribbons) of specific dimensions which when embedded to polymer matrices can be stretched to undergo large deformation without simultaneous buckling in the other direction (Fig.1a). The graphene flakes are produced both by the "scotch-tape" and the Chemical Vapor Deposition (CVD) techniques on silicon substrates. Graphene micro-ribbons are fabricated using standard lithographic processing (Fig.1b). After the photoloithographic step, dry etching by oxygen plasmas is used to remove the graphene layer from the exposed areas leaving the graphene on the designed patterns. The samples are then cleaned with acetone and propanol to remove the remaining photoresist. The dimensions of the micro-ribbons range between 1-5 μm (width) and 10-50 μm (length) while the ratio length over width is kept constant and equal to 10/1.

Finally, the produced micro-ribbons will be transferred onto thermoplastic and thermosetting polymer substrates in order to determine the full response of graphene to extreme axial deformation up to failure and to measure directly its strength, stiffness, strain-to-failure and the effect of orthogonal buckling to its overall tensile properties.

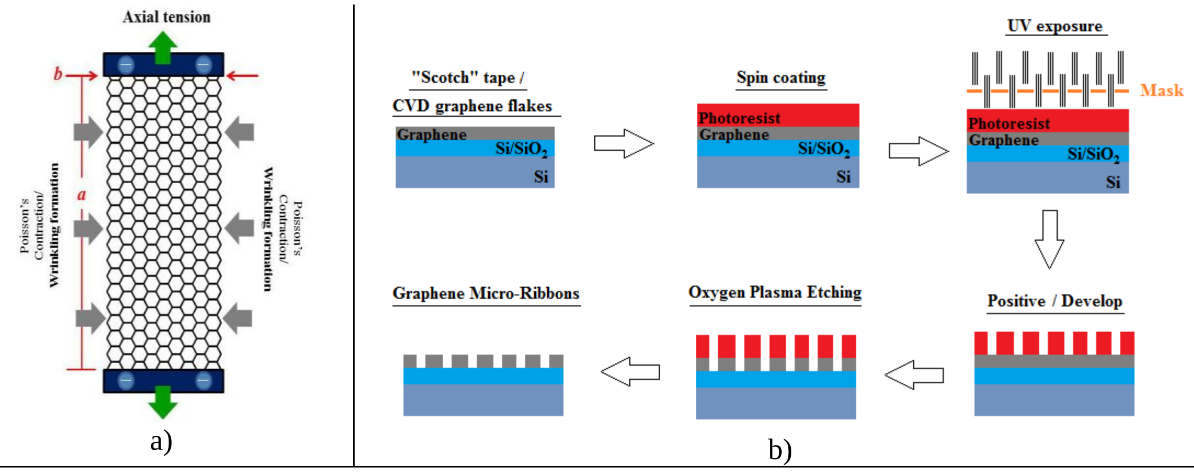

Fig. 1 a) Flake under tension experiencing compression in the lateral direction that leads to lateral (orthogonal) wrinkling and b) production of graphene micro-ribbons using positive photolithography.

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