Van der Waals Growth of 2D WS_2 Atomic Layers on CVD and Epitaxial Graphene

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Van der Waals heterostructures represent a promising technological perspective for exploiting bidimensional materials (graphene, hBN, WS_2, etc.) and their peculiar properties into innovative devices rather than as substitute of conventional bulk materials into well-established technologies.[1] In particular, the integration of monolayers of transition metal dichalcogenides, TMDs, (MoS_2, WS_2, WSe_2, etc) and graphene can provide the synergic exploitation of the direct band gap (in the visible) of TMDs and the high transport properties of graphene into 2D innovative optoelectronic devices.[2] The recent literature reports several examples of TMD/graphene heterostructures which are made by transferring and stacking different 2D crystals on top of each other.[3] However, this fabrication approach often results in impurities trapped at the heterojunction interface which strongly affect the individual properties of the 2D building blocks as well as the charge transfer processes between them. Conversely, the direct growth of TMDs on graphene has been demonstrated effective for allowing atomic order thickness and very abrupt interfaces owing to the occurrence of a "Van der Waals epitaxy" growth mode.[4]

Although previous works have demonstrated that high quality micrometer crystals of TMDs can be successfully grown on graphene, their controlled growth as continuous film with homogeneous optical properties, as required by applications based on 2D heterostructures, results still difficult. In this contribution, we report the successful direct synthesis by chemical vapor deposition, CVD, of continuous films of WS_2 on both epitaxial graphene (as obtained by Si sublimation from SiC substrates) and CVD graphene. In particular, we demonstrate the homogeneous photoluminescence response of WS_2 film as well as the possibility of localizing its deposition by tailoring the graphene surface energy.

References

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The deposition of atomic layers of WS_2 is carried out by using elemental sulfur and tungsten hexacarbonyl ($W(CO)_6$) as precursor. Experimental parameters (partial pressure of precursors, deposition time and temperature) are controlled for tuning the WS_2 morphology from isolated triangular crystals to continuous film (SEM images in figure 1) and, then, for defining the WS_2 thickness (layers number). The dependence of WS_2 Raman spectrum on the layers number (figure 2a) is exploited for achieving a fast control (also on large area by Raman mapping) on both WS_2 thickness and thickness homogeneity. The last is very important for the fabrication of Van der Walls heterostructures since WS_2 optical properties strongly depends on its layers number (figure 2b). Moreover, we take advantage from the dependence of the WS_2 growth dynamics on the graphene surface energy for providing an additional degree of control on its growth. In particular, we demonstrate that graphene wettability to WS_2 can be improved by structural or chemical modifications in order to provide the spatial control on the WS_2 growth. Analyses based on Raman, photoluminescence and spectroscopic ellipsometry measurements demonstrate that this synthetic route can provide WS_2/graphene heterostructures characterized by the absence of interface defects and strain and with homogeneous PL response.[5]

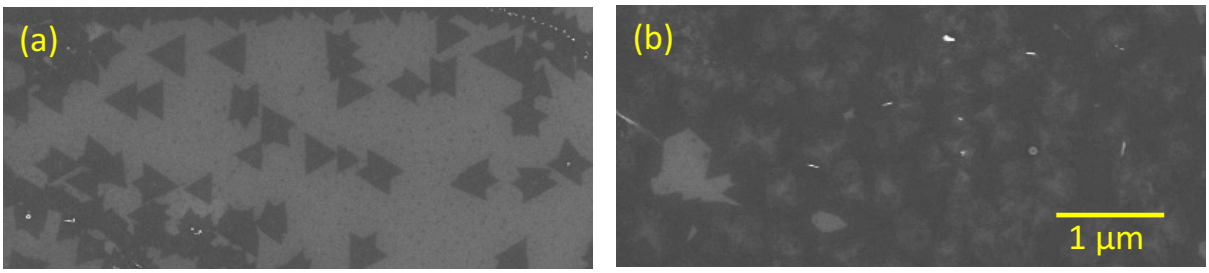

Figure 1: (a) Isolated triangular crystals and (b) continuous film of WS_2 grown on CVD graphene supported on Si/SiO_2 substrate.

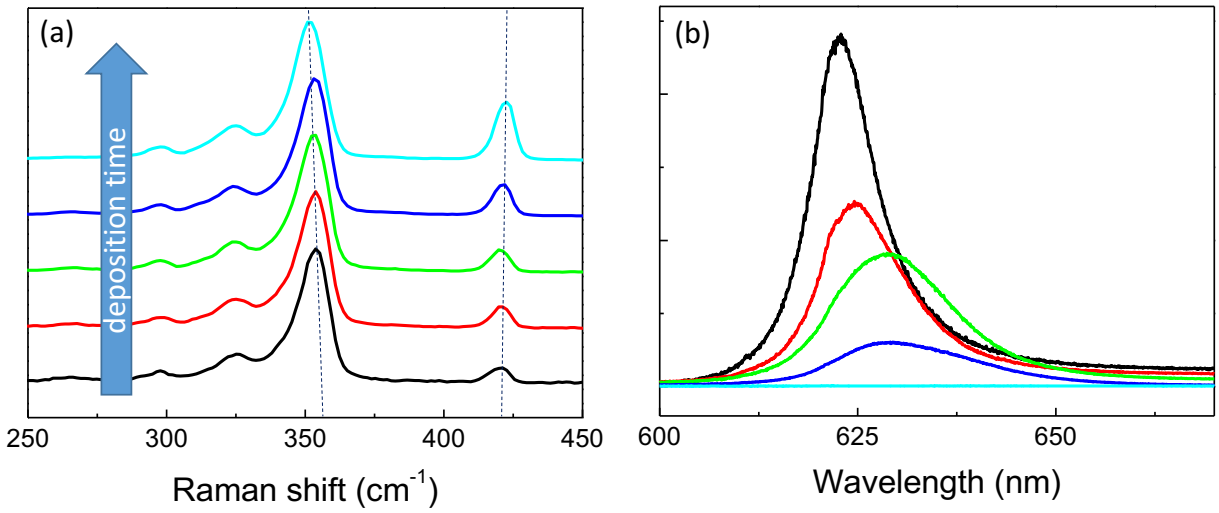

Figure 2: (a) Raman and (b) Photoluminescence spectra of WS_2 films grown on graphene with different deposition time.