Graphitic carbon molecular beam deposition on dielectric substrates

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There has been enormous progress in the synthesis of large area graphene layers, with much of the focus in the use of a catalytic reaction on a metal surface during Chemical Vapor Deposition (CVD) [1-3]. After the graphene is grown on a metal, it must be transferred to a dielectric substrate for its use in transport characterization and in devices. This exfoliation process inevitably induces degradation and contamination of the graphene layers. It would be desirable to be able to grow graphene layers directly on an insulating substrate allowing for high quality, transfer-free graphene devices. We explore a molecular beam epitaxy (MBE) approach to this challenge that could lead, in the future, to further benefits such as the capability to fabricate doped graphene, multilayer heterostructures and high carrier mobility layers.

We present here initial results on the fabrication of ultrathin graphitic layers on several dielectric substrates using a carbon by a molecular beam deposition MBD technique [4]. The samples have been characterized ex situ by: Raman spectroscopy, micro Raman spectroscopy, near-edge x-ray absorption fine structure (NEXAFS), AFM and STM. These results have been obtained on three different dielectric substrates: hexagonal-BN micro flakes (h-BN), SiO_2 and Mica.

The experimental growth set up (Figure 1) has been developed for this purpose that employs a UHV chamber with a carbon cell (figure 1, f) that can deposit sub-monolayer controlled graded amounts of carbon on a heated sample holder (s). The set-up allows in situ post growth high temperature annealing in a furnace as schematically shown in Figure 1.

The micro-Raman spectra (shown in Figure 2) reveal the Raman features D and G that are characteristic of graphitic material. On h-BN (red) an additional sharp and strong resonance is observed at ~1370 cm^{-1} that is from the underlying h-BN substrate. The spectrum taken on SiO_2 (black) shows also some structure around ~2700 cm^{-1}, which in graphene would be associated with a second-order Raman band. Finally, a Mica substrate presents a similar spectrum (blue). Although these Raman features are far away from ideal graphene, they show that it is possible to fabricate graphitic materials directly on dielectric.

NEXAFS measurements confirm the predominant sp^2 bond that confirms the graphitic character of the grown carbon layers. The NEXAFS analysis of a layer of carbon MBE-grown on Mica (figure 3) shows the following graphitic characteristics: an intense C=C π^* resonance at 285 eV (missing for sp^3-like diamond), a C=C σ^* resonance at ~292 eV, and a strong polarization dependence of π^* and σ^* resonances characteristic of an ordered 2-D bonding environment. Finally a fine structure in the σ^* region (photon energy > 290 eV) indicates long-range periodicity in the electronic structure.

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Figures

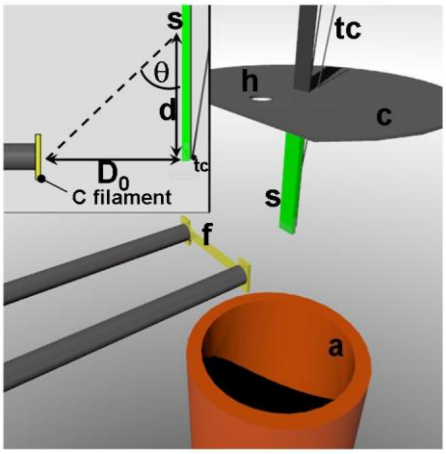

Figure 1: Illustration of the experimental MBE set-up. The carbon is evaporated from the filament (f) onto an elongated arbitrary substrate (s) and further annealed in a furnace (a). The Temperature is measured with the thermocouple (tc). The inset depicts a side view with labels of the geometrical parameters D_0 (13:3 mm), θ and d.

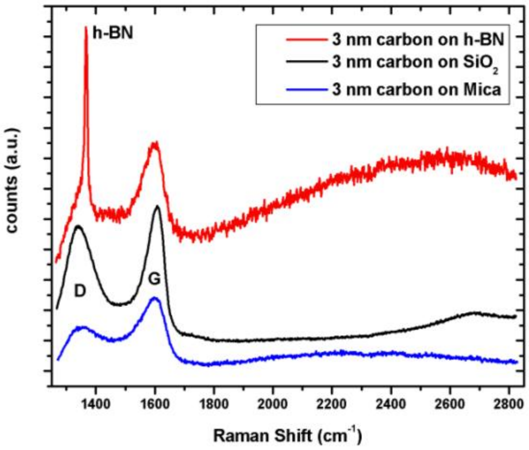

Figure 2: Micro Raman spectroscopy of 3 nm of carbon grown by MBE on hexagonal-BN (red), SiO_2 and Mica substrates.

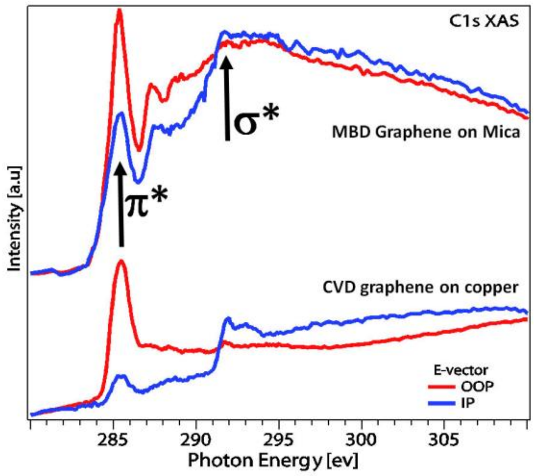

Figure 3: NEXAFS spectra of a MBE grown sample on Mica (top) and, for reference, a CVD grown sample on copper.