

# Growth of multi-layer graphene on SiC(000-1): thermal decomposition versus chemical vapor deposition

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Epitaxial growth of graphene by thermal decomposition of silicon carbide (SiC) is a classical and successful approach to obtain large-area continuous films directly on a semi-insulating substrate [1,2]. In this process the SiC crystal acts as precursor: the heating of the substrate at temperatures around 1350°-1450°C in Argon atmosphere causes Si sublimation, and the C atoms left behind rearrange in a honeycomb structure forming one or more layers of graphene [2]. Notably, the two different crystal basal planes of the hexagonal polytypes of SiC, indicated as SiC(0001) (Si-face) and SiC(000-1) (C-face), show significantly different growth modes for graphene. In particular, the graphene layers obtained on the C-face lack a defined azimuthal orientation (i.e., turbostratic graphene) so that each layer behaves as an isolated graphene layer and is electronically decoupled from the neighboring ones. For this reason, on this type of graphene, remarkable carrier mobilities have been measured [3]. A drawback of the growth via thermal decomposition of SiC(000-1) is that the number of layers grown can be hardly controlled. Recently, the growth of few to many layer graphene on the C-face of SiC via a classical chemical vapor deposition (CVD) approach has been demonstrated [4,5]. This approach makes possible a much finer control on the number of grown graphene layers [4]. CVD graphene on SiC(000-1) however, remains a system largely unexplored.

This work aims at comparing the structural, chemical and electronic properties of graphene grown on the C-face of SiC in a resistively heated cold-wall reactor (Aixtron HT-BM) by using the two different growth approaches: i.e., thermal decomposition and chemical vapor deposition. Before growth, the SiC substrates were treated with hydrogen etching to remove polishing damages and to obtain atomically flat surfaces. Few layer to multilayer graphene was grown on the C-face adopting the above-mentioned approaches. Specifically, CVD growth was carried out with methane as carbon precursor as described in [5] and thermal decomposition with the parameter set reported in [6]. Investigation of the structural, chemical and electronic properties was performed by using atomic force microscopy (AFM), Raman spectroscopy, scanning electron microscopy (SEM) and Hall effect measurements. The number of graphene layers obtained was determined from time to time via attenuation of the SiC signal in the Raman spectra [7] and by the absorption in the infrared region by using Fourier transform infrared (FTIR) spectroscopy [5].

Figure 1 shows typical AFM micrographs (plotted in 3D) and Raman spectra for multilayer graphene grown on SiC(000-1) via thermal decomposition (a) and CVD (b). Step bunching and narrow ridges were observed after thermal decomposition growth, while atomic terraces and no ridges were observed after CVD growth. Spatially-resolved Raman mapping – carried on using a Renishaw InVia system equipped with a 532 nm laser – confirmed in all instances a low defect density of the grown samples.

The possibility to grow with a rapid and tailored CVD process a high number of graphene layers (up to 90) with good crystallinity is extremely interesting for a number of electronic and optoelectronic applications. In particular, such turbostratic graphene has been shown to represent a favorable platform for obtaining high performance THz saturable absorbers, which would pave the way to novel graphene-based mode-locked THz lasers [5].

## References

- [1] P.N. First et al., MRS Bull. 35 296–305 (2011).
- [2] U. Starke et al., MRS Bull. 37 1177–86 (2012).
- [3] C. Berger et al., Science 312 (5777), 1191-1196 (2006).
- [4] W. Strupinski et al., Nano Lett. 11 (4), 1786-1791 (2011).
- [5] F. Bianco et al., Optics Express 23 (9), 11632-11640 (2015).
- [6] A. Candini et al., Beilstein J. Nanotechnol. 6, 711-719 (2015).
- [7] S. Shivaraman et al., J.Electron. Mater. 38 (6), 725-730 (2009).

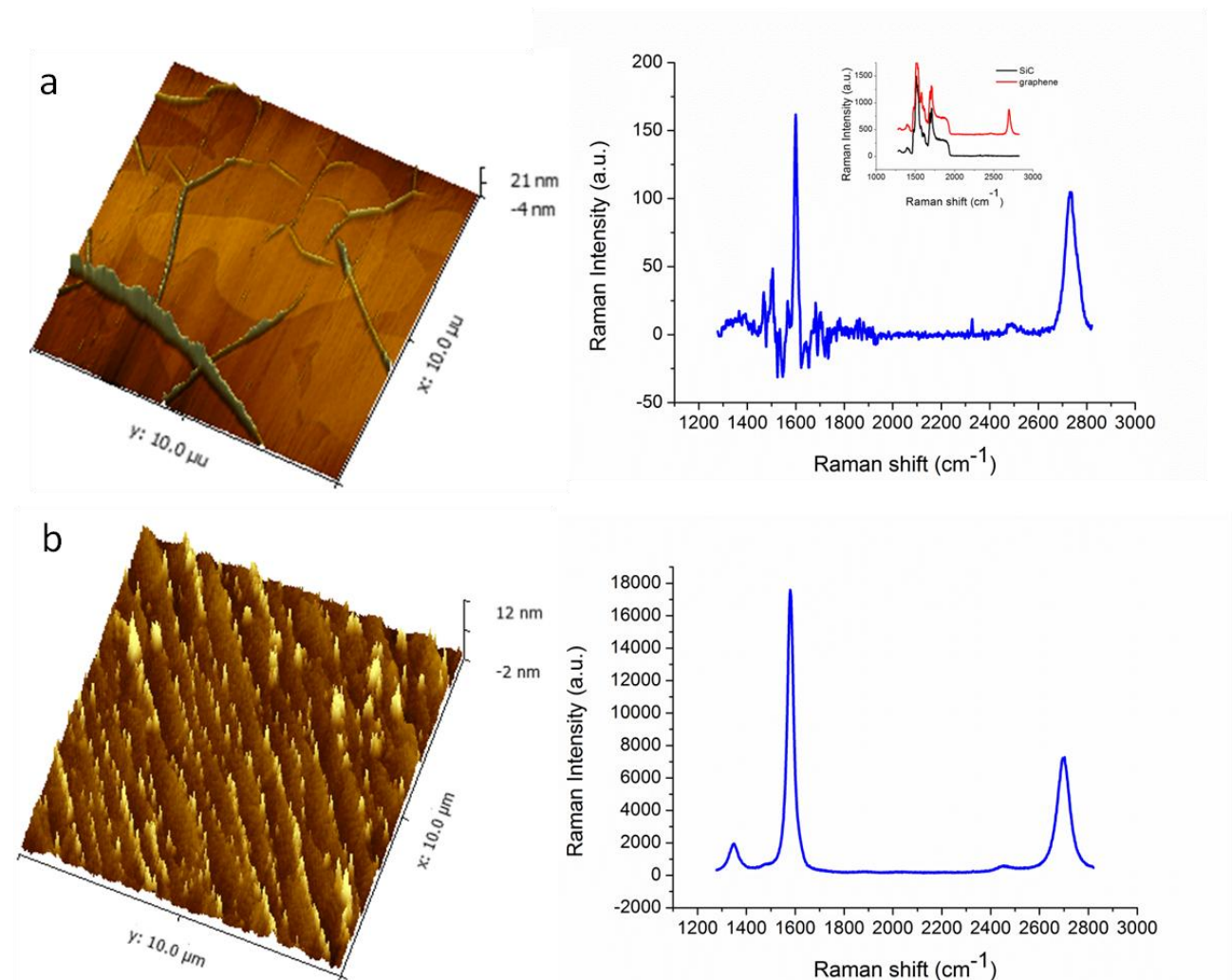


Figure 1: AFM 3D topography and Raman spectrum of graphene grown on the C-face of SiC by (a) thermal decomposition and (b) chemical vapor deposition.