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# Scalable metal-free CVD growth of graphene on sapphire

Here, we report that high-quality monolayer graphene can be obtained via chemical vapor deposition (CVD) on the c-plane of $Al_2O_3$(0001) substrates with a catalyst-free and single-step approach in a commercially available CVD reactor (HT-BM, Aixtron). The growth temperature in the presented CVD approach, i.e. 1200 °C, is lower than what typically reported in literature [1-2]. The structural and chemical properties of the synthesized graphene are investigated by Raman spectroscopy, atomic force microscopy (AFM), low-energy electron diffraction (LEED), Scanning tunnelling microscopy(STM) and X-ray photoelectron spectroscopy (XPS). Raman analysis reveals high-quality monolayer graphene over the entire sample through a high ($I_{2D}/I_G$) intensity ratio, which is more than 4.2, and a small D peak ($I_D/I_G$ averages at 0.55). The full width at half maximum (FWHM) of the 2D peak ranges from 29 to 35 $cm^{-1}$. AFM investigations show atomically flat sapphire surfaces and confirm the presence of graphene by imaging wrinkles, typical of CVD graphene upon thermal stress release. The wrinkles are several micrometers long and cross over the substrate terrace structure. C 1s binding energy is measured by XPS as 284.4 eV, confirming the sp2 nature of the grown carbon layer. No evidence of covalent interaction with the substrate is observed, indicating truly suspended graphene. In the acquired LEED micrographs, the diffraction spots of graphene and sapphire are clearly visible. Graphene preferential orientation is 30° rotated with respect to the sapphire substrate. The carrier mobility is above 2000 $cm^2$ /V.s. at room temperature. The presented metal-free CVD approach is of sure appeal in virtue of its implementation in a commercial system and by scalable yielding high-quality monolayer graphene it might have a positive impact on a number of optoelectronic applications.

## References

[1] J. Hwang, M.Kim, D. Cambell, M.Spencer et al., ACS Nano,(2013) 7(1),385-395.
[2] M.Fanton J. Robinson, C. Puls, D. Snyder et al., ACS Nano, (2011),5(10),8062-8069.

## Figures

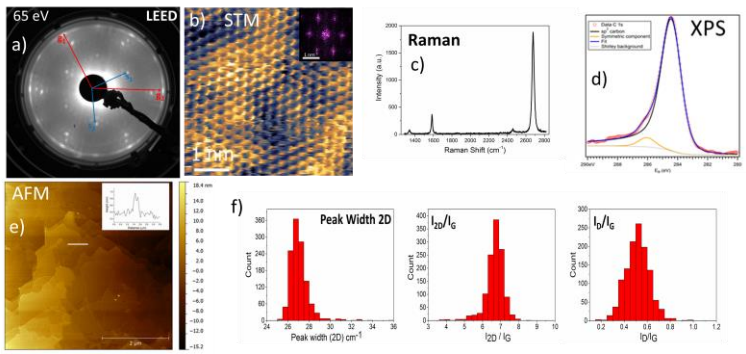


**Figure 1: Graphene on sapphire characterization via** (a) LEED at 65 eV; (b) STM; (c) Raman; (d) XPS - C1s spectrum; (e) AFM. (f) Histograms of 2D FHWM intensity ratio of 2D and G peaks and of D and G peaks.