

## Dielectric-Graphene and Silicon-Graphene integration for Graphene-Based Devices

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### Abstract

The integration of dielectrics or semiconductors on top of Graphene is of critical importance for the development of a new generation of Graphene-based devices, such as Graphene transistors amongst others. The deposition of a high-k dielectric, like Al<sub>2</sub>O<sub>3</sub>, or of Silicon on top of Graphene has still been challenging due to Graphene's lack of dangling bonds. In this paper, two strategies for the dielectric-Graphene and Silicon-Graphene integration will be presented.

The Physical Vapor Deposition (PVD) technique has been used to directly deposit dielectric materials on Graphene but often introduced significant defects in the Graphene layer, confirmed by Raman spectroscopy and mobility measurements of top-gated Graphene transistors<sup>1-3</sup>.

Atomic Layer Deposition (ALD) processes have been explored to deposit high-k dielectrics on Graphene with negligible Graphene damage. However, the dielectric film nucleation has been hindered by the chemical inertness of the Graphene surface<sup>4,5</sup>. Therefore, the ALD growth initiation on Graphene has required a functionalization of the pristine Graphene surface with reactive groups. For example, a functionalization by Xenon difluoride (XeF<sub>2</sub>) has been found to provide additional nucleation sites resulting in conformal films without pinholes<sup>6</sup>. However, XeF<sub>2</sub> is a toxic and strong oxidizing agent, which may ignite or explode on contact with combustible materials. Hence, the scope of our study was to test an alternative fluorinating agent, such as Nitrogen trifluoride (NF<sub>3</sub>), which is widely established in the microelectronics industry.

We tested the impact of NF<sub>3</sub> pre-treatments on transferred Graphene layers prior to the ALD of Al<sub>2</sub>O<sub>3</sub> at a substrate temperature of 400 °C. AFM revealed a substrate inhibition with a resulting island formation. Furthermore, AFM revealed that the Al<sub>2</sub>O<sub>3</sub> morphology seemed to be improved by the NF<sub>3</sub> pre-treatment due to an increased density of nucleation sites. As shown in Fig. 1, the pristine Graphene layer demonstrated a negligible D band as well as a proper G-to-2D intensity ratio, verifying a nearly defect-free monolayer Graphene. After the NF<sub>3</sub> pre-treatment and the ALD coating procedure, the D band as well as the G-to-2D intensity ratio remained rather unchanged.

Using low-temperature oxidized thin e-beam evaporated aluminum as seed layer for dielectric deposition can improve the nucleation and growth resulting in closed layers. However, methods such as the e-beam evaporation are often not compatible with large scale semiconductor device manufacturing.

In contrast, Chemical Vapor Deposition (CVD) as well plasma enhanced CVD (PECVD) are widely accepted manufacturing methods. PECVD is particularly interesting for applications requiring low thermal budgets such as the back end of line (BEOL) semiconductor device fabrication (< 450°C). However, high energy ion bombardment related to plasma exposure readily correlates with worsening of material properties<sup>7,8</sup>. Heintze et al. have demonstrated, that the ion energy in the plasma decreases with increasing frequency up to at least 180 MHz<sup>9</sup>. Using plasma excitation frequencies larger than 100 MHz frequencies is a unique feature in the field of PECVD methods.

We will demonstrate, that in contrast to the conventional radio frequency (RF, 13.56 MHz) PECVD a very high frequency (VHF, 140 MHz) PECVD can be used to cover CVD Graphene with thin a-Si:H layers very softly without changing the properties of the underlying Graphene significantly. Direct comparison of the RF and VHF methods demonstrated a decisive advantage of the VHF plasma: seed-free conformal coverage of Graphene at low temperatures without significant degradation of its crystalline quality. This striking difference was associated to the reduced ion energy in the VHF plasma.

An overview of Raman spectroscopy results obtained from Graphene samples covered with Si layers using RF and VHF PECVD methods is demonstrated in fig. 2. The Raman spectrum taken before Si deposition showed two strong peaks at ~ 1585 cm<sup>-1</sup> and 2680 cm<sup>-1</sup> which are assigned to the G and 2D bands, respectively. A negligible D band in this spectrum proved that a high quality Graphene layer was obtained after transfer. The appearance of a strong D-band (~1350 cm<sup>-1</sup>) in the spectrum taken from the RF sample clearly indicated damage of the Graphene crystalline lattice. In contrast, after the VHF

PECVD process, the D band was barely visible implying a good crystalline quality of the Graphene layer was preserved.

The herein presented deposition strategies demonstrated a significant progress towards a complete fabrication scheme of Graphene-based devices in Silicon technologies.

## References

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## Figures

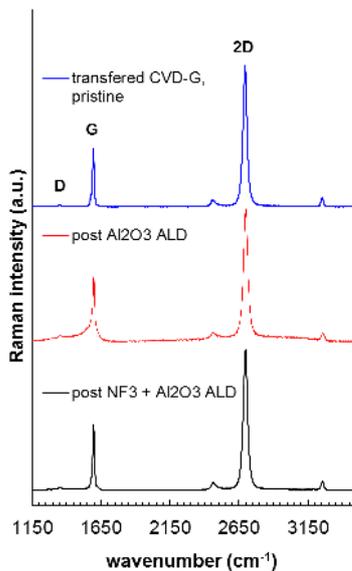


FIG 1: Raman spectra showing G and 2D Graphene bands for as transferred Graphene after the transfer (a), after 30 TMA-H<sub>2</sub>O ALD cycles at 400 °C (b), and after 180 s NF<sub>3</sub>-pre-treatment at 400 °C and 30 TMA-H<sub>2</sub>O ALD cycles at 400 °C (c).

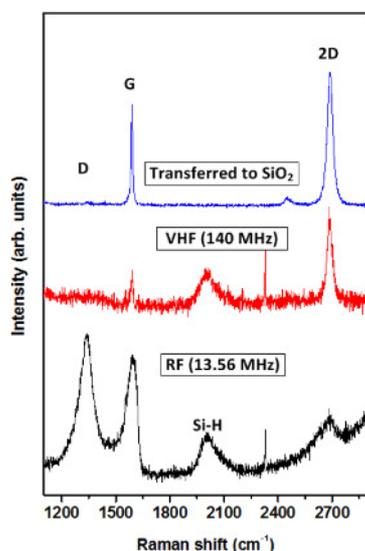


FIG. 2. Raman spectra showing G and 2D Graphene bands for as transferred CVD Graphene and after deposition of 20 nm of amorphous Si by RF (13.56 MHz) and VHF (140 MHz) PECVD. Signal-noise ratio worsening observed after Si deposition is associated with attenuation of the Raman signal from Graphene by the Si overlayer.