Remote epitaxy of III-V films on a universal template

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In remote epitaxy, a thin 2D material layer placed on a semiconductor substrate induces an interaction gap between substrate and growing layer allowing to peel-off the epitaxial layer from the substrates and to recycle the substrate [1], therefore reducing production cost of freestanding heterostructures and enabling versatile stacked heterostructures fabrication [1,2]. The thin 2D material layer is either manually transferred to a substrate or grown directly on a substrate at high temperature, thus limiting the process scalability or the choice of substrates. Here, we present a low-temperature (300 °C), cheap and wafer-scale fabrication process of ultrathin 2D-like sp^2-hybridised amorphous carbon layer templates on various substrates and their subsequent overgrowth [3]. High crystal-quality group III-arsenides layer growth on amorphous carbon covered InP and GaAs substrates is demonstrated as well as growth of metastable cubic group III-nitride layers on amorphous carbon covered 3C-SiC.

Atomic force microscopy measurements (Fig. 1a)) reveal an atomically smooth surface of the monolayer-like thin amorphous carbon layer and Raman and X-ray photoelectron spectroscopy measurements reveal a predominant sp^2-hybridisation of the carbon bonds (Fig. 1b)-c)); key factors for successful remote epitaxy [2]. We show that precisely tailoring the carbon layer thickness allows superior tunability of the substrate-layer interaction allowing to tune the nucleation behavior on the amorphous carbon coated substrates (Fig. 2a)-b)) while transferring the substrate crystal orientation to the epilayer (Fig. 2c)). Photoluminescence measurements of droplet etched $In_{0.57}Ga_{0.43}As$ quantum dots (Fig. 3b)) (important for infrared applications) on our amorphous carbon templates and high-resolution X-ray diffraction measurements (Fig. 3a)) verify a high crystal quality of the epitaxial layers; dislocation densities $<1 \times 10^7$ cm^{-2} are determined for optimized growth conditions. Our results show a universal approach to fabricate templates for remote epitaxy, e. g., for remote epitaxy on temperature sensitive substrates like GaAs or InP and growth of metastable phases. Lift-off of layers from their substrates is demonstrated by employing a Ni stressor approach (Fig. 3c)) [3].

[1] Kim, Y. et al. Nature 544, 340–343 (2017)

[2] Park, B-I. et al. ACS Nano. 24, 10 (2024)

[3] Henksmeier, T. et al. arXiv:2410.15487 (2024)

Fig. 1: Characterization of the fabricated monolayer-like amorphous carbon layer. a) 5x5µm^2 AFM image with surface roughness ≤0.3 nm, b) XPS spectrum and c) Raman spectrum both revealing sp^2-hybridised amorphous carbon.

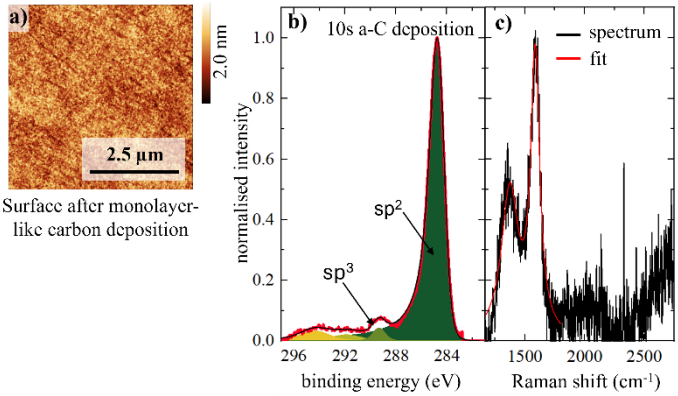

Fig. 2: Characterization of nucleation layers on the amorphous carbon template. a), b) 1x1µm^2 AFM images after 2 nm and 25 nm GaAs deposition, respectively, c) ADF-STEM image and GPA analysis of the substrate-carbon-epilayer interface indicating a crystal lattice stretching and lattice alignment through the interface.

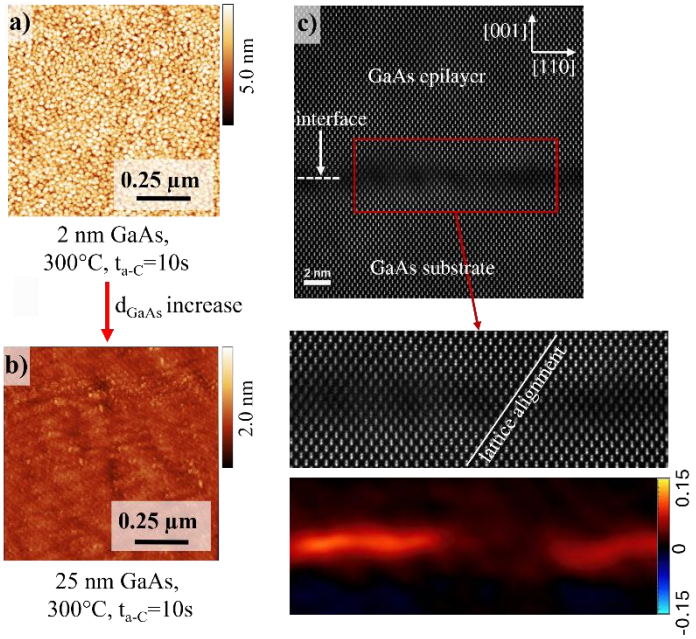

Fig. 3: HR-XRD and photoluminescence measurements of epitaxial films grown on amorphous carbon templates. a) HR-XRD measurements of $In_{0.65}Ga_{0.45}As$ on InP, $In_{0.09}Ga_{0.91}As$ on GaAs and c-GaN on 3C-SiC substrates. b) Photoluminescence measurements of droplet etched $In_{0.57}Ga_{0.43}As$ quantum dots; the inset shows a 200 nm thick film lifted-off by applying the Ni-stressor approach. c) $\theta/2\theta$-scan of the lifted-off film.