GaAs growth on graphene covered substrates towards substrate recycling

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The purpose of this work is to obtain transferable III-V thin films, by epitaxy above a graphene covered substrate. Studies showed that monocrystalline layers could be obtained, which are sufficiently weakly attached to the substrate thanks to the graphene plane to allow for their exfoliation. Ideally, the substrate could be recycled for several growth. In the field of photovoltaics, this would provide cost reductions by more than 30%, for devices presenting the highest efficiencies among available materials.

It was suggested that growth could occur *via* remote interaction through the graphene[1]. We have not observed this behavior in previous work, which resulted in a polycrystalline layer formation. A potential competing growth mechanism could proceed by nucleation at graphene holes, followed by lateral growth towards coalescence. We propose to explore this route, since we have evidenced that graphene can play the role of a mask compatible with selective area growth. In our case, graphene is grown on a germanium substrate and dry-transferred to GaAs[2], before patterning by electron beam lithography.

We investigate the growth behavior on graphene patterned as parallel stripes along different directions of the GaAs substrate. Before coalescence (fig. 1), we find that the <100> directions provide structures with smooth morphologies, and significant lateral growth over the graphene. <-110> resulted in nanowalls with negligible lateral growth, and <110> presented significant roughness, which could be due to twin formation on the formed {111} walls. Those results are consistent with the literature with silica masks[3]. Higher index directions present nanostructures with multi-atomic steps. After coalescence however, high index directions provided layers with the smoothest morphologies (fig. 2), while <-110> did not show significant coalescence, and <100> preserved a more significant roughness. Above a 500 nm buffer GaAs, we have grown a $Al_{0.8}Ga_{0.2}As/Al_{0.2}Ga_{0.8}As/Al_{0.8}Ga_{0.2}As$ (100/200/100 nm) heterostructure for luminescence tests (fig. 3). Consistently, no signal could be observed on directions <110> and <-110> while it increases for higher indexes. More precise studies as a function of graphene coverage and stripes orientation are ongoing, as well as cathodoluminescence and TEM.

Exfoliation tests have been carried out. First, a 30 nm Ti layer to enhance adhesion is deposited, followed by a 250 nm Ni layer and a thermal release tape. This tape is manually peeled off. Fig. 4 show an SEM picture of the remaining material on the substrate. The polycrystalline GaAs formed on graphene covered GaAs is successfully exfoliated. Coalesced GaAs structure on patterned graphene can be exfoliated for sufficiently large graphene coverage ratio. A dependance on the stripe orientation is observed, which is suspected to be related to the manual peel off direction. This dependance will be further investigated in the coming months.

1 *Kim, Y. et al. Nature 544, 340–343 (2017),* ***2*** *Macias, C. et al. Appl. Surf. Sci. 676, 160913 (2024),* ***3*** *Ironside, D. J. et al. Cryst. Growth Des. 19, 3085–3091 (2019)*

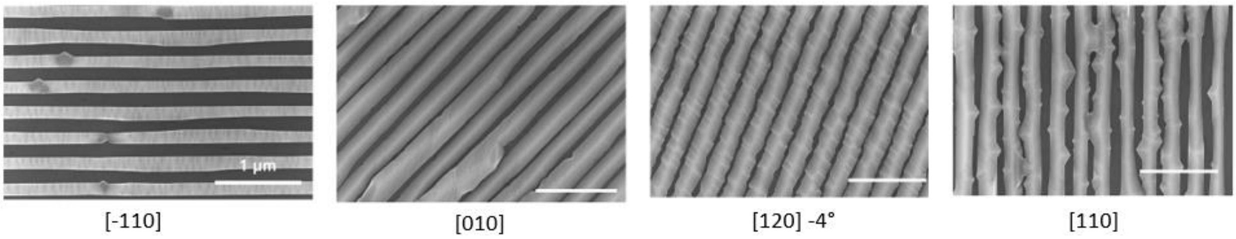

Figure 1 Deposition of 360 ML GaAs, at Tg~615°C and V/III ratio of 2, on a graphene covered GaAs substrate, patterned as stripes along various substrate orientations. Stripes opening are 50 nm wide, with a 300 nm repetition period.

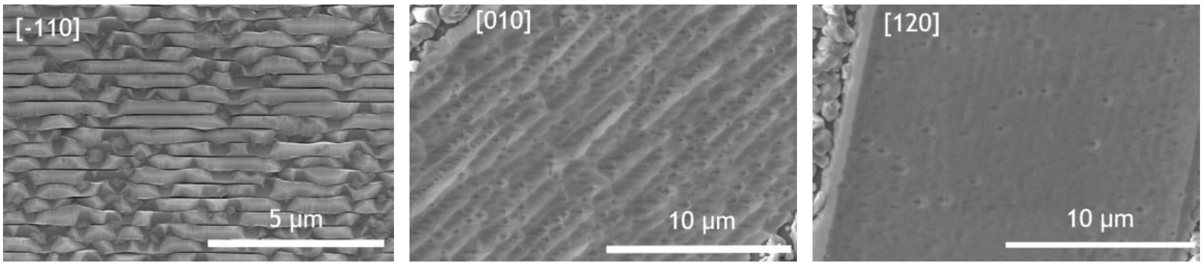

Figure 2 500 nm GaAs deposition, beyond coalescence on patterned graphene on GaAs. Stripes opening are 150 nm wide, with a 300 nm repetition period.

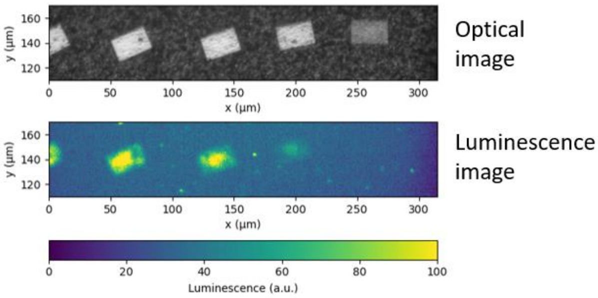

Figure 3 Optical image and corresponding luminescence under an LED illumination at 405 nm, for a $Al_{0.8}Ga_{0.2}As/Al_{0.2}Ga_{0.8}As/Al_{0.8}Ga_{0.2}As$ (100/200/100 nm) heterostructure, on a 500 nm GaAs buffer grown on a patterned graphene covered GaAs substrate.

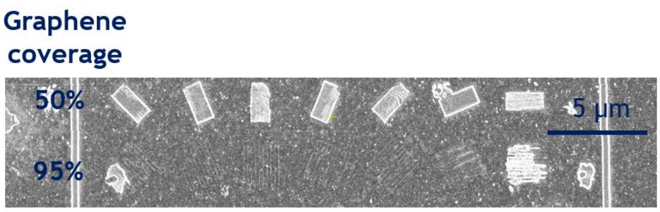

Figure 4 Remaining structures on the substrate after an exfoliation test. Exfoliation is obtained by depositing 30 nm Ti and 250 nm Ni, and attaching a thermal release tape, before manual peel off. Exfoliation depends on the graphene coverage. The angle between the graphene stripe orientation and peel off direction is suspected to play a role and has not been carefully investigated so far.