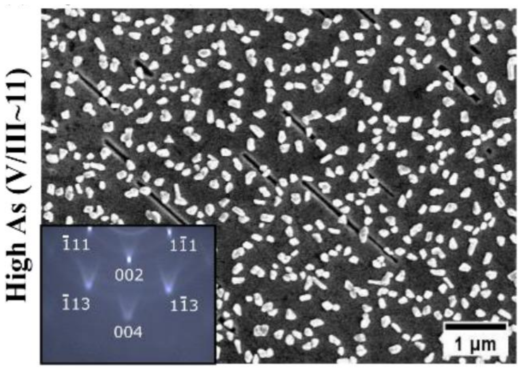
Graphene assisted III-V thin film growth towards substrate recycling

Amaury Delamarre
Carlos Macias, Naomie Messudom, Antonella Cavanna, Ali Madouri, Laurent Travers, Ludovic Largeau, Nathalie Bardou, Solène Béchu, Andrea Cattoni, Jean-Christophe Harmand
Centre for Nanoscience and Nanotechnology (C2N), CNRS, Univ. Paris-Sud, Univ. Paris-Saclay, 10 Boulevard Thomas Gobert, 91120 Palaiseau, France
amaury.delamarre@c2n.upsaclay.fr

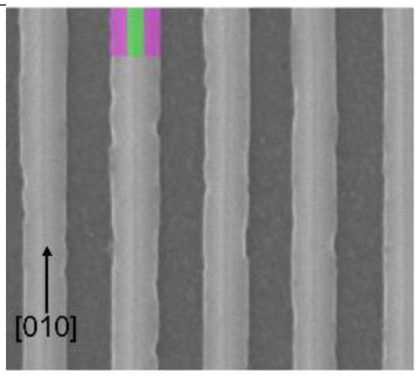
The goal of this work is the fabrication of transferable thin films of III-V materials, a material family of choice for their optoelectronic properties. Here, we want to recycle the monocrystalline III-V substrate after transfer, a process interesting for large aeras applications. In photovoltaics, III-V devices are the most efficient, but not economically viable. The substrate accounts for at least 30% of the cost, hence the objective of recycling it.
The strategy is to transfer a graphene layer above the substrate before the III-V growth, that should allow the epitaxy, but also the exfoliation, thanks to the mechanically weak graphene plane. Transferred LEDs have been demonstrated in the literature, with the III-V growth performed by MOVPE [1]. It was suggested that the epitaxial relation between the substrate and the thin film was due to a remote interaction through the graphene. Local nucleation at graphene openings followed by lateral growth is another possible mechanism.
We will present here dry-transferred graphene from germanium, with a nickel layer [2] and air-cushion pressing, originally developed for imprint lithography [3]. The transferred graphene shows characteristics compatible with epitaxy, without degradation or contamination.
During growth by Molecular Beam Epitaxy (MBE), we obtain nuclei with random orientations (fig. a, [3]), which indicates a lack of interaction through the graphene with our process. TEM further shows that an oxide layer is stabilised at the substrate surface below the graphene, which is otherwise removed by annealing under As pressure in MBE. We then patterned the graphene by e-beam lithography. We show that graphene plays the role of a mask, allowing selective area epitaxy through graphene openings. Using various patterns and growth conditions, we find that stripes oriented along the [010] direction of the substrate are the most favourable, avoiding twin defect formation, and promoting III-V lateral growth (fig. b).

References
[1] Y. Kim, et. Al., "Remote epitaxy through graphene enables two-dimensional material-based layer transfer," Nature 544(7650), 340–343 (2017).
[2] J. Kim, et. Al., "Layer-Resolved Graphene Transfer via Engineered Strain Layers," Science 342(6160), 833–836 (2013).
[3] C. Macías, et. Al., in Physics, Simulation, and Photonic Engineering of Photovoltaic Devices XII (SPIE, 2023), pp. 27–33.

Figures



(a)



(b)

Figure 1: (a) GaAs nuclei with random orientation, formed on graphene covered GaAs substrate. (b) Selective area growth of GaAs on patterned graphene. The stripes are oriented along the [010] direction of the substrate. The green area represents the stripe width, the purple area represents the lateral overgrowth.