Graphene assisted III-V epitaxy for substrate recycling

Naomie Messudom(1), Carlos Macias(2), Antonella Cavanna(1), Ali Madouri(1), Nathalie Bardou (1), Solène Béchu (2,3), Laurent Travers(1), Stéphane Collin (1,2), Jean-Christophe Harmand(1), Amaury Delamarre(1,2)

(1) Centre de Nanosciences et Nanotechnologies (C2N); (2) Institut PhotoVoltaïque d'Ile-de-France (IPVF); (3) Institut Lavoisier de Versailles (ILV)

To date, III-V solar cells are the most efficient technology available. However, their high cost is a significant barrier to their wider deployment. In order to reduce the production cost, this study proposes a strategy for recycling the substrate, which represents the largest cost during the manufacturing process, through the use of a two-dimensional material-based layer transfer (2DLT) method. This approach involves the insertion of a two-dimensional material, specifically graphene, onto the substrate prior to the epitaxial growth of the III-V material. The objective is to take advantage of the weak Van der Waals (VdW) bonds at the monolayer graphene plane to enable the epitaxially grown III-V material to be detached from the native substrate for later reuse. The process is described in Fig.1a.

A Ni-assisted dry transfer method was developed to transfer a graphene layer onto a GaAs substrate. The transferred graphene layer was found to be free of organic and oxide contamination, as confirmed by X-ray photoelectron spectroscopy and Raman analysis[1]. Experimental results showed that remote interactions through the graphene were not sufficient to achieve epitaxial growth as GaAs islands formed on the graphene were found misaligned with the underlying substrate. Nevertheless, the creation of openings in the graphene layer has enabled the control of nucleation. The process involved the selective growth of GaAs in graphene openings, followed by planar growth to reach GaAs coalescence. The selective area growth of GaAs in graphene openings was studied with the objective of identifying the most favorable orientation for coalescence. The results demonstrated that growth following the <001> directions yielded the most promising morphology, characterized by a good lateral overgrowth and the formation of straight, uniform and smooth facets (Fig. 1b). Upon coalescence step, the morphology of the GaAs appeared to be better when the apertures were oriented at an angle of 22.5° to the [001] (= 67,5°) direction. These initial results have prompted further investigation into the impact of orientation and its influence on lateral growth. Some studies, such as paper from G Nagda et al.[2] have demonstrated that misorientation can lead to an increase in step density resulting in enhanced material incorporation due to nucleation at step edges.

This study provides a guideline for the growth of a bulk material on a 2D layer, showing promise for III-V material transfer and substrate reuse, but also for the integration of 2D materials in III-V applications.

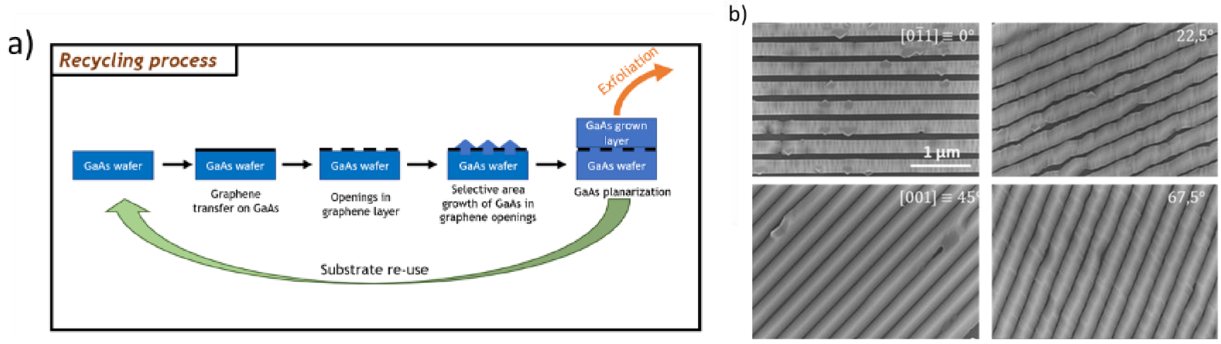

Fig 1: a) Recycling process of GaAs substrate using 2DLT method. b) SAG of GaAs growth on graphene patterned oriented in 4 directions.

1. C. Macías, et al., "Optimized Ni-assisted graphene transfer to GaAs surfaces: Morphological, structural, and chemical evolution of the 2D-3D interface," Applied Surface Science, 160913 (2024).
2. G Nagda, et al., "Effect of in-plane alignment on selective area grown homo-epitaxial nanowires," *Nanotechnology* **34** 275702 (2023)