

## Direct growth of GaSb on Ge, Ge-on-Si and SiGe-on-Si platforms for integrated mid infra-red photonics

M. Silvestre,<sup>1,2</sup> J.-B. Rodriguez,<sup>1</sup> S. Calcaterra,<sup>3</sup> G. Isella,<sup>3</sup> E. Tournié,<sup>1,4\*</sup>

<sup>1</sup>IES, University of Montpellier, CNRS, F – 34000 Montpellier, France

<sup>2</sup>RIBER SA, F – 95870 Bezons, France

<sup>3</sup>L-NESS, Politecnico di Milano Dipartimento di Fisica, I - 22100 Como Italy

<sup>4</sup>Institut Universitaire de France (IUF), F-75005 Paris, France

\*E-mail: [eric.tournie@umontpellier.fr](mailto:eric.tournie@umontpellier.fr)

Integrated mid infra-red (MIR) photonics is of major interest for free-space communications, bio-sensing, etc. III-V antimony based lasers are efficient light sources in the MIR range that can be grown on passive Si photonics circuits [1]. However, most Si-based materials absorb a large part of the MIR spectrum above 8  $\mu\text{m}$ , in contrast to germanium which has a wide MIR transparency window [2]. The direct growth of III-Sb materials on Ge substrates or Ge-on-Si templates would allow developing integrated photonic circuits operating at longer wavelengths (up to 14  $\mu\text{m}$ ). Still, III-V heteroepitaxy on group-IV substrates is hampered by various crystal defects. In particular, anti-phase boundaries (APBs) are 2D defects particularly detrimental to devices because they act as short circuits. In this work, we investigated the growth of GaSb on Ge substrates and on Ge-on-Si templates grown by low-energy plasma-enhanced CVD (LEPECVD) [3].

The starting surface preparation is critical for growing APB-free GaSb films on group-IV substrates [4]. We found that APB-free GaSb layers can be achieved only when the Ge substrates are prepared by UHV annealing in a narrow temperature window. The Ge-on-Si and SiGe/Si templates, however, exhibit cross hatch patterns arising from strain relaxation during template growth, which prevents proper surface organization prior and during III-V growth. This, in turn, precludes APB annihilation. This effect can be alleviated either by using slightly miscut ( $1^\circ$  -  $2^\circ$ ) Si substrates, or by smoothing the starting surface of on-axis Ge-on-Si templates by chemical-mechanical polishing. Under these conditions, APB-free GaSb layers can be achieved after 500 nm growth. They exhibit a rms roughness of 1.0 nm. Such layers can be used as templates for the direct growth of III-V devices. These results represent a further step in the development of integrated MIR photonics.

Part of this work was sponsored by "France 2030" (Equipex EXTRA, ANR-11-EQPX-0016, Equipex+ HYBAT, ANR-21-ESRE-0026) and the ANR-LightUp project (ANR-19-CE24-0002).

- [1] A. Remis, L. Monge-Bartolome, M. Paparella, A. Gilbert, G. Boissier, M. Grande, A. Blake, L. O'Faolain, L. Cerutti, J.-B. Rodriguez, and E. Tournié, *Light Sci. Appl.* **12**, 150 (2023).
- [2] R. Soref, *Nat. Photonics* **4**, 495 (2010).
- [3] G. Isella, D. Chrastina, B. Rössner, T. Hackbarth, H.-J. Herzog, U. König, and H. von Känel, *Solid-State Electron.* **48**, 1317 (2004).
- [4] M. Rio Calvo, J.-B. Rodriguez, C. Cornet, L. Cerutti, M. Ramonda, A. Trampert, G. Patriarche, and É. Tournié, *Adv. Electron. Mater.* **8**, 2100777 (2022).

