

# From Research to Production: How MBE can Unlock GaN-on-Si Technology

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**Abstract** — MBE has several advantages for the epitaxy of GaN-based heterostructures. More specifically, by controlling the interface between the AlN buffer layer and the silicon substrate, ammonia-MBE allows to grow innovative structures on silicon. Epitaxy on silicon necessarily requires a demonstration of scaling-up on large wafers used by the microelectronics industry. Properties of several epitaxial heterostructures grown on 200 mm substrate are presented and discussed, emphasizing the originality of these structures and the beneficial contribution of MBE. Also, prospects and future challenges are discussed.

**Keywords**—GaN-on-Si; Ammonia-MBE; Aluminum nitride; Hetero-epitaxy on Si;

Over the past 20 years, the epitaxy of GaN-based heterostructures on silicon substrates has undergone remarkable development [1]. MOCVD is the epitaxial technique used by industrial actors because it allows to easily grow low dislocation density ( $10^8 \text{ cm}^{-2}$ ) GaN on sapphire substrates and InGaN/GaN quantum wells having excellent internal quantum efficiencies. It is precisely these properties that made possible to revolutionize the lighting industry with the fabrication of highly efficient blue light-emitting diodes and then white lamps. GaN epitaxy on silicon, which necessarily involves the epitaxy of an AlN buffer layer, is more complex than epitaxy on sapphire. This complexity comes mostly from the high surface reactivity of silicon in the presence of residual species such as  $\text{NH}_3$ , Ga, In and Al. Moreover, these group-III elements may strongly diffuse into the silicon substrate especially considering the high growth temperature needed during MOCVD growth ( $> 1000^\circ\text{C}$ ). As a matter of fact, the nucleation of the AlN buffer by MOCVD on silicon still remains a subject of study today because it significantly influences the performance of GaN-on-Si components [2]. On the other hand, MBE, and more particularly ammonia-MBE, considering the UHV environment and the possibility of growing at lower temperature (nucleation at  $600^\circ\text{C}$ ), allows to perfectly control and reproduce the AlN/Si interface [3]. Using such advantage various extremely thin functional heterostructures have been grown on silicon which are difficult to achieve using MOCVD [4-8].

This presentation will explain how we went from an academic research work to the production of a 200 mm AlN-on-Si templates by going from a Riber Compact 21 reactor to a Riber MBE 49 reactor. The properties of AlN-on-Si templates are presented, and its advantages are discussed. To go further in the value chain and taking advantage of MBE specificities, original heterostructures, like ultra-thin AlGaIn/GaN HEMTs (epilayer thickness  $\ll 1 \mu\text{m}$ ) grown on silicon and AlGaIn channel HEMTs, are fabricated. The remarkable properties of these heterostructures are presented and discussed in view of producing innovative high-performance microwave components and power components capable of withstanding voltages beyond 1000 V. Finally, prospects and future challenges are discussed.

<sup>1</sup> GaN-on-Si: many opportunities are driven by microLED, power electronics and RF electronics, Yole Développement (2020)

<sup>2</sup> S. Besendörfer *et al.* J. Appl. Phys., **127**, 015701 (2020)

<sup>3</sup> F. Semond, MRS Bulletin Vol. 40 (2015)

<sup>4</sup> J. Sellès *et al.*, Scientific Reports Vol. 6, 21650 (2016)

<sup>5</sup> E. P. Malinowski *et al.*, Electron Device Letters Vol. 32, 1561 (2011)

<sup>6</sup> M. Mexis *et al.*, Optics Letters Vol. 36, 2203 (2011)

<sup>7</sup> P. N. Chyurlia *et al.*, Electronics Letters Vol. 46, 253 (2010)

<sup>8</sup> S. Sergent *et al.*, Applied Physics Express Vol. 2, 051003 (2009)