Templates: the fast track to GaN-on-Si LEDs

By using templates, costly development can be avoided and the advantages of GaN-on-Si can be easily exploited with extremely short design-in cycles, says Erwin Ysewijn of AZZURRO Semiconductors.

The LED industry is facing ever increasing cost pressures. One approach to resolve this has been the move to larger wafer diameters. Furthermore, instead of typically using expensive sapphire, the use of inexpensive silicon as a substrate material for epitaxial growth of gallium nitride (GaN) has been advocated. The technical challenges of using silicon substrates — such as poor crystalline quality and wafer bow — have been difficult to overcome. Here we present a solution for LED manufacturers to migrate to the GaN-on-Si material system without the need for costly, lengthy and risky developments.

Templates

In general, templates allow the user to grow additional epitaxial layers on the existing epi-structure of the template. Being the biggest single cost factor of an LED epiwafer, a reduction in the required growth time is the primary goal of using templates. An extra benefit, sometimes overlooked, is that templates can offer the user advantageous technological features.

In this case, LED structures can be deposited on a high-quality buffer grown on a large-diameter and low-cost silicon substrate (Figure 1). The LED structures often incorporate IP-protected and proprietary layers such as multi-quantum-wells. This enables LED manufacturers to continue using their own epitaxial structures while at the same time being able to migrate to GaN-on-Si and hence utilizing the large associated cost savings of 60% and more.

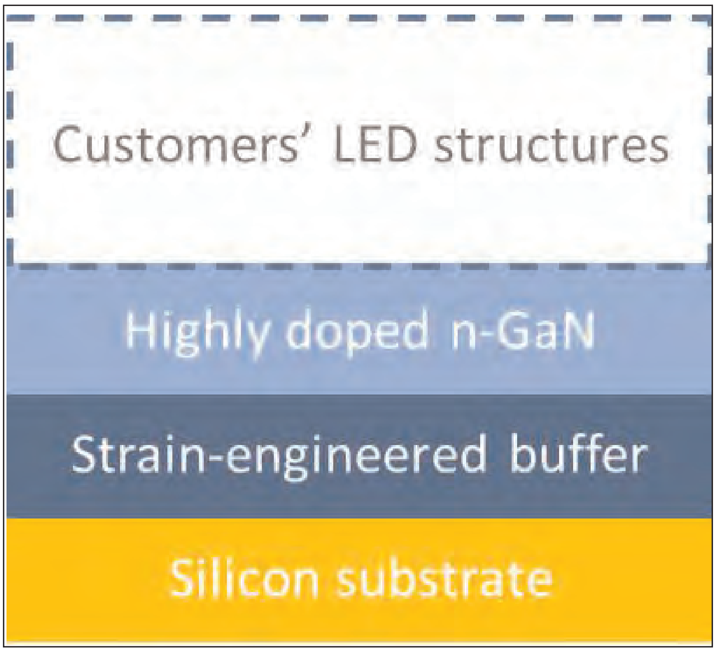

Figure 1: Template consisting of silicon substrate with high-quality strain-engineered buffer and highly doped n-GaN layer ready for overgrowth with LED structure.

To introduce templates successfully into LED production, the crystal quality must match that of epitaxial structures grown on sapphire substrates. Furthermore, GaN-on-Si templates must offer good homogeneities for good binning results.

The large mismatch between GaN and silicon in terms of their lattice constants and thermal expansion coefficients makes it difficult to achieve these preconditions. Thick GaN layers are needed to yield high crystal quality, and these are particularly challenging to achieve. Without excellent strain-management techniques, cracks and high wafer bow values limit the achievable GaN thickness and crystal quality. Strain management is also required to unlock the very significant homogeneity improvements that are possible by using GaN-on-Si. For the overgrowth of a wide range of different LED structures, the template also needs to offer large overgrowth thickness. With larger wafer diameter, the aforementioned challenges for GaN-on-Si increase. Finally, the resulting epiwafers need to offer large diameters of least 150mm and ideally 200mm, as well as very low bow values. These latter challenges are fundamental gating issues for epiwafers being processed in low-cost standard silicon lines.

In summary, GaN-on-Si templates offer huge saving potentials, but the technological challenges that need to be overcome require costly and lengthy development processes. Moreover, newcomers to the technology have to be aware of existing IP in the GaN-on-Si field.

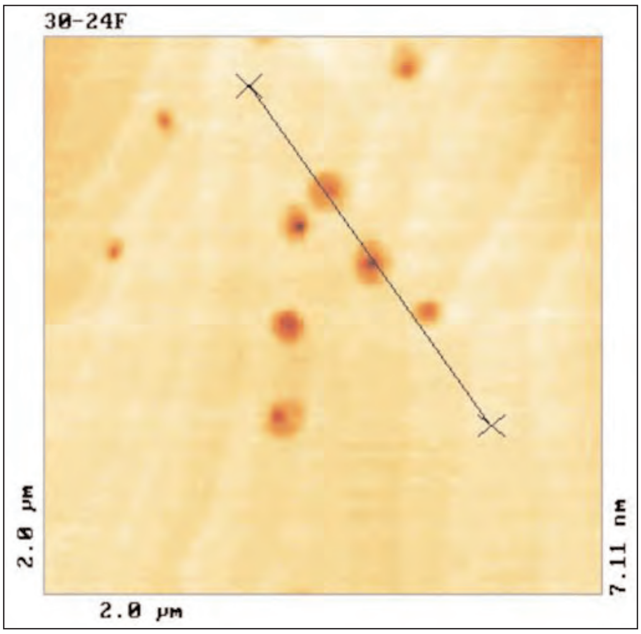

Figure 2: Crystal quality: low EPD of $2x10^8cm^{-2}$ and XRD result of 450 arcsec (for 102 plane).

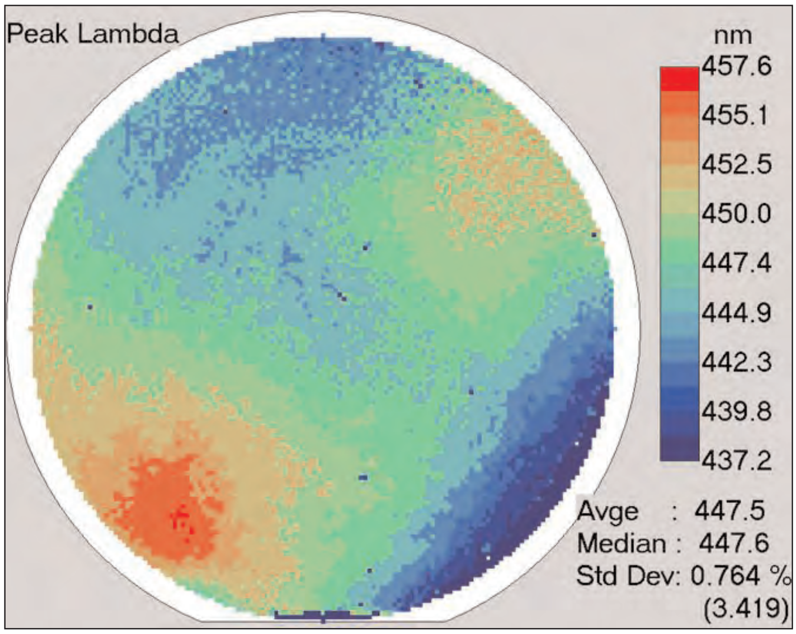

Figure 3: LED binning reduction made possible with strain-engineered 150mm GaN-on-Si templates.

Overcoming the challenges

Promising results with strain-engineered templates offer a road to migrating to GaN-on-Si and unlocking the savings potential of GaN-on-Si that can already be achieved today. Very good crystal quality has been achieved for highly n-doped ($5x10^{18}cm^{-3}$), 5.7µm-thick overgrown templates with x-ray diffraction (XRD) and etch-pit density (EPD) values in the range of those achieved on sapphire substrates (Figure 2). Also, excellent homogeneities have been demonstrated. These achievements on templates translate to an outstandingly narrow wavelength distribution for 150mm LED epiwafers, resulting in substantially reduced binning (see Figure 3).

To provide the epitaxial engineer overgrowing the templates with a wide range of LED structure designs, 3µm of highly doped ($5x10^{18}cm^{-3}$) GaN can be grown on top of the templates. All the above is achieved while the strain-engineering from the templates enables the resulting 150mm-diameter LED epiwafers to have a bow value of less than 20µm (Figure 4).

This allows the resulting LED epiwafers to gain from high-yield and low-cost processing in standard silicon lines.

Due to the high crystalline quality, the large overgrowth thickness and dedicated packages supporting the transfer of LED structure growth onto the GaN-on-Si templates, very short production phase-in times are facilitated.

Conclusions

Strain-engineering technology can enable high-quality GaN-on-Si templates. The templates discussed above enable the migration of LED production to the GaN-on-Si material system. LED manufacturers can transfer their own LED structures to the GaN-on-Si material system without the need for lengthy, risky and costly development of their own GaN-on-Si technology. The cost and homogeneity benefits from strain-engineered GaN-on-Si technology can be utilized quickly. ■

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www.azzurro-semiconductors.com

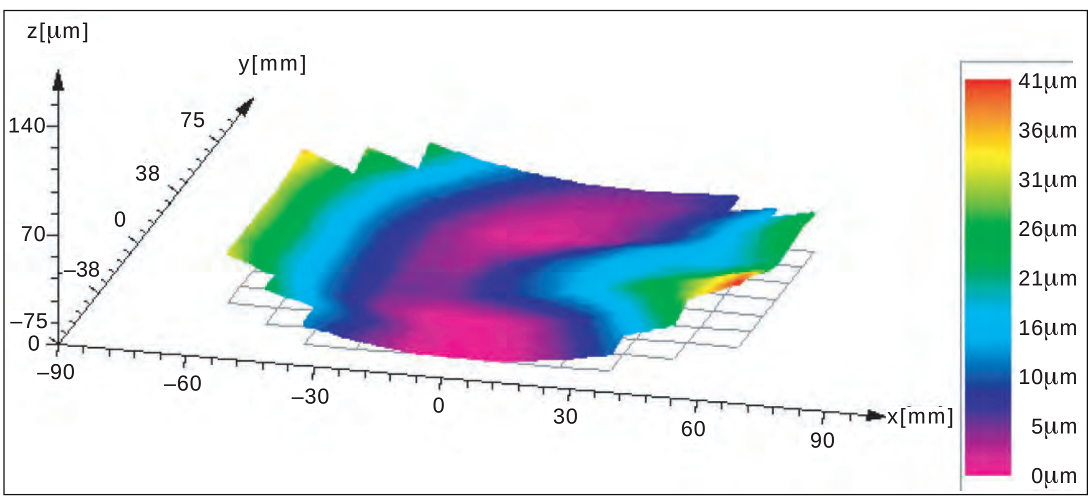

Figure 4: Strain-engineered low-bow wafer, ready for silicon processing lines.