# Dislocation Density Reduction in GaN Using Self-Assembled Masking Layers of Silica Microspheres

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**Motivation**—Gallium nitride (GaN) is an important semiconductor material used in light-emitting diodes (LEDs), laser diodes, and high-frequency, high-mobility, and high-power devices. Due to the lack in availability and high prices of bulk GaN substrates, GaN is typically grown heteroepitaxially on foreign substrates. The large resulting lattice mismatch results in the formation of high densities (mid-$10^8$-$10^9$ $cm^{-2}$) of extended defects called threading dislocations in the GaN layers. These dislocations degrade the efficiencies and lifetimes of visible LEDs, hindering the development of higher performance solid-state lighting (SSL).

**Accomplishment**—We have developed an innovative and inexpensive technique employing a monolayer of self-assembled silica spheres as a growth mask to achieve significant dislocation reduction in GaN epilayers on *c*-plane sapphire. Compared to conventional epitaxial lateral overgrowth (ELO) schemes currently used to reduce dislocations in GaN, this new technique is much less expensive and complex since no lithographic patterning is required. The technique involves depositing a close-packed layer of silica spheres onto a GaN epilayer grown on a substrate such as sapphire. The spheres are deposited using a Langmuir-Blodgett process which allows large-area, uniform monolayer sphere deposition. GaN is then selectively deposited through the sphere layer using selective metal-organic chemical vapor deposition (MOCVD) until a fully-coalesced film above the spheres is achieved. Figure 1 is a cross-section transmission electron microscopy (TEM) image showing GaN regrowth and coalescence through a single layer of 3 µm diameter silica spheres. Dislocations, appearing as dark vertical lines, are numerous in the initial "GaN-1" epilayer on sapphire, located beneath the sphere layer. However, upon reaching the sphere layer, the dislocations terminate, leading to a much lower dislocation density in the "GaN-2" regrowth layer coalesced above the sphere layer. Dislocations that would otherwise pass through the gaps between adjacent spheres are also seen to bend toward and terminate at the spheres, providing an additional mechanism for dislocation elimination. The dislocation densities of GaN films regrown with and without the use of the silica sphere masking layer were quantitatively determined by atomic force microscopy (AFM) and compared, as shown in Figure 2. The surface of the control GaN sample is dominated by a high density of dislocations ($3.3\times10^9$ $cm^{-2}$) which manifest as pits, as shown in Figure 2(a). In contrast, a much lower density of dislocations ($4\times10^7$ $cm^{-2}$) is seen on the GaN surface grown using the silica microsphere template, as shown in Figure 2(b), which represents a nearly two orders of magnitude reduction.

**Significance**—SSL has the potential to provide light that is much more efficient and longer-lasting that conventional technologies, resulting in huge future energy savings and reduced carbon emissions. By providing an inexpensive method for the improved growth of GaN, this technique could lead to improved efficiency and lower cost LEDs. In addition to better LEDs, this technology could also lead to improvements in other GaN-based technologies including blue laser diodes (e.g. Blu-Ray) and high-speed, high-power electronics. We anticipate that this method may be readily extended to other GaN orientations (e.g. nonpolar GaN) and substrates (e.g. Si), and even to other semiconductor materials systems.

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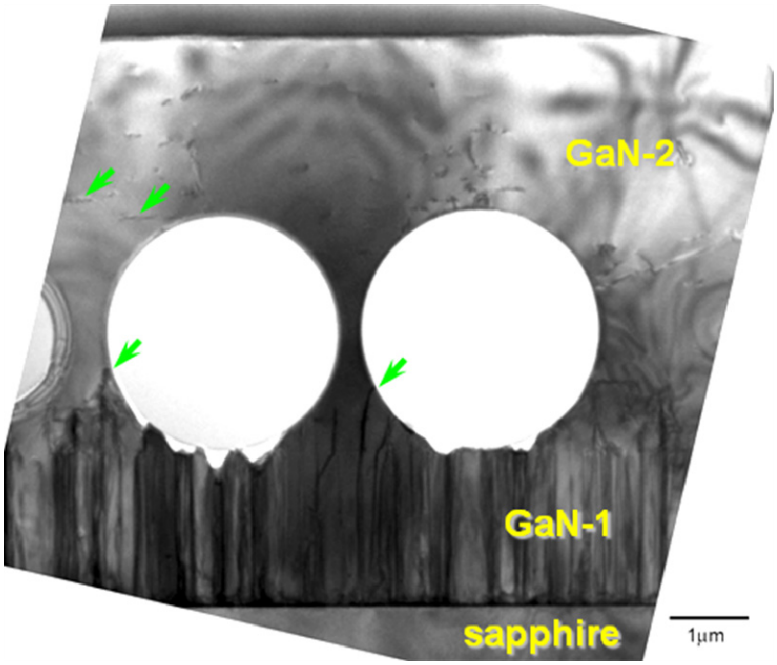


**Figure 1.** Cross-sectional TEM image showing GaN regrowth through a $SiO_2$ sphere layer. Dislocations (dark vertical lines) are seen bending towards a $SiO_2$ sphere and terminating at the GaN/$SiO_2$ interface, resulting in a low TDD film ("GaN-2") above the spheres.

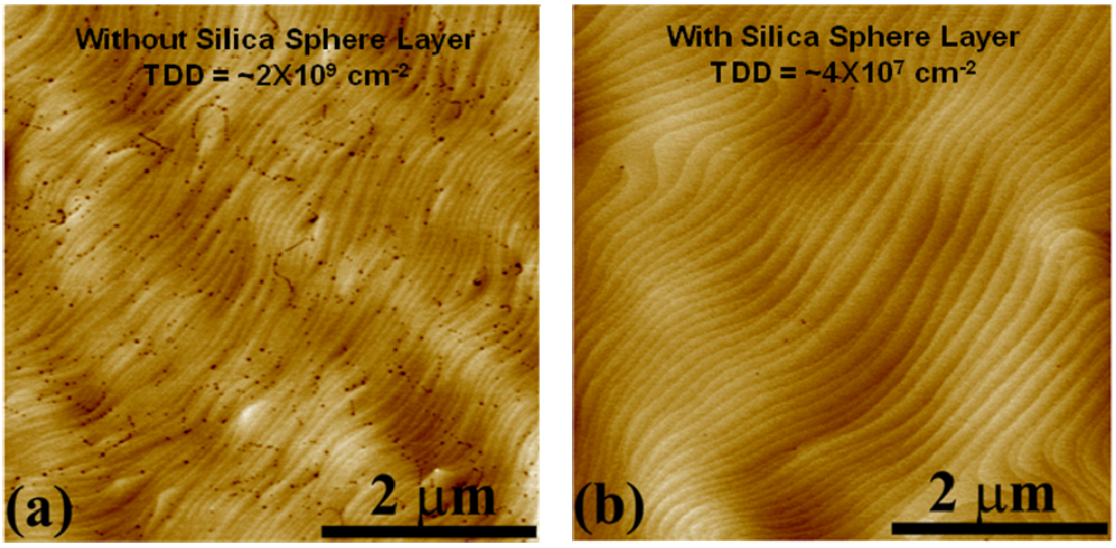


**Figure 2.** Typical 5×5 μm AFM scans of GaN regrown (a) without and (b) with the use of silica microspheres as a mask, which results in a nearly two-orders of magnitude reduction in dislocations (appearing as dark pits).