Close-Packed Monolayer of Silica Nanoparticles for use as Etch Mask in LED Active Region

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Abstract:

Uniform, nanostructured semipolar (NSSP) patterning of the active region of gallium nitride (GaN) light-emitting diodes (LEDs) improves several properties of the LEDs, including the efficiency, compared to planar active regions. We report the progress of a close-packed monolayer of silica nanoparticles for use as an etch mask, which was an essential part of creating this uniform pattern.

Introduction:

GaN LEDs show promise as efficient, solid-state lighting sources. However, improved efficiency and less dependence of output wavelength on injection current is necessary for GaN LEDs to compete with conventional lighting options [1]. Patterning the active region of the LEDs with an irregular NSSP texture reduces the polarization charges that contribute to these problems [2-3]. The incorporation of this texture has shown to improve the internal quantum efficiency by 30% compared to planar active regions, and significantly reduce the output wavelength's dependence on injection current [4]. By creating a more uniform NSSP pattern and using a less damaging surface treatment to create the pattern, the LED turn-on voltage can be lowered, resistance reduced, and internal quantum efficiency further improved. Essential to the regular patterning of the active region is an etch mask that results in periodic, nano-scale dips in the GaN (Figure 1). We report the progress of a close-packed monolayer of nanoparticles (NPs) on GaN implemented by spin-coating for use as this etch mask.

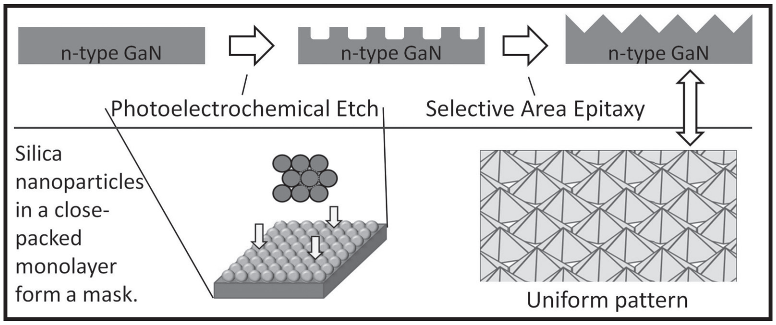

Figure 1: The proposed process for creating uniform NSSP.

Materials and Methods:

The nanoparticles we used to form the close-packed monolayer were silicon dioxide nanoparticles with 100 nm diameters in a 5 wt.% aqueous solution. The method we used was spin-coating the nanoparticles in solution onto the substrates, which were glass and n-type GaN grown using metal-organic chemical vapor deposition on *c*-plane sapphire. We used glass in addition to n-type GaN substrates to check whether the spin recipe needed to be adjusted or the quality of the GaN surface was impeding the formation of a close-packed monolayer. Prior to spin-coating, the NP solution was shaken for approximately 20 seconds to help ensure even dispersion of nanoparticles in the solution.

Results:

The primary parameters we adjusted in order to obtain a close-packed monolayer of nanoparticles were nanoparticle solution concentration and spin speed. Increasing the concentration of the solution resulted in a thicker nano-particle layer, and increasing the spin speed resulted in less coverage of the substrate surface. This was characterized by optical and scanning electron microscopy (SEM).

Mostly close-packed monolayers were first obtained reproducibly on glass substrates using a spin recipe of 10 sec at 500 rpm followed by 240 sec at 1000 rpm. The monolayer was not completely close-packed; rather, it contained regions of close-packed nanoparticles with some dislocations and breaks between regions (Figure 2). Regions with more uniform nanoparticle size and shape resulted in

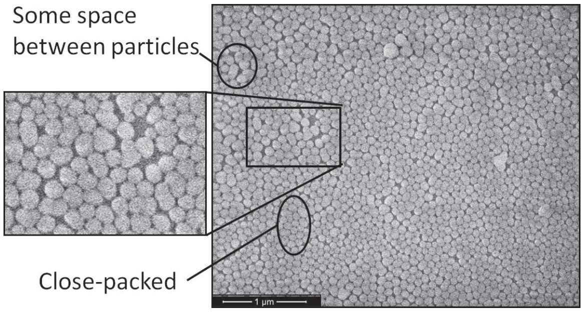

Figure 2: Mostly close-packed monolayer on glass. Spaces, close-packed regions, and irregularity of nanoparticles are highlighted.

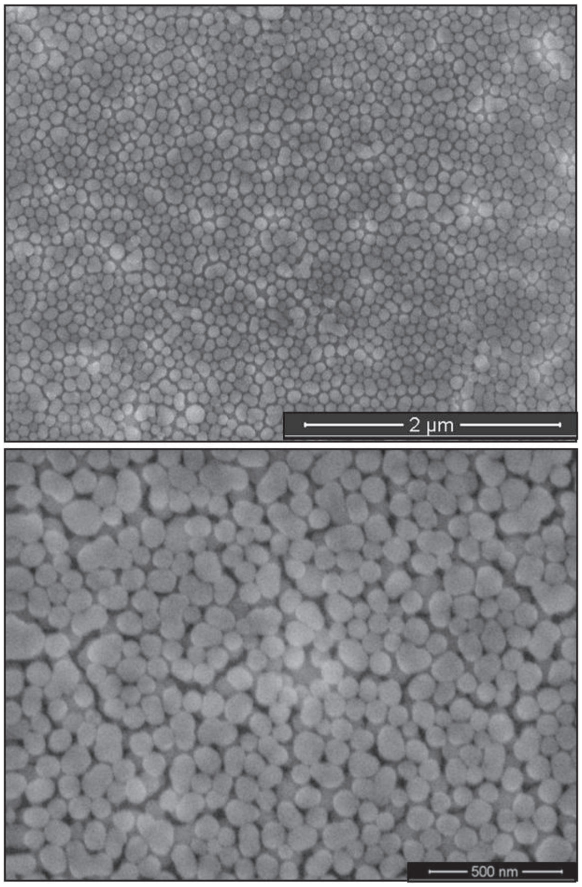

Figure 3: Monolayer and double layer, respectively, on GaN.

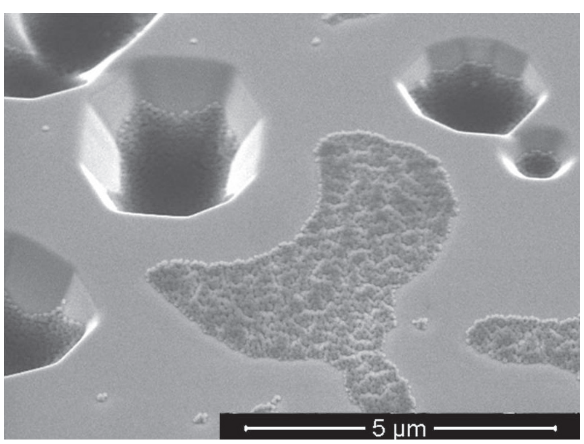

Figure 4: Sample illustrating the effect of many GaN defects on forming a monolayer.

much nicer close-packing. This indicates that the quality of the close-packed monolayer is currently limited by the non-uniformity in size and shape of the nanoparticles.

We then used this recipe on GaN and obtained a mostly close-packed monolayer on part of the GaN substrate as well; however, the coverage and thickness of the NP layer was less uniform.

On a different GaN substrate, we obtained a double layer of nanoparticles mostly uniformly over the substrate (Figure 3). Previous samples had shown that large numbers of defects in the substrate significantly affected the formation of a monolayer and that many of the nanoparticles fell into the defects (Figure 4). The irreproducibility of a close-packed monolayer on GaN so far indicates that the defects could still be affecting the formation of the monolayer, even on samples with few defects such as the monolayer and double layer on GaN discussed above.

Conclusions and Future Work:

We were able to obtain reproducible, mostly close-packed monolayers of silica nanoparticles on glass substrates. However, we were not able to do the same reproducibly on GaN substrates, likely because of the defects in the GaN. We plan to first try further optimizing the spin recipe on low-defect GaN substrates. If that does not result in reproducible layers, we plan to fill the GaN defects before spin-coating, or spin-coat close-packed monolayers onto glass and transfer the monolayers to GaN substrates.

Additionally, we observed that the non-uniformity of the NPs is limiting the close-packing of the nanoparticle monolayer. This can be addressed by obtaining NPs more uniform in size and shape.

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