High Aspect Ratio Dry Etching of Gallium Nitride

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Abstract:

Light emitting diodes (LEDs) are made by depositing doped layers of material through epitaxial growth on a substrate. However, substrates are usually foreign materials and have different crystal structures than their epilayer; because of this, epitaxy becomes nonideal and overall LED performance suffers. The focus of this project was to construct dry etched gallium nitride (GaN) pillars that can be generated on top of foreign substrates to improve epitaxial growth and maximize LED power by enabling a three-dimensional (3D) LED architecture. By using an inductively coupled plasma (ICP) system and changing etch plasma parameters, GaN pillars were constructed. These pillars were then analyzed by measuring their radius of curvature, characterizing their profile, and evaluating the quality of the fabricated pillars. As the GaN pillars developed, the magnitude of the radius of curvature increased. This relaxed the wafers and increased the potential for higher quality epitaxial growth. However, due to a decrease in pillar diameter and inconsistent pillar and surface roughness created by this process, more research needs to be done fabricating these types of pillars on foreign substrates for LED and electronic device use.

Introduction:

LEDs are a common electronic device in the world due to their high efficiency and long lifetime. One common material found in LEDs is GaN due to its good semiconductor properties and its applications to high temperature devices in the blue ultraviolet spectrum [1].

The first step in making an LED is growing a buffer layer of GaN on top of a foreign substrate, like sapphire, to limit the mismatch between the different crystal structures. From this, a negatively doped GaN layer, an indium gallium nitride (InGaN) active region, and a positively doped GaN layer are grown on the buffer layer with epitaxial growth (Figure 1); this allows the active region to emit light with a blue wavelength and shine through the substrate when a voltage is applied across the grown epitaxial structure [2]. However, even a buffer layer cannot overcome all issues caused by the different crystal structures of GaN and sapphire. Because of this, epitaxial growth is not optimized — creating features like uneven morphology and dislocations in the epitaxial structure, which diminish LED performance.

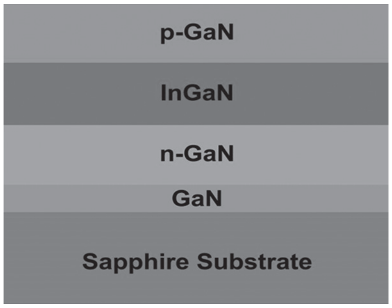

Figure 1: Standard GaN LED structure.

To improve this process, the initial GaN buffer layer must be transformed to produce higher quality epitaxial growth and maximize LEDs with the eventual goal of growing 3D epitaxial structures for LED construction [3]. This project focused on constructing dry etched GaN pillars with the hope that they can be generated on top of foreign substrates to improve epitaxial growth and enable a 3D architecture.

Experimental Procedure:

Eight micron (μm) thick GaN template wafers were employed and placed into a plasma enhanced chemical vapor deposition system, where 2 μm of silicon dioxide (SiO_2) were deposited. The wafers were then taken to a photolithography phase where a coating of positive photoresist was spun onto the wafers and then exposed to a masking pattern with 100 μm circles with 150 μm separation. Once exposed to ultraviolet light and developed, the photoresist served as a protective coating for the SiO_2.

After photolithography, the wafers underwent a SiO_2 etch with hydrofluoric acid to remove all the exposed SiO_2 and create a protective layer for the GaN layer. Following a quick liftoff process where the remaining photoresist was removed, the wafers were then taken to an ICP system for dry etching. Here, etch plasma removed the exposed GaN by physically knocking it off the surface and chemically changing the composition of the material to remove it (Figure 2). By changing pressure, chemical composition, and radio frequency power in the etch plasma, GaN pillars were fabricated. This was followed by a final SiO_2 etch removing the last of the SiO_2 and allowing the GaN pillars to be analyzed quantitatively.

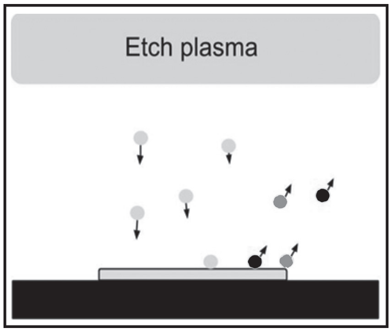

Figure 2: ICP etch schematic.

Results and Conclusion:

A Tencor Flexus system, which shines a laser onto a wafer surface and gives a map of its radius of curvature, showed that as the amount of GaN dry etched from the wafer increased, so did the magnitude of the radius of curvature in each of the wafers tested (Figure 3). Because of this, the wafer became more relaxed allowing for better crystallographic alignment of the GaN buffer layer and the potential for higher quality epitaxial growth. Microscopic analysis also showed minimal defects were found between the pillars and 4-17% of pillars had defects on top of them (Figure 4). However, this process created pillars with a decrease in diameter between 25-30% of the original mask pattern on each of the wafers. Further analysis with atomic force microscopy showed that the pillar and surface roughness were very inconsistent with one another. While half of the recipes created surfaces with little to no change in roughness, the other half created varying roughnesses between the surface, including a recipe with a worse roughness difference of over 100%. Because of this, even though dry etched GaN pillars become relaxed relative to continuous GaN layers, more research can be done to improve the decrease in pillar size with inconsistent surface roughnesses.

Future Work:

The next steps of this project will be to refine the lithography process and use a dry etch for SiO_2 removal, both of which are to minimize undercutting the SiO_2 etch mask so the pillar diameter does not decrease. In addition, more analysis will be done creating pillars of different thicknesses and geometries to see how pillar height and spacing affects the radius of curvature change.

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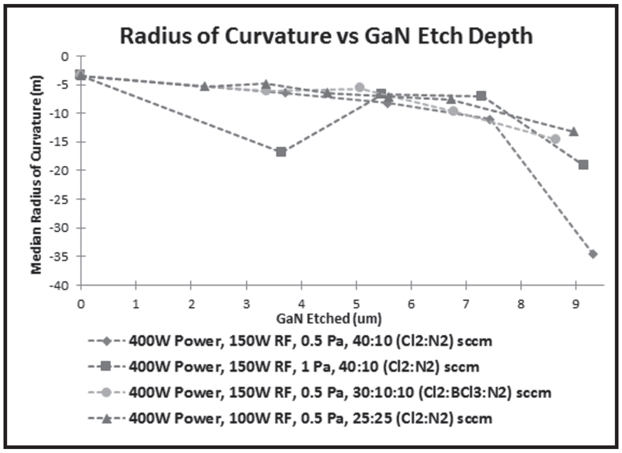

Figure 3: Comparison of radius of curvature vs. GaN etch depth with different etch recipes.

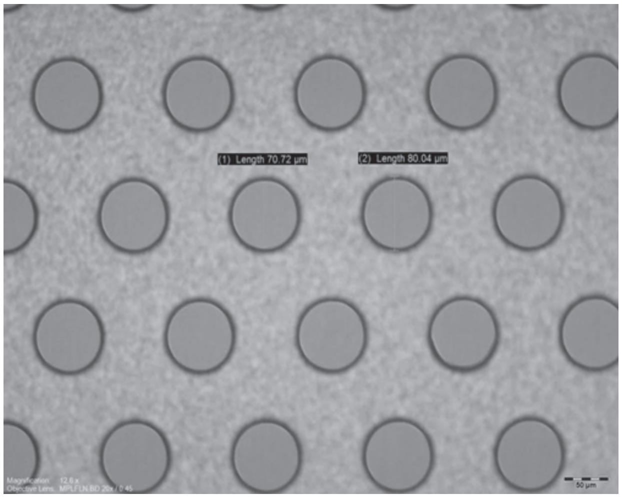

Figure 4: Microscope image of dry etched pillars created through a mask with 100 µm circles and a 150 µm separation between them.