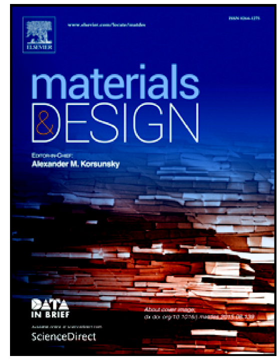

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Tuning photonic crystal fabrication by nanosphere lithography and surface treatment of AlGaN-based ultraviolet light-emitting diodes

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ABSTRACT Photonic crystal processing was performed using nanosphere lithography as a low-cost procedure to enhance the quantum efficiency of AlGaN-based ultraviolet light emitting diodes. Spectral transmissivity/reflectivity and photoluminescence measurements, in conjunction with finite-element modeling and electromagnetic simulations, provide an indication of radiance enhancement with a photonic crystal periodicity comparable to the emission wavelength. To recondition the plasma-damaged sidewalls, post-processing methods based on high temperature annealing and surface treatment were evaluated, which in general, established a significant increase in light extraction efficiency. X-ray photoelectron spectroscopy clarified the formation of surface oxides and hydroxides on the as-fabricated nanostructures, and their dissolution after wet-chemical processing is linked to enhanced optical output. Hydroxyl-termination was found to prevail after KOH etching, but significantly reduced after HCl or H_3PO_4 treatment. The two-step sequence of HCl followed by KOH treatment provided the best quality nanotextured surface for optical emission in this study, as indicated by the nearly 14.5-fold enhancement in photoluminescence intensity.

INDEX TERMS Photonic crystals, ray tracing, photoluminescence, periodic nanostructures, etching, heat treatment.

1. Introduction

The ultraviolet (UV) light-emitting diode (LED) is versatile, compact, durable, eco-friendly and non-toxic, and enables low power consumption compared to traditional light sources such as the mercury lamp. Huge prospects are expected in the global UV LED market, which is projected to reach US$ 1.16 billion by 2023 [1]. However, excessive thermal dissipation from UV LEDs might restrain their full technology adoption potential. Thus, developing design processes to enhance their wall-plug efficacy is crucial. Studies have increasingly matured on high-brightness semiconductor deep ultraviolet (DUV) light sources based on III-nitride LEDs, bringing about benefits for applications widely ranging from healthcare and homeland security to research and industry [1]. Nevertheless, the external quantum efficiency (EQE) of UV LEDs until recently is limited to 10 % [2],[3], which is eclipsed by that of high luminous efficacy white LEDs of above 80 % [4]. Due to performance bottlenecks in light generation and extraction, great importance is placed on having high Al content in the