Implanted Nano-hole Arrays for the Enhanced Efficiency of III-V Based Solar Cells and Light Emitting Diodes

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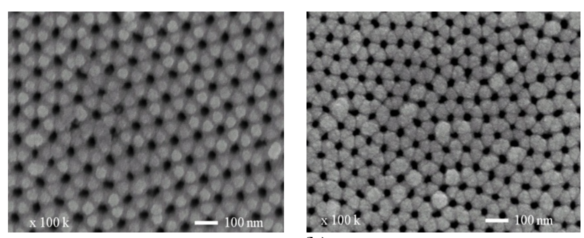
Recently, III-V based semiconductor material has been intensively studied and shown tremendous promise in solid state lighting and solar energy conversion applications. Significant progresses have been made to boost up the efficiency of these optoelectronics devices. Further enhanced device performances have been attracted and reported by using several approaches, including surface texturing, roughening, omni-directional reflectors, transparent electrodes, patterned substrates, photonic crystals, and surface plasmon [1-4]. Among these techniques, n4no-porous anodic aluminum oxide (AAO) membrane is widely used as a template for the formation of various nanostructures for opto-electronic devices due to its low cost and simple fabrication method. In this context, we have studied the fabrication, characterization, and application of AAO membrane to enhance conversion efficiency of GaAs single junction solar cell and cathodoluminescence (CL) of InGaN/GaN blue LEDs by making nano-hole arrays on the surfaces of these optoelectronics devices to the enhanced light absorption/extraction.

In this study, GaAs single junction solar cell and InGaN/GaN blue LED structures were grown by low-pressure metalorganic chemical vapor deposition (LP-MOCVD). Nano-porous AAO membranes have been fabricated through a two-step anodization process from an aluminum foil (99.99%, 100 μm in thickness, Tokai) with anodization voltages in range of 25 to 40 V in sulfuric acid or oxalic acid electrolyte. The pore density and diameter can be controlled by adjusting anodization voltage, while the film thickness can be changed by varying the anodization duration and considering the dependence of growth rate on the applied voltage and the electrolyte. Figure 1 shows the scanning electron microscopy images of AAO membranes with pore densities of 1.08×10^{10}, and 2.20×10^{10} cm^{-2} which were fabricated under applied voltages of 40, and 30V in oxalic acid solution. AAO membranes were then transferred onto the solar cell and LED wafers to serve as etching masks. Inductively coupled plasma (ICP) dry etching method was used to etch and define nano-hole array patterns on LED and solar cell surface through AAO masks. Etching gases include BCl_3 and Cl_2 were used under an ICP source power of 800W and RF bias power of 100W. The diameter and depth of nano-holes on sample surface can be controlled by optimizing the etching time. The nanohole arrays are finally formed on these samples after removing the AAO masks.

Illustrated in figure 2 is the AFM image of a GaAs solar cell with nano-hole arrays formed on top after 10-second ICP etching and removal of the AAO mask. The mean diameter and depth of nano-holes are estimated to be ~ 50 and 3nm, respectively. The diameters of implanted holes in solar cell sample are slightly larger than those of the AAO templates since AAO masks may be etched during plasma etching process and/or the surfaces of solar cell in contact with the AAO masks are not completely smooth. Shown in figure 3(a), we have achieved that an increase of 0.12% in energy conversion efficiency for GaAs solar cell with nano-hole arrays on the surface compared to other flat surface solar cells due to the enhance light absorption, resulted from the enhanced light scattering, and diffraction into solar cell devices. Moreover, we have further demonstrated that CL intensity of InGaN/GaN blue LED with the nanohole arrays is enhanced up to 8 times compared to that of LED sample without using nano-hole arrays as shown in figure 3(b). The increased CL intensity of the LEDs with nano-hole arrays may be attributed to the light scattering by the textured surface structures.

The detailed AAO membrane fabrication methods and their applications in enhancing the performance of GaAs single junction solar cell and InGaN/GaN blue light emitting diodes are being investigated and will be presented.



(b)

Figure 1: Morphologies of AAO films with different densities fabricated under applied voltages of 40, and 30V in oxalic acid.

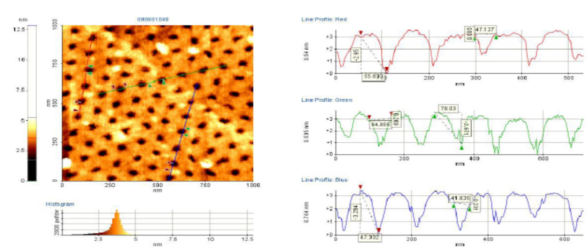
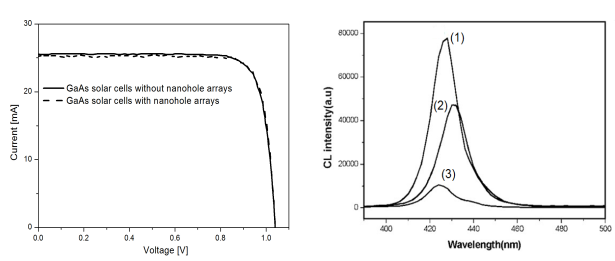


Figure 2: AFM image and profile data of the nanohole arrays formed on the GaAs solar cell sample layer after a 10-second ICP etching and removal of the AAO mask. The mean diameter and depth of the holes are about 50 and 3.5 nm, respectively.



(a) (b)

Figure 3: (a) Photovoltaic I-V characteristics for the GaAs solar cells with 50-nm holes arrays on the surface (solid line) and without nanoholes arrays on the surface (dash line). (b) The CL spectra of LEDs with 50-nm holes arrays (1), 70-nm holes arrays (2), and without nano-holes arrays (3) on the surface.

[1] J. Y. Cho *et al.*, *Nanoscale Res. Lett.*, **6,** 578 (2011). [2] M. Rattier *et al.*, *App. Phys. Lett.*, **83,** 1283 (2003). [3] K. Kim *et al.*, *Appl. Phys. Lett.*, **90,** 181115 (2007). [4] S. Noda *et al.*, *Nat. Photonics,* **1,** 449 (2007).