Optical Characterization of Nanostructured Wide Bandgap Semiconductors for Energy Applications

Jessica Smith

Physics and Mathematics, Austin College

NNIN REU Site: Michigan Nanofabrication Facility, The University of Michigan Ann Arbor
NNIN REU Principal Investigator: Professor Pei-Cheng Ku, Electrical Engineering & Computer Science, University of Michigan
NNIN REU Mentors: Min Kim and Luke Lee, Electrical Engineering and Computer Science, University of Michigan
Contact: jmsmith@austincollege.edu, peicheng@umich.edu, minwkim@umich.edu, leelk@umich.edu

Abstract

Illumination applications for light emitting diodes (LED's) have been increasing. Therefore, LED's are the dominant focus in the field of solid state lighting. The issue concerning lighting today is the trade-off occurring between high efficiency and high color rendering capabilities. For high efficiency, a white light can be constructed using blue and yellow components. However, to render the color faithfully, the white light must contain at least the primary components blue, green, and red. We explored improving color rendering in a highly efficient dichromatic system.

Introduction

To increase the color rendering index of the dichromatic white light, we broadened the spectral line widths of light emitted at blue and yellow to cover also the green and red components. To prove this concept, we used the selective area epitaxy (SAE) technique for growing indium gallium nitride quantum wells (InGaN QWs). Our methods included changing the pattern of the dielectric mask including pitch and area, and changing the indium incorporation and growth rate of InGaN QWs in different areas to achieve a broader linewidth. To characterize variations of emission wavelengths on the pattern, we used micro-photoluminescence (PL) to locally concentrate high energy. We plan to stack blue and yellow QWs on one LED, and characterize the color rendering index and efficiency of the proposed LED.

When having two layers of GaN separated by a layer of InGaN, a QW forms. Because electrons can occupy a lower energy state in InGaN than GaN, excited electrons tend to go to lower energy states in the InGaN layer. The QW increases the probability of electrons recombining with holes. When electrons and holes recombine, photons are emitted.

Previous results revealed linewidth broadening at blue emission using SAE. To further prove our concept in attaining high color rendering index dichromatic white light, we increased the wavelength to green/yellow. This was achieved by increasing the indium composition of the material to create a different lattice for emitting light and increasing the QW thickness to lower the energy of the photon released. To broaden the emission linewidth, we varied the growth rate of the QW across the wafer by SAE, in turn creating varying QW thicknesses. We adjusted the conditions affecting the concentration gradient that the molecules form, and altered the pattern at which our QWs grew. The pattern had multiple sites that included different shapes and densities to have different QW thicknesses that emit slightly different wavelengths of light at each site, thus the one LED will have a broader spectrum of emission.

Experimental Process

To define the pattern for SAE, we deposited a layer of silicon dioxide (SiO_2) then a layer of S1805 resist on a GaN template. We used photolithography to expose selected areas of resist to UV light. Then we developed those certain areas by removing the exposed resist with MF AZ 300. Finally, we etched those certain areas into the SiO_2 with a solution of BHF and water.

For QW growth, we used metal-organic chemical vapor deposition. The product that forms when the gas phases of indium and gallium, both attached to an organic molecule when added to ammonia, is InGaN. When incorporating the indium, we used ~ $In_{0.2}Ga_{0.8}N$. The concentration gradient of the molecules was increased/decreased and the pattern was altered, each partially determining how fast the molecules reached the exposed GaN template. Since the materials always wants to grow at the most stable planes in SAE, the GaN oriented in a hexagonal pyramidal shape.

For micro-PL, we arranged a beam splitter, UV objective lens, as well as other lenses and mirrors to concentrate the UV light onto one micro-pyramid and measure variations of the wavelength emitted from site to site on the pattern. We used the spectrometer to read the spectrum emission.

Results and Conclusions

With the planar QW results, we obtained an InGaN peak at about 510 nm, with the GaN peak at a less intensity. The micro-pyramid QWs were obtained using the same recipe as the planar QWs; however, the micro-pyramid InGaN signal was low as shown in Figure 1. Unfortunately we were not able to obtain micro-PL signal from individual micro-pyramids, possibly due to the weak signal. (Micro-pyramid growth at the ~ 10 μm site is shown in Figure 2. The SEM was under maintenance at the time of measurement.) We also cannot know how the QW thickness and indium incorporation separately affected the wavelength emitted, since both together must be qualities of the QW.

With further testing of possible causes for unattainable micro-PL measurements, we can detect if there is a problem with laser alignment on a micro-pyramid or sample defects. One possible cause could be due to the micro-PL setup. We used a UV objective lens that is coated for light in the non-visible wavelength range, thus the lens was not ideal for light in the green wavelength range when the signal is weak.

Nonetheless, we have proven it is possible to get green emission from micro-pyramid QWs in our PL measurements. Once we have increased the wavelength of light emission and characterized the light produced by measuring each site of our pattern, then we will stack blue and yellow QWs accordingly to improve efficiency. Finally, we will have one LED, and with anticipation the LED will have improved color rendering properties and efficiency.

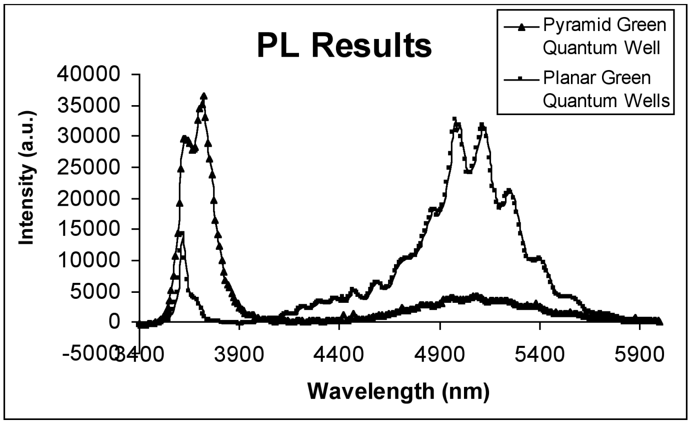

Figure 1: Compared photoluminescence results of planar and micro-pyramid quantum wells.

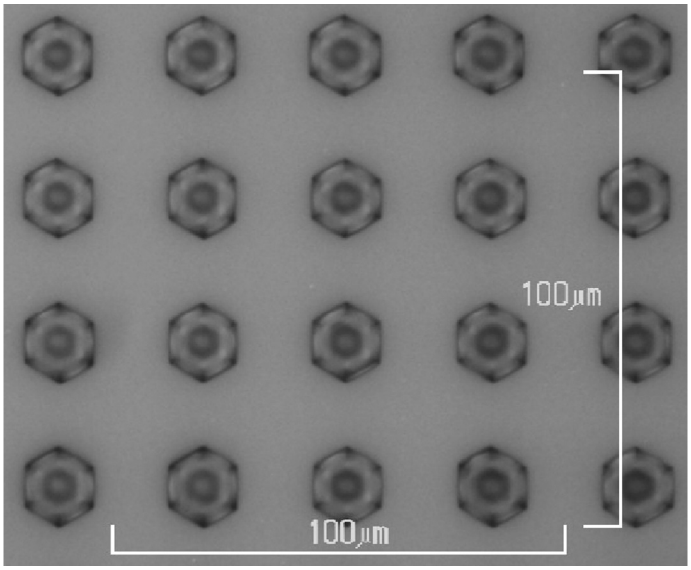

Figure 2: ~ 10 µm diameter array of micro-pyramids.

Acknowledgements

This work was performed in part at the Michigan Nanofabrication Facility, a member of the National Nanotechnology Infrastructure Network Research Experience for Undergraduates Program, which is supported by the National Science Foundation. Thank you to Dr. Sandrine Martin and Prof. Pei-Cheng Ku, along with his research group.

References

[1] Schubert, E. Fred (2006). "Light Emitting Diodes (2nd ed.)." New York: Cambridge University Press.

[2] H. Yu, T. Jung, L. Lee, and P. C. Ku, "Multiple Wavelength Emission from Semipolar InGaN/GaN Quantum Wells Selectively Grown by MOCVD," Conference of Laser and Electro-Optics, Baltimore, MD (2007).