# Study of the Electron Blocking Layer in Gallium Nitride Devices

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## Abstract:

The electron blocking layer (EBL) is thought to increase efficiency in gallium nitride (GaN) light emitting diodes (LEDs) and laser diodes. In the LED, electrons pass through the active region, which is the region where electrons transition to a lower energy level and emit a photon. An EBL will rebound electrons that escape the quantum well back into the active region and produce light. For our project, we looked at how two different substrate growth planes, m-plane and c-plane, affect the potency of the EBL. The LED m-plane and c-plane samples were grown using metal organic chemical vapor deposition (MOCVD) on sapphire substrate and bulk GaN substrates, respectively. After processing the samples, we looked at external quantum efficiency (EQE), which is the percentage of electrons that produce photons, and its dependence on temperature and current. For the c-plane LEDs without an EBL there was a decrease in EQE by up to 15% as compared to the samples with an EBL. The m-plane samples, however, showed that there is possibly a slight efficiency gain for samples with an EBL as compared to those without and EBL for the currents considered in this study. This shows that growth plane has a significant effect on the necessity of the EBL.

## Introduction:

With lots of energy waste being created by inefficient lighting, LED research is important to combat the energy crisis. LEDs significantly reduce heat output, last longer, have faster response times, and are safer than traditional light sources.

LEDs work by taking advantage of quantized electronic transitions. During a transition from higher energy to lower, the energy released is in the form of a photon. This happens billions of times a second, which produces the beautiful bright light of LEDs. For every electron that enters the LED on the negative electrode there is an electron vacancy, called a hole, flowing toward the electron. The electron and hole meet at the active region and recombine. This recombination produces light and the electron travelling in its original direction but of lower energy. LEDs are more efficient than incandescent bulbs because LEDs do not rely on current heating up a filament to produce light, rather just by reducing an electron's energy.

## Experimental Procedure:

We grew the LEDs using metal organic chemical vapor deposition (MOCVD) and used two different growth planes, c-plane and m-plane, for our substrates. The c-plane LEDs were grown using a sapphire substrates, while the m-plane LEDs used bulk GaN substrate. After growing the LED using MOCVD, we processed them in the UCSB Nanofabrication Facility.

The first step was removing surface oxide with hydrofluoric acid, and then laying down an indium-tin-oxide (ITO) current-spreading layer for the positive electrode, using photolithography and electron beam deposition. After that, we etched down to the negatively doped material. Finally, we applied an electrode so we could pass current from the positive electrode through the active region and into the negative electrode. After fabrication, we used Nakamura's Packaging Lab to test the LEDs.

After testing multiple wavelength LEDs for c-plane, we concluded that the c-plane samples all needed EBLs. This was due to the polarization of the c-plane quantum well (QW), the region where the electrons make an energy transition, because we had to decrease the width of the QW to correct for the fact that the electrons and holes are separated spatially. The spatial separation of electrons and holes allowed electrons to accumulate on the p-side of the QW and this made it easier for electron escape. The EBL rebound most escaped electrons from leaving into the QW, where they recombine to produce light.

## Results and Conclusions:

It is difficult to draw conclusions from our m-plane data because of our lack of devices without an EBL. But there may be improvements in efficiency from having an EBL, though efficiency gains are lesser than those seen for the c-plane devices. However, we found that for every other wavelength from 415 nm to 490 nm there was a slight difference in efficiency between LEDs with an EBL and LEDs without an EBL. But once again, there was a larger difference in efficiencies for longer wavelengths.

We also did temperature dependence measurements on both m-plane and c-plane samples, but could not determine conclusively if the EBL affected the thermal droop.

| Energy Efficiency & Energy Costs | Light Emitting Diodes | Incandescent Light Bulbs | Compact Fluorescent |
|---|---|---|---|
| Life Span | 50,000+ hours | 1200 hours | 8000 hours |
| Watts of electricity used | 6-8 Watts | 60 Watts | 13-15 Watts |
| Kilowatts used | 329kW/yr | 3285kW/yr | 767kW/yr |
| Annual operating cost | $32.85/yr | $328.60/yr | $76.70/yr |

*Figure 1: This table is based on each type of light bulb producing 800 lumens of light.*

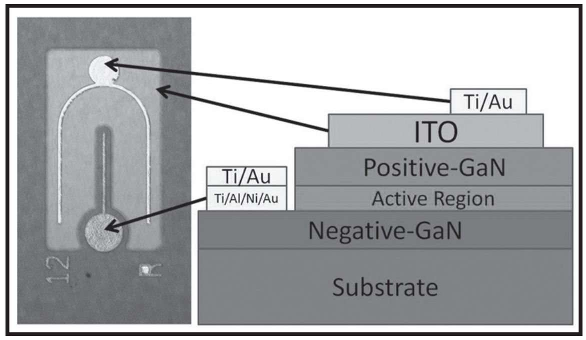


*Figure 2: A diagrammatic schematic of our LED.*



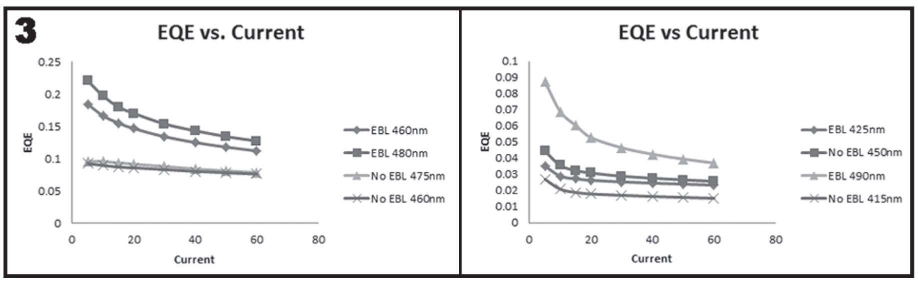


*Figure 3: The EQEs of c-plane LEDs on the right are higher due to apparatus change. However, the overall trend is that the EBL increases the EQE of the c-plane LED.*

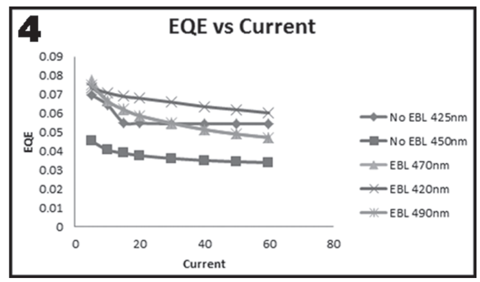


*Figure 4: From the graph we see, for m-plane samples, that longer wavelength devices might benefit from an EBL more than shorter wavelength devices.*

## Future Work:

This study only investigated the wavelengths of 415 nm to 490 nm and only two growth planes. This research was performed as a follow up project of a paper published in Japan Applied Physics in April 2013. Kawaguchi, et al., concluded that, for non-polar and certain semi-polar growth planes, above a certain critical wavelength there is no increase in efficiency resulting from including an EBL. There are still more semi-polar growth planes on which to explore the impact of EBLs.

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