Inhomogeneous electroluminescence for characterizing lateral transport in semiconductor devices

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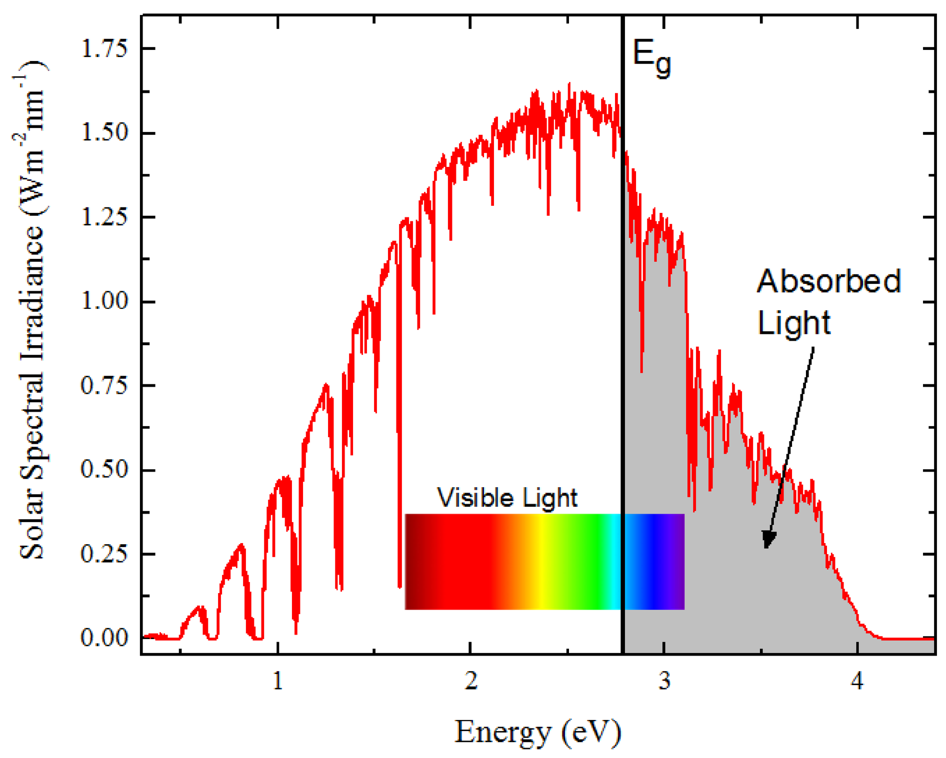
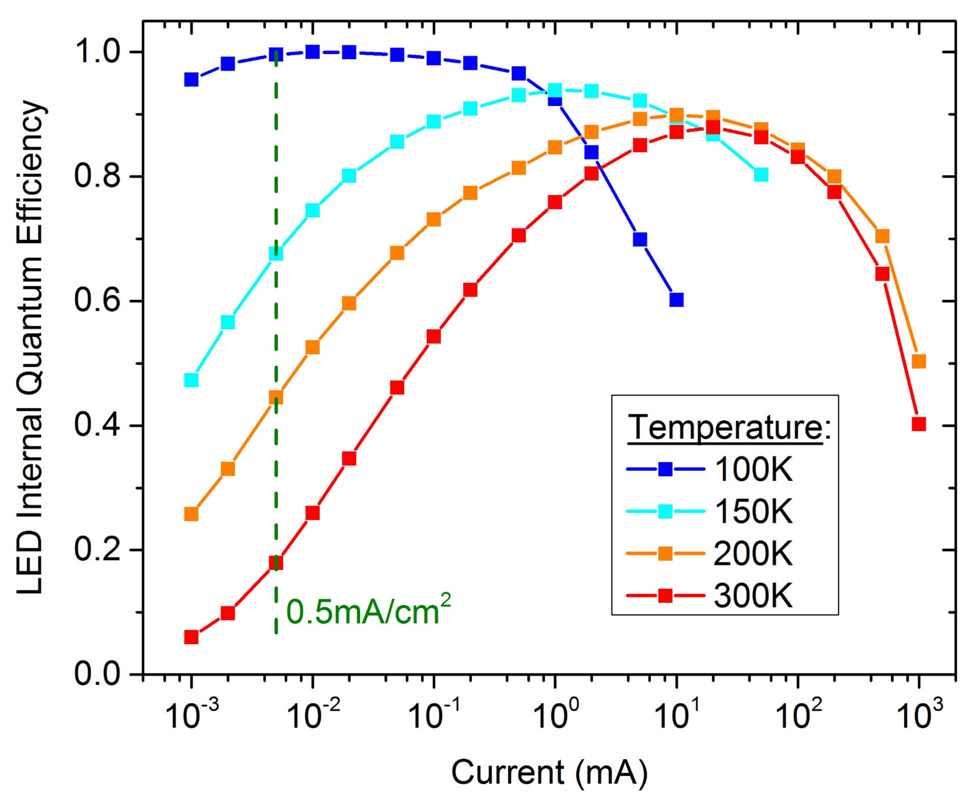
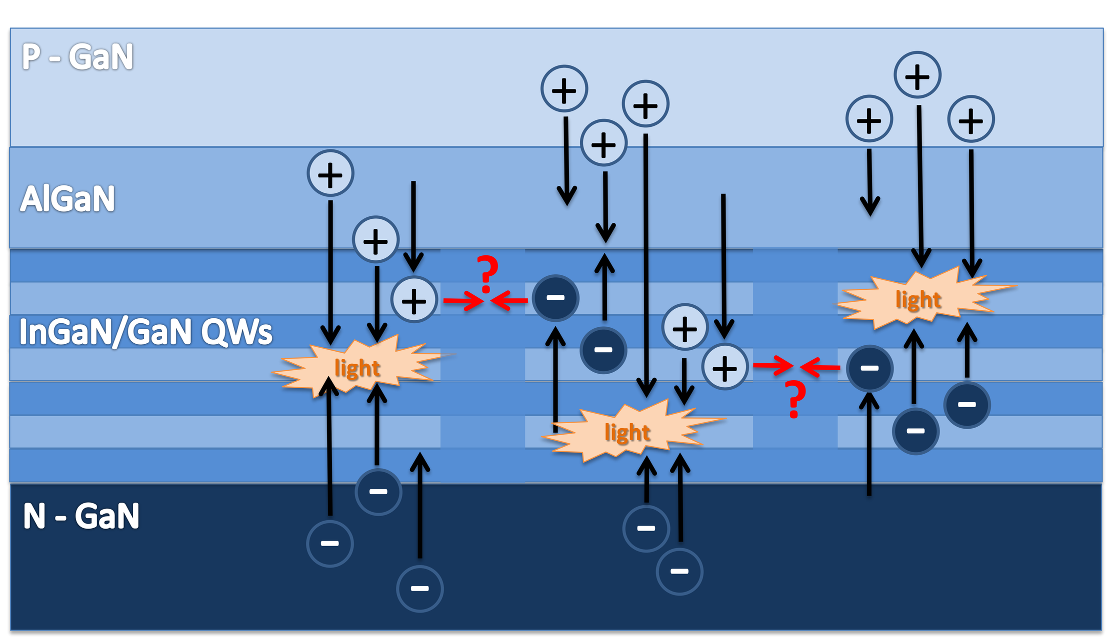
Motivation: InGaN PV and LED Droop





The high energy portion of the solar spectrum can be converted into electricity most efficiently by a wide-bandgap semiconductor. Nitride-based blue LEDs operate effectively in this regime, only in reverse: they convert current into light. But the LED conversion efficiency falls off at high current, a phenomenon commonly referred to as droop. We study the emission of blue LEDs as a function of temperature and Injection current to investigate charge transport and assess the utility of nitride semiconductors in high-energy PV applications.

Side-View of Current Channels in the Device

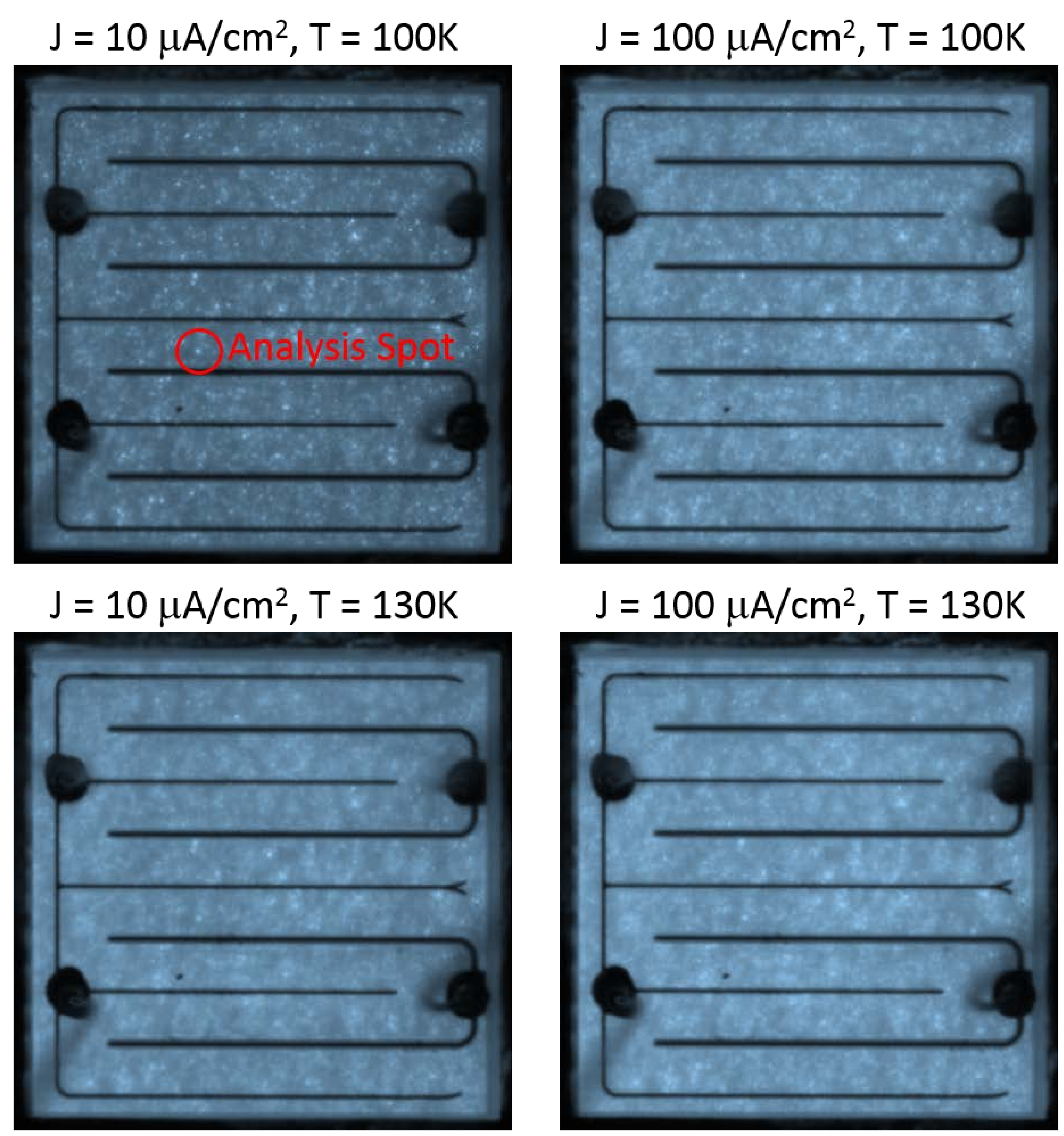


If carrier concentrations are not uniform across the device, carriers will diffuse from regions of high concentration to regions of low concentration. Since this mechanism is driven by thermal energy, potential barriers can inhibit the process at low temperature.

Abstract

In multilayer semiconductor devices, carrier transport perpendicular to the growth axis is important for generating uniform current density and minimizing local heating. However, lateral transport within individual layers of the structure can be hindered by fluctuations in layer thickness, alloy composition, and other defects. Impediments to lateral transport can be analyzed by imaging electroluminescence as a function of temperature and injection density. Inhomogeneity in the emission pattern distinguishes preferred current channels from less favorable pathways through the device. The temperature dependence of the nonuniformity can be used to gauge the localization energy and the dependence on injection current can be used to estimate the density of laterally localized states. In this report, we use an InGaN/GaN diode to demonstrate this characterization technique. We find that lateral transport in the device is thermally activated with an activation energy of 37 meV. Our analysis also shows that the density of localized states in the lower energy regions is relatively small, saturating at a current density of approximately 0.5 mA/cm^2.

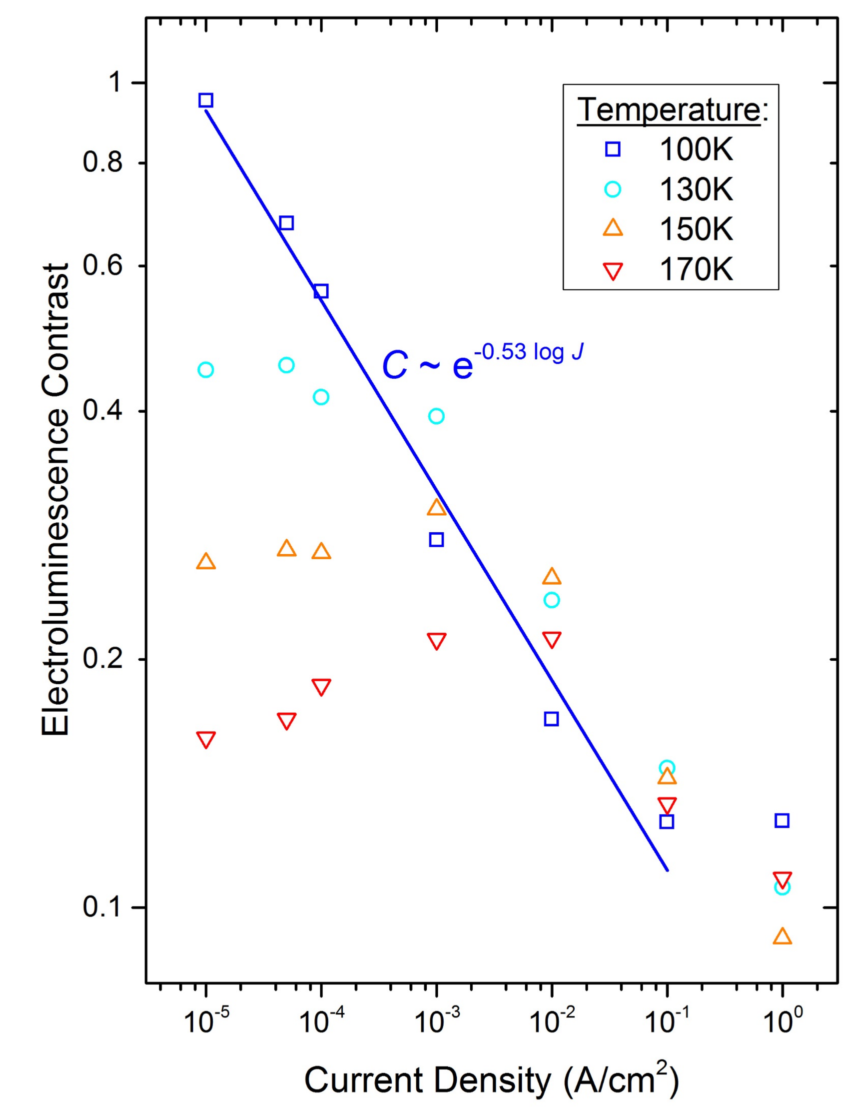
Temperature- and Injection-Dependent Electroluminescence Images



Representative plan-view EL images showing the inhomogeneous emission pattern under different experimental conditions. The bright EL spot used for contrast analysis is circled in red in the top left image.

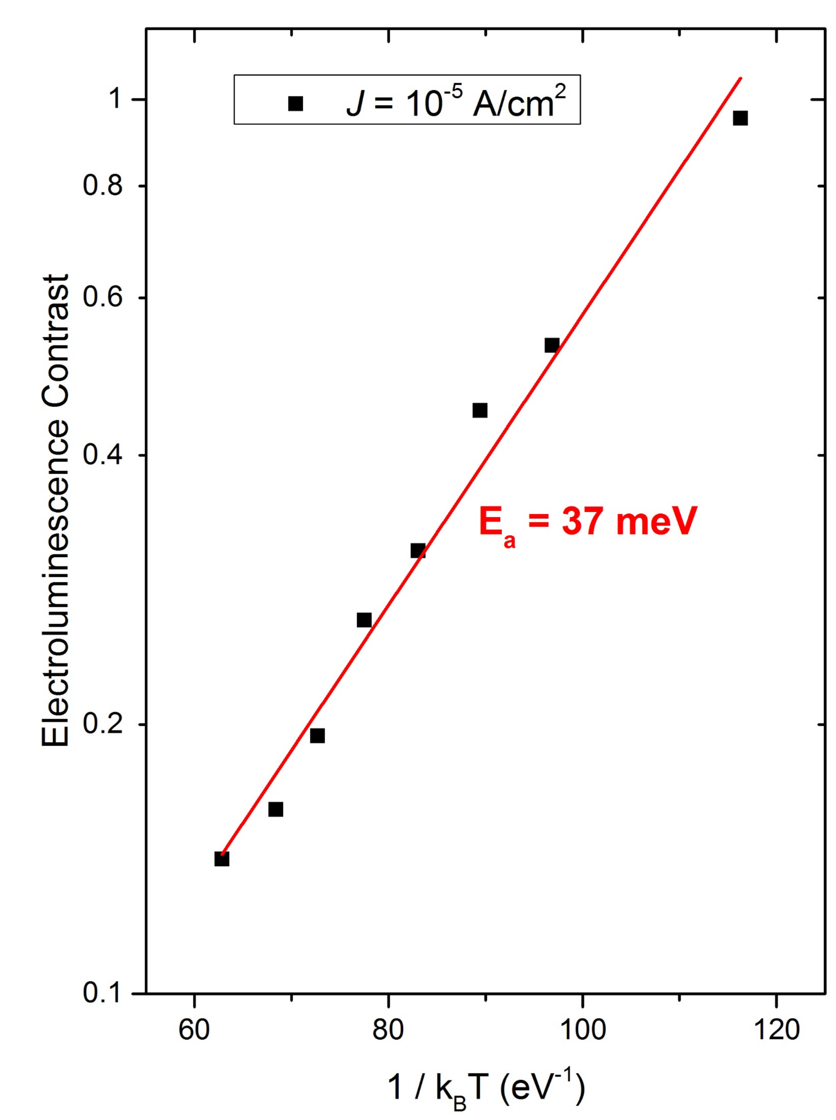
$$Contrast = \frac{EL_{local} - EL_{avg}}{EL_{avg}}$$

Electroluminescence Contrast



Electroluminescence contrast vs. injection current density at several representative temperatures. A linear fit to the 100K data yields the solid blue line, which corresponds to a fractional decrease of 0.6 per decade.

Thermal Activation Energy



Arrhenius plot of the temperature-dependent electroluminescence contrast at an injection current of 0.01 mA/cm^2. The slope yields a thermal activation energy of approximately 37 meV.

Conclusions

- Diffusive in-plane motion, which spreads the carriers uniformly across the device, requires thermal activation over energetic barriers within the constituent layers.
- The density of localized states in the lower energy channels is relatively small, saturating at a current density of ~ 0.5 mA/cm^2.
- Localization of charge flow yields higher device efficiency by restricting access to detrimental extended defects.

Acknowledgement

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