

# Design of Three-terminal GaN Light Emitting HBT for Free Space Communication

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**Abstract:** This abstract presents design and simulation results of a GaN-based multi-quantum well (MQW) heterojunction transistor (HBT) LED. The combination of the narrow base and collector terminal allows a very fast turn-off delay in the device.

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## 1. Introduction

III-V Nitride-based semiconductors have attracted enormous research effort in lighting and display applications. The material combination of AlInGaN covers a wide spectrum range from ultraviolet (UV) to red [1]. In addition to being a light source, light emitting diode (LED) is also attractive for its potentials in intelligent lighting systems, high speed information access and energy conservation.

In recent years, there is a rising interest in the dual use of lighting LEDs for both illumination and free space communication. For present nitride based lighting LEDs, the typical bandwidth is on an order of several megahertz range due to intrinsic capacitance and long carrier lifetime. The capacitance of a LED can be reduced by shrinking the size of the device, whereas the carrier lifetime is a material parameter which is on the order 20~50ns for the state of the art of nitride crystal growth. Thus, it suggests a bandwidth approximately about 50 MHz for a carrier lifetime limited LED. In this work, we present the design and analysis of a three-terminal GaN light emitting transistor that exhibits significantly reduced turn-off delay by removing carriers via drift current through the third terminal.

## 2. Device structure

The structure of the proposed device is shown in Figure 1, and the device is biased under forward active mode. The emitter-base junction forms the light emitting region, where the radiative recombination takes place. Some of the injected minority carriers recombine within the base, while most minority carriers pass the base and enter the collector giving rise to collector current. Different from conventional LED, the carriers with long lifetime diffuse into the collector instead of being recombined in the base. In a common emitter configuration, the input signal at the base terminal modulates both the light emission and the collector current of the transistor. In this design, a small junction width of  $6\mu\text{m}$  is chosen in the light emitting HBT to reduce the parasitic capacitance.

The proposed NPN light emitting HBT grows on a  $1\mu\text{m}$ -thick heavily doped GaN buffer, and on top are the sub-collector and a collector layer. The base contact layer is  $30\text{nm}$ -thick with p-type doping of  $1\times 10^{19}\text{cm}^{-3}$ . The base region also includes a p-type doped GaN barrier layer. The  $0.1\mu\text{m}$ -thick GaN emitter is on the top of the structure. The light emitting region of the device primarily locates in the two  $\text{In}_{0.2}\text{Ga}_{0.8}\text{N}$  quantum wells (QWs). Since the purpose of this design is to swiftly eliminate carriers with long carrier lifetime during the turn-off process, the emitter and the base layers are thin. There is no electron blocking layer (EBL) in the design to enable electrons pass the base. The current HBT design is in favor of reduced turn-off delay, but can only obtain limited radiation quantum efficiency.

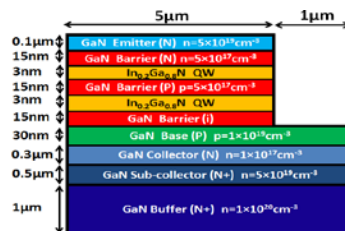


Figure 1 Cross-sectional schematic of GaN-based HBT LED

### 3. Simulation results

The electrical and optical property of the proposed device is analyzed using Crosslight APSYS package. Figure 2 shows  $I_E$ - $V_{BE}$  ( $V_{CE} = 0V$ ) curve, emission spectrum ( $V_{CB} = 1V$ ), and light power versus  $I_E$  ( $V_{CB} = 1V$ ) curve. The  $I_E$ - $V_{BE}$  plot suggests that the emitter-base junction turns on at about 2.3V, at which strong spontaneous emission begins to occur. The emission peak is about  $0.47\mu m$  for this device.

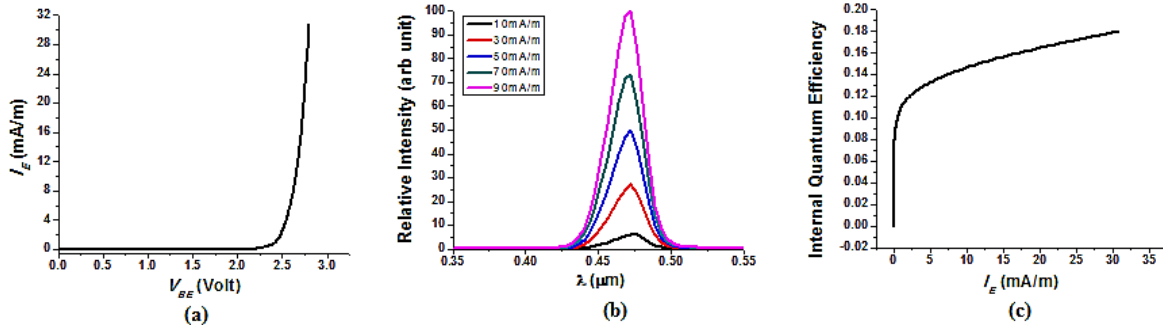


Figure 2 (a)  $I_E$ - $V_{BE}$  curve at  $V_{CE}=0V$  (b) emission spectrum vs.  $I_E$  and (c) light power vs.  $I_E$  at  $V_{CB}=1V$

Transient simulation is performed to investigate the response of  $I_B$ ,  $I_C$ , and  $L$  to a  $V_{BE}=2.6V$  voltage swing, with  $V_{CB}$  fixed at 1V. The ramp time for the  $V_{BE}$  pulse is 1ns. As is seen from Figure 3, the optical power does not increase notably until  $t \approx 3ns$ , but turn-off delay from 90% to 10% is about 1ns. At  $t = 8ns$  when  $V_{BE}$  begins to switch off, the optical power has not yet reached its steady state value. It is therefore evident that the GaN-based LED has a long turn-on delay, which is primarily determined by the slow spontaneous recombination process and cannot be reduced by device engineering.

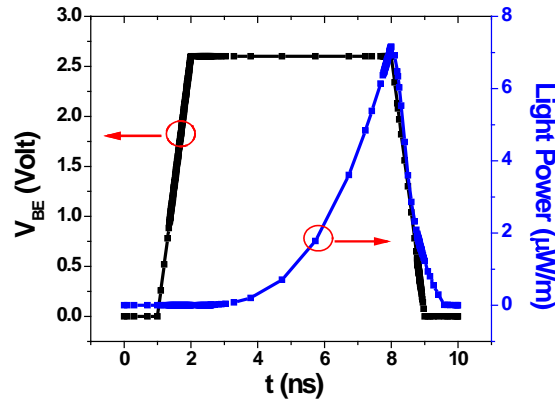


Figure 3 Transient response of light power at  $V_{CB}=1V$ , with  $V_{BE}$  switching between 0V and 2.6V

### 4. Conclusion:

By introducing HBT design, the GaN-based LED can rapidly realize fast turn off, and thus help to enhance digital modulation bandwidth.

### 5. Reference

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- [2] M.Feng, N.Holonyak, Jr., W.Hafez, "Light-emitting transistor: Light emission from InGaP/GaAs heterojunction bipolar transistors," Appl. Phys. Lett. **84**, 151-153 (2004).