Determination of Minority Carrier (Hole) Transport Properties in GaN-based LEDs

by Steven R. Kurtz and Robert J. Kaplar

Motivation—Bipolar devices are required in most optoelectronic and electronic applications of wide bandgap, GaN-based materials. At Sandia, one of our main thrusts is the development of bright light-emitting diodes (LEDs) and lasers at UV, blue, or green wavelengths. These devices would find wide-scale utilization, ranging from solid-state white lighting, displays, and data storage (blue and green) to bio-agent sensors (UV).

Transport of massive holes ($m^*_h \approx 1.8\ m_e$) in nitride-based bipolar devices, such as LEDs, is a critical factor determining performance. Conventional majority-carrier Hall mobility measurements overlook the influence of a large density of defects, and minority-carrier transport needs to be investigated directly. Towards this end, we have modified techniques and models which were initially proposed 50 years ago. Our combined optical and electrical transient study provides the first picture of minority carrier diffusion in nitride devices.

Accomplishment—To determine the transport properties of massive, minority-carrier holes in GaN, we have implemented a new technique that combines the measurement of electrical and optical transient responses of an LED to a forward-to-reverse bias voltage pulse. Using this method, we have observed hole transport in a p^+-n single quantum well (SQW) InGaN/GaN LED, where the SQW was positioned in the n-region. The device was grown on sapphire using metal-organic chemical vapor deposition. Hole transport results may depend strongly on growth substrate and conditions. SQW LED emission occurred at a wavelength of 400 nm.

Transient responses of the LED were induced using a transmission-line technique (see inset Fig. 1a). We observed that both the electrical current (Fig. 1a) and optical emission transients (Fig. 1b) displayed two-step decays, a signature of diffusive behavior. A classic solution to the time-dependent diffusion equation describes transient forward-to-reverse bias dynamics of the minority carrier distribution. (shown in Fig. 2). This model produced a self-consistent description of both optical and electrical data and accurately determined the GaN minority-carrier hole lifetime (≈ 760 ns), diffusion length (≈ 590 nm), and mobility (≈ 0.2 cm^2/Vs), which is more than an order of magnitude lower than typically reported values of majority-carrier hole mobility. Further, temperature-dependent measurements of the hole mobility indicated that it is thermally activated ($E_\mu \approx 50$ meV). The magnitude and temperature dependence of the mobility imply that minority hole transport is trap-modulated, and the lifetime is suggestive of slow recombination processes occurring through deep levels.

Significance—Experimental techniques and models have been developed to provide the first characterization of minority carrier diffusion in bipolar GaN devices. In future studies we hope to understand the mechanisms controlling hole injection and transport. These methods should lead to improved performance of GaN devices and provide guidance for device design and optimization.

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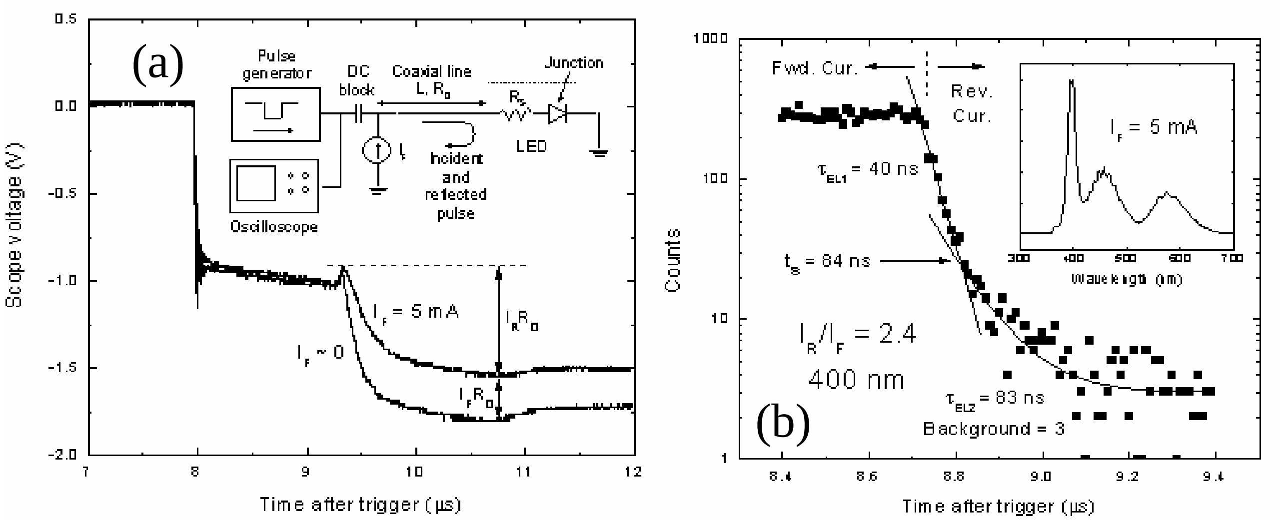

Figure 1. (a) Step-recovery oscilloscope traces showing the current transient of the SQW LED with high (I_F = 5 mA) and low (I_F ≈ 0) forward current [inset (a): Pulse recovery experiment]. (b) Transient emission of the SQW LED under bias/pulse conditions identical to those used for the high-current experiment of (a) [Inset (b): 300 K LED emission spectrum at I_F = 5 mA].

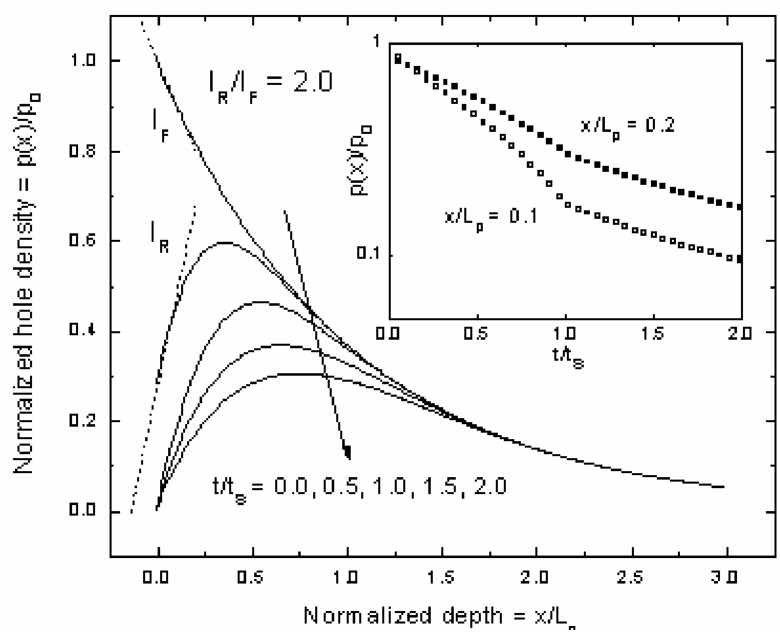

Figure 2. Minority-carrier hole distribution in the n-type side of the SQW LED for various times, obtained by solving the diffusion equation. Inset: Temporal decay of the hole density for two positions in the distribution.