Optoelectric Device Simulation of a Dual-Base BJT Using *Luminous*

Introduction

With the continuing emergence of optical technologies, optoelectronic device structures are becoming increasingly important for modern telecommunications and data network applications. Like other semiconductor technologies, two-dimensional numerical simulation can be an invaluable tool for studying and understanding semiconductor device behavior in response to optical stimulation. This article seeks to demonstrate the simulation of optoelectric device structures using **Luminous**.

The first section of the article discusses briefly the capabilities of **Luminous** and how it models the interaction of light with semiconductor materials. The following sections briefly overview the methodology for optoelectric simulation using **Luminous** and present the optoelectric simulation results for a dual-base BJT structure.

Background

Luminous is the general purpose ray trace and light absorption program available within the **ATLAS** framework. Designed to model light absorption and photogeneration in non-planar semiconductor devices, **Luminous** provides the capability to simulate DC, AC, transient, and spectral responses of generic device structures in the presence of arbitrary optical sources. **Luminous** is applicable to a wide array of device technologies including, but not limited to, pn and pin photodiodes, optical transistors, solar cells, and charged coupled devices (CCDs). Optoelectronic simulation within **Luminous** is separated into two distinct models.

The optical ray tracing model uses the real component of the optical index of refraction for a given semiconductor material to calculate optical intensity at each simulation grid point. By using this geometric model, **Luminous** is able to account for arbitrary topologies, internal and external reflections and refraction, polarization dependencies
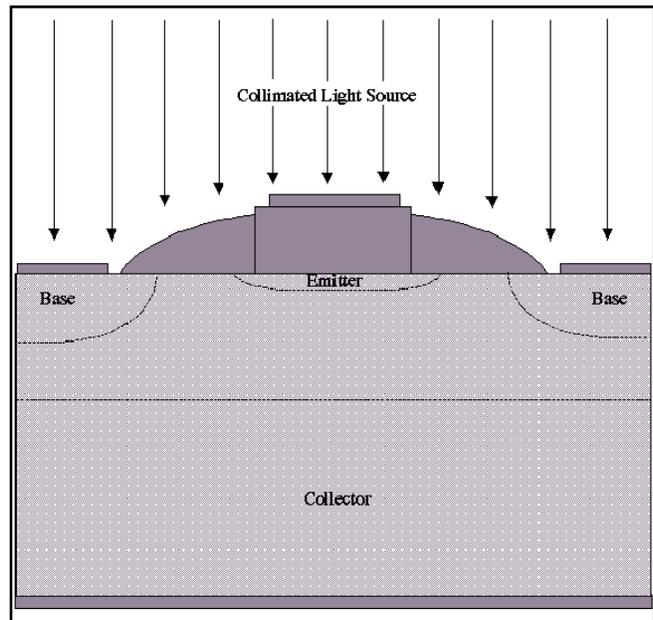

Figure 1. Diagram of dual-base BJT structure used for opto-electric device structure.

and dispersion. In **Luminous**, an optical beam is modeled as a collimated source entering the device through a prescribed illumination window. To resolve topological differences, **Luminous** automatically splits the beam into a series of rays covering the width of the illumination window. The optical rays are further separated into transmitted and reflected rays as they cross material interfaces.

The second model accounts for absorption and photogeneration within the device structure. Using the imaginary component of the optical index of refraction, the carrier concentrations are calculated at each simulation point as follows:

$$G = \eta_0 \frac{P^*\lambda}{hc}\, \alpha e^{-\alpha y}$$

P* represents the cumulative effects of reflections, transmissions, and loss due to absorption over the ray path, η_0 is the internal quantum efficiency (representing the number of carrier pairs generated per photon observed), y is a relative distance for the ray in question, h is Planck's constant, λ is the wavelength, and c is the speed of light. α is the absorption coefficient defined as:

$$G = \eta_0 \frac{P^*\lambda}{hc}\, \alpha e^{-\alpha y}$$

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  File ▽    View ▽    Edit ▽    Find ▽     Main Control ▽     Commands ▽    Tools ▽
 go atlas

 # read in device structure
 mesh inf=bjt.str

 # specify models
 models consrh auger conmob fldmob print

 # obtain initial solution
 solve init

 # define beam
 beam num=1 x.origin=0 y.origin=-1 angle=90 wavelength=0.8

 # specify solution scheme
 method gummel newton trap

 # solve
 solve b1=1 vcollector=0.5

 ATHENA started                                              ATHENA
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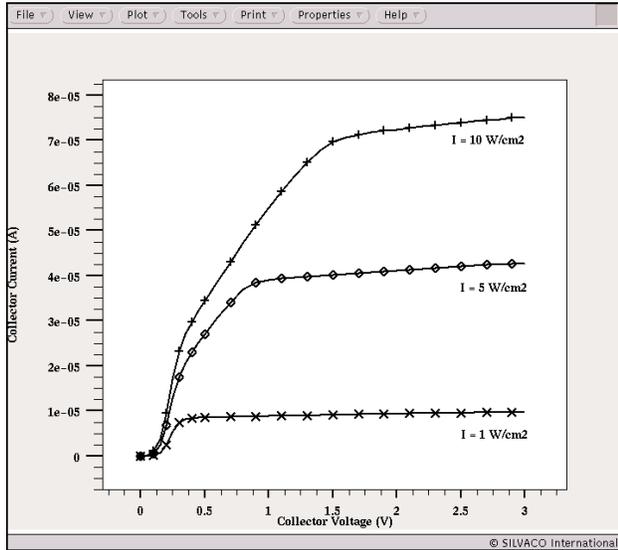Figure 2. Example input deck for optoelectric device simulation.

Figure 3. Common-emitter output characteristics (Ic vs. Vce) for dual-base BJT.
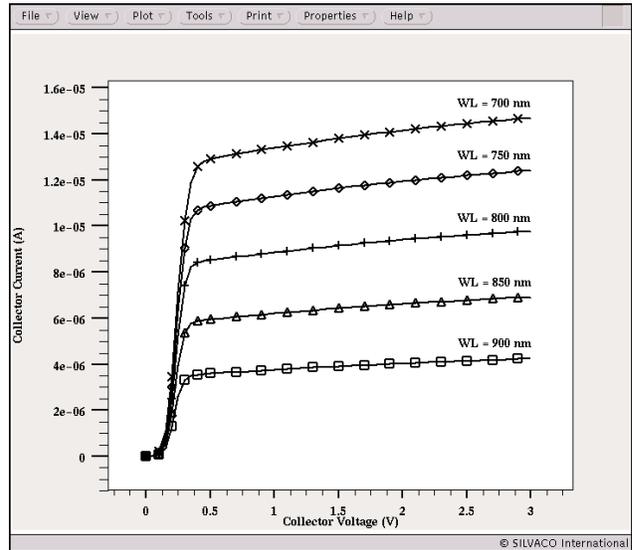

Figure 4. Common-emitter output characteristics (Ic vs. Vce) for dual-base BJT.

where k is the imaginary component of the optical index of refraction. The cumulative effects of the reflection coefficients, transmission coefficients, and the integrated loss due to absorption over the ray path are saved for each ray. In *Luminous*, the optical ray trace model and the adsorption/ photogeneration model are calculated at each DC bias point or transient time step prior to electrical simulation. The calculated carrier concentrations are then used within *S-Pisces* or *Blaze* to calculate the terminal currents.

Simulation Setup

A diagram of the dual-base BJT device structure used for this work is presented in Figure 1. The structure was created using the general purpose process simulator

ATHENA. Optoelectric simulations are initiated through the definition of one or more optical sources.

Optical sources are specified in the form of a collimated beam of light using the BEAM statement. The minimum set of conditions necessary to conduct an optoelectric simulation include the beam's origin (x,y coordinates), its wavelength, and its propagation angle in relation to the semiconductor surface. The source's intensity is specified using the SOLVE statement. Figure 2 presents an example input deck for an optoelectric simulation using *Luminous*. Here, the BEAM statement specifies a single optical source (labeled numerically as 1) originating one micron above the semiconductor surface. The source's wavelength λ is 0.8 μm, or 800 nm, and it enters the device vertically (90 degrees from the horizontal axis). The second SOLVE statement specifies
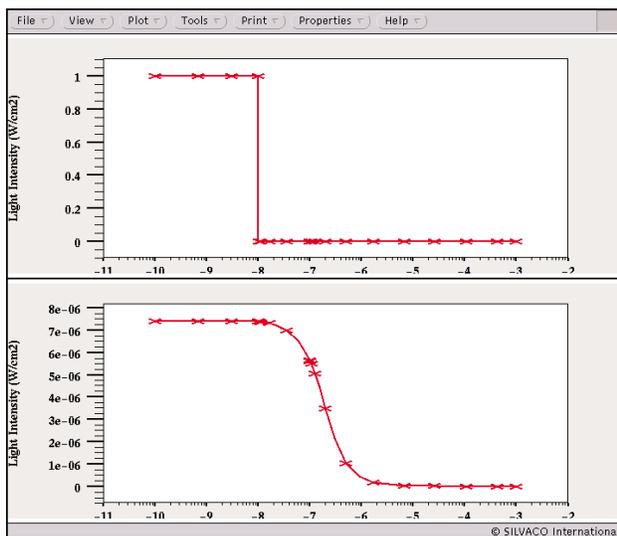

Figure 5. Device turn-off characteristics of dual-base BJT (in seconds). Source intensity = 1 W/cm^2, Source wavelength = 800 nm.
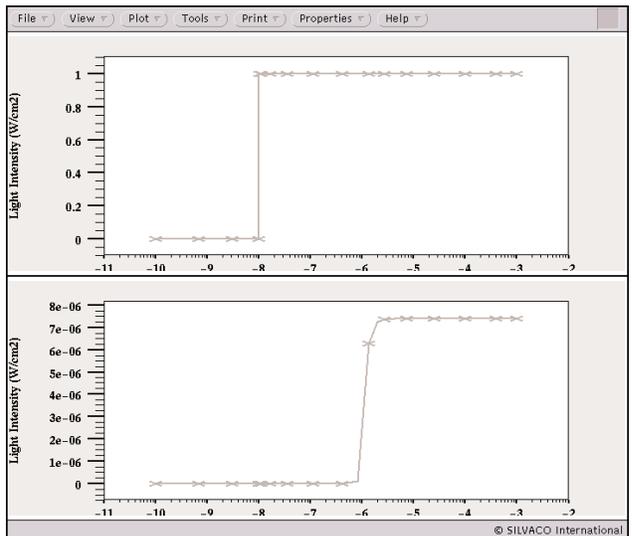

Figure 6. Device turn-on characteristics of dual-base BJT (in seconds). Source intensity = 1 W/cm^2, Source wavelength = 800 nm.
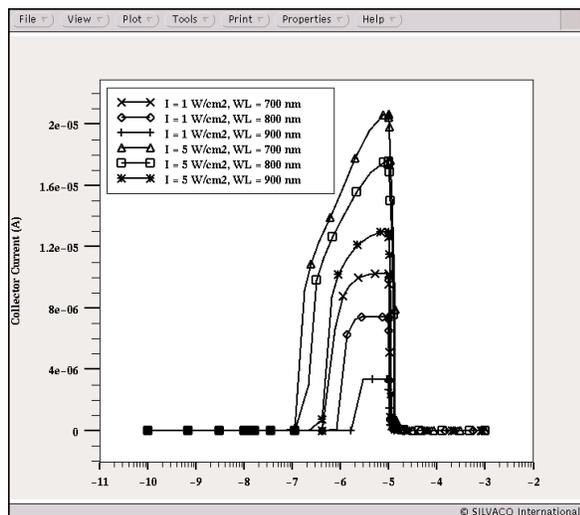
Figure 7. Device pulse response of dual-base BJT (in seconds) for varying source intensities and wavelengths.

a solution for a collector voltage of 0.5V and a light intensity of 1 W/cm². More advanced controls of the optical source (including definition of multi-spectral sources) are available using the BEAM statement, but are outside the scope of this article.

Results

To demonstrate optoelectric device simulation using *Luminous*, a series of DC and transient analyses were conducted on a dual-base BJT structure. For all analyses, the emitter was grounded and the base and collector acted as the input and output terminals, respectively. The optical source was the only source of current in the base areas of the device.

Figure 3 presents the common-emitter output characteristics (Ic vs Vce) of the dual-base BJT for varying levels of light intensity. As shown, three levels of light intensity were simulated: 1, 5, and 10 W/cm². As the light intensi-

ty increases, the collector current, output conductance, and saturation voltage all increase. Figure 4 presents the same output characteristics for varying wavelengths of light. The wavelength was stepped from 700 to 900 nm in increments of 50 nm. As shown, the saturation current is inversely proportional to the wavelength of light and both the output conductance and saturation voltage remain constant.

Figure 5 presents the turn-off characteristics of the dual-base BJT. Initially on, the optical source (intensity = 1 W/cm², wavelength = 800 nm) was removed after 10 ns. The fall time was approximately 0.7 μs. Here, fall time was defined as the time required for Ic to reach 10% of its initial value. Figure 6 presents the turn-on characteristics of the BJT. Initially off, the device was illuminated after 10 μs (intensity = 1 W/cm², wavelength = 800 nm). Defined as the time for the output current to reach 90% of its final value, the rise time of the dual-base BJT was approximately 7 μs.

Figure 7 presents the device's response to a pulse of light with varying intensities and wavelengths. The device was illuminated after 10 ns and the light source was removed after 10 us. The wavelength was varied from 700 to 900 nm in increments of 100 nm. The intensity was stepped from 1 to 5 W/cm2.The device exhibits the same basic behavior seen in Figures 5 and 6.

Summary

The accurate simulation of optical processes in semiconductors is a valuable tool for the development of current and future optoelectric device structures. This article presented an overview of the optoelectric device simulation capabilities of *Luminous*. The basic device models incorporated in *Luminous* were presented, an example input deck for completing an optoelectric device simulation was included, and the results of the DC and transient simulation results for a dual-base BJT device structure were discussed.