A Robust Drift-diffusion Equations Solver Enabling Accurate Simulation of Photodetectors

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Abstract— Since the 1990s, the drift-diffusion equations (DDEs) solvers have been widely used to study photodetectors and emitters deploying thin semiconductor layers [1–3]. Complex mechanisms such as thermionic emission at the heterojunction boundaries, incomplete ionization, impact ionization, and the Franz-Keldysh effect can play an important role in the nonlinear behavior of these photonic components [1–3]. In this work, we will describe how we incorporate these complex effects in the DDEs to create a highly robust DDEs solver capable of realistically simulating photodetectors with any number of layers and calculating their impulse response.

The developed DDEs solver has three components: mesh generator, static solver, and dynamic solver. The mesh generator creates a non-uniform mesh for the given number of layers and layer thicknesses, where the mesh-density is higher close to the edges. In the static solver, DDEs governing charge densities, impurity concentrations, electric field, and generation and recombination rates, are solved **using an implicit finite-difference method** assuming the photodetector is excited with a constant light source until the output current reaches a steady state. Since this output current is unknown at the start of the calculations, it must be determined iteratively. Hence, the iterative solver starts with an initial guess, determines the output current, updates the initial guess, and repeats the current calculation until the difference between the two is negligibly small. The current densities for electrons and holes are described using diffusion coefficients as well as field- and doping-dependent electron and hole drift velocities. The generation rate is calculated as a function of material properties and position in the device. The total current output is the sum of the hole, electron, and displacement currents integrated over the photodetector. Thermionic emission, incomplete ionization, impact ionization, and the Franz-Keldysh effect are all included in the model with proper triggering conditions. The dynamic solver assumes a very short and small perturbation in the excitation and computes how the output current changes. The time-dependent change in the output current is then divided by the total change to yield the impulse response. Since the impulse response varies exponentially in the time domain [2, 3], we integrate the change in the output current logarithmically. Then we calculate the phase noise of the device using the impulse response assuming that the electrons in each current pulse are Poisson-distributed [3]. Logarithmic integration reduces the computation time more than one order of magnitude while assuring 0.1% or less difference in the overall phase noise compared to a linear integrator [3].

At the conference, we will discuss how the previously mentioned complex mechanisms affect the nonlinear behavior of various types of photodetectors (p-i-n, uni-traveling-carrier, modified uni-traveling-carrier, etc.) that use different types of semiconductors.

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