4. Conclusions

This thesis presented the models incorporated in the SimWindows optoelectronic device simulator. SimWindows solves three sets of equations that yield the electrical, optical, and thermal characteristics of optoelectronic devices.

The electrical equations extend the standard drift-diffusion models by adding effects not included in other semiconductor device simulators. A quantum confinement model allows SimWindows to simulate optoelectronic devices that incorporate quantum wells. Thermionic emission and tunneling current are necessary to simulate heterojunctions. SimWindows implements these effects using Fermi-Dirac statistics. Many of the relations using Fermi-Dirac statistics had not been previously derived, but were necessary to model highly doped semiconductors.

The optical equations incorporate electromagnetic field reflections at material interfaces as well as computing resonant frequencies of vertical cavity lasers. These two features help SimWindows to couple better the optical equations to the electrical and thermal models. Without this coupling, SimWindows could not predict many of the key effects present in optoelectronic devices.

SimWindows implements two thermal models that yield either the lattice or electron temperature. The single temperature model assumes that there is an instantaneous equalization of energy between the carriers and the lattice while the hot electron model assumes that the electrons are out of equilibrium with the lattice. The single temperature model includes both parallel and lateral lattice heat flows. This allows SimWindows to predict better the self heating within devices. The hot electron temperature model applies when electrons are excited out of equilibrium with the lattice. The fundamental feature of both models is that the resulting temperature influences the electrical and optical models through a variety of temperature dependent parameters. Band gap, electron affinity, thermal conductivity, mobility, and refractive index are all temperature dependent and that dependence can have a strong influence on the characteristics of devices.

This thesis also presented the simulation results of two different optoelectronic devices: a vertical cavity surface emitting laser, and a multi-quantum well solar cell. In the case of the laser, the simulation results showed that the tight coupling between the electrical, optical, and thermal models produces the correct trends in the laser characteristics. The laser analysis focused on the distributed Bragg reflectors and showed that the design of the n-type and p-type reflectors should be independent from each other. A constant 30% aluminum transition layer decreased the resistance of the n-type DBR by a factor of 3.3 while linear grading reduced the resistance of the p-type DBR by a factor of 7.1 over a standard constant 60% aluminum transition layer design for both DBRs. By using these specific designs, SimWindows showed corresponding improvements in electrical power dissipation, temperature rise, and emitted optical power for the laser. For an emitted optical power of 1.1 mW, the improved VCSEL dissipated 14 mW of electrical power versus the 37 mW for the standard VCSEL. This translated into a peak internal temperature of 324 K for the improved design versus 414 K for the standard VCSEL.

For the multi-quantum well solar cell, simulation results showed an unanticipated decrease in the short circuit current resulting from hot electrons diffusing towards the wrong contact. SimWindows showed that modifying the direction of light illumination would minimize this effect. For right illumination, the short circuit current increased from 10.7 mA cm^{-2} to 12.1 mA cm^{-2}. This resulted in an increase from 11.3 mW cm^{-2} to 13.3 mW cm^{-2} in the maximum power for the solar cell. SimWindows also showed that hot electrons produce higher open circuit voltages than the isothermal model.

There are a number of features that SimWindows does not currently model. A third base contact, transient analysis, edge emitting lasers, Schottky contacts, and finite surface recombination would extend the usefulness of SimWindows not only in optoelectronic devices, but also in non-optoelectronic devices. The strength of SimWindows is that it provides flexibility to programmers to add new models or new physical effects while leaving old models undisturbed. SimWindows also provides flexibility to users to modify specific models for individual needs.