Sandia National Laboratories' benefits plans are maintained at the discretion of National Technology and Engineering Solutions of Sandia, LLC (NTESS). They do not create a contract of employment. The plans may be suspended, modified, or discontinued at any time and without prior notice, subject to applicable collective bargaining agreements and except as otherwise provided by applicable law. If there is any discrepancy between the information on this website and the Summary Plan Descriptions, then the Summary Plan Descriptions supersede.
Staffing and Funding

**Personnel**
- 1355
- Larry Musson
- Gary Hennigan
- Suzey Gao
- Mihai Negoita
- Andy Huang
- Jason Gates
- Joe Castro

**Funding**
- ASC/IC
- ASC/P&EM
- ASC/V&V
What is Charon?

- Semiconductor TCAD code with support for modeling displacement damage due to neutron radiation as well as effects from other sources of radiation (e.g. ionization)
- Finite-volume and finite-element discretizations of governing PDEs
  - Drift-Diffusion
  - Drift-Diffusion + Energy (Lattice Heating)

\[
\nabla \cdot \left( \epsilon \vec{E} \right) = q \left( p - n + C \right) \quad \text{Electric Potential} \\
\vec{E} = -\nabla V
\]

\[
\begin{align*}
\nabla \cdot \vec{J}_n &= q \left( n \mu_n \vec{E} + D_n \nabla n \right) \\
\nabla \cdot \vec{J}_p &= q \left( p \mu_p \vec{E} - D_p \nabla p \right)
\end{align*}
\]

\[
\begin{align*}
\nabla \cdot \vec{J}_n - qR &= q \frac{\partial n}{\partial t} \\
\nabla \cdot \vec{J}_p - qR &= q \frac{\partial p}{\partial t}
\end{align*}
\]

\[
\nabla \cdot \left( \kappa \nabla T_L \right) + H = \rho c \frac{\partial T_L}{\partial T}
\]

Constitutive Relations

Conservation

Lattice Heating
Unique Capabilities Provided by Charon

- Two & three dimensional + parallel capability
- Production quality code using current best practices for software development
  - Adheres to formal SQE practices
  - Monitored with periodic audits
  - Utilizes rigorous verification
    - MMS (Method of Manufactured Solutions)
    - Automated regression testing (nightly/weekly)
- Utilizes latest solver technology
  - Via solvers in Sandia’s Trilinos toolkit
- Incorporates empirical (fast running) and high fidelity physics models for displacement damage
Environments & Device Modeling Capability

- **Environments**
  - Normal
  - Dose Rate – reactor environments
  - Total Dose – not validated
  - SEE – Some early, limited capability

- **Devices**
  - Diodes
  - BJT (Si)
  - HBT (III-V)
  - FETs
  - Memristor
  - Ultra-Wide Band Gap Diodes (new models)
Normal Environment Characterization (COTS BJT Example)

SIMS and SR dopant and impurity concentration measurements

Fit of analytic functions for doping (Gaussian)

Comparison of computed and experimental Gummel data
Bandgap in a Np⁺ Heterojunction

The discontinuities act as a barrier to normal carrier flow.

There are two other mechanisms however that will allow carrier transport:

- **Thermionic Emission**
  - Carriers receive enough energy via thermal processes to overcome the barrier

- **Tunneling**
  - Carriers may tunnel through the barrier
Capabilities Added to Charon to Support HBT Modeling

- Fermi-Dirac Statistics (highly doped)
- III-V Material Models
- Thermionic Emission
- Tunneling
- Recombination Terms
  - Direct
  - Auger
- Discontinuity of Concentrations at Heterojunction
Ongoing/Future Charon Development

- Expanding Physics Capability
  - SEE/SEU
    - Simple linear charge input available
  - Si HVD Analysis
  - GaN development
    - High Voltage Diodes (support of UWBG GC)
    - HEMTs
  - Frequency Domain Modeling (HB)
    - Both linear and non-linear
  - Improved coupled electrical & thermal

- Next Generation Development
  - In preparation of next gen computational Hardware
Progression of Charon Capabilities

Normal Environment PnP HBT

2D Modeling of HBTs

Cluster Damage Model for GaAs in HBTs

Empirical Damage Model for HBTs

Normal Environment Npn HBT

FET models with multi-region support

QASPR Circuit Prototype (Silicon BJTs, Mixed-mode)

QASPR Device Prototype (Silicon NPN BJTs)

PN Diodes

Research Code (CSRF & LDRC)

Single Event Effect Modeling

Cluster Damage Model for Si

Progression of Charon Capabilities

III-V Work

Silicon Work
Charon1 SG shows strong mesh dependence of the gain when going from 20K to 80K quad elements, while Charon2 SG shows mesh convergence even for 20K elements!
Patrick R. Mickel et al., A physical model of switching dynamics in tantalum oxide memristive devices, APL 102, 223502 (2013).
Charon Limitations

- Not a commercial code
- Limited documentation
- Generally requires developer help
  - Non-intuitive input deck
    - A python interface is currently under development
- Different workflow from commercial codes
  - Cubit
  - Non-sequential input
Charon Availability

- No restrictions for Sandians
- Charon is categorized as an ITAR/Export Control Simulator
  - We have a Government Use Notice (GUN) in place with AWE
  - GUN provides a U.S. government agency or contractor access to software limited to government use
- Open-Source may be a future path
  - Currently in review