# Semiconductor Device Modeling


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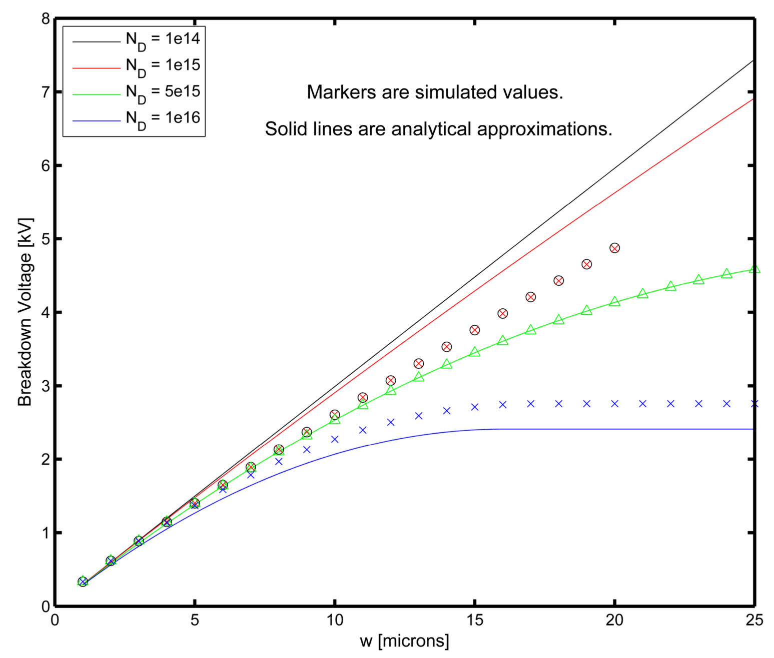
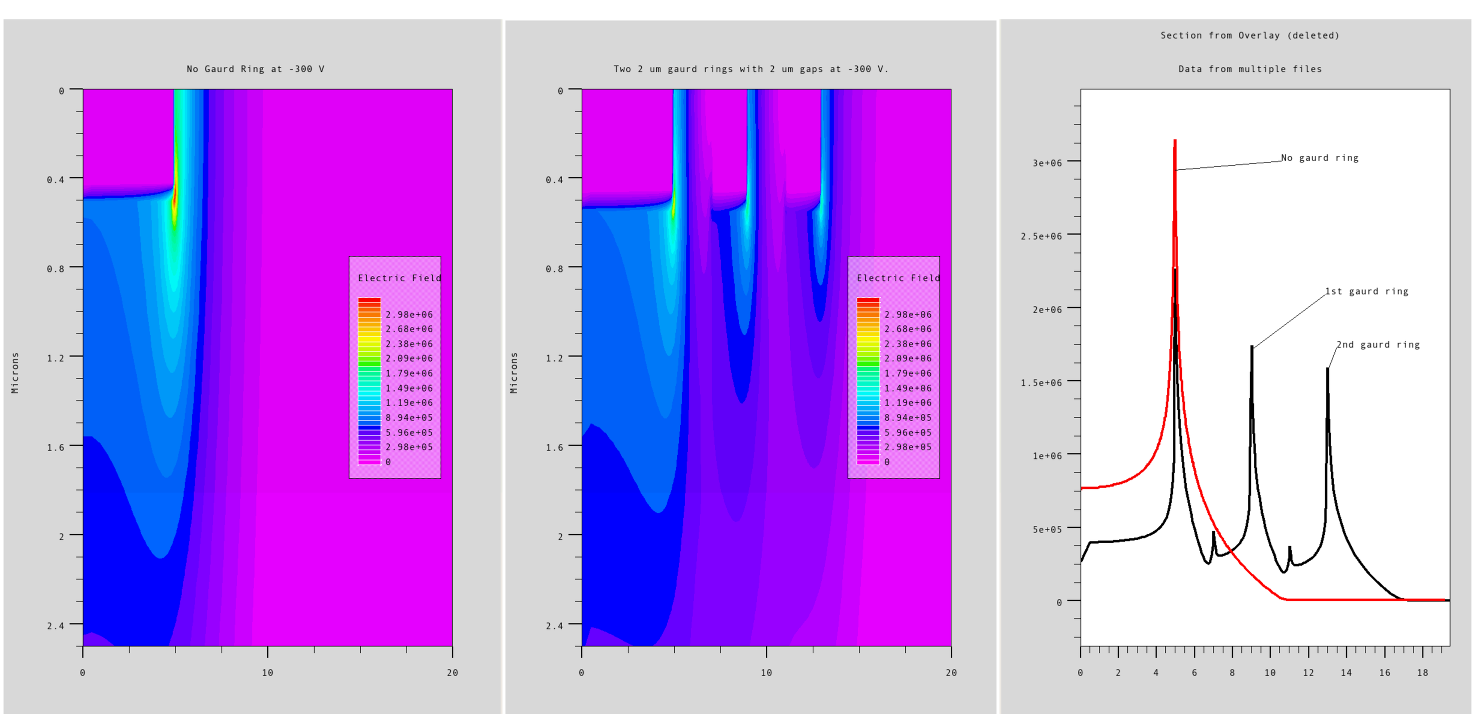
## III-Nitride Vertical Power Diodes

One of the most important figures of merit for vertical power diodes is the breakdown voltage. At the breakdown voltage the current increases by several orders of magnitude with small increases in voltage and can quickly destroy the device.

The breakdown voltage for a planar device, where the anode and cathodes are treated as infinite parallel plates, can be calculated analytically. The analytical results were compared to simulations as shown to the right as a function of background doping, $N_D$, and the thickness of the intrinsic region of the device, w.

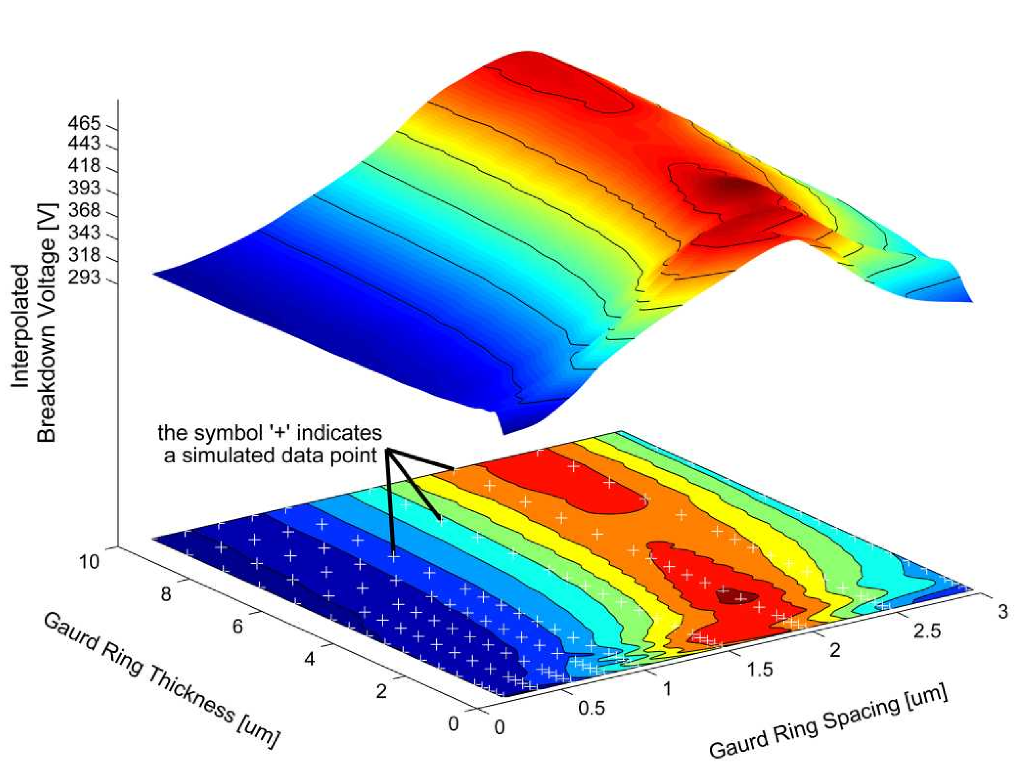


Physically realizable power diodes of course do not have infinite parallel plates, and as such, the strong electric field that develops on the corner of the contact can drastically lower the breakdown voltage of the device and decrease performance.

One method of dealing with this problem is to add guard rings which can spread the electric fields out and increase the breakdown voltage.

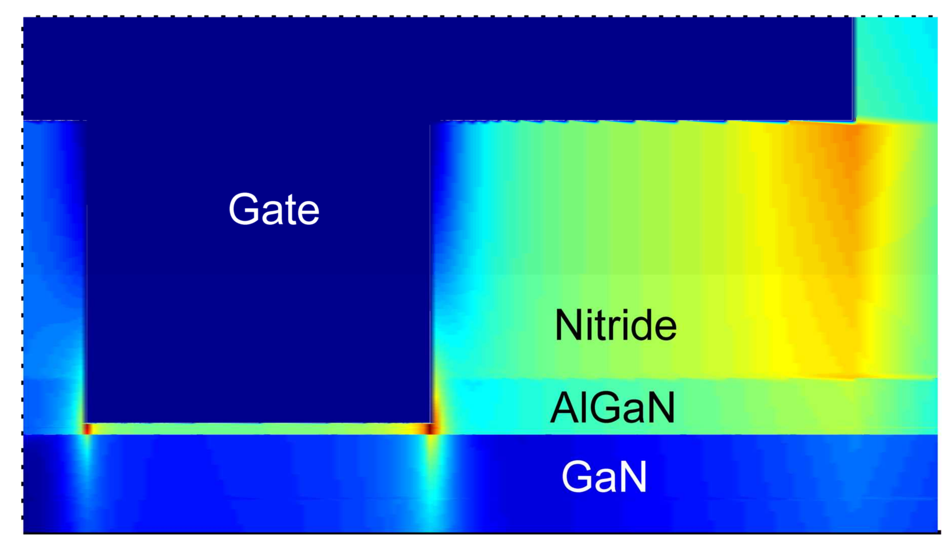
The figures above show the electric field in a device with no guard rings (left) and a device with two guard rings (center). A cutline through the device near the peak electric field (right) shows how the guard rings reduce the peak field for a given voltage compared to the no-termination device.




Multiple simulations of the vertical device with a single guard ring were performed in order to investigate the parameter space consisting of the guard ring thickness and the spacing distance between the guard ring and the metal contact.

These simulations indicated that the spacing of the guard ring was more critical to device performance than guard ring thickness.

## III-Nitride High Electron Mobility Transistors (HEMTs)

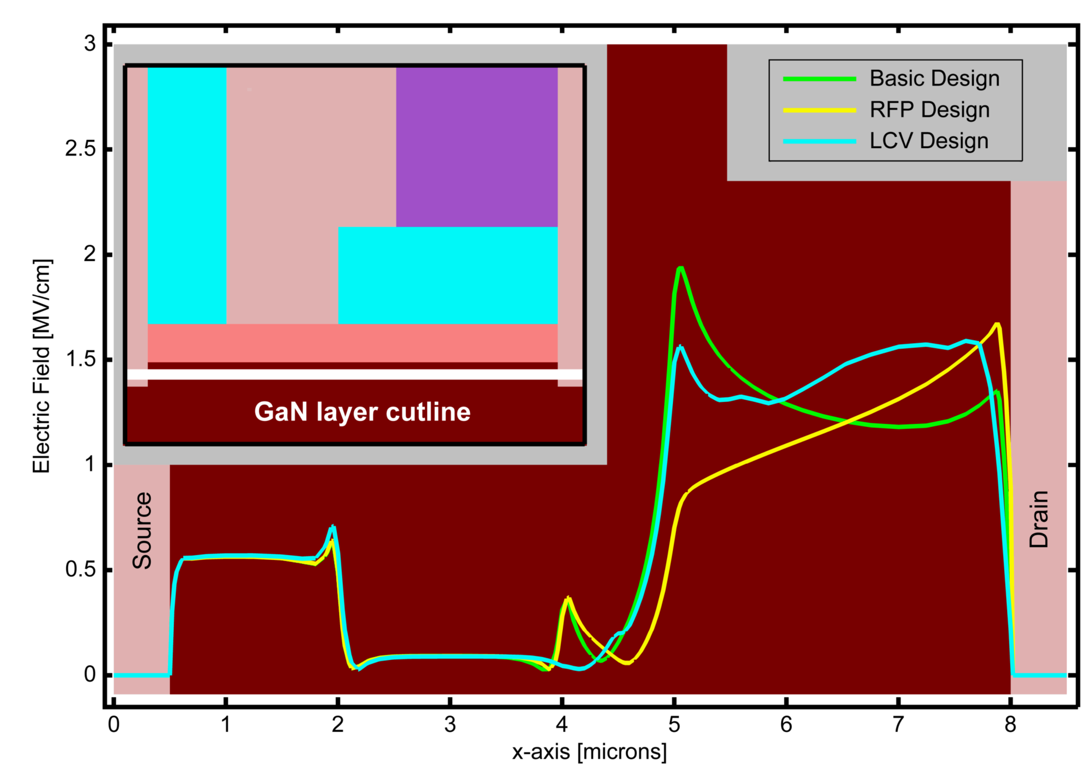


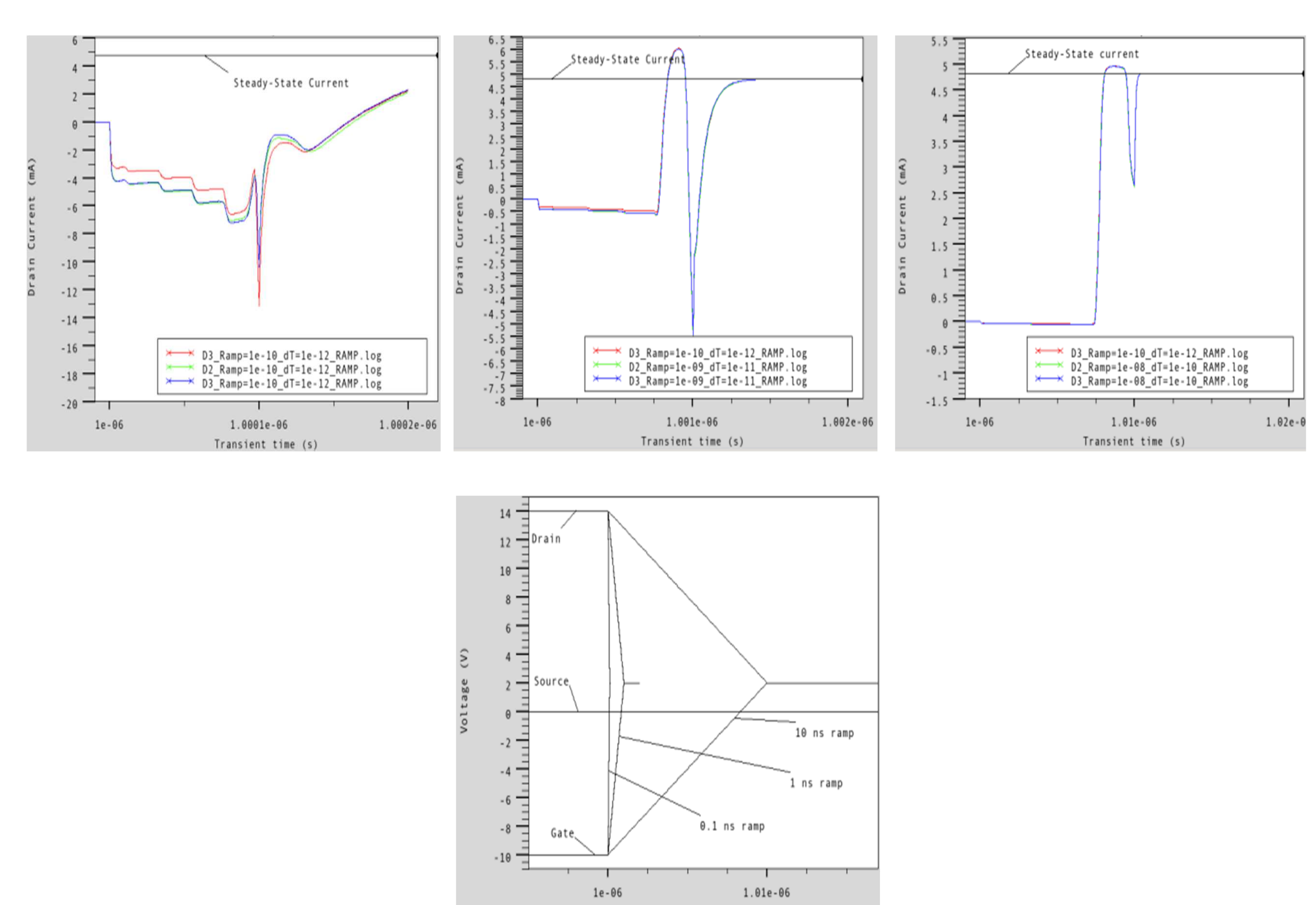

While the operating principle of the lateral HEMT device is different from the vertical power diode, the peak electric field between the gate and drain contacts is a similar problem.

The figure to the left shows that the highest electric field (red) occurs in the AlGaN region at the corner of the gate contact closest to the drain contact which is to the right of the figure.

The Electric field profiles in the GaN layers of three different designs of a lateral HEMT device are shown as a function of position.

In general, devices degrade at the location of the highest peak in the electric field, thus as expected the LCV design allowed for the highest breakdown voltage.



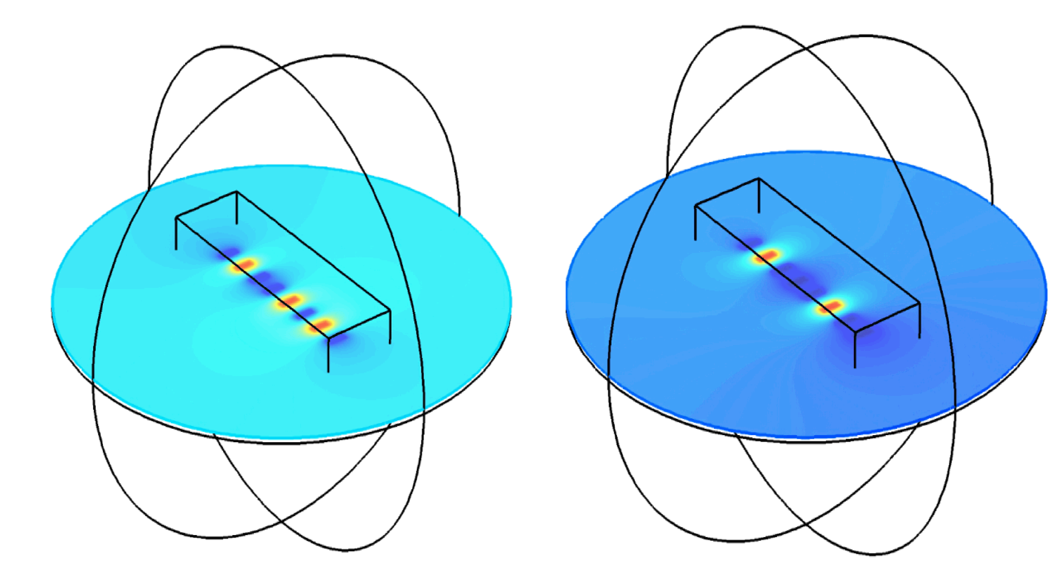



Transient simulations enable a closer look on how a device behaves as a function of time for a given signal. The above figures show the transient response of the drain current as a function of dV/dt (bottom figure). For slow switching, the device quickly approaches the steady state value (top right), however for faster switching (top left), the device does not have time to reach the steady state condition and would be expected to perform poorly.

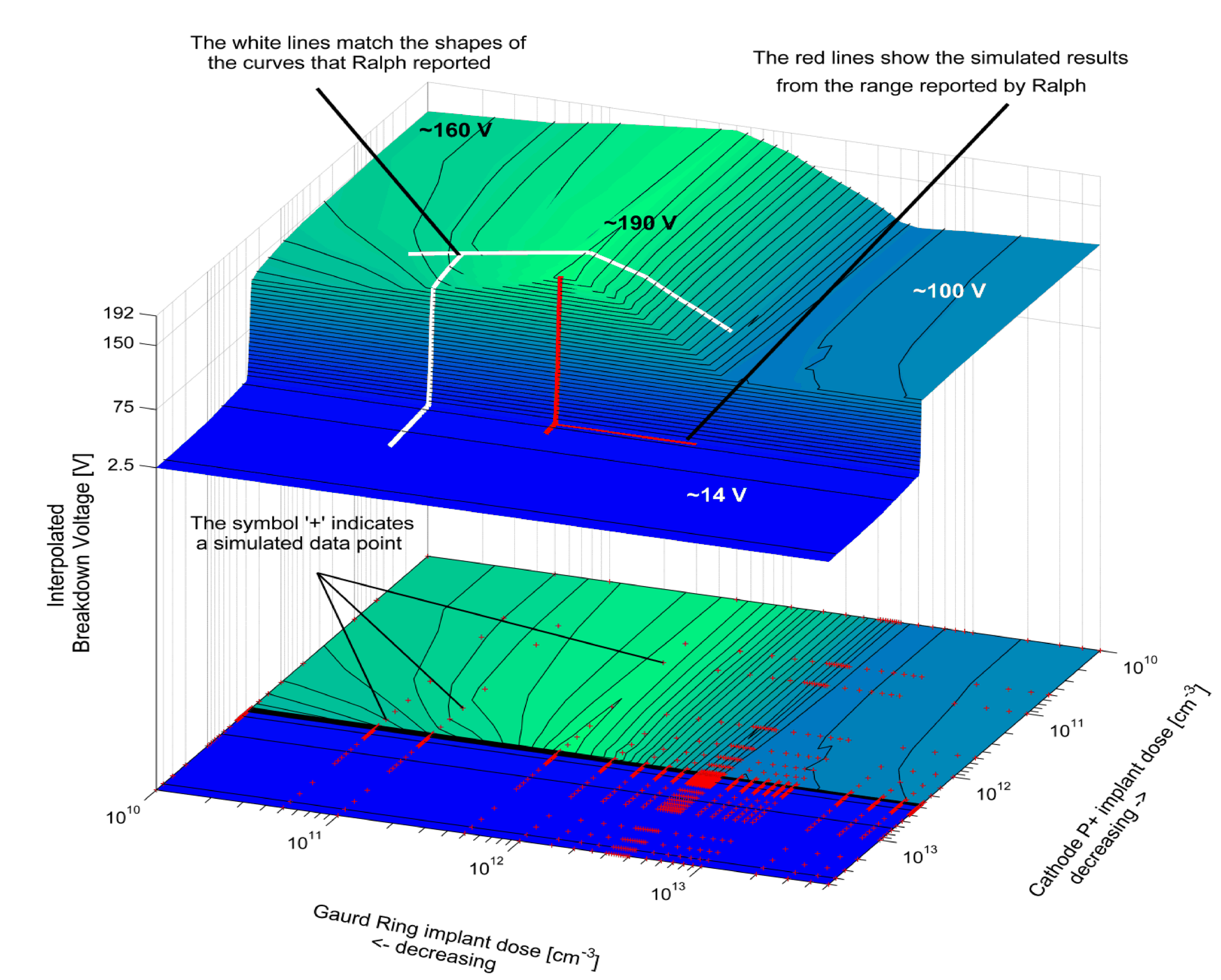
## Semiconductor Modeling

- As a vital part of the Ultra-Wide Bandgap Power Electronics Grand Challenge LDRD, simulations of device level physics provide useful insights into achieving superior-quality prototypes and targeting high-risk design areas.
- The SILVACO TCAD software is used to calculate current-voltage curves, impact ionization, transient responses, and many other important figures of merit.
- My work has focused on the III-nitride material system, specifically AlGaN/GaN HEMTs and vertical power devices, but has also extending into modeling avalanche photo-detectors for quantum computing, solar cells, and a bi-layer graphene device.

## Silicon based devices



In addition to the SILVACO TCAD package, COMSOL is useful for simulating 3D images of the electric field in complex devices.




Another project needed the breakdown voltage characteristics of an avalanche photo-detector as a function of doping in a two different regions. As can be seen in this figure, the Cathode P+ region doping can dominate the device functionality for high doping levels.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