TCAD Simulations of a Photoconductor

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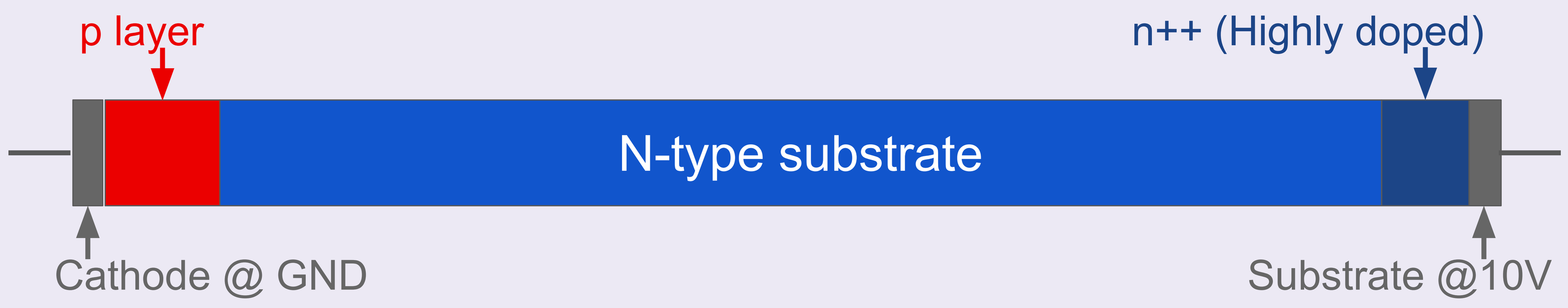
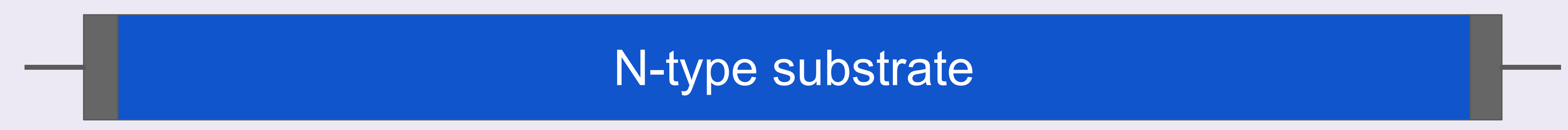
Introduction

Silicon sensors are ubiquitous, from the cheap manufacturing, the maturity of the technology, the fast turnaround and the silicon intrinsic capabilities to detect charged particles and photons in a huge energy range. Usually, the silicon sensors are based on a diode, a p-n junction where a Boron-doped layer (p-type) contacts a Phosphorus-doped layer (n-type). However, even a simple silicon bar, which is a resistor, can act as a sensor: this is the “photoconductor”. In this work, by means of numerical simulations conducted with TCAD (Technology Computer Aided Design) software from Silvaco, we study some performance of the diode vs the photoconductor, by changing a few parameters in the physics simulation.

Diode (p-n junction) structure



Photoconductor structure



Creation of silicon structures

We used Silvaco’s *Athena* simulator to create the geometry of the silicon chips. This is the code we used to generate a 1D photoconductor or diode in Silvaco, 100 microns thick, with deposits of aluminum on both sides serving as the electrodes. Keywords beginning with $ are variables that we inputted the values of.

```
# Define the initial rectangular grid.
line x loc=0 spac=0.5
line x loc=1 spac=0.5
line y loc=0 spac=0.1
line y loc=$si_len spac=0.1
# Define the initial substrate from the rectangular grid, using Silicon.
init silicon c.$dopant_bulk_m=$dopant_c orientation=100 two.d
if cond = ($device_t = Diode)
  # Add Boron doping to the edge in the case of Diode.
  implant boron dose=1.0e15 energy=10 tilt=0 rotation=0 amorph
if.end
# Deposit a layer of aluminum at the top.
deposit aluminum thick=$al_len division=5
# Deposit a layer of aluminum at the bottom.
structure flip.y
if cond = ($device_t = Diode)
  # Dope the silicon with phosphorus in the case of Diode.
  implant phosphor dose=1.0e15 energy=10 tilt=0 rotation=0 amorph
if.end
deposit aluminum thick=$al_len division=5
structure flip.y
```

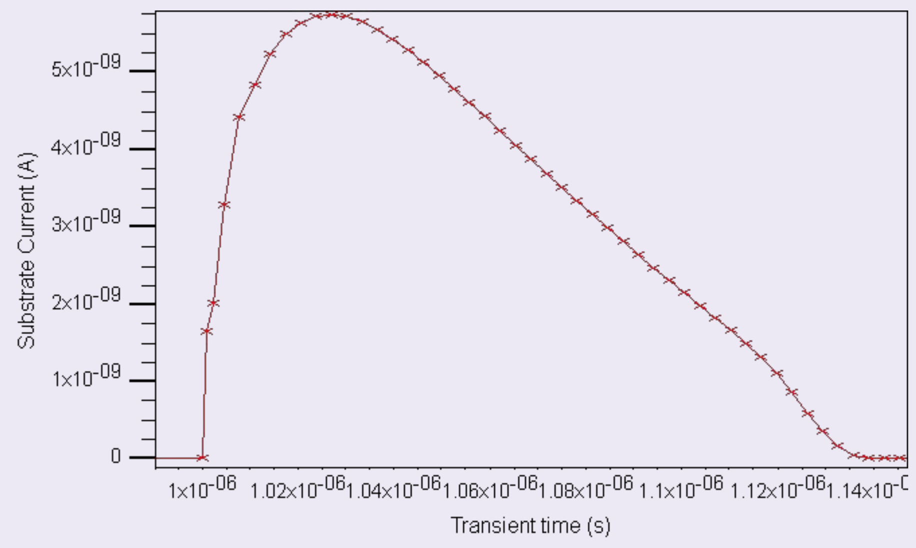
Simulating semiconductor physics

We used Silvaco’s *Atlas* simulator to apply an external voltage across the silicon bar, and introduce a single-event upset at 1μs. This single-event upset hits the device with a charged particle, generating electron/hole pairs which move through the bar. This is the code we used to run our simulations with different parameters.

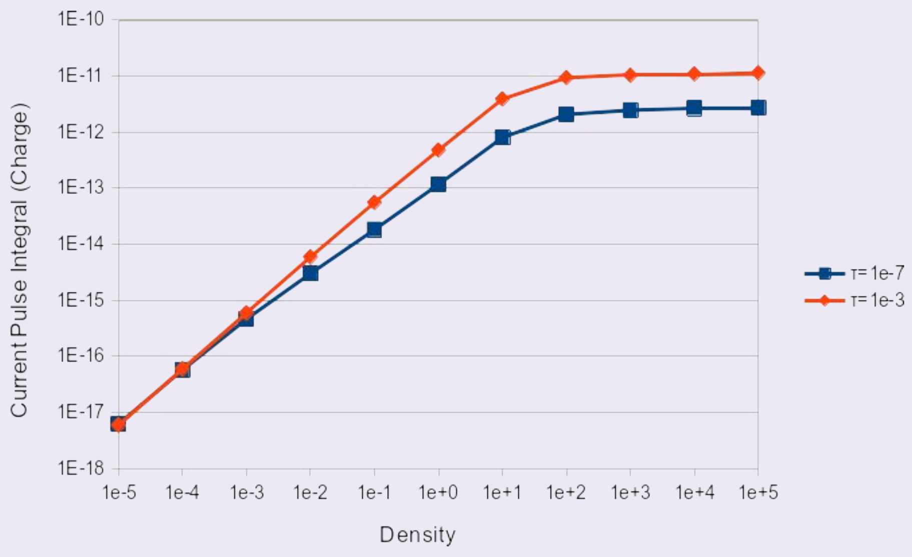
```
# Configure the electron and hole lifetime parameters.
material region=1 taun0=$lifetime taup0=$lifetime
# Use Newton's method for solving, specifying the maximum time-step.
method newton carriers=2 trap itlimit=20 maxtraps=10 dt.max=0.02e-9
# Introduce a single-event upset, with a given number of electron-hole pairs.
singleeventupset entrypoint="0,50" exitpoint="1,50" pcunits \
    b.density=$ehp_density radialgauss radius=1 t0=$time_event_start tc=0
# Solve with initial parameters.
solve initial
# Include the net charge in the output.
output charge
# Solve with an increasingly high voltage applied to the substrate electrode.
solve vsubstrate=0 vstep=1 vfinal=$voltage name=substrate
# Simulate the pedestal of the current, with large time-steps.
method newton carriers=2 trap itlimit=20 maxtraps=10 dt.max=100e-9
solve tfinal=$time_event_start tstep=1e-9
# Simulate the development of the pulse, with smaller time-steps.
method newton carriers=2 trap itlimit=20 maxtraps=10 dt.max=$pulse_width/50
# Simulate the rest of the pedestal.
method newton carriers=2 trap itlimit=20 maxtraps=10 dt.max=100e-9
solve tfinal=2*$time_pulse_end tstep=1e-9
```

Results on diode

Our simulation code outputs the current of the device as a function of transient time. We can calculate the charge of the device by taking the the integrals of the current pulses. Here, we study these charges with relation to the density of the generated electron/hole pairs.



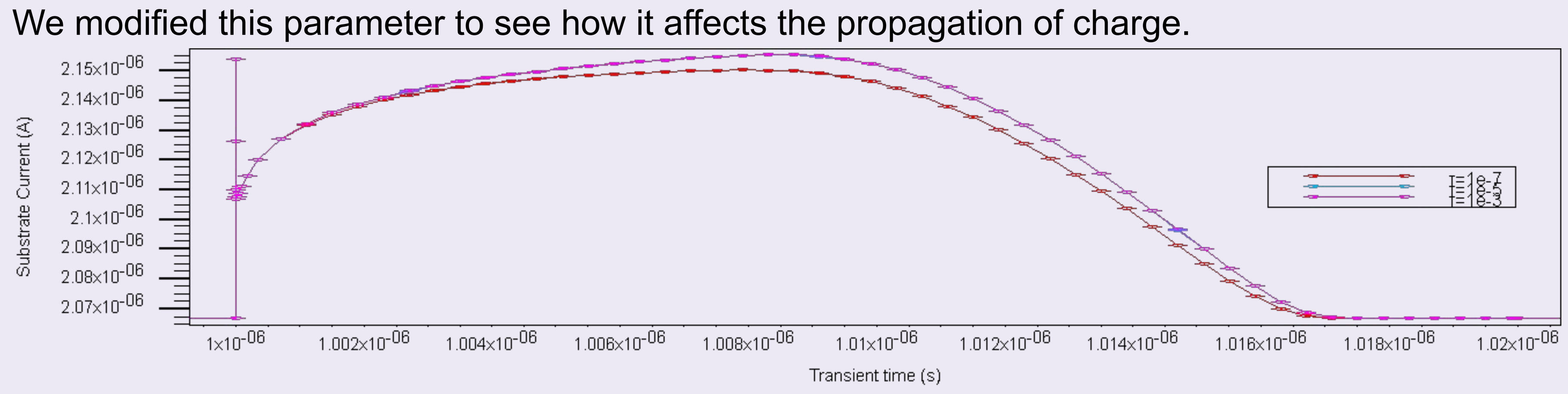
Waveform of the current of the diode with 10V applied, τ=1e-7s, and a density of 1e-3pC/um.



Total charge within the diode vs. electron/hole pair density, for lifetimes τ=1e-7s and τ=1e-3s.

Results on photoconductor

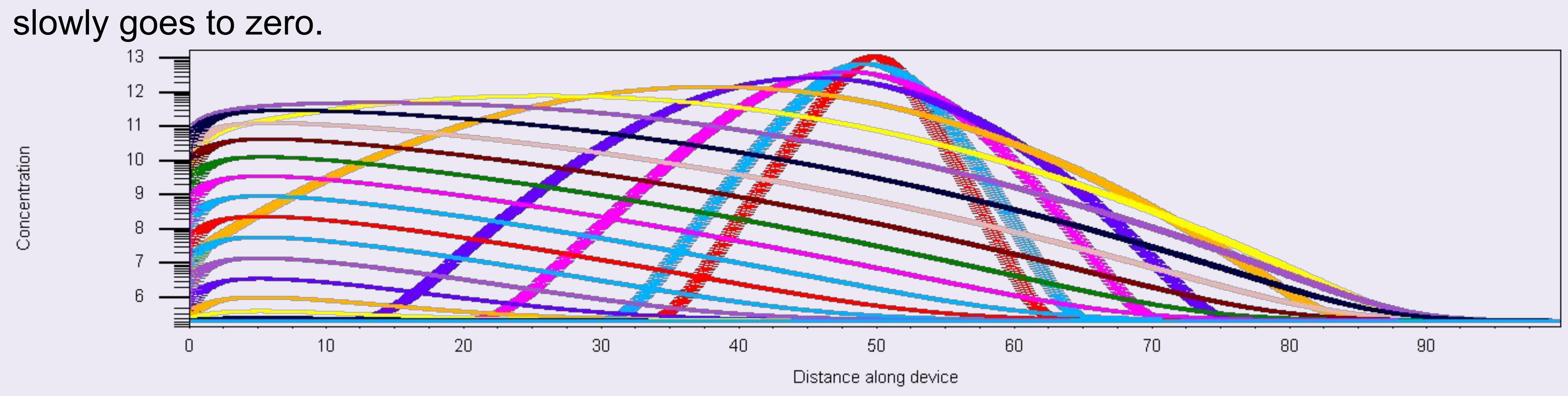
Since we have doped the semiconductor with phosphorus, electrons are more abundant than holes. Over time, the minority charge carriers, holes, will recombine with the other charge carrier, electrons. The lifetime of the minority carrier is how long it takes until this recombination occurs. We modified this parameter to see how it affects the propagation of charge.



Waveforms of the current of the photoconductor with 10V applied, with a density of 1e-3pC/um, for lifetimes τ=1e-7s, τ=1e-5s, and τ=1e-3s.

Movement of holes

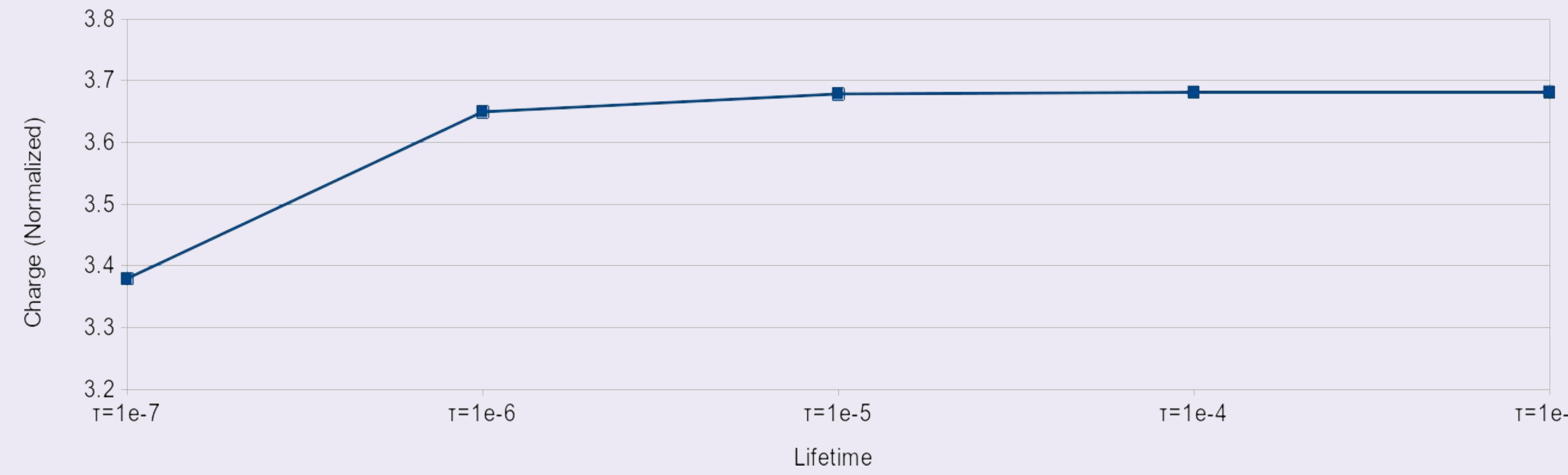
Using Tonyplot, we can analyze the concentration of holes in the photoconductor over time.This illustrates how the single-event upset starts as a dense hole cloud, before flattening out. To keep charge neutrality in the substrate, electrons are injected to compensate for the hole charge, which slowly goes to zero.



Concentration of holes vs. distance along the photoconductor. Each line here represents a different time, with the earliest being the thin red line, and the latest being the flat lines. Compared to the hole concentration, the electron concentration is constant throughout, at 1e15cm-3.

Comparing normalized results

We normalized the charge values of the photoconductors by dividing by the charge value of the diode at lifetime τ=1e-7. We then compared the normalized photoconductor results, to find that increasing the lifetime increases the amount of charge, plateauing after 1e-5s. Theoretically, however, the charge should increase proportionally to lifetime.



Normalized photoconductor charge vs. lifetime, with 10V applied, with a density of 1e-2pC/um, for lifetimes τ=1e-7s through τ=1e-3s.

Conclusion

Silvaco TCAD enables one to quickly prototype silicon devices with varying parameters, which we used to determine the effectiveness of changing the electron/hole lifetime, electron/hole pair density, and voltage. Here, the theoretically expected variation wasn’t found, so more work will be necessary. I would like to give a special thanks to Brookhaven National Laboratory for providing the resources and tool for this project, and to the BNL Office of Educational Programs for making this program possible.