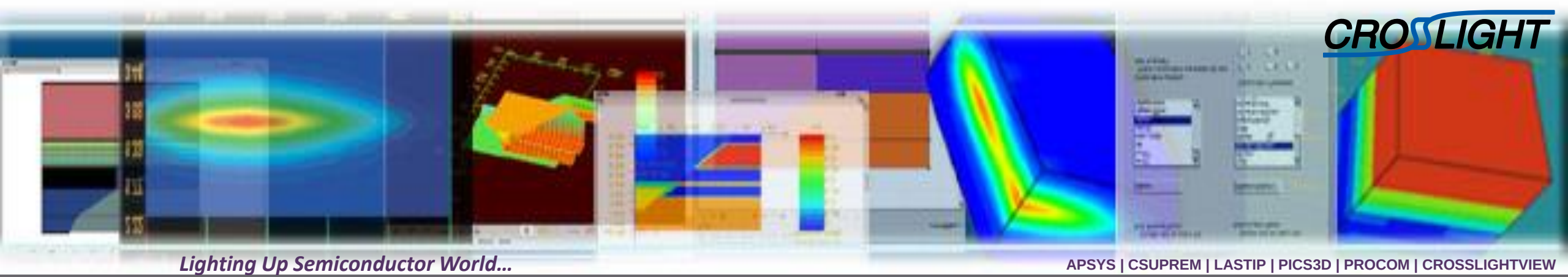
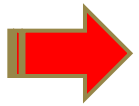


Crosslight Simulation of Switching and AC Characteristics for TrenchMOS

CROSSLIGHT

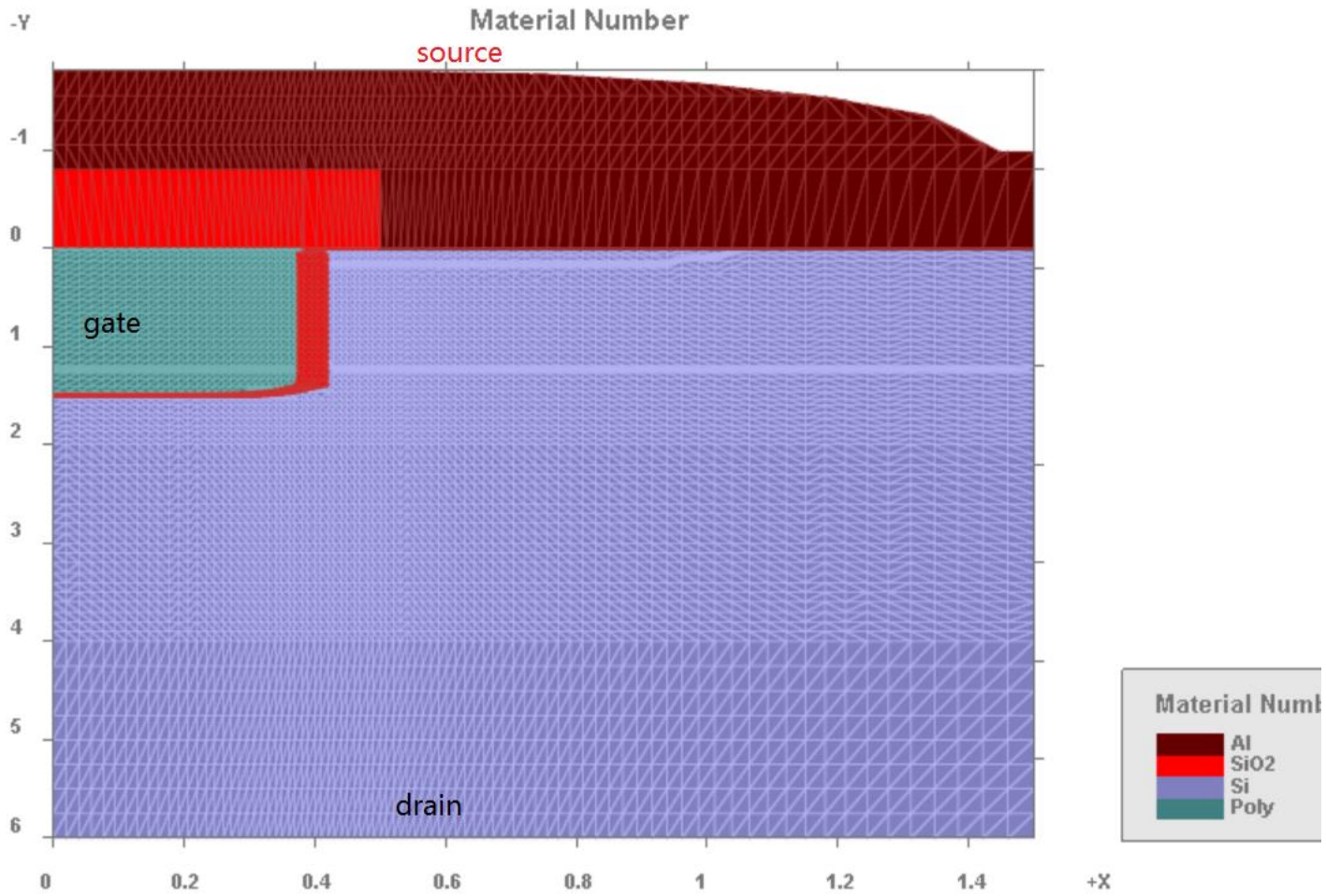
Contents



- Double pulse testing simulation
- Capacitance-voltage simulation
- Summary

Final structure

CSUPREM is used to build half of a Trench-MOSFET

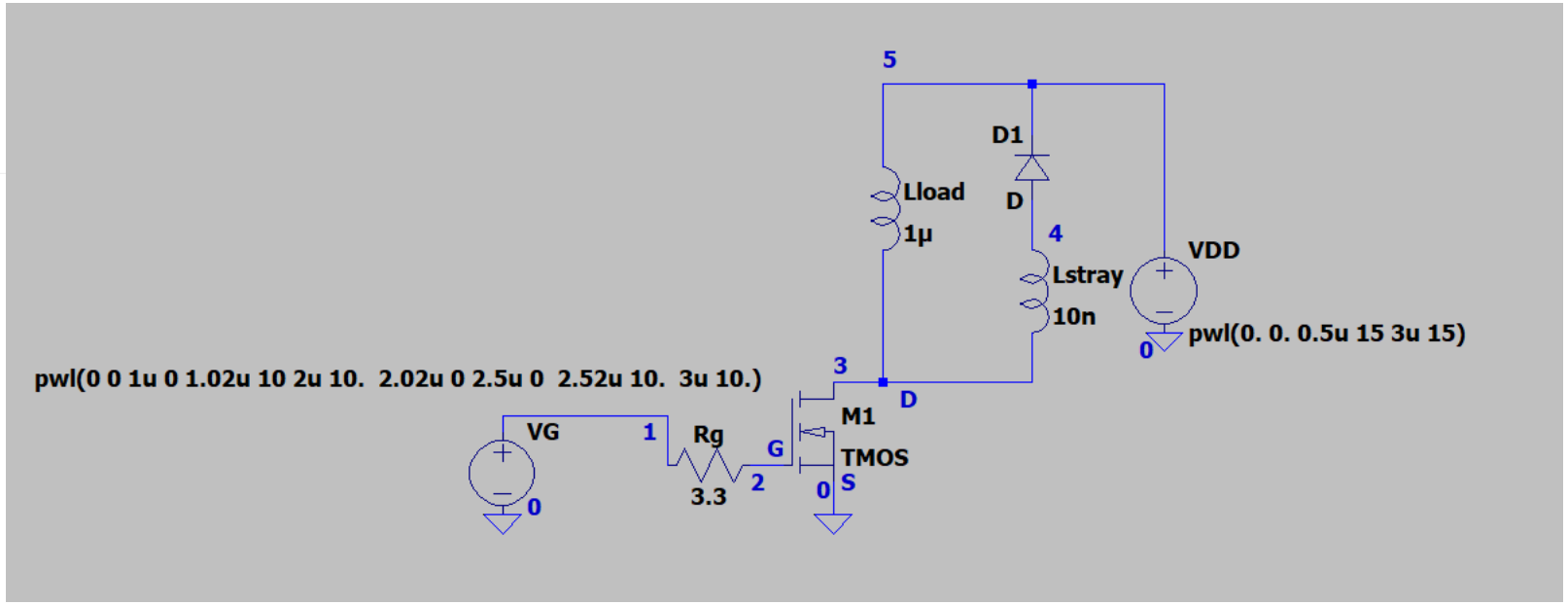


Double-pulse testing (DPT) method uses a double-pulse external circuit in a mixed-mode simulation to extract Turn-off Delay Time, Rise Time, Turn-on Delay Time, and Fall Time. This is defined in the APSYS project file (dpt.sol).

```
# A switching test circuit
VG 1  0  pwl(0 0 1u 0 1.02u 10 2u 10.  2.02u 0 2.5u 0  2.52u 10.  3u 10.)
RG 1  2  3.3
# TCAD mesh
Ztmos  3  2  0  TMOS
#testing wire on top of TMOS
Lstray 3  4  10n
#Dfwd 4  5  FWD 1e-5
Dfwd 4  5  ideal 1e-8
Lload 3  5 1u
#Use transient to ramp up the Vdd to get better convergence
VDD 5  0  pwl(0.  0.  0.5u 15 3u 15)
# optionally, more elaborate diode model can be used
#.MODEL FWD D(AF=1 BV=1200 CJO=0.  EG=1.11
#+ FC=0.  IBV=1.E-10 IS=1.E-14
#+ KF=0 M=0.5 N=1 RS=1e-10 TT=1e-6
#+ VJ=1.0 XTI=3.00E+00)
```

External circuit described in dpt.cir file for minispice command

Output on node 4 includes package parasitic inductance



APSYS transient simulation scan to 3 µs

dpt.sol

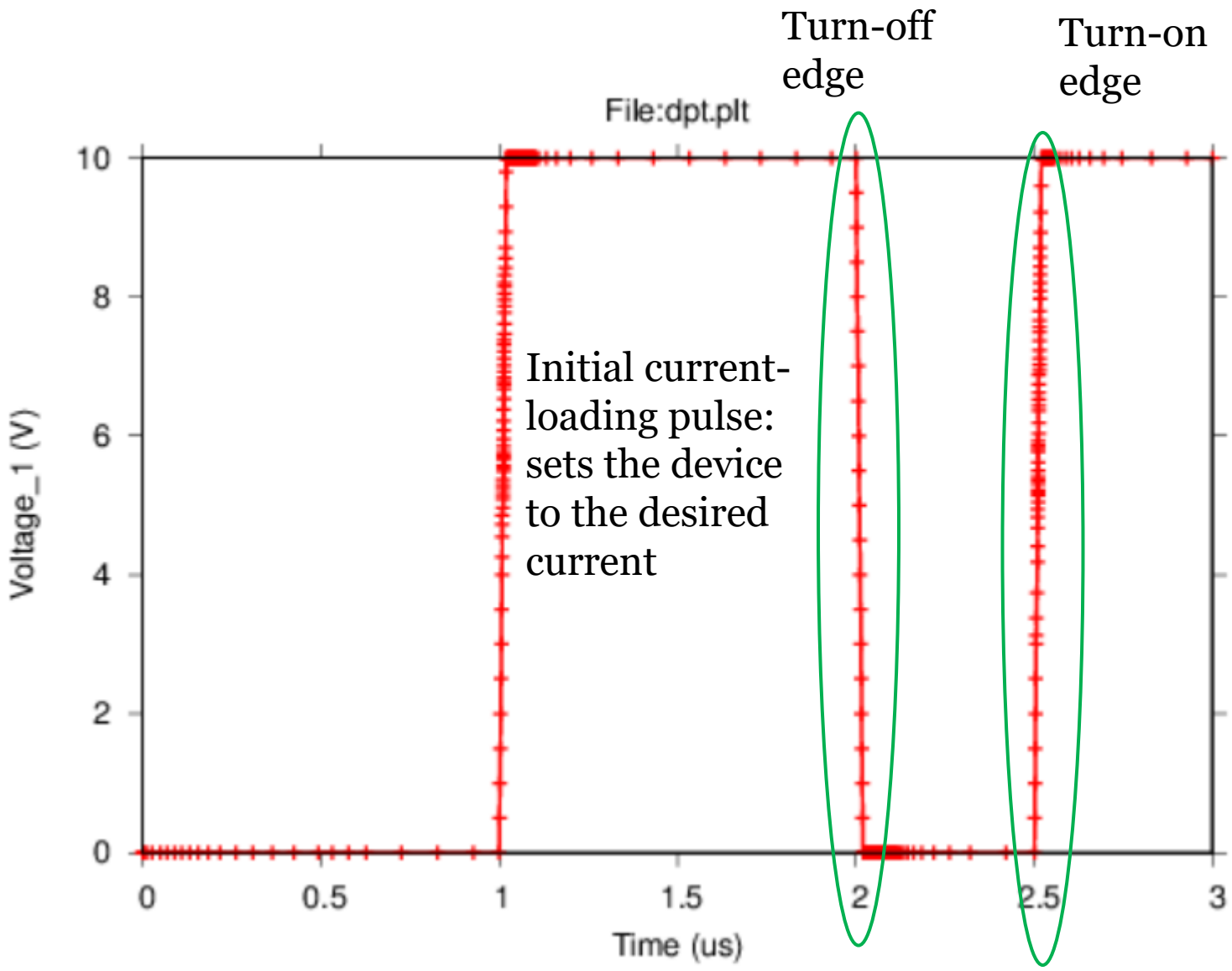
```
scan var=time value_to=1.e-6 init_step=1e-9 min_st
max_step=0.1e-6

scan var=time value_to=1.1e-6 init_step=1e-9 min_s
max_step=0.001e-6
scan var=time value_to=2.e-6 init_step=1e-9 min_st
max_step=0.1e-6
$ let us scan in fine steps for 50n
scan var=time value_to=2.05e-6 init_step=1e-9 min_
max_step=0.001e-6
scan var=time value_to=2.5e-6 init_step=1e-9 min_s
max_step=0.1e-6
$ let us scan in fine steps for 50n
scan var=time value_to=2.55e-6 init_step=1e-9 min_
max_step=0.001e-6
scan var=time value_to=3.0e-6 init_step=1e-9 min_s
```

APSYS post-processing to get minispice results at various circuit nodes & elements.

art Page | dpt.sol | dpt.plt

```
plot_minispice variable=voltage node=1 data_file=Vg_wv.txt
plot_minispice variable=voltage node=3 data_file=Vd.txt
plot_minispice variable=voltage node=4 data_file=Vd_pack.t
plot_minispice variable=voltage node=4 hori_range=(2. 2.1
plot_minispice variable=voltage node=4 hori_range=(2.5 2.6
plot_minispice variable=current node=3 element=Ztmos &&
    vert_factor=-1
plot_minispice variable=current node=3 element=Ztmos hori_
    vert_factor=-1
plot_minispice variable=current node=3 element=Ztmos hori_
    vert_factor=-1
plot_minispice variable=current node=1 element=RG hori_ran
 data_file=Qg_current.txt
```

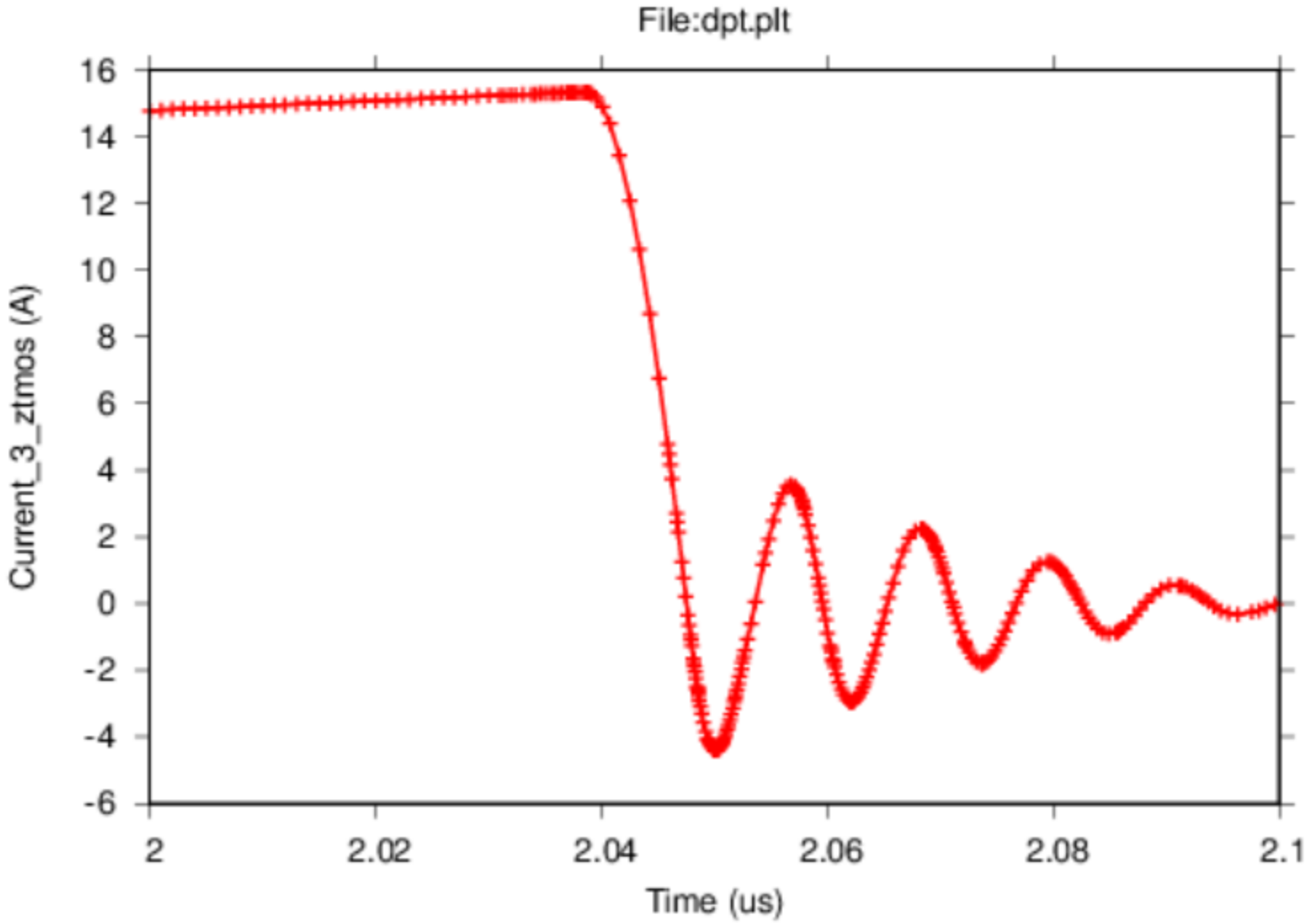
```
plot_minispice variable=voltage node=1 data_file=Vg_wv.txt
```



Input Signal

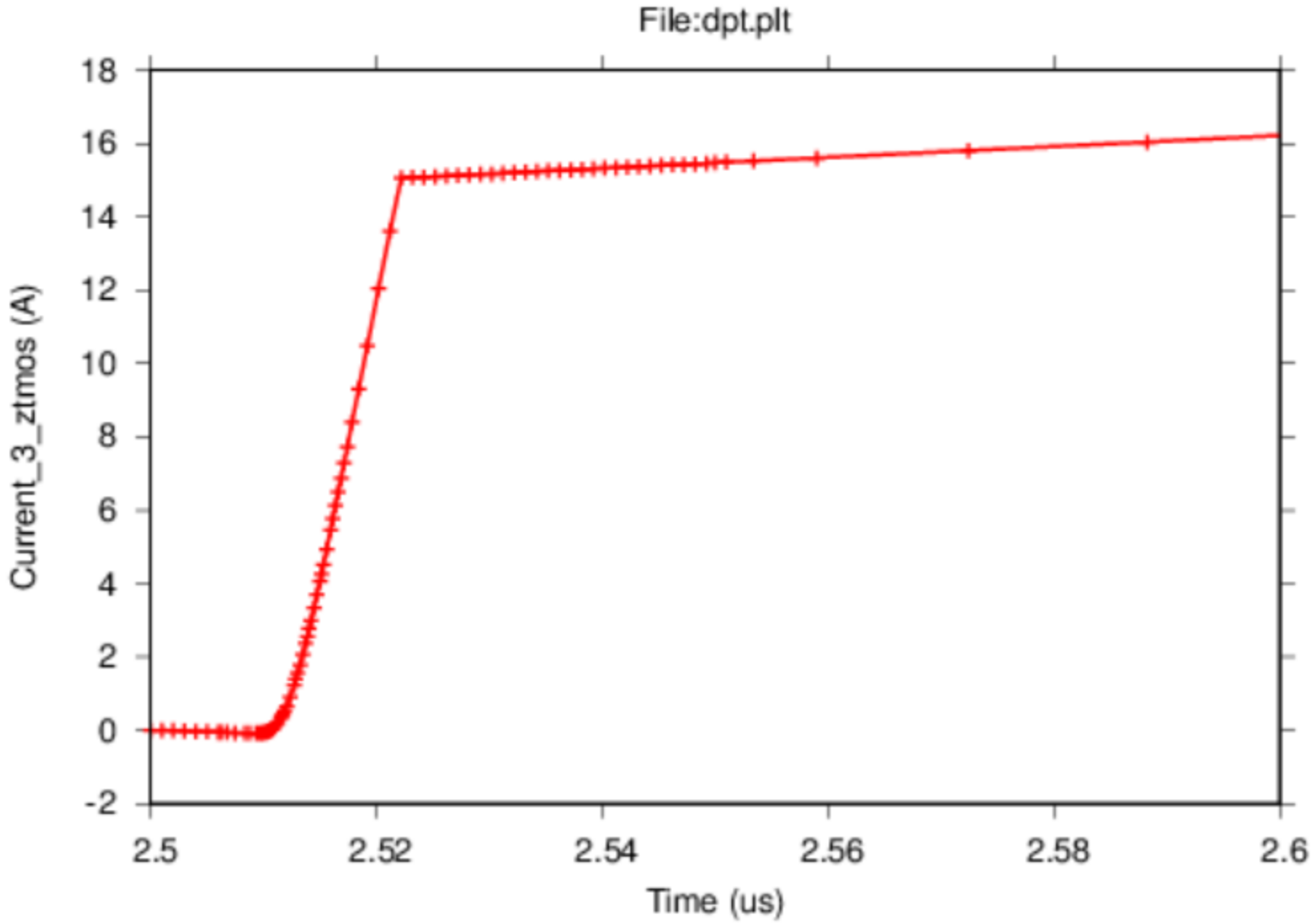
plot_minispice variable=current node=3 element=Ztmos hori_range=(2. 2.1) &&
vert_factor=-1

Device turn-off current from TrenchMOS



plot_minispice variable=current node=3 element=Ztmos hori_range=(2.5 2.6)
&&
vert_factor=-1

Device turn-on current from TrenchMOS

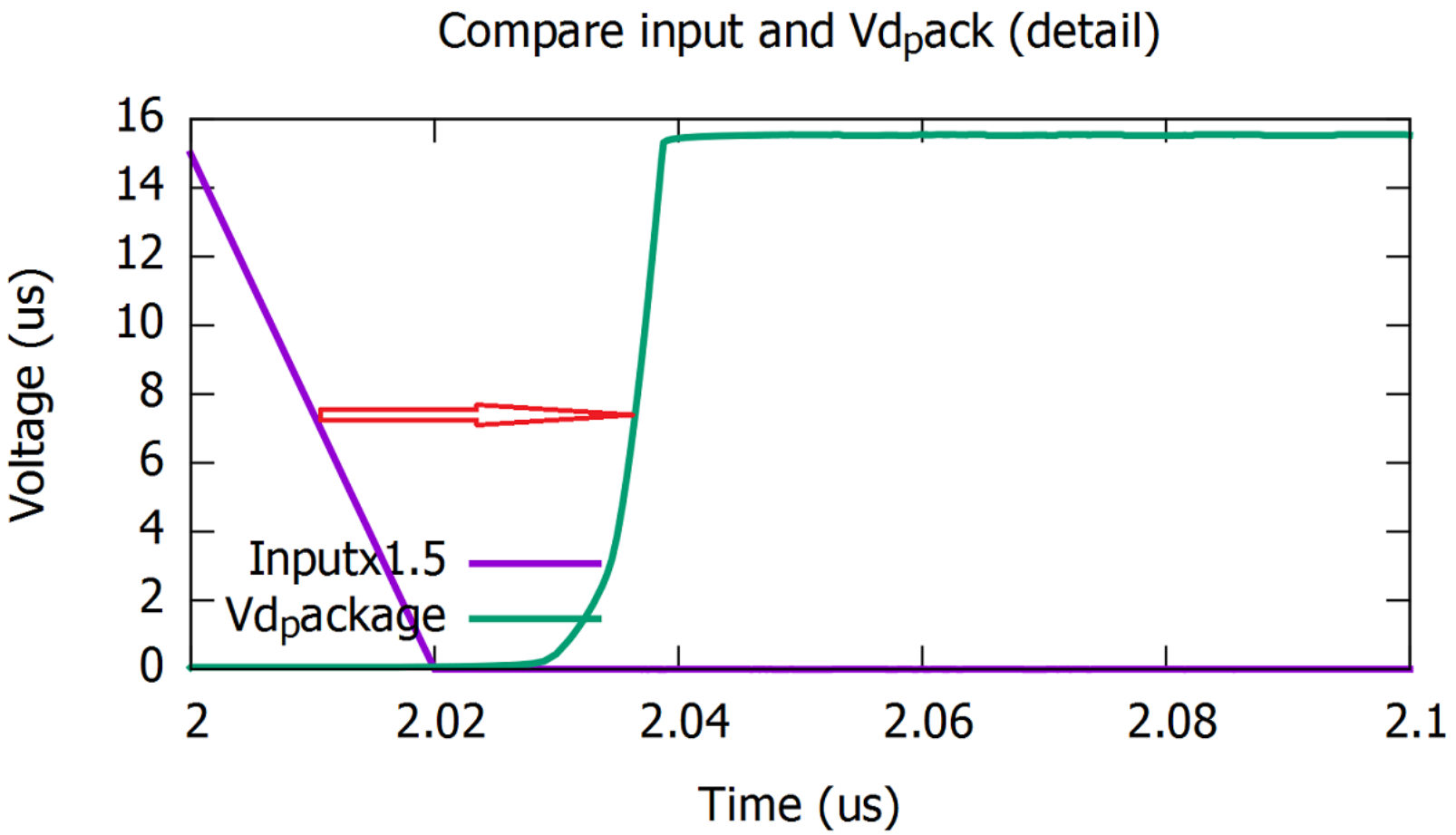


Use of 3rd party software to plot multiple curves together for the purpose of data extraction

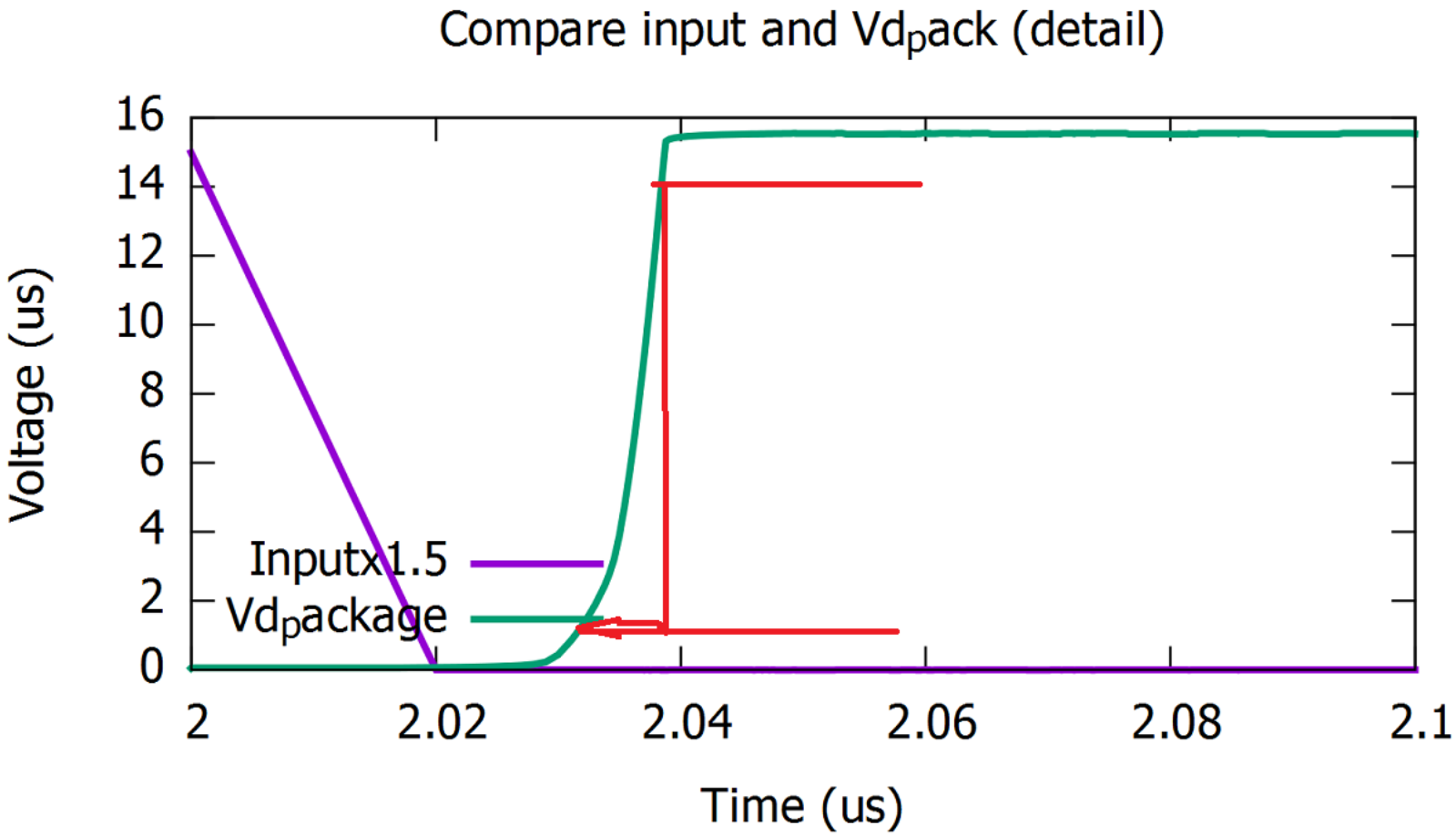
```
c:\NovaTCAD\Apsys\apsys\gnuplot.exe
```

```
gnuplot> set title "Compare input and Vd_pack (detail)"
gnuplot> set key left bottom
gnuplot> set xlabel "Time (us)"
gnuplot> set ylabel "Voltage (us)"
gnuplot> set xrange [2:2.1]
gnuplot> plot "Vg_wv.txt" using 1:(1.5*($2)) w l lw 3 t "Inputx1.5", "Vd_pack.txt" w l lw 3 t "Vd_package"
gnuplot>
```

turn-off delay of about 25ns at 7.5V



Using criteria of time to get from 10% to 90% of green line, rise time of about 8 ns

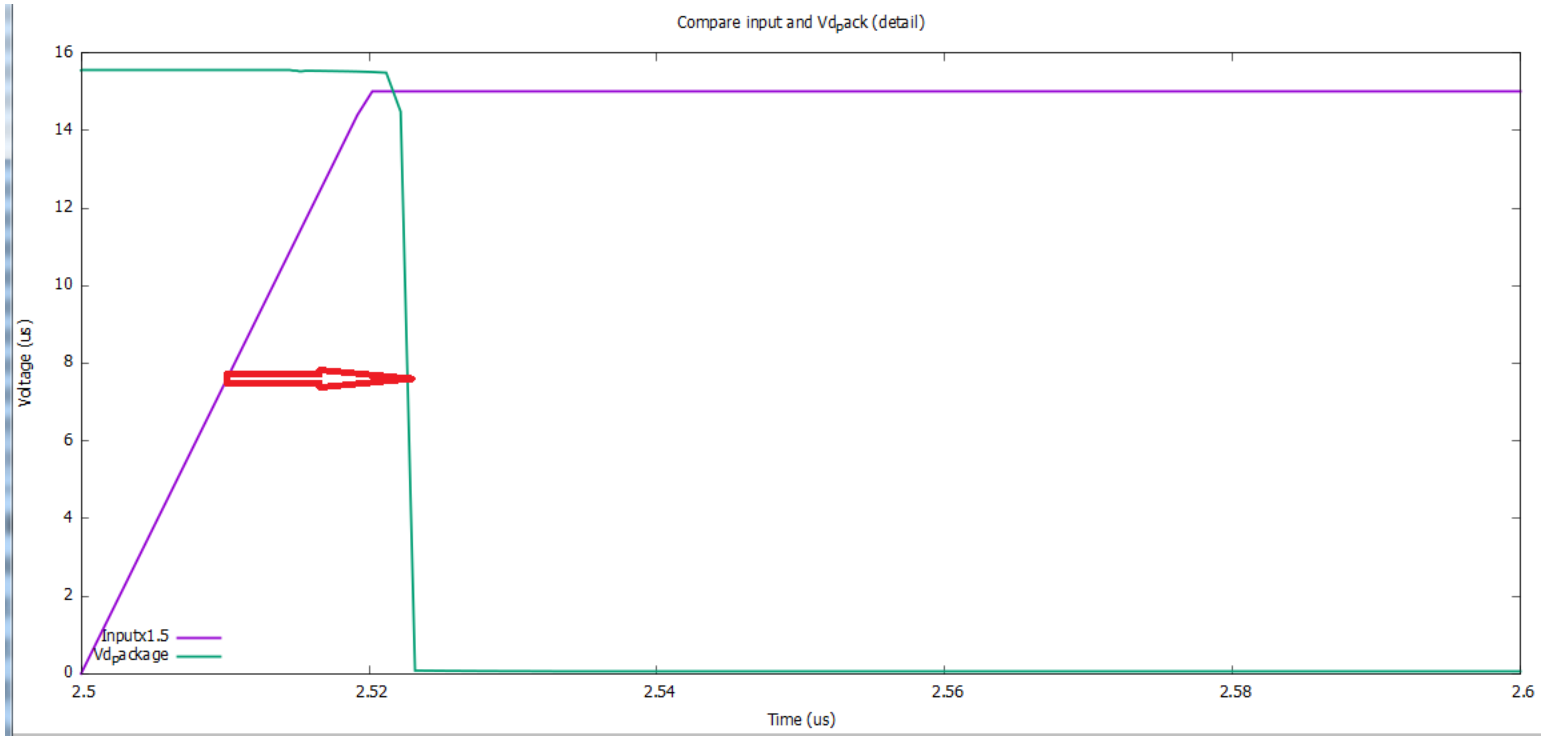


Plotting of second pulse:

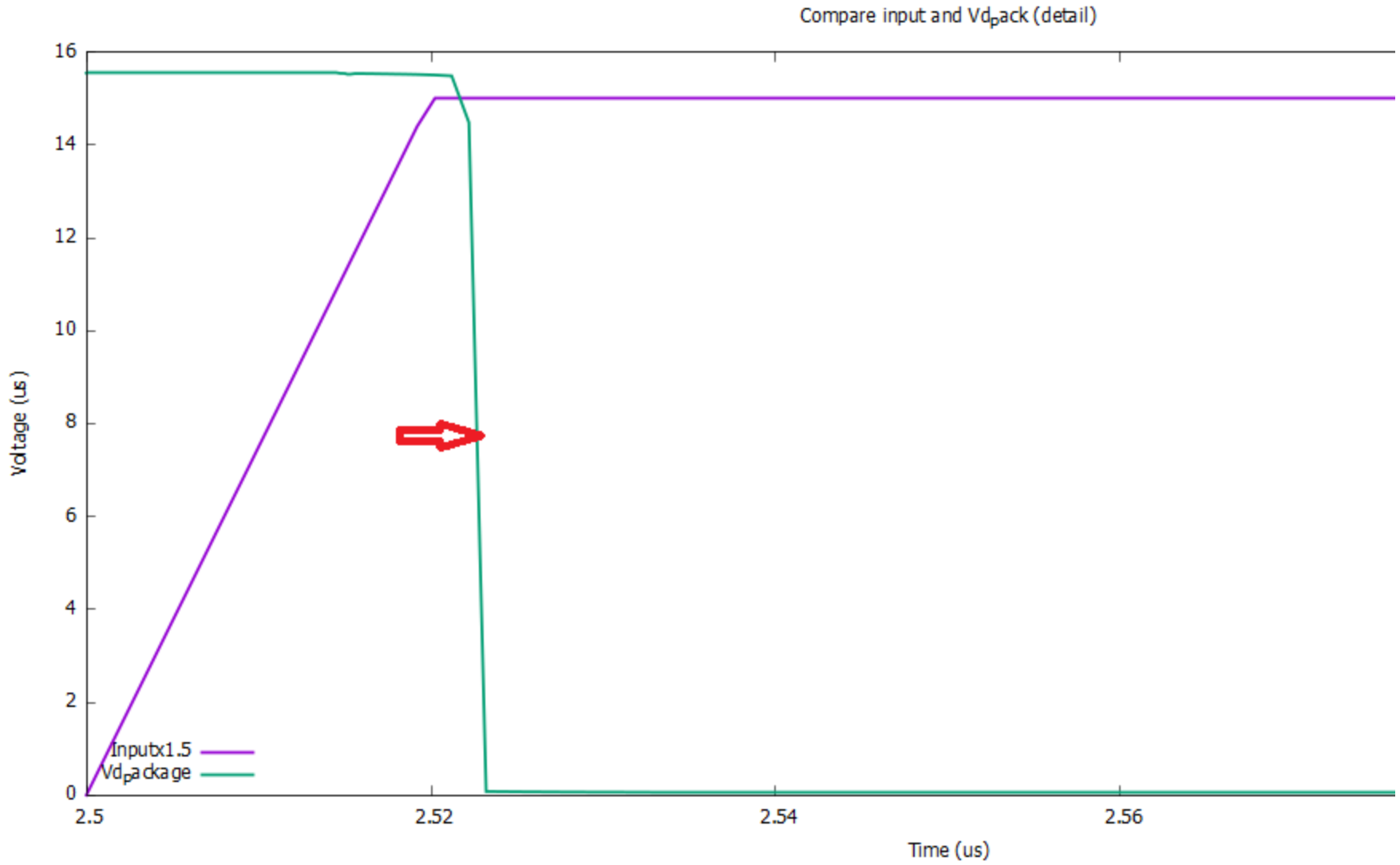
```
c:\NovaTCAD\Apsys\apsys\gnuplot.exe
```

```
gnuplot> set title "Compare input and Vd_pack (detail)"
gnuplot> set key left bottom
gnuplot> set xlabel "Time (us)"
gnuplot> set ylabel "Voltage (us)"
gnuplot> set xrange [2.5:2.6]
gnuplot> plot "Vg_wv.txt" using 1:(1.5*($2)) w l lw 3 t "Inputx1.5", "Vd_pack.txt" w l lw 3 t "Vd_package"
```

turn-on delay of about 11ns at 7.5V



fall time of about 2 to 3ns



Q_g:

Q_g is just integration of $I_g(t)$

Small program provided to do the integral:

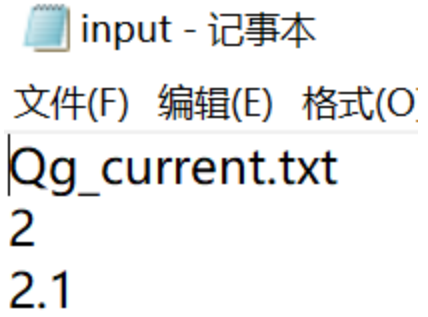
Qg_calculator.exe < input.txt

Interactive or piped command input:

first line is data file for $I_g(t)$

second line is start of integral

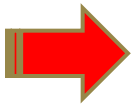
third line is endpoint of integral



Result is 44.7nC

```
Hello, please enter the txt file with time-current data
Starting time for integral (whatever unit in txt)?
Ending time for integral (whatever unit in txt)?
 Integral range=   2.000000000000000        2.099403558720000
 Qg (using units in txt)=  4.473301453921580E-002
 ------end of calculator-----
 Please enter to close.
```

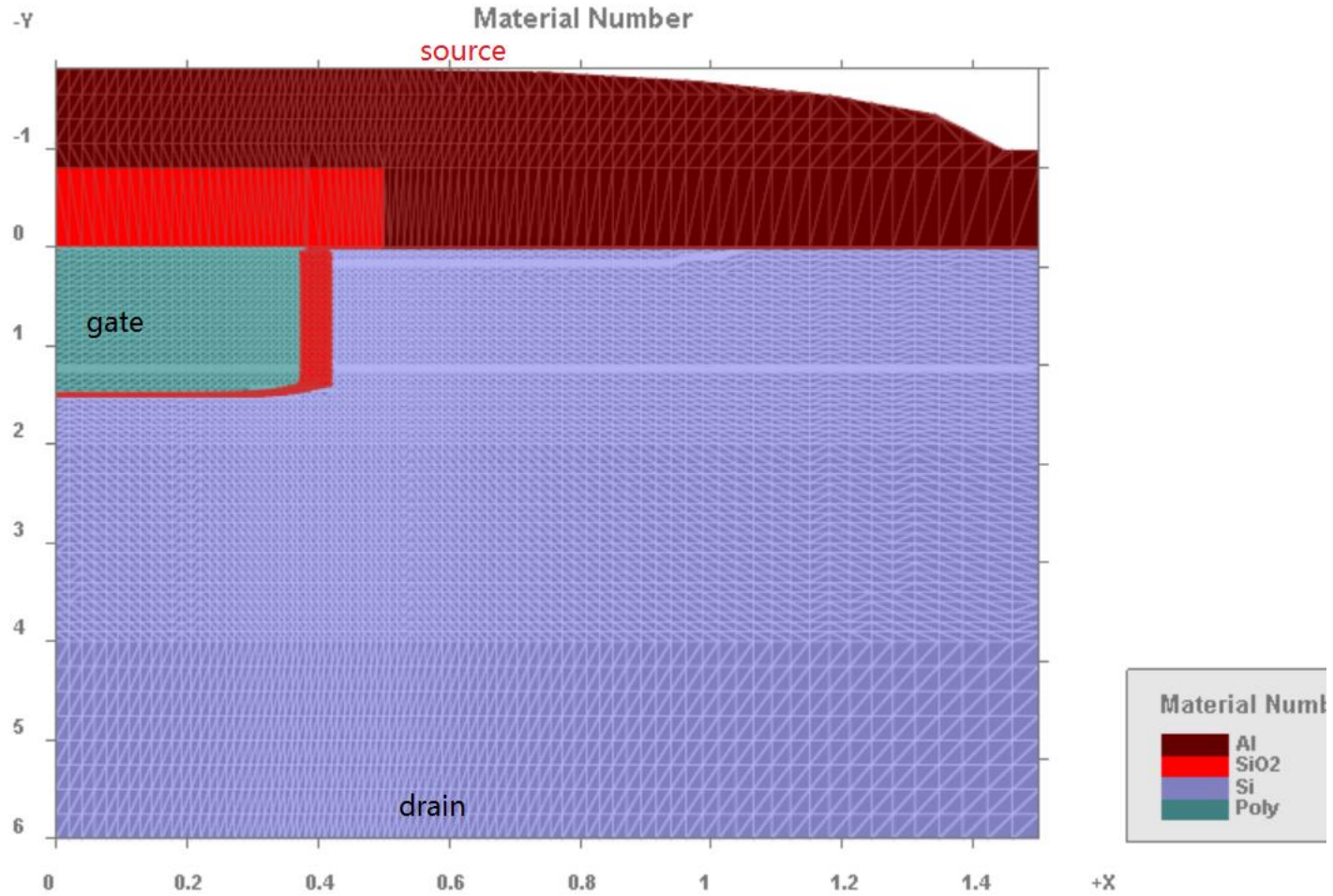
Contents



- Double pulse testing simulation
- Capacitance-voltage simulation
- Summary

Users can obtain C_{OSS}, C_{ISS} and C_{RSS} through the AC analysis of the breakdown simulation.

Final structure



Set ac_data=yes in cv.sol

```
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
$  Define Output Data
$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$$
more output space_charge=yes impact_ionization=yes &&
 ac_data=yes elec_mobility=yes hole_mobility=yes
```

Print data needed for AC analysis at 1V intervals

```
scan var=voltage_3 value_to=300 min_step=1e-6 max_step=0.5 &&
auto_finish=current_3 auto_until=7e-4 auto_condition=above &&
init_step=0.001 print_step=1.0
```

For this example, AC print 63 data files.

```
  5,643 cv.out_0043
  5,643 cv.out_0044
  5,643 cv.out_0045
  5,643 cv.out_0046
 10,011 cv.out_0047
 10,011 cv.out_0048
  7,099 cv.out_0049
  8,555 cv.out_0050
  5,643 cv.out_0051
  5,643 cv.out_0052
  5,643 cv.out_0053
  5,643 cv.out_0054
  5,643 cv.out_0055
  5,643 cv.out_0056
  5,643 cv.out_0057
  5,643 cv.out_0058
  5,643 cv.out_0059
  5,643 cv.out_0060
  8,555 cv.out_0061
  5,643 cv.out_0062
 39,139 cv.out_0063
```

$ source=contact1
$ gate=contact2
$ drain=contact3

AC analysis not possible at equilibrium; data also less reliable on final breakdown point (loss of convergence). So data sets #1 and #63 are excluded from the analysis.

AC analysis applies 1V of AC bias at specified contact: capacitance is part of the AC current response to that AC bias.

```
$ Coss = Cap or displacement current of drain due to voltage change at drain
$ Ciss = Cap or displacement current of gate due to voltage change at gate
$ Crss = Cap or displacement current of drain due to voltage change at gate
$ input
get_data  main_input=cv.sol sol_inf=cv.out &&
  xy_data=(2 2) scan_data=(2 62)
$ output
ac_voltage log_freq1=6. log_freq2=6. contact_num=3 &&
  freq_point=2 versus_bias=yes
set_xydata_for_scan scan_var=voltage_3
plot_ac_curr variable=capacitance_3 data_file=coss.txt
```

For C_{ISS}:

```
$ input
get_data  main_input=cv.sol sol_inf=cv.out &&
  xy_data=(2 2) scan_data=(2 62)

ac_voltage log_freq1=6. log_freq2=6. contact_num=2 &&
  freq_point=2 versus_bias=yes
set_xydata_for_scan scan_var=voltage_3
plot_ac_curr variable=capacitance_2 data_file=ciss.txt
```

For C_{RSS}:

```
$ cross from gate to drain
get_data  main_input=cv.sol sol_inf=cv.out &&
  xy_data=(2 2) scan_data=(2 62)

ac_voltage log_freq1=6. log_freq2=6. contact_num=2 &&
  freq_point=2 versus_bias=yes
set_xydata_for_scan scan_var=voltage_3
plot_ac_curr variable=capacitance_3 data_file=crss.txt
```

Because AC analysis calculation is very slow (more than 10 minutes), so we use command-line calculation instead of GUI calculation. Time needed for calculation may cause timeout issues with GUI.

Run command:

C:\NovaTCAD\Apsys\apsys\apsys.exe cv.plt

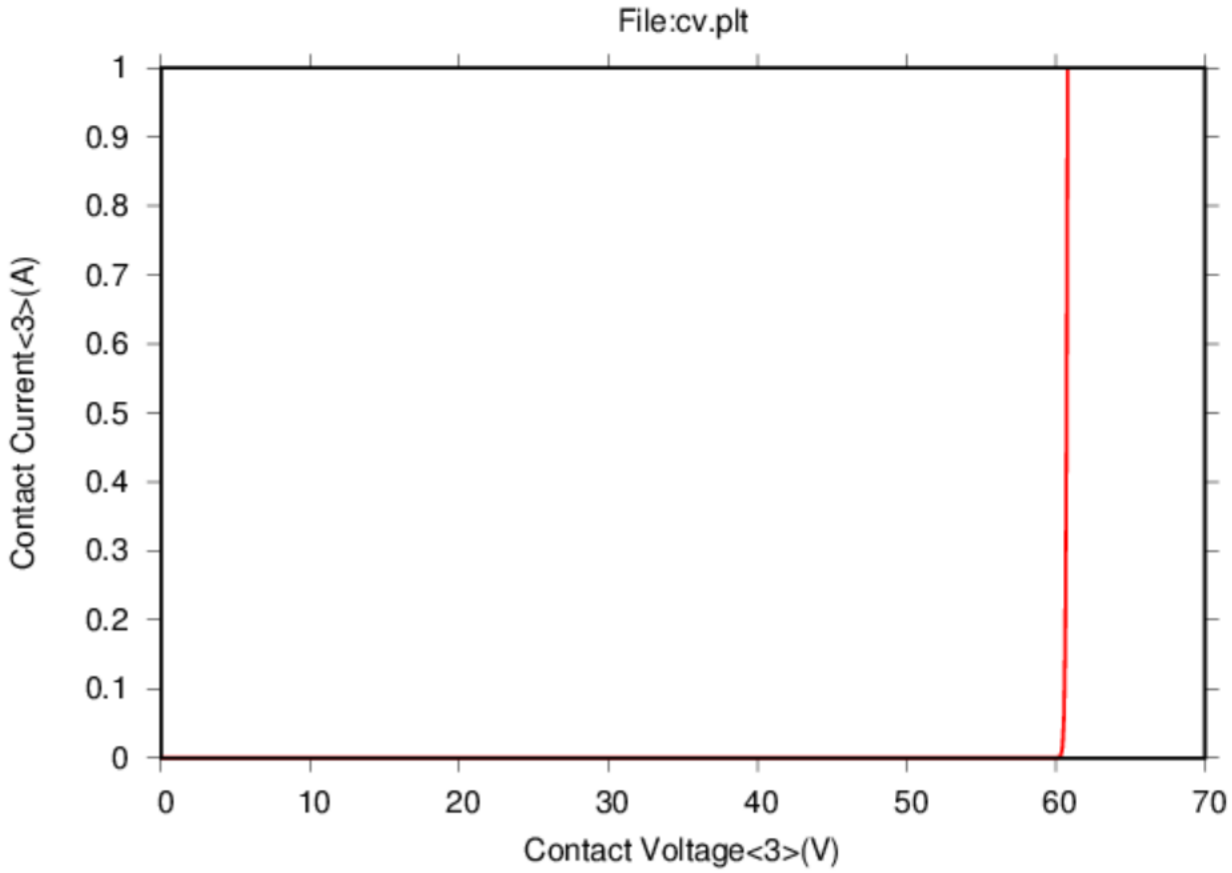
```
F:\gaosheng\TMOS>C:\NovaTCAD\Apsys\apsys\apsys.exe  cv.plt
 ---3D flow option required.
 ----CSuprem-Builder option required
 ----CSuprem option required
 ==>Warning: Special single plane 3D simulation.
 Segment/Mesh=           1        7082
 Total mesh points=        7082
>>Generating filling-volume data....
Done. Runtime:      0.00  minutes.
```

APSYS's .plt file generates a set of Gnuplot commands to create a postscript output file (output.ps).

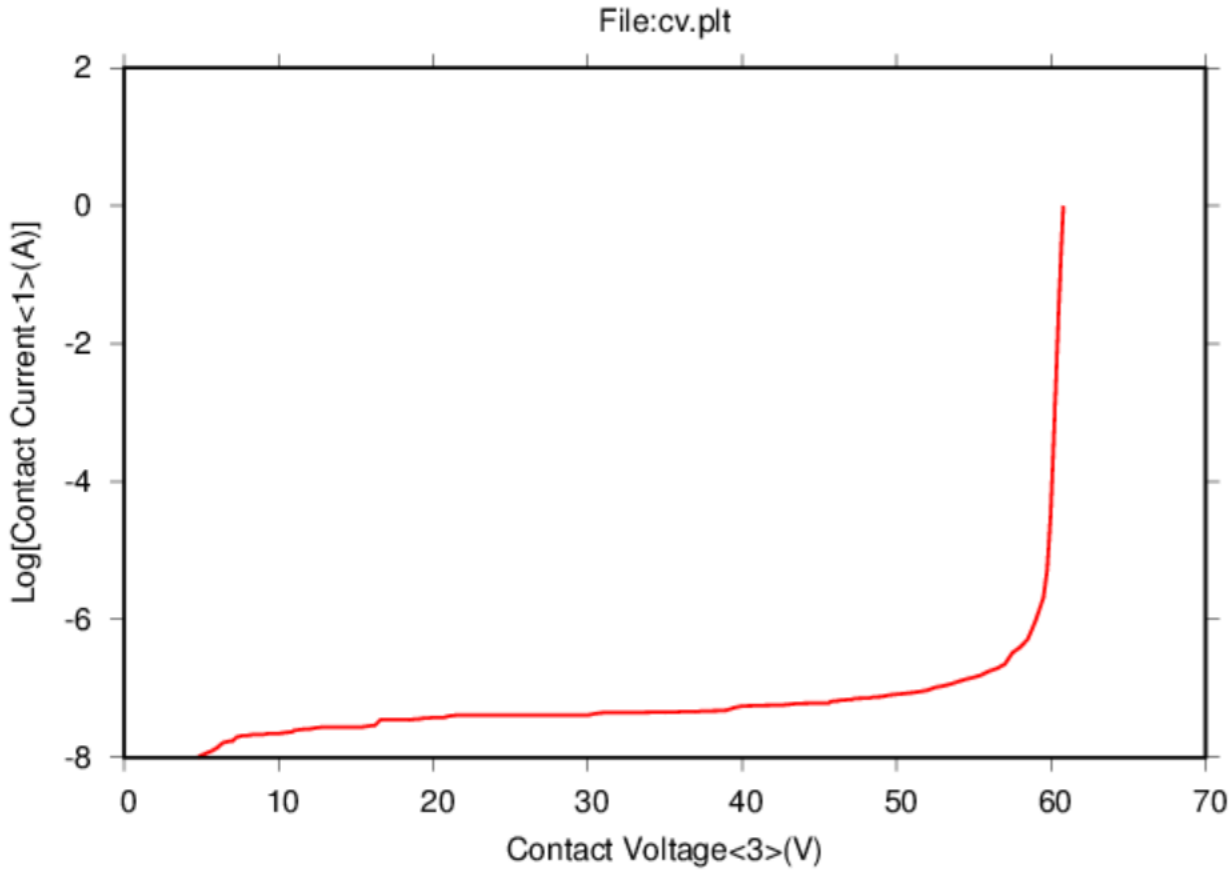
Run command:

C:\NovaTCAD\Apsys\apsys\gnuplot.exe junkg.tmp

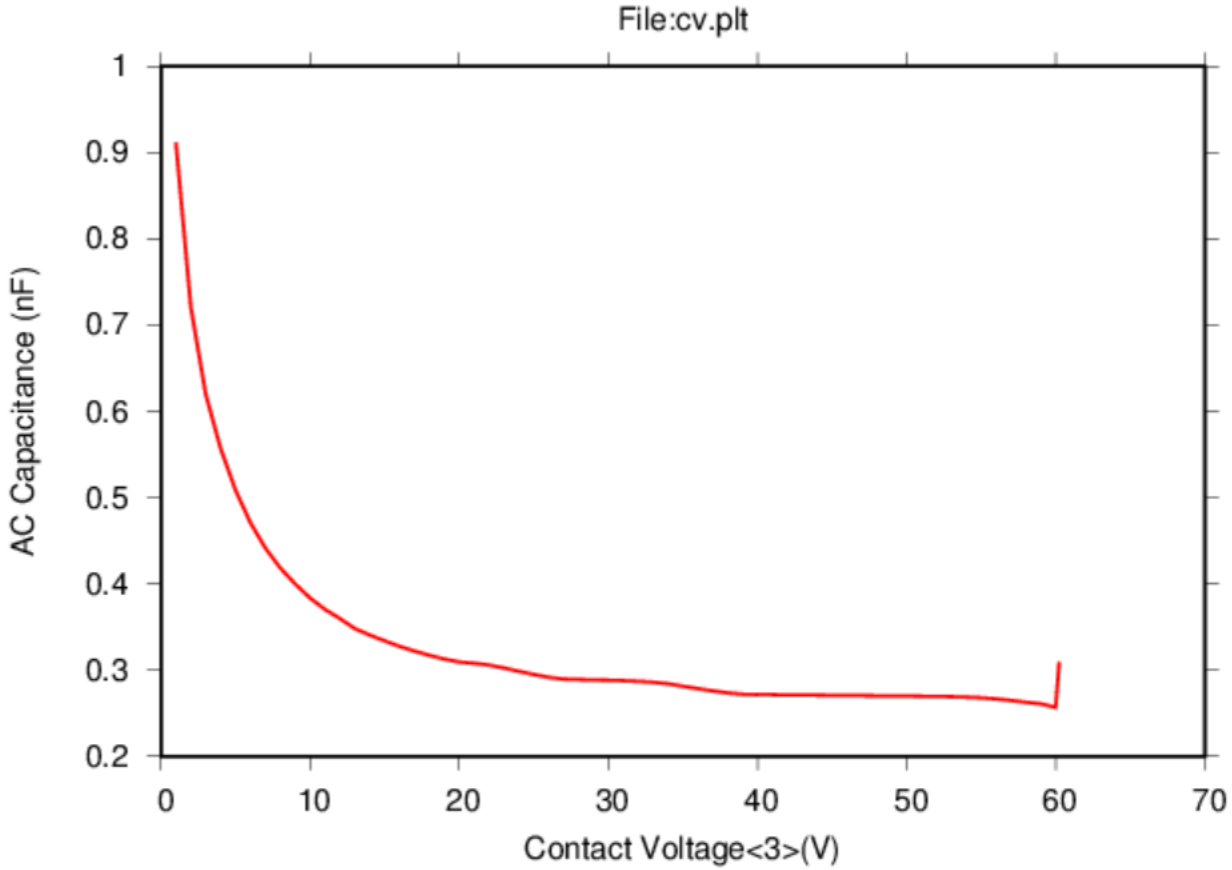
Breakdown characteristics



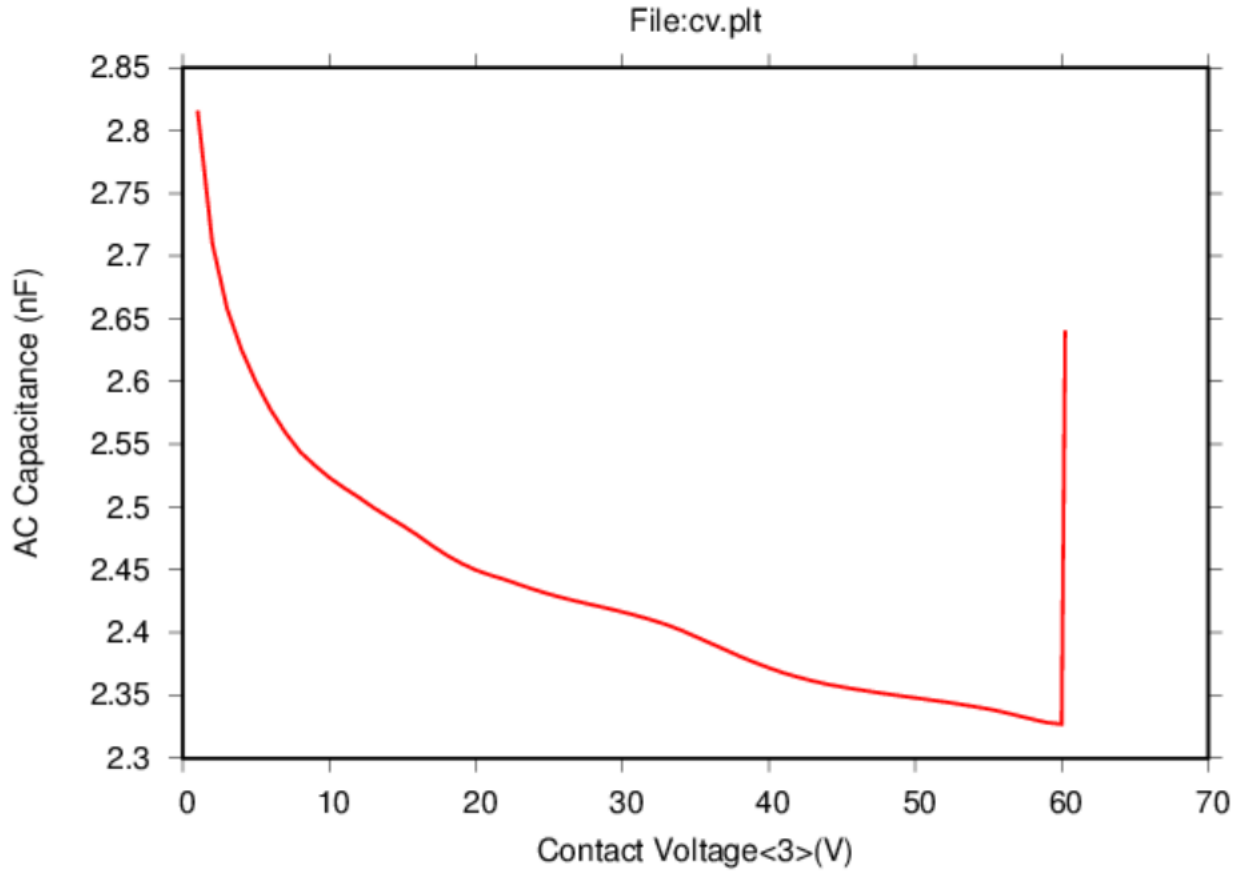
BV curve in log scale



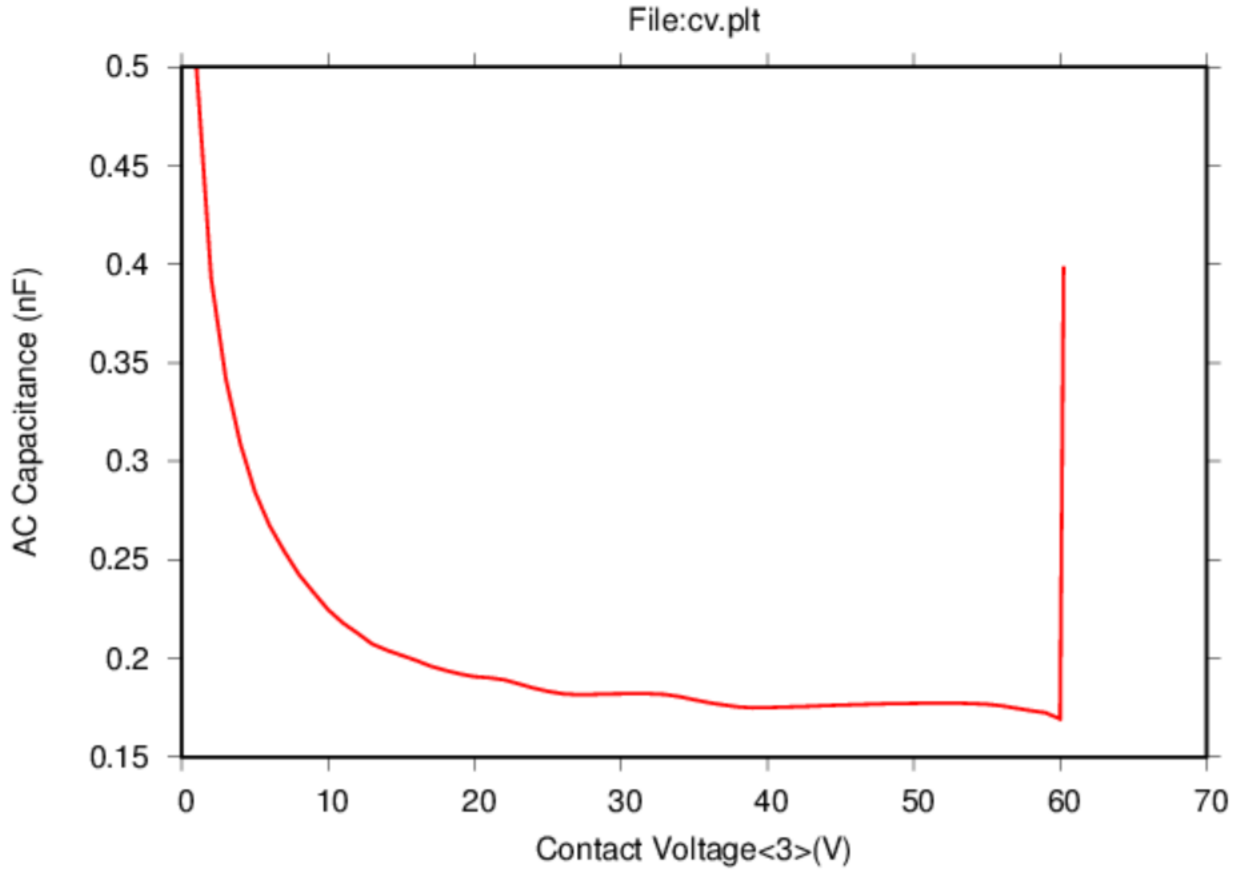
C_{OSS} output capacitance vs. Vd



C_{ISS} Input capacitance



C_{RSS} Reverse Transfer capacitance



Summary: Crosslight TCAD can extract most parameters in a datasheet for a power device

Thanks for your attention!

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